INTRODUCTION TO Aircraft Maintenance

THIRD EDITION

AVOTEK INFORMATION RESOURCES

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Preface

This textbook, the first in a series of four, was written for the Aviation Maintenance Technician student of today. It is based on the real-world requirements of today's aviation industry. At the same time, it does not eliminate the traditional subject areas taught since the first Aviation Maintenance schools were certificated.

This series of textbooks has evolved through careful study and gathering of information offered by the Federal Aviation Administration, the Blue Ribbon Panel, the Joint Task Analysis report, industry involvement, and AMT schools nationwide.

The series is designed to fulfill both current and future requirements for a course of study in Aviation Maintenance Technology.

Textbooks, by their very nature, must be general in their overall coverage of a subject area. As always, the aircraft manufacturer is the sole source of operation, maintenance, repair and overhaul information. Their manuals are approved by the FAA and must always be followed. You may not use any material presented in this or any other textbook as a manual for actual operation, maintenance, or repair.

The writers, individuals and companies which have contributed to the production of this textbook have done so in the spirit of cooperation for the good of the industry. To the best of their abilities, they have tried to provide accuracy, honesty and pertinence in the presentation of the material. However, as with all human endeavors, errors and omissions can show up in the most unexpected places. If any exist, they are unintentional. Please bring them to our attention.

Email us at comments@avotek.com for comments or suggestions.

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1

General Mathematics

Section 1

Introduction to Mathematics

The use of mathematics is so interwoven into nearly every aspect of everyday life that we seldom, if ever, fully realize how very helpless we would be in the performance of most of our daily work without the knowledge of at least the simplest form of mathematics. Performing mathematical computations with success requires an understanding of the correct procedures and continued practice in the use of those mathematical procedures.

Aviation technicians are continually required to perform tasks that require accurate mathematical computations. Tolerances in aircraft and engine components are often so critical that it requires measurements to within a thousandth or ten-thousandth of an inch. Because of the close tolerances that must be adhered to, it is critical that aviation maintenance personal be able to make accurate measurements and precise mathematical calculations.

Mathematics may be thought of as a tool kit, with each mathematical operation in the solving of a problem being compared to the use of one of the tools. The basic operations of addition, subtraction, multiplication, and division are the tools available to aid us in the solution of any particular problem. With today's easy access to hand-held calculators capable of doing extremely complex problems involving multiple variables, using paper and pencil seems outdated. However, the ability to perform longhand calculations is very useful when no calculator is available.

Learning Objectives

REVIEW
- Whole numbers and principle operations
- Decimals: numbers, fractions, rounding
- Fractions, common denominator and arithmetic operations
- Measurement types

DESCRIBE
- Mixed numbers and typical operations
- Percentage, ratio and proportion and their applications

EXPLAIN
- How to find and compute numerical powers and roots
- Trigonometric functions in aviation

APPLY
- Find the area of geometric shapes
- Measure the volume of a solid
- Read and interpret charts and graphs

Left. Basic math skills are essential to working in a production or maintenance environment.

The Number Systems

The decimal system. From the Latin word decimus, meaning tenth, the decimal system is a number system using combinations of the ten numbers 0 through 9. While it may sound silly to modern man, it is speculated that the ten number decimal system was chosen by early man because he had ten digits on his hands that could be used to help him count and keep track of numbers.

In order to provide an infinite quantity of numbers, the decimal system allows the reuse of the ten base numbers (0 through 9) more than one time.

Above the number nine, two base numbers are used together to make the number ten (10), followed by eleven (11), and so on until all of the ten base numbers have been used in all of the possible combinations of two numbers. Combinations of two numbers that begin with the number 1 are referred to as teens; those that begin with the number 2 are twenties; numbers beginning with 3 are the thirties; followed in order by the forties, fifties, sixties, seventies, eighties, and nineties.

After all combinations of two numbers are used, the numbers are combined in groups of three base numbers. The first of these numbers is 100, and after changing one number at a time until all possible combinations of three numbers are used, the last possible combination is the number 999. These numbers are referred to as hundreds, beginning with one hundred (100), two hundred (200), and continuing on to nine hundred (900). When used in combination, the number is referred to by its hundred value first, then its ten value, and finally by its base number. For example, the number 843 is referred to as eight hundred forty-three.

By continuing to increase the number of combinations, the decimal system can be used to provide the infinite quantity of numbers, which was previously mentioned. Combinations of four numbers are thousands; five numbers are ten thousands, and six numbers are referred to as hundred thousands. The next combination above the thousands are the millions, followed by billions, trillions, quadrillions, and so forth. A thousand thousands is a million. A thousand millions is a billion, a thousand billions is a trillion, and the possibilities continue to infinity.

Numbers of less than 0 are possible using the decimal numbering system by identifying them with a negative (–) sign. The numbers used are the same as those above 0, with the base numbers followed by tens, hundreds, and so on to infinity. By adding the negative sign any number can be made to be less than 0, with the exception of the number 0 itself. Negative numbers are covered in greater detail in the signed numbers section of this chapter.

Between any two numbers in the decimal system are fractions or pieces of the quantity between the two numbers. For example, if all numbers were spaced at equal distances between each other, the distance between each number would be divided into fractional parts. In the decimal system there are two forms of fractions: common fractions and decimal fractions.

Common fractions are used when the imaginary spaces between numbers are divided into equal distances such as thirds (where the space is divided into three equal segments), fourths (four equal segments), or any other number. If, as an example, the imaginary distance between two numbers were divided into thirds, one of the segments of that division would be one-third (1/3). Two of those segments would be two-thirds (2/3). Three of the segments (or three-thirds) in this example would be equal to the distance between the two numbers, and therefore is equal to one. Common fractions are discussed in greater detail in section 6 of this chapter titled Common Fractions.

Decimal fractions are created when the imaginary space between two numbers is divided into ten (or a multiple of 10) equal parts, and are written as a number after a period known as a decimal point. For example, 0.1 is one-tenth, 0.2 is two-tenths, and so on. When two numbers are written after the decimal point, the decimal fraction is in hundredths. For example, 0.01 is one-hundredth, and 0.45 is forty-five one-hundredths. Three numbers after the decimal point are thousandths, four numbers become ten thousandths, and so on into the millionths, billionths, etc. Section 4 of this chapter covers decimal fractions in greater detail.

The binary system. Binary is a numbering system that uses only two numbers (usually the numbers one [1] and zero [0]). The binary system became particularly important with the advent of, and advancement in, pocket calculators and computer technology, where circuits within the calculator or computer are either switched ON or OFF to perform a given task or function. By converting switch positions (ON or OFF) to mathematical numbers (1 for ON or 0 for OFF), computer systems can be designed, programmed, and operated using combinations of only two numbers.

The principle of operation of the binary system is quite simple. While reading the following paragraphs, use Table 1-1-1 to help in understanding this system, and imagine

Binary numbers							Decimal Numbers
64	32	16	8	4	2	1	
0	0	0	0	0	0	1	1
0	0	0	0	0	1	0	2
0	0	0	0	0	1	1	3
0	0	0	0	1	0	0	4
0	0	0	0	1	0	1	5
0	0	1	1	0	1	1	27
0	1	1	0	0	0	0	48
1	0	1	1	1	0	0	92
1	1	1	0	1	0	1	117

Table 1-1-1. Conversion of binary numbers into decimal numbers.

each number as a switch in a calculator being either ON or OFF.

- If only one switch exists, it can be either OFF or ON. If it is OFF, it equates to zero, whereas if it is ON, it equates to one.

- If two switches exist, the second switch is equal to twice the value of the first switch, or in this case two. Thus, if the first switch is OFF, and the second is ON, it equates to a value of two. If both switches are ON, then the two, represented by the second switch, and the one, represented by the first, totaled together would equal three (since two plus one equals three).

- If more than two switches exist, each switch is equal to twice the value of the switch before it. Therefore, the third switch would be equal to four, the fourth equal to eight, the fifth equal to 16, and so on. By adding the numbers of the ON switches only, a total can be derived.

Section 2

Whole Numbers

In the previous section, the decimal system was described as the base numbers 0 through 9, and combinations of these numbers. These numbers (base numbers and combinations of base numbers) are referred to as whole numbers or integers (as opposed to common or decimal fractions, which will be discussed later in this chapter). To be of any functional use, whole numbers are calculated or manipulated using addition, subtraction, multiplication, and division.

Addition. The process of finding the combined total amount of two or more numbers is called addition. The resultant total is called the sum. Addition is indicated by the plus (+) symbol.

When adding several whole numbers, such as 46, 92, and 332, these numbers contain units of value known as ones, tens, and hundreds, etc. These units are placed in columns so that they correspond to their proper value.

EXAMPLE:

hundreds	tens	ones
	4	6
	9	2
3	3	2
4	7	0

The sum, which is the total of these three whole numbers, is then 4 hundreds, 7 tens, and 0 ones, or commonly called four-hundred seventy. The addition is straightforward in that the 6, 2, and 2 are totaled. These figures equal 10, or one unit of ten and zero ones. This one unit of ten is carried, or transferred, to the tens column and added with the tens column figures. The 4, 9, and 3, plus the one unit of ten from the ones column, are added and totals to 17 units of ten. Ten units of ten equal 100, therefore, if we have 17 units of ten, we in effect have one unit of hundreds and seven units of ten. The one unit of hundreds is transferred to the hundreds column and added to the three units of hundreds that are already there. This total is four units of hundreds, seven units of ten, and zero units of one in value. This same type of addition operation is used with all units, including 1,000, 10,000, 100,000, etc.

To check addition, either add the figures again in the same order, or add them in reverse order.

Subtraction. Subtraction is the process of finding the difference between two numbers by taking the quantity of one number away from that of another number. The number which is subtracted is called the subtrahend, the number from which the subtrahend is subtracted is the minuend, and the resulting number is called the remainder. When first learning subtraction, problems are normally given where the minuend is larger than the subtrahend. However, this is not always the case in subtraction, which will be seen later in this chapter. Subtraction is indicated by the minus (–) symbol.

To find the remainder, write the subtrahend under the minuend, as in addition. Beginning at the right, subtract each figure in the subtrahend from the figure above it and write the individual remainder below in the same column. When the process is completed, the number below the subtrahend is the remainder.

The process of subtraction can be seen in the following example. As with addition, remember to align the whole numbers or decimal numbers in relation to the ones, tens, and hundreds columns. To subtract the number 346 from the number 663, align the figures with the larger number above (minuend), and the lesser number below (subtrahend).

EXAMPLE:

hundreds	tens	ones
6	6	3
-3	4	6
3	1	7

The solution, or remainder, is three-hundred seventeen, or 317, and is arrived at by first subtracting the 6 in the ones column from the 3 in the ones column. This is not possible without *borrowing* from the tens column one unit of ten and adding this ten to the original three ones for a total of 13. Then 6 can be subtracted from 13 with a remainder of 7. After borrowing from the tens column, the remainder left is now five tens in the tens column from which 4 will be subtracted for a remainder of one ten in the tens column. The hundreds column is now subtracted in the same manner of 6 minus 3 equals 3 remainder.

To check subtraction, add the remainder and the subtrahend together. The sum of the two should equal the minuend.

Multiplication. Multiplication is the process of finding a quantity by repeatedly adding a given number a specified number of times. Thus, the sum of 6 + 6 + 6 + 6 = 24 can be expressed by multiplication as 6 × 4 = 24. The numbers 6 and 4 are known as the factors of the multiplication and 24 as the product. Multiplication can be indicated by multiplication signs (× or sometimes *) or can be indicated in equations and formulas by the lack of any other operation signs.

The product, which is the solution in multiplication problems, is formed by multiplying the factors regardless of the numbers of digits in each factor. These factors are the multiplicand, which is the number to be multiplied, and the multiplier is the number by which the multiplicand is to be multiplied.

When the multiplier is a single digit, the multiplication operation can best be shown as in the following example. Multiply the number 34 by the number 4.

EXAMPLE:

$$\begin{array}{r} 34 \\ \times\ 4 \\ \hline 136 \end{array}$$

The *product* in this example is arrived at by the following process. The multiplier is 4, and 34 is the multiplicand. First, 4 times 4 equals 16, which is one unit of ten and six ones. Enter the 6 in the ones column and carry, or transfer, the one unit of ten to the tens column. Multiply the 4 times the 3 to find the product of 12, and then add the one ten from the ones column, or 13. Enter this number as 3 in the tens column and (since there is nothing else in the hundreds column) place the one in the hundreds column. The result is 1 hundred, 3 tens, and 6 ones, or 136.

When both factors are multiple digit integers, the product is formed by multiplying each digit in the multiplicand by each digit in the multiplier. Each digit in the multiplier becomes an individual multiplier in and of itself. Once each multiplicand has been used as a multiplier, the products of each multiplication operation are added together to arrive at a total product. Before adding the products, however, they must be aligned properly. Alignment of the partial products is critical to the addition of these partial products to arrive at the total product.

EXAMPLE:

$$\begin{array}{r} 376 \\ \times\ 42 \\ \hline 752 \\ 15040 \\ \hline 15{,}792 \end{array}$$

Notice that each digit of the multiplier (in this case the 4 and the 2 in 42) is in direct alignment with the last digit of their respective products. The 2 in 752 is directly under the 2 in 42, and 4 in 1504 is directly under the 4 in 42. This alignment must be maintained to arrive at the correct total product when adding the partial products.

When multiplying a series of numbers, the final product will be the same, regardless of the order in which the numbers are arranged.

EXAMPLE:
Multiply: (7) (3) (5) (2) = 210

$$\begin{array}{r} 7 \\ \text{x } 3 \\ \hline 21 \end{array} \quad \begin{array}{r} 21 \\ \text{x } 5 \\ \hline 105 \end{array} \quad \begin{array}{r} 105 \\ \text{x } 2 \\ \hline 210 \end{array} \quad \text{or} \quad \begin{array}{r} 7 \\ \text{x } 5 \\ \hline 35 \end{array} \quad \begin{array}{r} 3 \\ \text{x } 2 \\ \hline 6 \end{array} \quad \begin{array}{r} 35 \\ \text{x } 6 \\ \hline 210 \end{array}$$

Division. The reverse of multiplication, division is the process of finding how many times one number is contained in another number. The first number is called the divisor, the second the dividend, and the result is the quotient.

The correct method of dividing one number by another involves the operation of addition, subtraction, and multiplication to arrive at the correct quotient.

Division is indicated by the use of the division sign (÷) with the dividend to the left and the divisor to the right of the sign, or draw division bracket, with the dividend inside the sign and the divisor to the left (known as long division), or by placing the dividend over a line, and the divisor under the line in a fractional form. (Fractions are described later in this chapter.)

Division operations can best be described by example. As an example, divide the number 624 by the number 16.

```
    39
16)624
   48
   144
   144
     0
```

The first step in the division process is to break the dividend into smaller numbers for the divisor to be divided into.

In the example, 16 is more than the 6 in 624, so the next possible breakdown is with the 62 in 624. Here we find that 16 will *go* into the 62 a total of 3 times. Thus, 3 is the first number of our answer, and is placed above the 2 in the dividend when using the division sign. We must then multiply the 3 by the divisor (16) and find a product of 48. The 48 is placed under and subtracted from the 62 in the dividend, the difference of which is 14. The 4 in the original dividend of 624 is then brought down to the right of the 14, creating a new dividend of 144.

The new dividend (144) is now divided by the divisor (16), and we find that 16 will go into 144 exactly 9 times. Therefore, 9 is the second number of the quotient, and is placed above the 4 in the original dividend (624) when using the division sign. We then multiply 16 by 9, finding a product of 144, which is placed under the new dividend of 144 and subtracted. In this case, the remainder is 0. So the first number in the quotient is 3, and the second number is 9 giving us a quotient of 39.

While division is a series of simple steps in order to arrive at the correct quotient, the quotient for the example given is a whole number. This will not always be the case, as will be discussed in the next and later sections.

Section 3

Decimal Fractions

If a given quantity is greater than one whole number but less than the next whole number, that quantity is a fraction. When the difference between 2 whole numbers is divided into 10 equal parts, or equal parts in multiples of 10 (such as hundreds, thousands, etc.) that difference can be expressed in decimal fractions.

When using decimal fractions, a mark called a decimal point (.) is used as a reference. The whole number is placed to the left of the decimal point, and the decimal fraction is indicated by placing one or more digits to the right of a reference. The following is an example of decimal fractions:

0.6 is read six tenths.
0.06 is read six hundredths.
0.006 is read six thousandths.
5.06 is read five and six hundredths.

When writing a decimal, any number of zeros may be written to the right of the decimal number without changing the value of the decimal. This may be illustrated in the following manner:

$$0.5 = \frac{5}{10} = \frac{1}{2}; 0.50 = \frac{50}{100} = \frac{1}{2}; 0.500 = \frac{500}{1{,}000} = \frac{1}{2}$$

A pure decimal is a decimal fraction, such as 0.6, 0.06, etc., where no whole number is used. When a whole number and a decimal fraction are written together, such as 3.6, 12.2, 131.12, etc., the number is known as a mixed decimal.

Addition of decimal fractions. To add decimal expressions, arrange the decimals so that the decimal points align vertically, and add as with integers. Place the decimal point in the sum directly below the aligned decimal points above.

The following example demonstrates addition of decimal fractions. The total resistance of the series circuit (Figure 1-3-1) is equal to the sum of the individual resistances. What is the total resistance for the diagram shown in this example?

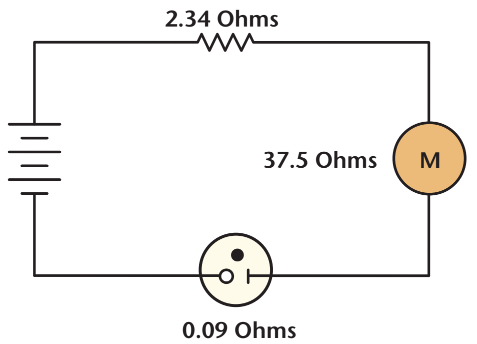


Figure 1-3-1. A series circuit.

1. Arrange the decimals in a vertical column so that the decimal points are in alignment.

```
 2.34
37.5
 0.09
```

2. Complete the addition following the technique used in adding whole numbers. Place the decimal point in the result directly below the other decimal points.

```
  2.34
 37.5
  0.09
 ------
 39.93 ohms
```

Subtraction of decimals. To subtract decimal expressions, arrange the decimals so that the decimal points align vertically, and subtract in the same manner as with integers. Place the decimal point in the difference directly below the aligned decimal points above.

The following example demonstrates subtraction of decimal fractions. A series circuit containing two resistors has a total resistance of 37.27 ohms. One of the resistors has a value of 14.88 ohms. What is the value of the remaining resistor?

1. Arrange the decimals in a vertical column so that the decimal points are in alignment.

```
  37.27
 −14.88
```

2. Perform the subtraction process using the procedure for subtracting whole numbers. Place the decimal point in the result directly below the other decimal points.

```
  37.27
 −14.88
 -------
  22.39 ohms
```

Multiplication of decimals. When multiplying decimals, ignore the decimal points and multiply the terms as though they were whole numbers. To locate the decimal point in the product, count the number of digits (decimal places) to the right of the decimal points in both the multiplier and multiplicand. The decimal point in the product should be placed so that the same number of digits in the product are to the right of the decimal as the total of those in the multiplier and multiplicand.

The following example demonstrates multiplication with decimals. Using the formula, Watts = Amperes × Voltage, determine the wattage of an electric heater that uses 9.45 amperes from a 120-volt source.

1. Arrange the terms and multiply. Ignore the decimal point.

```
     ┌──────── Two decimal places
     ▼
    9.45
   × 120
   -----
     000
   1890
   945
  ------
  113400
```

2. Locate the decimal point. Count the number of decimal places to the right of the decimal in both the multiplier and multiplicand. Begin at the right of the product and place the decimal point to the left the number of places that will equal the total of the decimal places in both the multiplier and the multiplicand.

```
     9.45
    × 120    Count from right to
   ------    left numbers of
   18900     decimal places.
    945
  -------
  1134.00
```

In some cases, the number of digits in the product may be less than the sum of the decimal places in the multiplier and multiplicand. When this occurs, merely add zeros to the left of the product until the number of digits after the decimal equals the sum of the decimal places in the multiplier and multiplicand.

As an example of a situation requiring the addition of zeros to the product, multiply the number 0.218 by 0.203.

1. Arrange the terms and multiply, ignoring the decimal point.

```
   0.218 ◄─┐
 X 0.203 ◄─┴──── Six decimal places
 -------
     654
   4360
 -------
   44254
```

2. Locate the decimal point. Add a zero to the left of the product so that the number of places will equal the sum of the decimal places in the quantities multiplied.

```
    0.218
 ×  0.203
 --------
      654    Move from right
   4360      to left six
 --------
 0.044254    decimal places.
   654321
```

The multiplication of one decimal fraction by another will always produce an answer smaller than either of the two numbers. When a decimal fraction is multiplied by a whole number or by a mixed decimal, the answer will lie between the two numbers.

Division of decimals. When performing division of decimals, the following three principles apply:

- When the divisor involves a decimal fraction, the quotient is found by converting the divisor into a whole number by moving the decimal point in the divisor to the right. If the decimal in the divisor is moved, the decimal in the dividend must also be moved in the same direction and the same number of spaces.

- If the divisor is a whole number, the decimal place in the quotient will align vertically with the decimal in the dividend when the problem is expressed in long division form.

- When the dividend and divisor are multiplied by the same number, the quotient remains unchanged.

To divide decimal expressions, count off to the right of the decimal point in the dividend the same number of places that are located to the right of the decimal point in the divisor. Insert a caret (^) to the right of the last digit counted. If the number of decimal places in the dividend is less than the number of decimal places in the divisor, add zeros to the dividend, remembering that there must be at least as many decimal places in the dividend as in the divisor. Divide the terms, disregarding the decimal points entirely. Place the decimal point in the quotient so that it aligns vertically with the caret mark in the dividend.

The following example demonstrates the division of decimal fractions. The wing area of a certain airplane is 245 square feet; its span is 40.33 feet. Divide the area of the wing by its span to find the chord of the wing.

1. Arrange the terms as in long division and move the decimal point to the right, adding zeros as necessary, and insert a caret.

```
Two decimal
places in divisor  →  40.33 | 245.00^  ←  Insert caret two places from original
```

2. Divide the terms, disregarding the decimal points entirely. Add additional zeros to the right of the dividend to permit carrying the quotient to the desired accuracy.

```
40.33 | 245.000^0
        241 98
          3 020      Zeros are added
          0 000      for accuracy
          3 0200
          2 8231
            1969
```

3. Place the decimal point in the quotient so that it aligns vertically with the caret mark in the dividend.

```
            6.07 feet
40.33^ | 24500^00
         24198
          3020
          0000
          30200
          28231
           1969
```

Section 4

Scientific Notation, or the Powers of Ten

The difficulty of performing mathematical problems with very large (or very small) numbers, and the counting and writing of many decimal places are both an annoyance and a source of error. The problems of representation and calculation are simplified by the use of scientific notation, commonly referred to as *the powers of ten* (Table 1-4-1.)

Scientific notation requires the use and understanding of the principles of a device known as the exponent. The exponent is a number or symbol that is normally written to the right and above the number to which the exponent applies.

The positive exponent (or power) of a number is a shorthand method of indicating how many times the number is multiplied by itself. For example, 2^3 (read as 2-cubed or 2 to the third power) means 2 is to be multiplied by itself 3 times: 2 × 2 × 2 = 8. A number with a negative exponent may be defined as its inverse or reciprocal (1 divided by the number) with the same exponent made positive. For example, 2^{-3} (read as 2 to the minus 3 power) is the same as:

$$\frac{1}{(2)^3} = \frac{1}{2 \times 2 \times 2} = \frac{1}{8}$$

Power of 10	Expansion	Value
10^6	10 x 10 x 10 x 10 x 10 x 10	1,000,000
10^5	10 x 10 x 10 x 10 x 10	100,000
10^4	10 x 10 x 10 x 10	10,000
10^3	10 x 10 x 10	1,000
10^2	10 x 10	100
10^1	10	10
10^0		1
The velocity of light, 30,000,000,000 centimeters per second, simplifies to 3×10^{10} centimeters per second.		
$10^{-1} = \frac{1}{10}$	$\frac{1}{10}$	$\frac{1}{10}$ =0.1
$10^{-2} = \frac{1}{10^2}$	$\frac{1}{10 \times 10}$	$\frac{1}{100}$ =0.01
$10^{-3} = \frac{1}{10^3}$	$\frac{1}{10 \times 10 \times 10}$	$\frac{1}{1,000}$ =0.001
$10^{-4} = \frac{1}{10^4}$	$\frac{1}{10 \times 10 \times 10 \times 10}$	$\frac{1}{10,000}$ =0.0001
$10^{-5} = \frac{1}{10^5}$	$\frac{1}{10 \times 10 \times 10 \times 10 \times 10}$	$\frac{1}{100,000}$ =0.00001
$10^{-6} = \frac{1}{10^6}$	$\frac{1}{10 \times 10 \times 10 \times 10 \times 10 \times 10}$	$\frac{1}{1,000,000}$ =0.000001
The mass of an electron, 0.000,000,000,000,000,000,000,000,000,911gram becomes 9.11×10^{-28} gram.		

Table 1-4-1. Powers of ten and their equivalents.

Any number, except zero, to the zero power is equal to 1. When a number is written without an exponent, the value of the exponent is 1. When an exponent has no sign (+ or –) preceding it, the exponent is positive.

The value of a number does not change when it is both multiplied and divided by the same factor ($5 \times 10 \div 10 = 5$). Moving the decimal point of a number to the left is the same as dividing the number by 10 for each place the decimal point moves. Conversely, moving the decimal point to the right is the same as multiplying the number by 10 for each place the decimal point moves.

Multiplication by scientific notation. Multiplication employing powers of ten may be performed in three simple steps. In the following example, the number 754 will be multiplied by 220. While this is normally a simple multiplication problem, it can be used to demonstrate the simplicity of using the powers of ten.

Reduce all numbers to values between 1 and 10 multiplied by 10 to the proper power.

- In the sample problem 754 can be reduced to 75.4×10, and further reduced to 7.54×100. This reduction brings our number down to between 1 and 10 as was previously suggested. Since the powers of ten require the use of multiples of ten, the 100 in our problem must be further reduced to 10^2 (since $10 \times 10 = 100$). So the first number of the problem is reduced to 7.54×10^2.

- The second number in the problem is reduced in the same manner as the first. The number 220 is reduced to 22.0×10, and further reduced to 2.20×10^2.

- The problem is now changed from 754×220 to $(7.54 \times 10^2) \times (2.20 \times 10^2)$.

Perform the indicated operations. Using the sample problem, the number 7.54 is multiplied by 2.20 with a result of 16.588.

Add the exponents of the tens. Again using the sample problem, $10^2 \text{ x } 10^2 = 10^4$.

After the multiplication and additions operations, the result of our sample problem is 16.588×10^4. This can be converted into a whole number by multiplying the 16.588 by the 10^4, simply by moving the decimal to the right four numbers. Since there are only three to the right of the decimal, a zero must be added, giving us a total of 165,880.

Division by scientific notation. Division operations using scientific notation are performed in the same manner as multiplication operations with the following exceptions.

Divide instead of multiplying the reduced numbers.

When converting back to a whole number, there is no need to move the decimal if divisor and dividend have the same exponent. This is because, as was stated in the section on division of decimals, when the dividend and divisor are multiplied by the same number, the quotient remains unchanged.

Section 5

Common Fractions

A common fraction is an indicated division that expresses one or more of the equal parts into which a unit is divided. For example, the fraction 2/3 indicates that the whole has been divided into 3 equal parts and that 2 of these parts are being used or considered.

Components of the common fraction.

- The number above the line is referred to as the numerator.

- The number below the line is the denominator.

Types of fractions

- A proper fraction exists when the numerator of the fraction is smaller than the denominator. A proper fraction always represents a quantity of less than 1.

- An improper fraction results when the numerator of a fraction is equal to or larger than the denominator. When the numerator and denominator are the same number, the fraction is equal to one (1). Otherwise, improper fractions are greater than 1.

- A mixed number is the result of the division of an improper fraction. Mixed numbers are discussed in detail in section 7 of this chapter.

$$\frac{15}{8} = 1\frac{7}{8}$$

- Complex fractions contain one or more fractions or mixed numbers in either the numerator or denominator. The following fractions are examples of complex fractions:

$$\frac{1/2}{2/3}, \quad \frac{5/8}{2}, \quad \frac{3/4}{5/8}, \quad \frac{3\,1/2}{2/3}$$

The same fundamental operations performed with whole numbers can also be performed with fractions. These are addition, subtraction, multiplication, and division.

Finding the least common denominator. To be able to add or subtract common fractions, a common denominator among the fractions must be found. This is a denominator into which each of the denominators of the fractions can be divided a whole number of times.

When the denominators of fractions to be added or subtracted are such that a common denominator cannot be determined readily, the least common denominator (LCD) can be found by the continued division method.

To find the LCD of a group of fractions, write the denominators in a horizontal row. Next, divide the denominators in this row by the smallest integer other than one that will exactly divide two or more of the denominators. Bring down to a new row all the quotients and numbers that were not divisible. Continue this process until there are no two numbers in the resulting row that are divisible by any integer other than one. Multiply together all the divisors and the remaining terms in the last row to obtain the least common denominator.

As an example, find the LCD for 7/8, 11/20, 8/36, 21/45.

1. Write the denominators in a horizontal row and divide this row by the smallest integer that will exactly divide two or more of the numbers.

$$\begin{array}{r|rrrr} 2 & 8 & 20 & 36 & 45 \\ \hline & 4 & 10 & 18 & 45 \end{array}$$

2. Continue this process until there are no two numbers in the resulting row that are divisible by any integer other than one.

$$\begin{array}{r|rrrr} 2 & 8 & 20 & 36 & 45 \\ \hline 2 & 4 & 10 & 18 & 45 \\ \hline 3 & 2 & 5 & 9 & 45 \\ \hline 3 & 2 & 5 & 3 & 15 \\ \hline 5 & 2 & 5 & 1 & 5 \\ \hline & 2 & 1 & 1 & 1 \end{array}$$

3. Multiply together all the divisors and terms greater than 1 remaining in the last row to obtain the LCD.

$$\text{LCD} = 2 \times 2 \times 3 \times 3 \times 5 \times 2 = 360$$

4. Once the LCD is found, the numerator of each fraction is multiplied by the quotient of the common denominator divided by the original denominator. This new numerator, when placed over the common denominator, is equal to the original fraction.

As an example, the fractions 1/2 and 2/3 will be reduced to their LCD.

1. The LCD between the numbers 2 and 3 must be found. The result is the number 6.

2. Next the new numerators are found by first dividing the common denominator (6) by each of the original denominators (2 and 3).

   $6 \div 2 = 3$ and $6 \div 3 = 2$

3. After dividing the LCD by the original denominator, you must multiply each original numerator by the quotient.

   $1 \times 3 = 3$ and $2 \times 2 = 4$

4. Then the new numerators are placed over the common denominator, resulting in two new fractions, equal to the two original fractions. Since these equivalent fractions have a common denominator, they may be added or subtracted.

   $\frac{3}{6} = \frac{1}{2}$ and $\frac{4}{6} = \frac{2}{3}$

Addition of common fractions. In order to add fractions, all the denominators must be alike. Therefore all fractions to be added must be reduced to their LCD.

When adding fractions, once they have been reduced to their LCD, it is only necessary to add the numerators and express the result as the numerator of a fraction whose denominator is the common denominator. The sum of the added fractions can then be reduced to its lowest terms in a process described in detail in section 8 of this chapter.

The following problem is an example requiring the addition of common fractions. A certain switch installation requires 5/8-inch plunger travel before switch actuation occurs. If 1/8-inch travel is required after actuation, what will be the total plunger travel?

1. Add the numerators.

   $5 + 1 = 6$

2. Express the result as the numerator of a fraction whose denominator is the common denominator.

   $\frac{5}{8} + \frac{1}{8} = \frac{6}{8} = \frac{3}{4}$ inch travel

Subtraction of common fractions. In order to subtract fractions, all the denominators must be alike. Therefore all fractions to be added must be reduced to their LCD.

When subtracting fractions, once they have been reduced to their LCD, it is only necessary to subtract the numerators and express the result as the numerator of a fraction whose denominator is the common denominator. The difference of the added fractions can then be reduced to its lowest terms (described in section 8).

As an example of a common fraction subtraction problem, the total travel of a jackscrew is 13/16 of an inch. If the travel in one direction from the neutral position is 7/16 of an inch, what is the travel in the opposite direction?

1. Subtract the numerators.

   13 – 7 = 6

2. Express the result as the numerator of a fraction whose denominator is the common denominator.

   $\frac{13}{16} - \frac{7}{16} = \frac{6}{16}$ of an inch, or $\frac{\not{6}^{\,3}}{\not{16}_{\,8}} = \frac{3}{8}$

Section 6

Mixed Numbers

Addition of mixed numbers. Mixed numbers can be added by changing them to improper fractions and adding the improper fractions as was previously described.

As an example of the addition of mixed numbers, consider the addition of a 2 2/3-inch extension added to a piece of 5 3/4-inch long bar stock. Find the new total length of the bar stock.

(Convert the mixed numbers to improper fractions.)

$2^2/_3 = {}^3/_3 + {}^3/_3 + {}^2/_3 = {}^8/_3$

$5^3/_4 = {}^4/_4 + {}^4/_4 + {}^4/_4 + {}^4/_4 + {}^4/_4 + {}^3/_4 = {}^{23}/_4$

Find the LCD between the improper fractions, and convert the fractions.

LCD = 3 × 4 = 12

Since 3 goes into 12 a total of 4 times

8 x 4 = 32 therefore ${}^8/_3 = {}^{32}/_{12}$

Since 4 goes into 12 a total of 3 times

23 x 3 = 69 therefore ${}^{23}/_4 = {}^{69}/_{12}$

Add the numerators, placing the sum over the common denominator.

32 + 69 = 101 which then becomes ${}^{101}/_{12}$

Divide the numerator by the denominator to find a whole number, and place any remainder of the division over the denominator.

101 ÷ 12 = 8 with a remainder of 5 = 8 ${}^5/_{12}$

If there is a remainder in the previous operation, when it is placed over the denominator the resulting fraction is then reduced to its lowest terms. Reduction to the lowest terms will be discussed later in this chapter.

Thus, the result of our calculations shows that the addition of a 2 2/3-inch extension to a 5 3/4-inch piece of bar stock results in a new length of 8 5/12-inches.

Subtraction of mixed numbers. Mixed numbers can be subtracted, as with addition, by changing them to improper fractions and performing the subtraction operations on the improper fractions.

As an example of the subtraction of mixed numbers, consider the cutting of a 1 1/2-inch section from a piece of 8 7/8-inch long bar stock. Find the new total length of the bar stock.

1. Convert the mixed numbers to improper fractions.

   $1^1/_2 = {}^2/_2 + {}^1/_2 = {}^3/_2$

   $8^7/_8 = {}^8/_8 + {}^8/_8 + {}^8/_8 + {}^8/_8 + {}^8/_8 + {}^8/_8 + {}^8/_8 + {}^8/_8 + {}^7/_8 = {}^{71}/_8$

2. Find the LCD between the improper fractions, and convert the fractions.

   LCD = 2 × 8 = 16

   Since 2 goes into 16 a total of 8 times,

   3 x 8 = 24 therefore ${}^3/_2 = {}^{24}/_{16}$

   Since 8 goes into 16 a total of 2 times,

   71 x 2 = 142 therefore 7 ${}^1/_8 = {}^{142}/_{16}$

3. Subtract the numerators, placing the difference over the common denominator.

   142 - 24 = 118 which then becomes ${}^{118}/_{16}$

4. Divide the numerator by the denominator to find a whole number, and place any remainder of the division over the denominator.

   118 ÷ 16 = 7 with a remainder of 6 = 7 ${}^6/_{16}$

When there is a remainder, as in this example, it is placed over the denominator and the resulting fraction is then reduced to its lowest terms. In this example, 7 6/16 is reduced to 7 3/8. Reduction to the lowest terms is discussed in the next section.

Section 7

Reduction of a Common Fraction to Its Lowest Terms

To make the numbers in a fraction as small as possible, the fraction is reduced to its lowest terms. While not reducing the fraction is still considered correct, it is generally considered proper and, in most cases, necessary to reduce all fractions to their lowest terms.

If the denominator is evenly divisible by the numerator, then reducing the fraction is made simple. The denominator is divided by the numerator with the result becoming the new denominator. When the numerator is divided by itself, the result will always be one.

8/32 is reduced to 32 ÷ 8 = 4 with no remainder,
therefore 32 ÷ 8 = 4 and 8 ÷ 8 = 1,
therefore 8/32 is reduced to 1/4

If the denominator is not divisible by the numerator, a number is searched for by which both the denominator and numerator are both evenly divisible. If a number is found, both the denominator and numerator are divided by that number and a new fraction is formed. A number is then searched for that will evenly go into both the denominator and numerator of the new fraction.

25/95 is reduced to 95 ÷ 25 = Not evenly divisible
Not evenly divisible by 2, 3, or 4,
95 ÷ 5 = 19 and 25 ÷ 5 = 5,
therefore 25/95 is reduced to 5/19
5/19 is not evenly divisible by any number.

Useful rules:

- Both numbers even, divisible by 2.
- Both numbers end in 0 or 5, divisible by 5.
- Both numbers end in 0, cancel zeros top and bottom.

When no number can be divided evenly (without any remainder) into both denominator and numerator of a fraction, the fraction is said to be reduced to its lowest terms.

Section 8

Multiplication of Fractions

The product of two or more fractions is obtained by multiplying the numerators to form the numerator of the product, and by multiplying the denominators to form the denominator of the product. The resulting fraction is then reduced to its lowest terms.

A common denominator need not be found in the multiplication of fractions because the new denominator will, in most cases, be different from that of all the original fractions.

The following example illustrates the multiplication of fractions: What is the product of 3/5 × 12/22 × 1/2?

Multiply the numerators together.

$3 \times 12 \times 1 = 36$

Multiply the denominators together.

$5 \times 22 \times 2 = 220$

The multiplication operations result in a new fraction.

$^{3}/_{5} \times {}^{12}/_{22} \times {}^{1}/_{2} = {}^{36}/_{220}$

Reduce the resulting fraction to its lowest terms. The LCD is found to be 4. Therefore:

${}^{36}/_{220} = {}^{9}/_{55}$

Section 9

Simplification of Fractions by Cancellation

General procedures for cancellation. Cancellation is a technique of dividing out, or canceling, all common factors that exist between numerators and denominators. This aids in locating the ultimate product by eliminating much of the burdensome multiplication.

To help illustrate cancellation, the following sample problem is provided. What is the product of:

${}^{18}/_{10} \times {}^{5}/_{3} = ?$

The product can be found by multiplying 18 × 5 and 10 × 3, then dividing the product of the numerators by the product of the denominators. A much easier method of solution is by cancellation.

The 10 in the denominator of 18/10 and the 5 in the numerator of the fraction 5/3 can both be divided an exact number of times by 5.

$$\frac{18}{\underset{2}{\cancel{10}}} \times \frac{\overset{1}{\cancel{5}}}{3} =$$

The 18 in the numerator of 18/10 and denominator 3 in the fraction 5/3 are exactly divisible by 3.

$$\frac{\overset{6}{\cancel{18}}}{\underset{2}{\cancel{10}}} \times \frac{\overset{1}{\cancel{5}}}{\underset{1}{\cancel{3}}} =$$

The 6 in the numerator and the 2 in the denominator of the resultant fraction are both divisible by 2.

$$\frac{\overset{\overset{3}{\cancel{6}}}{\cancel{18}}}{\underset{\underset{1}{\cancel{2}}}{\cancel{10}}} \times \frac{\overset{1}{\cancel{5}}}{\underset{1}{\cancel{3}}} = \frac{3 \times 1}{1 \times 1} = \frac{3}{1} = 3$$

The fraction is thus reduced to its lowest terms, and the final multiplication and division steps are performed with ease, when compared with the task of multiplying and dividing the larger fractions.

Section 10

Division of Common Fractions

To divide common fractions, the mathmatical function of multiplication, not division, is used. To divide one fraction by another, simply invert the denominator then multiply the numerators together and the denominators together. This is known as the inverted divisor method.

Keep in mind the order in which the fractions are written. It is important in the division of fractions that the proper fraction be inverted. Remember that it is always the divisor that is inverted, never the dividend.

To illustrate the division of fractions, the following example is provided. Divide 1/3 by 1/2.

$$\frac{1}{3} \div \frac{1}{2} = \frac{1}{3} \times \frac{2}{1} = \frac{1 \times 2}{3 \times 1} = \frac{2}{3}$$

Section 11

Converting Common Fractions into Decimals

A decimal fraction is obtained by dividing the numerator of a common fraction by the denominator and showing the quotient as a decimal. If necessary, zeros are added to the right to permit carrying the quotient to the desired accuracy. As an example, 5/8 is converted into a decimal by dividing the 5 by the 8 which is equal to 0.625.

Section 12

Converting Decimal Fractions into Common Fractions

To change a decimal fraction to a common fraction, count the number of digits to the right of the decimal point. Express the number as the numerator of a fraction whose denominator is 1 followed by the number of zeros that will equal the number of digits to the right of the decimal point.

As an example, the number 0.375 is converted into a common fraction by first counting the numbers to the right of the decimal, which is 3. The number 375 is then placed over the number 1 with 3 zeros behind it.

$$0.375 = \frac{375}{1000}$$

Reduction of the new fraction is then accomplished if it is desired or necessary.

$$\frac{375}{1000} = \frac{15}{40} = \frac{3}{8}$$

Section 13

Rounding Off Decimal Numbers

The whole realm of measurement involves numbers that are only approximations of precise numbers. The degree of accuracy of these measurements depends on the refinement of the measuring instruments. To prevent having to use unrealistically large or small, but extremely accurate, numbers where precision to that degree is not necessary, decimal numbers are rounded off.

A decimal expression is *rounded off* by retaining the digits for a certain number of places and discarding the rest.

The retained number is an approximation of the computed or exact number. The degree of accuracy desired determines the number of digits to be retained.

When the digit immediately to the right of the last retained digit is 5 or greater, increase the last retained digit by 1. When the digit immediately to the right of the last retained digit is less than 5, leave the last retained digit unchanged.

As an example of a situation where it is necessary to *round* a number to some value that is practical to use, a measurement is computed to be 29.4948 inches. It is impractical, if not impossible, to measure this accurately with a steel rule which is accurate only to 1/64 of an inch. We can use the process of rounding to find a practical measurement.

For this example, it is assumed that the measuring equipment, which we will use, is accurate to the nearest tenth. Based on this assumption, round 29.4948 to the nearest tenth.

1. Determine the number of digits to retain. In this case, one-tenths being the first place to the right of the decimal point.

   29.4948

2. Change the value of the last retained digit, if required. In this case, since 9 is greater than 5, the final decimal is expressed thus:

   29.4948 becomes 29.5 inches

Section 14

Signed Numbers

Signed numbers are numbers that have directional value from a given starting point, which is usually zero. Numbers above or to one side (usually right) of zero are called positive, and are designated by the use of the plus or positive sign (+). Those numbers below or to the opposite side (usually left) of zero are designated as negative, and are designated by the use of the minus or negative sign (–). Figure 1-14-1 is representative of signed numbers on a horizontal scale.

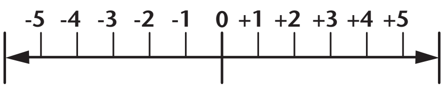


Figure 1-14-1. A scale of signed numbers.

Addition of signed numbers. When adding two or more positive numbers, whether whole or fractional numbers, normal addition procedures are used. The result will be a positive number. Using Figure 1-14-1, addition of positive numbers is always done to the right on the scale.

When adding two or more negative numbers, whether whole or fractional, normal addition procedures are used. The result will always be a negative number. Using Figure 1-14-1, addition of negative numbers is always done to the left on the scale.

To add a positive and a negative number, find the difference in their actual values and give this difference the sign (+ or –) of the larger number. The secret to adding a negative number to a positive one is that adding a negative is the same as subtracting a positive number. If the negative number is smaller then the positive number, just simply subtract.

Subtraction of signed numbers. When subtracting two or more positive numbers, whether whole or fractional numbers, normal subtraction procedures are used. If the subtrahend is smaller then the minuend, the remainder will be a positive number. If the subtrahend is larger then the minuend, the remainder will be a negative number. Using Figure 1-14-1, subtraction of positive numbers is always done to the right on the scale.

When subtracting two or more negative numbers, whether whole or fractional, normal subtraction procedures are used. If the subtrahend is smaller then the minuend, the remainder will be a negative number. If the subtrahend is larger then the minuend, the remainder will be a positive number. Using Figure 1-14-1, subtraction of negative numbers is always done to the left on the scale.

To subtract positive and negative numbers, change the sign of the subtrahend (the number to be subtracted) and proceed as in addition.

Subtracting positive and negative numbers can be illustrated by finding the temperature difference between a temperature reading of +20 at 5,000 feet and a reading of –6 at 25,000 feet. Follow the rule, *a change in temperature is equal to the first reading, subtracted from a second reading.*

Change the sign of the number to be subtracted.

+20 becomes –20

Combine the two terms, following the procedures for adding like signs.

(–6) + (–20) = –26 degrees

Multiplication of signed numbers. Multiplication of signed numbers follows the same procedures as multiplication of any other number or fraction. After the multiplication process is completed, the product must be assigned a sign.

To find the product of any two signed numbers, there are three simple rules to remember.

- The product of two positive numbers is always positive (+).
- The product of two negative numbers is always positive (+).
- The product of a positive and a negative number is always a negative (–) number.

The following examples illustrate multiplication of signed numbers:

$3 \times 6 = 18 \quad -3 \times 6 = -18$
$-3 \times -6 = 18 \quad 3 \times -6 = -18$

Division of signed numbers. Division of signed numbers follows the same procedures as division an any other number or fraction. After the division process is completed the quotient must be assigned a sign.

To find the quotient of any two signed numbers, there are three simple rules to remember.

- The quotient of two positive numbers is always positive (+).
- The quotient of two negative numbers is always positive (+).
- The quotient of a positive and a negative number is always a negative (–) number.

The following examples illustrate division of signed numbers:

$6 \div 3 = 2 \quad -6 \div 3 = -2$
$-6 \div -3 = 2 \quad 6 \div -3 = -2$

Section 15

Percentage

Percentage is simply the division of a whole into 100 even parts, and expressing the number of those parts that apply in a given situation. When using percentage, rather than refer to *one-half* or *fifty hundredths*, the term 50 percent is used.

Finding a number that is a given percentage of another. The technique used in determining a percent of a given number is based on the fundamental process of multiplication. It is necessary to state the desired percent as a decimal or common fraction and multiply the given number by the percent expressed.

The following example is used to illustrate finding the percentage of a given number:

In an example to illustrate finding a number from a percentage of another number, the cruising speed of an airplane at an altitude of 7,500 feet is 290 knots. What is the cruising speed at 9,000 feet if it has increased 6 percent?

1. State the desired percent as a decimal.

   $6\% = 0.06$

2. Multiply the given number by the decimal expression.

   $290 \times 0.06 = 17.40$

3. Add the new product to the given number. This is the new cruising speed.

   $290 + 17.4 = 307.4$ knots

Finding what percentage one number is of another. Determining what percent one number is of another is done by writing the partial number as the numerator of a fraction and the whole number as the denominator of that fraction, and then expressing this fraction as a percentage.

As an example, a motor rated as 12 horsepower is found to be delivering 10.75 horsepower.

What is the motor efficiency expressed in percent?

1. Write the partial number (10.75) as the numerator of a fraction whose denominator is the whole number (12).

   $\frac{10.75}{12}$

2. Convert the fraction to its decimal equivalent.

   $10.75 \div 12 = 0.8958$

3. Express the decimal as a percent.

   $0.8958 = 89.58\%$ efficient

Finding the total number when part of the number and its percentage are known. To determine a number when a percent of it is known, express the percent as a decimal and divide the known number by the decimal expression.

As a sample problem, 80 ohms represent 52 percent of a circuit's total resistance. Find the total resistance of this circuit.

1. Express the percent as a decimal.

   52% = .52

2. Divide the known number by the decimal expression.

   80 ÷ .52 = 153.8 ohms total resistance

Section 16

Ratio

An important application of the common fraction is that of ratio. A ratio represents the comparison of one number to another number.

Comparison by the use of ratios has widespread application in the field of aviation. A ratio is used to express the comparison of the volume of a cylinder when the piston is at bottom center, to the volume of a cylinder when the piston is at top center. This is referred to as the compression ratio. The aspect ratio of an aircraft wing is a comparison of the wing span to the wing chord. The relationship of maximum speed, wing area, wing span, loaded weight, and horsepower of different makes and models of aircraft may be compared through the use of ratios.

A ratio is the quotient of one number divided by another number, expressed in like terms. It is, therefore, the fractional part that one number is of another.

- Ratios may be expressed as fractions, or may be written using the colon (:) as the symbol for expressing ratio. Thus the ratio 7/8 can be written 7:8.
- Ratios may also be expressed as decimal equivalents, such as 7:8 = 0.875

This decimal equivalent is especially useful when expressing air/fuel ratios as used in modern engines.

Section 17

Proportion

A proportion is a statement of equality between two or more ratios.

The first and last terms of the proportion are called the extremes. The second and third terms are called the means. Thus the following example is read 3 is to 4 as 6 is to 8.

$$\frac{3}{4} = \frac{6}{8}\text{; or } 3:4 = 6:8$$

In any proportion, the product of the extremes is equal to the product of the means. In the proportion

$$2:3 = 4:6$$

the product of the *extremes*, 2 × 6, is 12; the product of the *means*, 3 × 4, also is 12. An inspection of any proportion will show this to be true. This rule simplifies the solution of many practical problems.

As an example, an airplane flying a distance of 300 miles used 24 gallons of gasoline. How many gallons will it need to travel 750 miles?

1. Find related quantities (like labels).
2. Set them as a fraction.
3. Write an equals sign.
4. Place the third known value on the same line as its like label.

$$\frac{300 \text{ miles}}{750 \text{ miles}} = \frac{24 \text{ gal}}{x \text{ gal}}$$

$$300:750 = 24:x$$
$$300x = 750 \times 24$$
$$300x = 18{,}000$$
$$x = 60 \text{ gal of gasoline}$$

This example should be written as:

$$300:750 = 24:x$$
$$(300)(x) = (750)(24)$$
$$300x = 18{,}000$$
$$x=60$$

Sixty gallons of gasoline will be required to travel a distance of 750 miles.

Section 18

Powers and Roots

Raising a number to a given power. When one number, the base, is used as a factor two or more times, the result is a power of that base.

A positive integral exponent, written as a small number just to the right and slightly above the base number, indicates the number of times the base is used as a factor. Thus, 4 squared or 4^2

means 4 × 4, which is 16. The 4 is the base, the 2 is the exponent, and the 16 is the power.

Extracting the root of a number. A root of a number is one of two or more equal numbers that, when multiplied together, will produce the number. Such a number is called an *equal factor.*

Thus, two equal factors that will produce 9 when multiplied together are 3 and 3. Therefore, the square root of 9 equals 3. This may be written $\sqrt{9} = 3$. The symbol $\sqrt{}$ is called a radical sign.

Another method of indicating the square root of a number is to use a fractional exponent such as $9^{1/2} = 3$. If the root to be taken is other than a square root, it may be shown in a similar manner; that is, the cube root of 9 may be written $9^{1/3}$. For example, the cube root of 8 equals 2 and may be written $\sqrt[3]{8} = 2$, or $8^{1/3} = 2$; the fourth root of 256 equals 4 and may be written $\sqrt[4]{256} = 4$, or $256^{1/4} = 4$.

Computation of square root. It is comparatively easy to determine the square root of such numbers as 4, 9, 16, and 144. The numbers are the perfect squares of small numbers. Unfortunately, all numbers are not perfect squares; neither are they small.

The square of a number is the product of that number multiplied by itself. The square root of a number is the reverse process of squaring a number, and is essentially a special division process. A description of this process is presented in the following example:

Find the square root of 213.16.

```
 √213.16
```

Starting at the decimal point, and marking off in both directions from the decimal point, separate the number into periods of two figures each. The last period at the left end need not have two figures; all others must have two figures. A zero may be added to the right end so that the period will have two figures.

```
 √2 13. 16
```

Next select the largest number that can be squared in the first period. Place the selected number above the radical sign, and place the square of this number under the first period and subtract.

```
     1
   √2 13. 16
1    1
     1
```

Then bring down the next pair.

```
     1
   √2 13. 16
1    1
     1 13
```

Multiply the root by 2 and place the product to the left of the remainder as the trial divisor.

```
     1
   √2 13. 16
2    1
     1 13
```

Determine the number of times the trial divisor will go into that portion of the remainder that is one digit more than the trial divisor. Write this number to the right of the digit in the trial divisor to form the final divisor and also to the right of the digit in the root.

```
      1 4.
    √2 13. 16
      1
24    1 13
```

Multiply this number times the completed divisor. If the resulting product is larger than the remainder, reduce the number by one, both in the root and in the final divisor, and repeat the multiplication process.

```
      1 4.  6
    √2 13. 16
      1
24    1 13
        96
```

Subtract the product formed from the remainder and bring down the next pair to form a new remainder.

```
      1 4.  6
    √2 13. 16
      1
24    1 13
        96
        17 16
```

To complete the solution of extracting the square root, simply repeat the procedure set forth in this step for each period of numbers remaining. It is unnecessary to carry the root beyond the number of digits possessed by the original number.

```
       1 4.  6
     √2 13. 16
       1
 24    1 13
         96
286      17 16
         17 16
```

The decimal is placed in the root so that the number of digits in the whole number portion of the root is equal to the sum of the periods, or pairs, in the whole number portion of the number from which the root was extracted.

Section 19

Computing Area

Formulas used in measuring deal with the dimensions, areas, and volumes of geometric figures. There are six geometric figures with which the technician should be familiar, and there is a separate formula for finding the area of each. These figures are the rectangle, the square, the triangle, the parallelogram, the trapezoid, and the circle.

Areas are measured in different units. An area that is square and 1 inch on each side is called a square inch. All area units are square units, such as square inch, square foot, square yard, square rod, square mile, square centimeter, and the square meter. The area of a figure is equal to the number of square units it contains (Table 1-19-1.)

The technique for determining the area of any geometric shape is based upon the use of formulas. To solve a problem by formula, it is necessary to:

1. Select the formula that covers the problem situation.
2. Insert the known values in the selected formula.
3. Then make the necessary mathematical manipulations to find the unknown quantity.

Table of areas	
144 square inches (in.^{2})	= 1 square foot
	= L x W
	= 12" x 12"
	= 144 in^2
9 square feet (ft.^{2})	= 1 square yard
	= L x W
	= 3' x 3'
	= 9 ft^2
30 1/4 square yards (yd.^{2})	= 1 square rod
	= L x W
	= 5.5 yd x 5.5 yd
	= 30 1/4 yd^2
160 square rods (rd^2)	= 1 acre
	= L x W
	= 12.64 rd x 12.64 rd
	= 160 rd^2
640 acres (A)	= 1 square mile
	= L x W
	= 25.29 A x 25.29 A
	= 640 A

Table 1-19-1. Table of areas.

Area of a rectangle. A rectangle is a four-sided figure whose opposite sides are of equal length. All angles of the rectangle are right angles (90°), the sum of which equals 360°. The cross-sectional area of many beams, rods, fittings, etc. (Figure 1-19-1) are rectangles.

The area of a rectangle is the product of the measures of the length and width when they are expressed in the same units of linear measure. The area may be expressed by the formula:

$$A = LW$$

Where:
A = Area
L = Length of rectangle
W = Width of rectangle

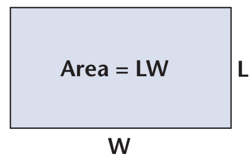


Figure 1-19-1.
A rectangle.

As an example, a certain aircraft panel is in the form of a rectangle having a length of 24 inches and a width of 12 inches. What is the area of the panel expressed in square inches?

First determine the known values and substitute them in the formula.

$$A = LW$$

$$A = 24'' \times 12''$$

Perform the indicated multiplication; the answer will be the total area in square inches.

$$A = 24 \times 12 = 288 \text{ in}^2$$

Area of a square. A square is a figure having four equal sides and four right angles (Figure 1-19-2). The sum of all angles of a square, like the rectangle, equal 360°.

To determine the area of a square, find the product of the length of any two sides. Since a square is a figure whose sides are equal, the formula can be expressed as the square of the sides or:

$$A = S^2$$

where A is the area and S is the length of a side.

As an example, what is the area of a square plate whose side measures 25 inches?

Determine the known value and substitute it in the formula

$$A = S^2$$
$$A = 25^2$$

Next, perform the indicated multiplication. The answer will be the total area in square inches.

$$A = 25 \times 25 = 625 \text{ in}^2$$

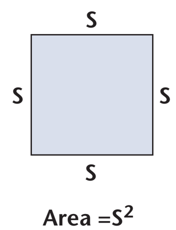


Figure 1-19-2.
A square.

Area of a triangle. A triangle is a three-sided polygon. There are three basic types of triangle: scalene, equilateral or equiangular, and isosceles. A scalene triangle is one in which all sides and angles are unequal, whereas the equilateral triangle, being just the opposite, has equal sides and equal angles. A triangle that has two equal sides and angles is known as an isosceles triangle. The various types of triangles are shown in Figure 1-19-3.

The sum of all of the angles of a triangle equal 180º.

Triangles may be further classified as either right, obtuse, or acute. These terms are descriptive of the included angles of the triangle. A right triangle is one that has one angle measuring 90º. In an obtuse triangle, one angle is greater than 90º, while in an acute triangle all the angles are less than 90º.

The base of a triangle is the side upon which the triangle is supposed to stand. Any side may be taken as the base.

Vertex is a common endpoint of the angles, or the point where the sides of the triangle meet.

The *altitude* of a triangle is the perpendicular line drawn from the vertex to the base. In some triangles, as in Figure 1-19-4, it may be necessary to extend the base so that the altitude will meet it.

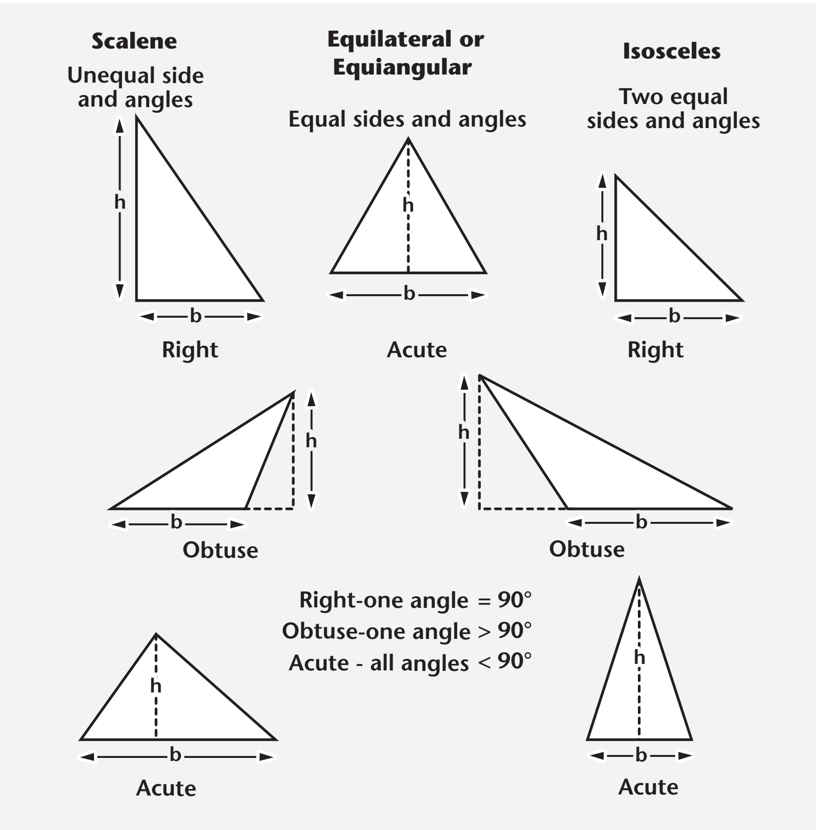


Figure 1-19-3. Types of triangles.

The *hypotenuse* of a triangle is the side which is neither the altitude nor the base. It is most often the longest side in scalene and isosceles triangles.

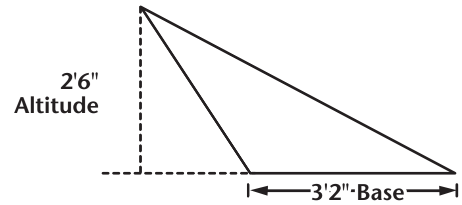


Figure 1-19-4. Triangle.

The area of any triangle may be calculated by using the formula:

$$A = \frac{1}{2}ab$$

where A is equal to Area; 1/2 is a given constant; a is the altitude of the triangle; and b is the base.

As an example, find the area of the triangle shown in Figure 1-19-4.

First, substitute the known values in the area formula.

$$A = \frac{1}{2}ab = A = \frac{1}{2} \times 2'6'' \times 3'2''$$

Then, solve the formula for the unknown value.

$$A = \frac{1}{2} \times 30 \times 38 = \frac{1140}{2}$$
$$A = 570 \text{ in}^2$$

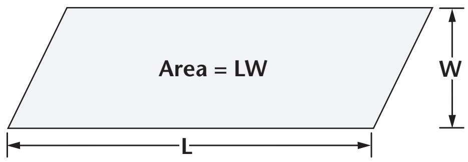


Figure 1-19-5. Finding the area of a parallelogram.

Area of a parallelogram. A parallelogram can be simply described as a rectangle with corner angles other than 90º. However, like the rectangle, opposite sides are of equal length, and the sum of all corner angles is equal to 360º. Diametrically opposite corner angles of a parallelogram are equal (Figure 1-19-5).

The area of a parallelogram is computed in the same manner as that of the rectangle with one principal difference; width is measured perpendicular to the length, not along the perimeter (outside edge) as in a rectangle (Figure 1-19-5.)

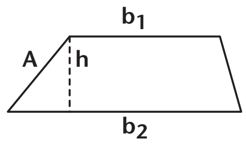


Figure 1-19-6. A trapezoid.

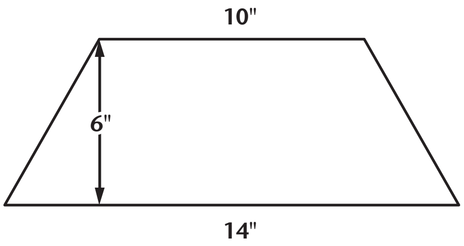


Figure 1-19-7. Computing the area of a trapezoid.

Area of a trapezoid. A four sided polygon, the trapezoid consists of two parallel sides, and two sides adjacent to the parallel sides which, unlike the rectangle or parallelogram, are not parallel to each other. While the total of all four angles of the trapezoid equal 360º, diametrically opposite corner angles of the trapezoid are not equal, as they are in the parallelogram.

The area of a trapezoid is computed by using the formula:

$$A = 1/2\,(b_1 + b_2)\,h$$

where A is the area; 1/2 is the given constant; b_1 and b_2 are the lengths of the two parallel sides; and h is the height (Figure 1-19-6.)

The following example illustrates calculation of the area of a trapezoid. What is the area of a trapezoid whose bases are 14 inches and 10 inches, and whose altitude is 6 inches? (Figure 1-19-7.)

Substitute the known values in the formula.

$$A = {}^1/_2\,(b_1 + b_2)\,h$$
$$A = {}^1/_2\,(10 + 14)\,6$$

Next, solve the formula for the unknown value.

$$A = {}^1/_2\,(24)\,6$$
$$A = {}^1/_2 \times 144$$
$$A = 72\ in^2$$

Area of a circle. To find the area of a circle, it is necessary to use a number called pi (π). This number represents the ratio of the circumference to the diameter of any circle. Because that ratio is the same regardless of the size of the circle, π is a constant. Which means that it is a fixed figure, which does not change. But π cannot be found exactly because it is, theoretically, a never-ending decimal. However, expressed to four decimal places it is 3.1416, which is accurate enough for most computations (Figure 1-19-8.)

The area of a circle, as in a rectangle or triangle, must be expressed in square units. The diameter of a circle is the distance between any two most distant points on the circle. In other words, the diameter is the distance across the circle. The distance that is one-half the diameter of a circle is known as the radius.

The area of any circle is found by squaring the radius and multiplying by π. The formula is expressed thus:

$$A = \pi r^2$$

where A is the area of a circle; π is the given constant; and r is the radius of the circle.

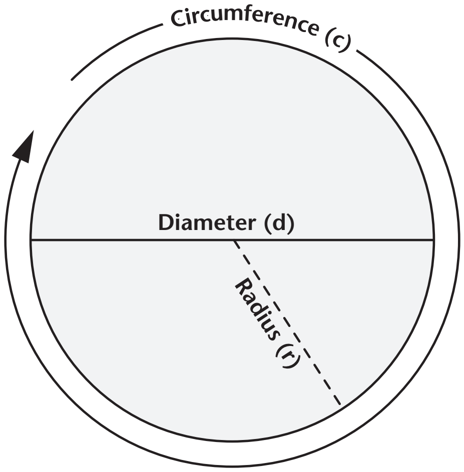


Figure 1-19-8. A circle.

In a sample problem to determine area of a circle, the bore (inside diameter) of a certain aircraft engine cylinder is 5 inches. Find the cross sectional area of this bore.

First substitute the known values in the formula, $A = \pi r^2$.

$$A = 3.1416 \times 2.5^2$$

Then solve the formula for the unknown value.

$$A = 3.1416 \times 6.25$$
$$A = 19.635\ in^2$$

Section 20

Measurement of Solids

Solids are objects with three dimensions; length, breadth, and thickness. They are of many shapes, including prisms, cylinders, pyramids, cones, and spheres. Occasionally, it is necessary to determine the volume of some of the most common solids, such as the rectangle, the cube, the cylinder, or the sphere.

Since all volumes are not measured in the same units, it is necessary to know all the common units of volume and how they are related to each other.

1,728 in.^{3}	=	1 ft. ^{3}
27 ft.^{3}	=	1 yd.^{3}
231 in.^{3}	=	1 gal.
7.5 gal.	=	1 ft.^{3}
2 pt.	=	1 qt.
4 qt.	=	1 gal.

Table 1-20-1. Units of space measure.

For example, the technician may know the volume of a tank in cubic feet or cubic inches, but when the tank is full of gasoline, he will be interested in how many gallons it contains. Table 1-20-1 shows the relationship between some of the common units of volume.

Volume of a rectangular solid. A rectangular solid is a solid bounded by rectangles. In other words, it is a square-cornered volume, such as a box (Figure 1-20-1).

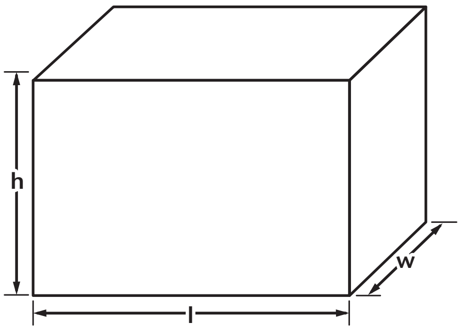


Figure 1-20-1. A rectangular solid.

The formula for determining the volume of a rectangular solid may be expressed thus:

$$V=lwh$$

where:

V=Volume
w = width
l=length
h=height

As an example, a rectangular-shaped baggage compartment measures 5 feet 6 inches in length, 3 feet 4 inches in width, and 2 feet 3 inches in height. How many cubic feet of baggage will it hold?

Substitute the known values into the formula.

$$V=lwh$$
$$V=5'6'' \times 3'4'' \times 2'3''$$

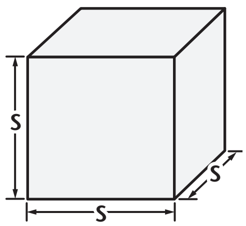


Figure 1-20-2. A cube.

Next, solve the formula for the unknown value.

$$V = 5'6'' \text{ x } 3'4'' \text{ x } 2'3''$$
$$V = 5\tfrac{1}{2}' \text{ x } 3\tfrac{1}{3}' \text{ x } 2\tfrac{1}{4}'$$
$$V = 5\tfrac{1}{2} \text{ x } 3\tfrac{1}{3} \text{ x } 2\tfrac{1}{4}$$
$$V = \frac{11}{2} \text{ x } \frac{10}{3} \text{ x } \frac{9}{4}$$
$$V = \frac{165}{4} = 41.25 \text{ ft}^3$$

Notice the figures retain the ft increments for ease of conversion.

Volume of a cube. If the solid has equal dimensions, it is called a cube and the formula can be expressed by using an exponent.

The formula for a cube, or rectangular solid (Figure 1-20-2), can be expressed as the cube of the sides:

$$V=S^3$$

where V is the volume and S is the side measurement of the cube.

$$V=S^3$$
$$V=(12'')^3$$
$$V=1{,}728 \text{ in}^3$$

Volume of a cylinder. A solid having circular ends with a length between those ends, such as a can, length of pipe, or other such object is called a cylinder. To be a true cylinder, the circular ends must be identical in size, as shown in Figure 1-20-3.

The volume of a cylinder may be found by multiplying the cross-sectional area of the circular ends, by the height of the cylinder. The formula may be expressed as:

$$V = \pi r^2 h$$

where V is the volume; π is the given constant; r^2 is the square of the radius of the cylinder; and h is the height of the cylinder.

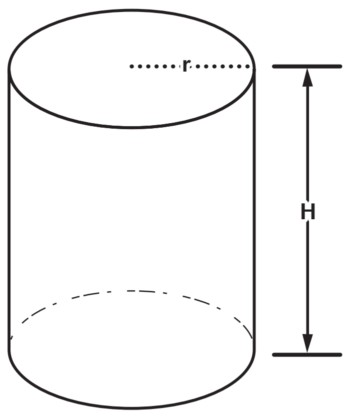


Figure 1-20-3. A cylinder.

The following example is used to illustrate finding the volume of a cylinder. The cylinder of an aircraft engine has a bore (inside diameter) of 5.5 inches and the engine has a stroke of 5.5 inches. What is the piston displacement of one cylinder? The stroke represents the height of the cylinder to be measured, because the volume displaced by the piston depends on the length of the stroke. (Figure 1-20-4)

First substitute the known values in the formula.

$V=\pi r^2 h$
$V=(3.1416)\ (2.75^2)\ (5.5)$

Then solve the formula for the unknown value.

$V = 17.28 \times 7.56$
$V = 130.64\ in^3$

Volume of a sphere. A sphere is a round three-dimensional object whose entire surface is located at an equal distance from the point which is the exact center of the sphere. Because of its strength and ability to withstand extremely high internal pressures, the sphere is used in a variety of applications on aircraft where these attributes are needed, such as liquid oxygen converters and hydraulic accumulators.

The volume of a sphere is determined by multiplying the cube of the diameter by a factor which is one-sixth of π, or 0.5236.

As an example of determining the volume of a sphere, if a spherical hydraulic accumulator is 8 inches in diameter, what is the total volume?

First, cube the diameter.

$8^3 = 8 \times 8 \times 8 = 512$

Then multiply the cubed diameter by one-sixth of π.

512 (0.5236) = 268.08 = 268 cubic inches

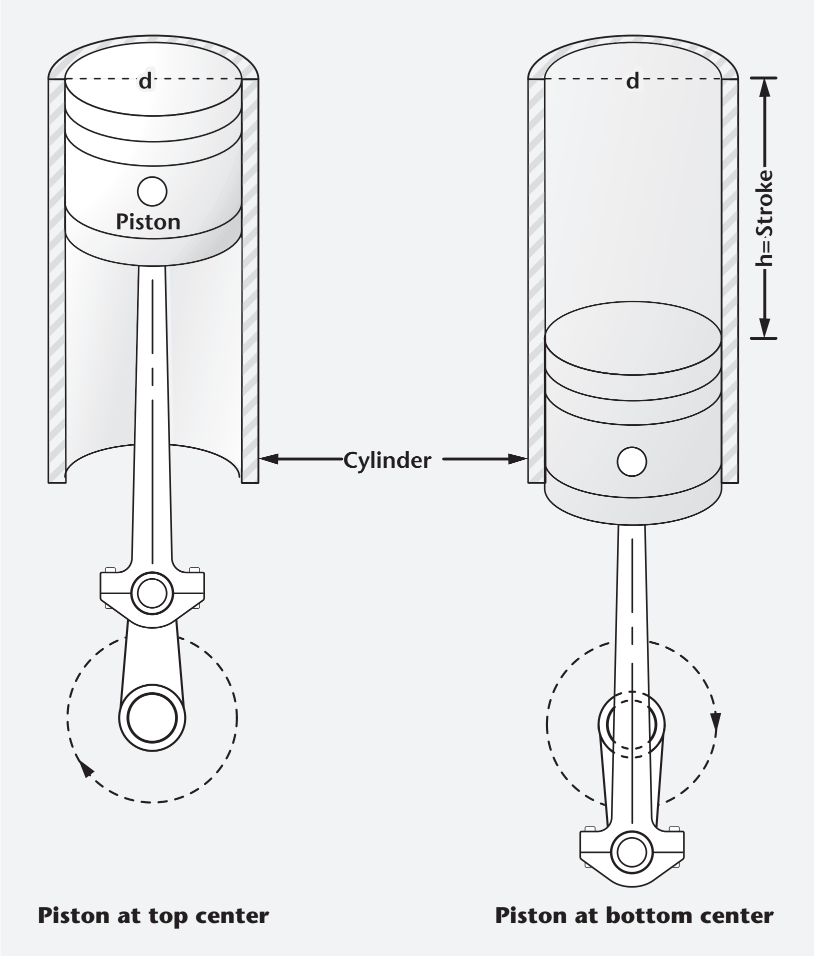


Figure 1-20-4. How cylinder displacement is measured.

Section 21

Trigonometric Functions

Trigonometry is a very practical and handy tool for use in the measurement of triangles. Its use simplifies many of our layout problems in sheet metal, and it makes possible the understanding of such subjects as alternating current electricity.

Trigonometry deals with relationships that exist between the lengths of the three sides and the three angles of a triangle. While trigonometry can become very complex, for the purposes of the aircraft technician, the primary concern will be with right triangles.

Figure 1-21-1 is a right triangle with the angles and sides identified. Angle C is the right angle. For this explanation, we will use angle A as the angle for which we are setting up the relationships. Side c is the hypotenuse, which, by definition, is the side opposite the right angle. Side a is the side opposite angle A, and side b is the side adjacent, or next to, angle A.

The *sine* of angle A is the ratio of the length of the side opposite the angle to the length of the hypotenuse. For any degree of angle A, this ratio will be constant, regardless of the size of the triangle. In the chart of Table 1-21-1, we see that the sine of 30°, which is written Sin 30°, is 0.500. This means that the side opposite the 30° angle will be 50 percent, or one-half, the length of the hypotenuse. For a 45° angle, the ratio is 0.7071. The side opposite the 45° angle is 0.7071 times the length of the hypotenuse.

The *cosine* (cos) of an angle is the ratio of the length of the side adjacent to the angle to the length of the hypotenuse, and is found in the same way we found the sine of the angle. The cosine of 25° is 0.9063, and for 75°, it is 0.2588.

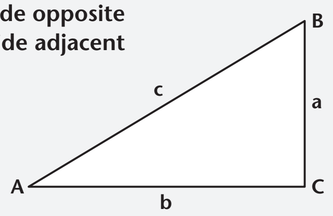
The *tangent* is the third ratio of interest in this brief introduction to trigonometry. This is the ratio of the length of the side opposite the angle, to the side adjacent the angle. The tangent of 20° is 0.3640, and for 70° is 2.747.

Trigonometric charts usually list the angles only to 45° in a single column, as can be seen by the numbers in the left-hand column of Table 1-21-1. But notice that in the extreme right-hand column,

Trigonometric functions					
Deg	Sin	Cos	Tan	Cotan	
0	0.0	1.0000	0.0		90°
1	0.0175	0.9999	0.0175	57.29	89°
2	0.0349	0.9994	0.0349	28.64	88°
3	0.0523	0.9986	0.0524	19.08	87°
4	0.0698	0.9976	0.0699	14.30	86°
5	0.0872	0.9962	0.0875	11.43	85°
6	0.1045	0.9945	0.1051	9.514	84°
7	0.1219	0.9926	0.1228	8.144	83°
8	0.1392	0.9903	0.1405	7.115	82°
9	0.1564	0.9877	0.1584	6.314	81°
10	0.1737	0.9848	0.1763	5.671	80°
11	0.1908	0.9816	0.1944	5.145	79°
12	0.2079	0.9782	0.2126	4.705	78°
13	0.2250	0.9744	0.2309	4.331	77°
14	0.2419	0.9703	0.2493	4.011	76°
15	0.2588	0.9659	0.2680	3.732	75°
16	0.2756	0.9613	0.2868	3.487	74°
17	0.2924	0.9563	0.3057	3.271	73°
18	0.3090	0.9511	0.3249	3.078	72°
19	0.3256	0.9455	0.3443	2.904	71°
20	0.3420	0.9397	0.3640	2.747	70°
21	0.3584	0.9336	0.3839	2.605	69°
22	0.3746	0.9272	0.4040	2.475	68°
23	0.3907	0.9205	0.4245	2.356	67°
24	0.4067	0.9136	0.4452	2.246	66°
25	0.4226	0.9063	0.4663	2.145	65°
26	0.4384	0.8988	0.4877	2.050	64°
27	0.4540	0.8910	0.5095	1.963	63°
28	0.4695	0.8830	0.5317	1.881	62°
29	0.4848	0.8746	0.5543	1.804	61°
30	0.5000	0.8660	0.5774	1.732	60°
31	0.5150	0.8572	0.6009	1.664	59°
32	0.5299	0.8481	0.6249	1.600	58°
33	0.5446	0.8387	0.6494	1.540	57°
34	0.5592	0.8290	0.6745	1.483	56°
35	0.5736	0.8192	0.7002	1.428	55°
36	0.5878	0.8090	0.7265	1.376	54°
37	0.6018	0.7986	0.7536	1.327	53°
38	0.6157	0.7880	0.7813	1.280	52°
39	0.6293	0.7772	0.8098	1.235	51°
40	0.6428	0.7660	0.8391	1.192	50°
41	0.6561	0.7547	0.8693	1.150	49°
42	0.6691	0.7431	0.9004	1.111	48°
43	0.6820	0.7314	0.9325	1.072	47°
44	0.6947	0.7193	0.9657	1.036	46°
45	0.7071	0.7071	1.0000	1.000	45°
	Cos	Sin	Cotan	Tan	Deg

Table 1-21-1. Table of trigonometric functions.

C = Right angle
c = Hypotenuse
A = Angle being considered
a = Side opposite
b = Side adjacent



$$\text{Sine A (Sin A)} = \frac{\text{Side opposite}}{\text{Hypotenuse}} = \frac{a}{c}$$

$$\text{Cosine A (Cos A)} = \frac{\text{Side adjacent}}{\text{Hypotenuse}} = \frac{b}{c}$$

$$\text{Tangent A (Tan A)} = \frac{\text{Side opposite}}{\text{Side adjacent}} = \frac{a}{b}$$

Figure 1-21-1. The trigonometric relations of a right triangle.

the numbers start at 45° and go upward to 90°. In addition, the names of the columns at the bottom are opposite the names at the top of the same column. Reading up in the right column, we find 60°, and in the *sine* column (at the bottom of the chart) we find that sine 60° = 0.8660.

In any triangle, the sum of the angles is always 180°. With the use of trigonometry, when we know the size of angle A, we can find angle B, or angle C. And when we know the length of one side and one angle (other than the 90° angle), all other sides and angles can be computed for right triangles.

Angle B = 90° – Angle A

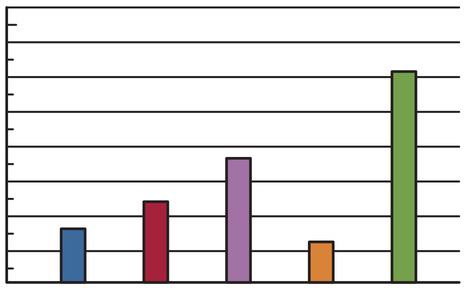
Section 22

Graphs and Charts

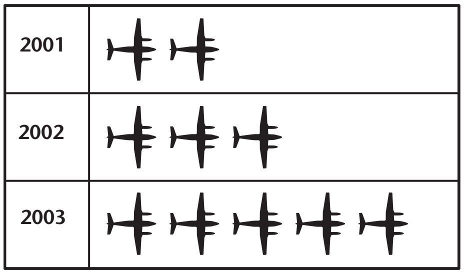
Graphs and charts are pictorial presentations of data, equations, and formulas.

The relationship between two or more quantities may be more clearly understood through their use. Also, a person can see certain conditions or relationships at a glance, while it would require considerable time to obtain the same information from a written description. Graphs may be used in a number of ways, such as representing a single equation or formula, or to solve two equations for a common value.

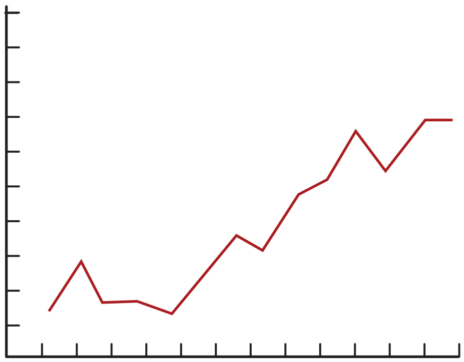
Graphs and charts take many forms. A few of the more common forms are called bar graphs, pictographs, broken-line graphs, continuous-



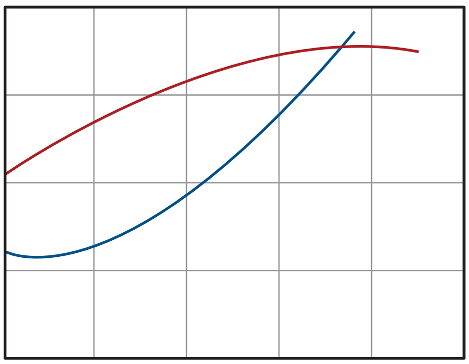
A. Bar graph



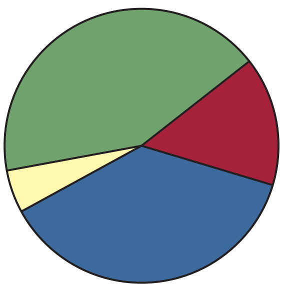
B. Pictograph



C. Broken line graph



D. Continuous curved line graph



E. Pie chart

Figure 1-22-1. Types of graphs.

curved-line graphs, and pie charts. An example of each is shown in Figure 1-22-1. The most useful of these graphs in technical work is the continuous-curved-line graph.

Interpreting or reading graphs and charts. It is more important, from the mechanic's viewpoint, to be able to read a graph properly than it is to draw one. The relationship between the horsepower of a certain engine at sea level and at any altitude up to 10,000 feet can be determined by use of the chart in Figure 1-22-2. To use this type of chart, simply find the point on the horizontal axis that represents the desired altitude; move upward along this line to the point where it intersects the curved line; then move to the left, reading the percent of sea level horsepower available on the vertical axis.

As an example, what percent of the sea level horsepower is available at an altitude of 5,000 feet?

First locate the point on the horizontal axis that represents 5,000 feet. Move upward to the point where the line intersects the curved line.

Then move to the left, reading the percent of sea level horsepower available at 5,000 feet. The available horsepower is 80 percent.

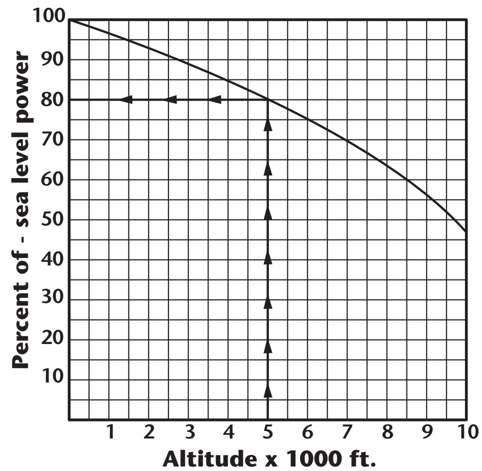


Figure 1-22-2. Horsepower vs. altitude chart.

Nomograms. It is often necessary to make calculations using the same formula, but with different sets of values for the variables. It is possible to obtain a solution by use of a calculator, or by preparing a table giving the solution of the formula resulting from successive changes of each variable. However, in the case of formulas involving several mathematical operations, the labor involved is usually very extensive.

It is possible to avoid all this labor by using a diagram representing the formula, in which each variable is represented by one or more graduated lines. From this diagram, the solution of the

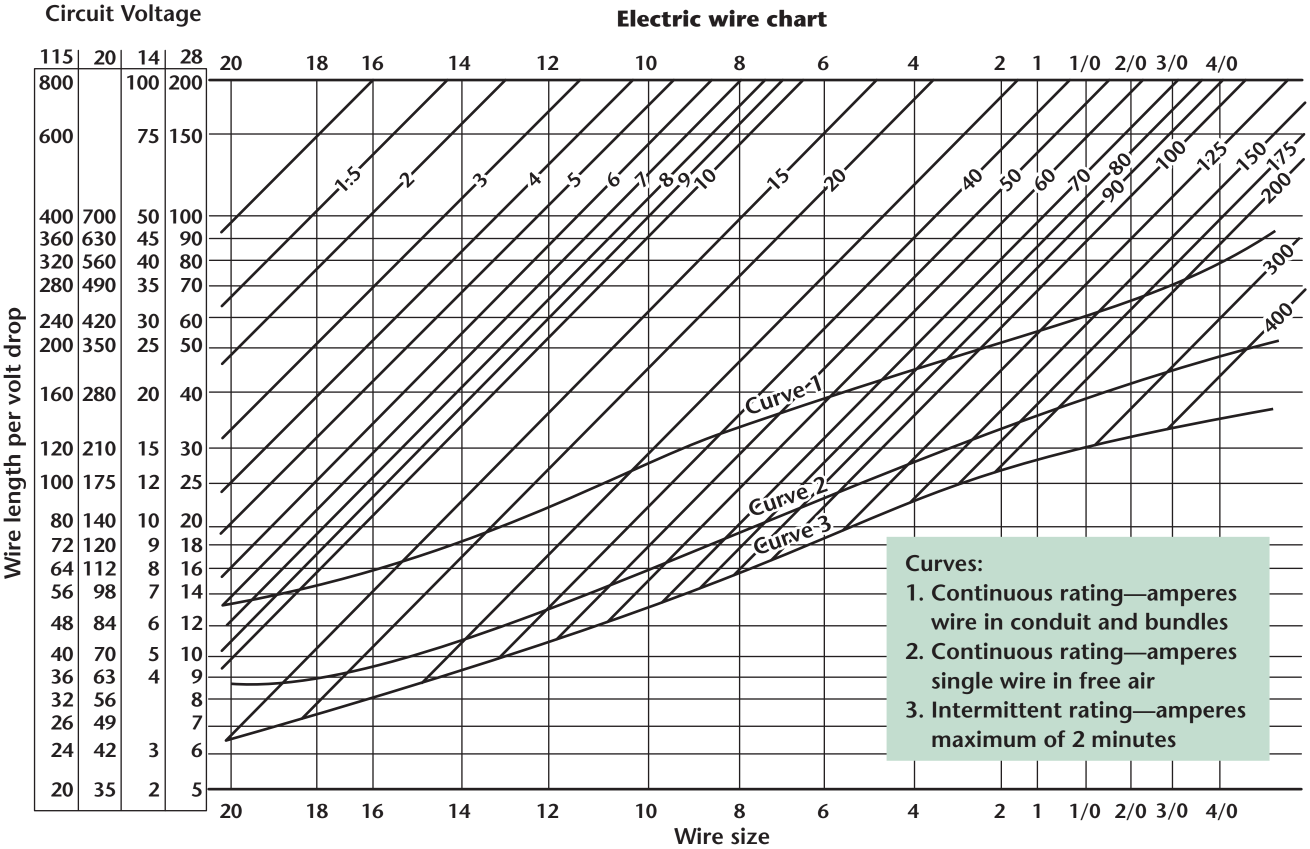


Figure 1-22-3. Sample of a nomogram.

formula for any given variable may be read by means of an index line. A diagram of this type is known as a nomogram (Figure 1-22-3).

Much of the information needed to solve aeronautical problems is presented in nomogram form. Instruction manuals for the various aircraft contain numerous nomograms, many of which are quite complex. Many of them will possess several curves on the same coordinate axis, each curve drawn for different constants in the equation. In the latter case, it is essential to select the proper curve for the desired conditions.

Metric length	Mass	Volume	Temperature	Electric	Time
Meter	Kilogram	Liter	Celsius/centigrade	Ampere	Second
Customary (English)					
Inch Foot Fathom Rod Mile	Ounce Pound Ton Grain Dram	Fluid ounce Teaspoon Tablespoon Cup Pint Quart Gallon Barrel Peck Bushel	Fahrenheit	Ampere	Second Minute Hour

Table 1-23-1. Some common units.

Section 23

Measurement Systems and Conversion

Our customary system of measurement involves the English units of inches, feet, yards, and miles that have been refined from earlier crude measuring units and devices. An example of common English and metric units is contained in Table 1-23-1.

The metric system is the dominant language of measurement in use in the world today. The United States is the only developed country in which the metric system of measurement is not in widespread use.

Using a *meter* as a standard, the metric system was developed by the French statesman, Talleyrand, in 1789. The meter is a specific portion of the circumference of the earth at the equator. It was intended to equal 10^{-7} or one ten-millionth of the length of the meridian through Paris from pole to the equator. From this base measurement the meter was developed and accepted as the standard. Divisions and multiples of the meter are based on the decimal system. In 1983 the CGPM (General Conference on Weights and Measures, or Conférence Générale des Poids et Mesures) replaced the previous definition with the following one: the meter is the length of the path traveled by light in vacuum during a time interval of 1/299,792,458 of a second.

No other system of measurement that has been actually used can match the inherent simplicity of the metric system. It was designed deliberately to fill all the needs of scientists and engineers. Laymen need only know and use a few simple parts of it.

It is logically streamlined. At this time there are only six base units in the International Metric System.

- The unit of length is the *meter.*
- The unit of mass is the *gram.*
- The unit of time is the *second.*
- The unit of electric current is the *ampere.*
- The unit of temperature is the *Kelvin* (which in common use is translated into the degree Celsius, formerly called degree centigrade).
- The unit of luminous intensity is the *candela.*

All the other units of measurement in the International Metric System are derived from these six base units. Area is measured in square meters; speed in meters per second; density in kilograms per cubic meter.

- The newton, the unit of force, is a simple relationship involving meters, kilograms, and seconds; and the pascal, unit of pressure, is defined as one newton per square meter.
- In some other cases, the relationship between the derived and base units must be expressed by rather more complicated formulas which is inevitable in any measurement system, because of the innate complexity of some of the things we measure.
- Similar relationships among mass, area, time, and other quantities in the customary system usually require similar formulas, made all the more complicated because they can contain arbitrary constants. For example, one horsepower is defined as 550 foot-pounds per second.

When you know:	You can find:	If you multiply by:
Length		
Inches	Millimeters	25.4
Feet	Centimeters	30.0
Yards	Meters	0.9
Miles	Kilometers	1.6
Millimeters	Inches	0.04
Centimeters	Inches	0.4
Meters	Yards	1.1
Kilometers	Miles	0.6
Area		
Square inches	Square centimeters	6.5
Square feet	Square meters	0.09
Square yards	Square meters	0.8
Square miles	Square kilometers	2.6
Acres	Square hectometers (Hectares)	0.4
Square centimeters	Square inches	0.16
Square meters	Square yards	1.2
Square kilometers	Square miles	0.4
Square hectometers (Hectares)	Acres	2.5
Mass		
Ounces	Grams	28.0
Pounds	Kilograms	0.45
Short tons	Megagrams (Metric tons)	0.9
Grams	Ounces	0.035
Kilograms	Pounds	2.2
Megagrams (Metric tons)	Short tons	1.1
Liquid volume		
Ounces	Millimeters	30.0
Pints	Liters	0.47
Quarts	Liters	0.95
Gallons	Liters	3.8
Milliliters	Ounces	0.034
Liters	Pints	2.1
Liters	Quarts	1.06
Liters	Gallons	0.26
Temperature		
Degrees Fahrenheit	Degrees Celsius	5/9 (after subtracting 32)
Degrees Celsius	Degrees Fahrenheit	9/5 (then add 32)

Table 1-23-2. Converting customary units.

English-metric conversion multiples and prefixes. Based on the decimal system, multiples and sub-multiples of any given unit are always related by powers of 10 in the metric system. For instance, there are 10 millimeters in 1 centimeter; 100 centimeters in 1 meter; and 1,000 meters in 1 kilometer. This greatly simplifies converting larger to smaller measurements. For example, in order to calculate the number of meters in 3.794 kilometers, multiply by 1,000 (move the decimal point three places to the right) and the answer is 3,794. For comparison, in order to find the number of inches in 3.794 miles, it is necessary to multiply first by 5,280 and then by 12 (Table 1-23-2).

Multiples and submultiples of all the International Metric units follow a consistent naming scheme, which consists of attaching a prefix to the unit, whatever it may be. For example, kilo stands for 1,000: 1 kilometer equals 1,000 meters, and 1 kilogram equals 1,000 grams. Micro is the prefix for one millionth: one meter equals one million micrometers, and one gram equals one million micrograms (Table 1-23-3).

To convert inches to millimeters, multiply the number of inches by 25.4. (Example: 25 in to mm = 25 × 25.4 = 635 mm)

To convert millimeters to inches, multiply millimeters by .04. (Example: 625 mm × .04 = 25 in)

To convert square inches to square centimeters, multiply by 6.5. (Example: 100 in^2 × 6.5 = 650 cm^2)

To convert square centimeters to square inches, multiply by 0.16. (Example: 100 × 0.16 = 16 in^2)

Provided for ease in converting fractions, decimals, and millimeters, in Table 1-23-4 various measurements starting at 1/64 inch up to 20 inches have been converted to decimal divisions of inches and to millimeters.

Prefix	Exp.	Means	Symbol
Tera	(10^{12})	One trillion times	T
Giga	(10^{9})	One billion times	G
Mega	(10^{6})	One million times	M
Kilo	(10^{3})	One thousand times	k
Hecto	(10^{2})	One hundred times	h
Deca	(10)	Ten times	da
Deci	(10^{-1})	One tenth of	d
Centi	(10^{-2})	One hundredth of	c
Milli	(10^{-3})	One thousandth of	m
Micro	(10^{-6})	One millionth of	µ
Nano	(10^{-9})	One billionth of	n
Pico	(10^{-12})	One trillionth of	p

Table 1-23-3. Names and symbols for metric prefixes.

Section 24

Functions of Numbers

The Functions of Numbers chart (Table 1-24-1) is included in this chapter for convenience in making computations. Familiarization with the various parts of this chart will illustrate the advantages of using *ready-made* computations.

The number (No.) column contains the numbers 1 through 100. The other columns contain computations for each number.

The square column is the product obtained by multiplying a number by itself: 1 × 1 = 1, 2 × 2 = 4, 17 × 17 = 289. Squaring may be considered a special form of area computation: Area = Length multiplied by Width (A = L × W).

The cube column is the product obtained by multiplying a number by itself, then multiplying that product by the number again: 1 × 1 × 1 = 1, 2 × 2 × 2 = 8, 13 × 13 × 13 = 2,197. Cubing may be considered a specialized form of volume computation: Volume = Length multiplied by Width by Height (V = L × W × H).

The square root column is the opposite of a squared number. The square root of a number is that number which when multiplied by itself (squared) will produce the original or desired number: For example, the square root of 1 is 1, 1 × 1 = 1. The square root of 4 is 2. The square root of 24 is 4.8990.

The cube root column represents the opposite of the cube column. The cube root of a number is that number which when multiplied by itself (cubed) will produce the original or desired number. The cube root of 1 is 1, 1 × 1 × 1 = 1. The cube root of 27 is 3, 3 × 3 × 3 = 27. If a container of 100 cubic inches and cubic in shape is desired, then the length of each side would be 4.6416.

The circumference column represents the circumference of a circle. Circumference is the linear measurement of the distance around a circle. The circumference is calculated by multiplying the diameter of the circle by the constant 3.1416 (π). This constant was calculated by dividing the circumference of circles by their diameter.

The area column represents the area of a circle. Area of a circle is the number of square units of measurement contained within the area circumscribed by a circle of the diameter of the listed number. This is calculated by the formula (π) × r^2 = a, (π) multiplied by the radius squared equals area. The radius is equal to one-half the diameter.

Inches	Decimals	mm
—	0.0004	.010
—	0.0040	.100
—	0.0100	.250
1/64	0.0156	.400
—	0.0197	.500
—	0.0295	.750
1/32	0.0312	.790
—	0.0395	1.00
3/64	0.0469	1.19
—	0.0590	1.50
1/16	0.0620	1.59
5/64	0.0787	2.00
—	0.0984	2.50
7/64	0.1090	2.78
—	0.1181	3.00
1/8	0.1250	3.17
—	0.1378	3.50
9/64	0.1410	3.65
5/32	0.1560	3.97
—	0.1575	4.00
11/64	0.1720	4.37
—	0.1770	4.50
3/16	0.1875	4.76
—	0.1969	5.00
13/64	0.2030	5.16
—	0.2165	5.50
7/32	0.2190	5.56
15/64	0.2340	5.95
—	0.2362	6.00
1/4	0.2500	6.35
—	0.2559	6.50
17/64	0.2656	6.75
—	0.2756	7.00
9/32	0.2810	7.14
—	0.2953	7.50
19/64	0.2970	7.54
5/16	0.3120	7.94
—	0.3150	8.00
21/64	0.3280	8.33
—	0.3350	8.50
11/32	0.3440	8.73
—	0.3543	9.00
23/64	0.3590	9.13
—	0.3740	9.50
3/8	0.3750	9.53
25/64	0.3910	9.92
—	0.3937	10.00
13/32	0.4060	10.32
—	0.4130	10.50
27/64	0.4220	10.72
—	0.4331	11.00
7/16	0.4380	11.11
29/64	0.4530	11.51
—	0.4724	12.00
31/64	0.4840	12.30
—	0.4920	12.50
1/2	0.5000	12.70
—	0.5118	13.00
33/64	0.5156	13.10
17/32	0.5310	13.49
35/64	0.5470	13.89
—	0.5512	14.00
9/16	0.5630	14.29
—	0.5710	14.50
37/64	0.5780	14.68
—	0.5906	15.00
19/32	0.5940	15.08
39/64	0.6090	15.48
5/8	0.6250	15.87
—	0.6299	16.00
41/64	0.6406	16.27
—	0.6496	16.50
21/32	0.6560	16.67
—	0.6693	17.00
43/64	0.6720	17.07
11/16	0.6875	17.46
45/64	0.7030	17.86
—	0.7087	18.00
23/32	0.7190	18.26
—	0.7283	15.50
47/64	0.7430	18.65
—	0.7480	19.50
3/4	0.7500	19.05
49/64	0.7656	19.45
25/32	0.7810	19.84
—	0.7874	20.00
51/64	0.7970	20.24
13/16	0.8125	20.64
—	0.8268	21.00
53/64	0.8280	21.03
27/32	0.8440	21.43
55/64	0.8590	21.83
—	0.8661	22.00
7/8	0.8750	22.23
57/64	0.8906	22.62
—	0.9055	23.00
29/32	0.9062	23.02
59/64	0.9220	23.42
—	0.9449	24.00
61/64	0.9530	24.21
31/32	0.9690	24.61
—	0.9843	25.00
63/64	0.9844	25.00
1	1.0000	25.40
—	1.0236	26.00
1—1/32	1.0312	26.19
1—1/16	1.0620	26.99
—	1.0630	27.00
1—3/32	1.0940	27.78
—	1.1024	28.00
1—1/8	1.1250	28.57
—	1.1417	29.00
1—5/32	1.1560	29.37
—	1.1811	30.00
1—3/16	1.1875	30.16
1—7/32	1.2190	30.96
—	1.2205	31.00
1—1/4	1.2500	31.75
—	1.2958	32.00
1—9/32	1.2810	32.54
—	1.2992	33.00
1—5/16	1.3120	33.34
—	1.3386	34.00
1—11/32	1.3440	34.13
1—3/8	1.3750	34.92
—	1.3779	35.00
1—13/32	1.4060	35.72
—	1.4173	36.00
1—7/16	1.4380	36.51
—	1.4567	37.00
1—15/32	1.4690	37.31
—	1.4961	38.00
1—1/2	1.5000	38.10
1—17/32	1.5310	38.89
—	1.5310	39.00
1—9/16	1.5620	39.69
—	1.5748	40.00
1—19/32	1.5940	40.48
—	1.6142	41.00
1—5/8	1.6250	41.27
—	1.6535	42.00
1—21/32	1.6562	42.07
1—11/16	1.6875	42.86
—	1.6929	43.00
1—23/32	1.7190	43.66
—	1.7323	44.00
1—3/4	1.7500	44.45
—	1.7717	45.00
1—25/32	1.7810	45.24
—	1.8110	46.00
1—27/32	1.8440	46.83
—	1.8504	47.00
1—7/8	1.8750	47.63
—	1.8898	48.00
1—29/32	1.9062	48.42
—	1.9291	49.00
1—15/16	1.9375	49.21
—	1.9685	50.00
1—31/32	1.9690	50.01
2	2.0000	50.80
—	2.0079	51.00
2—1/32	2.0312	51.59
—	2.0472	52.00
2—1/16	2.0620	52.39
—	2.0868	53.00
2—3/32	2.0940	53.18
2—1/8	2.1250	53.97
—	2.1260	54.00
2—5/32	2.1560	54.77
—	2.1650	55.00
2—3/16	2.1875	55.56
—	2.2047	56.00
2—7/32	2.2190	56.36
—	2.2440	57.00
2—1/4	2.2500	57.15
2—9/32	2.2810	57.94
—	2.2835	58.00
2—5/16	2.3120	58.74
—	2.3228	59.00
2—11/32	2.3440	59.53
—	2.3622	60.00
2—3/8	2.3750	60.32
—	2.4016	61.00
2—13/32	2.4060	61.12
2—7/16	2.4380	61.91
—	2.4409	62.00
2—15/16	2.4690	62.71
—	2.4803	63.00
2—1/2	2.5000	63.50
—	2.5197	64.00
2—17/32	2.5310	64.29
—	2.5590	65.00
2—9/16	2.5620	65.09
2—19/32	2.5940	65.88
—	2.5984	66.00
2—5/8	2.6250	66.67
—	2.6380	67.00
2—21/32	2.2560	67.47
—	2.6772	68.00
2—11/16	2.6875	68.26
—	2.7165	69.00
2—23/32	2.7190	69.06
2—3/4	2.7500	70.00
2—25/32	2.7810	70.64
—	2.7953	71.00
2—13/16	2.8125	71.44
—	2.8346	71.44
2—27/32	2.8440	72.23
—	2.8740	73.00
2—7/8	2.8750	73.02
2—29/32	2.9062	73.82
—	2.9134	74.00
2—15/16	2.9375	74.81
—	2.9527	75.00
2—31/32	2.9690	75.41
—	2.9921	76.00
3	3.0000	76.20
3—1/32	3.0312	76.99
—	3.0315	77.00
3—1/16	3.0620	77.79
—	3.0709	78.00
3—3/32	3.0940	78.58
—	3.1102	79.00
3—1/8	3.1250	79.37
—	3.1496	80.00
3—5/32	3.1560	80.17
3—3/16	3.1875	80.96
—	3.1890	81.00
3—7/32	3.2190	81.76
—	3.2283	82.00
3—1/4	3.2500	82.55
—	3.2677	83.00
3—9/32	3.2810	83.34
—	3.3071	84.00
3—5/16	3.3120	84.14
3—11/32	3.3440	84.93
—	3.3464	85.00
3—3/8	3.3750	85.73
—	3.3858	86.02
3—31/32	3.4060	86.52
—	3.4252	87.00
3—7/16	3.4380	87.31
—	3.4646	88.00
3—15/32	3.4690	88.11
3—1/2	3.5000	88.90
—	3.5039	89.00
3—17/32	3.5310	89.69
—	3.5433	90.00
3—9/16	3.5620	90.49
—	3.5827	91.00
3—19/32	3.5940	91.21
—	3.6220	92.00
3—5/8	3.6250	92.07
3—21/32	3.6560	92.87
—	3.6614	93.00
3—11/16	3.6875	93.66
—	3.7008	94.00
3—23/32	3.7190	94.45
—	3.7401	95.00
3—3/4	3.7500	95.25
—	3.7795	96.00
3—25/32	3.7810	96.04
3—13/16	3.8125	96.83
—	3.8189	97.00
3—27/32	3.8440	97.63
—	3.8583	98.00
3—7/8	3.8750	98.42
—	3.8976	99.00
3—29/32	3.9062	99.21
—	3.9370	100.00
3—15/16	3.9375	100.01
3—31/32	3.9690	100.80
—	3.9764	101.00
4	4.0000	101.60
4—1/16	4.0620	103.18
4—1/8	4.1250	104.77
—	4.1338	105.00
4—3/16	4.1338	106.36
4—1/4	4.2500	107.95
4—5/16	4.3120	109.53
—	4.3307	110.00
4—3/8	4.3750	111.12
4—7/16	4.4380	122.71
4—1/2	4.5000	114.30
—	4.5275	115.00
4—9/16	4.5620	115.88
4—5/8	4.6250	117.47
4—11/16	4.6875	119.06
—	4.7244	120.00
4—3/4	4.7500	120.65
4—13/16	4.8125	122.23
4—7/8	4.8750	123.82
—	4.9212	125.00
4—15/16	4.9375	125.41
5	4.0000	127.00
—	5.1181	130.00
5—1/4	5.2500	133.35
5—1/2	5.5000	139.70
—	5.1161	140.00
5—3/4	5.7500	146.05
—	5.9055	150.00
6	6.0000	152.40
6—1/4	6.2500	158.75
—	6.2992	160.00
6—1/2	6.5000	165.10
—	6.6929	170.00
6—3/4	6.7500	171.45
7	7.0000	177.80
—	7.0866	180.00
—	7.4803	190.00
7—1/2	7.5000	190.50
—	7.8740	200.00
8	8.0000	203.20
—	8.2677	210.00
8—1/2	8.5000	215.90
—	8.6614	220.00
9	9.0000	229.60
—	9.0551	230.00
—	9.4488	240.00
10	10.000	254.00
—	10.236	260.00
—	10.629	270.00
11	11.000	279.40
—	11.023	280.00
—	11.417	290.00
—	11.811	300.00
12	12.000	304.80
13	13.000	330.20
—	13.779	350.00
14	14.000	355.60
15	15.000	381.00
—	15.748	400.00
16	16.000	406.40
17	17.000	431.80
—	17.716	450.00
18	18.000	457.20
19	19.000	482.60
—	19.635	500.00
20	20.000	508.00

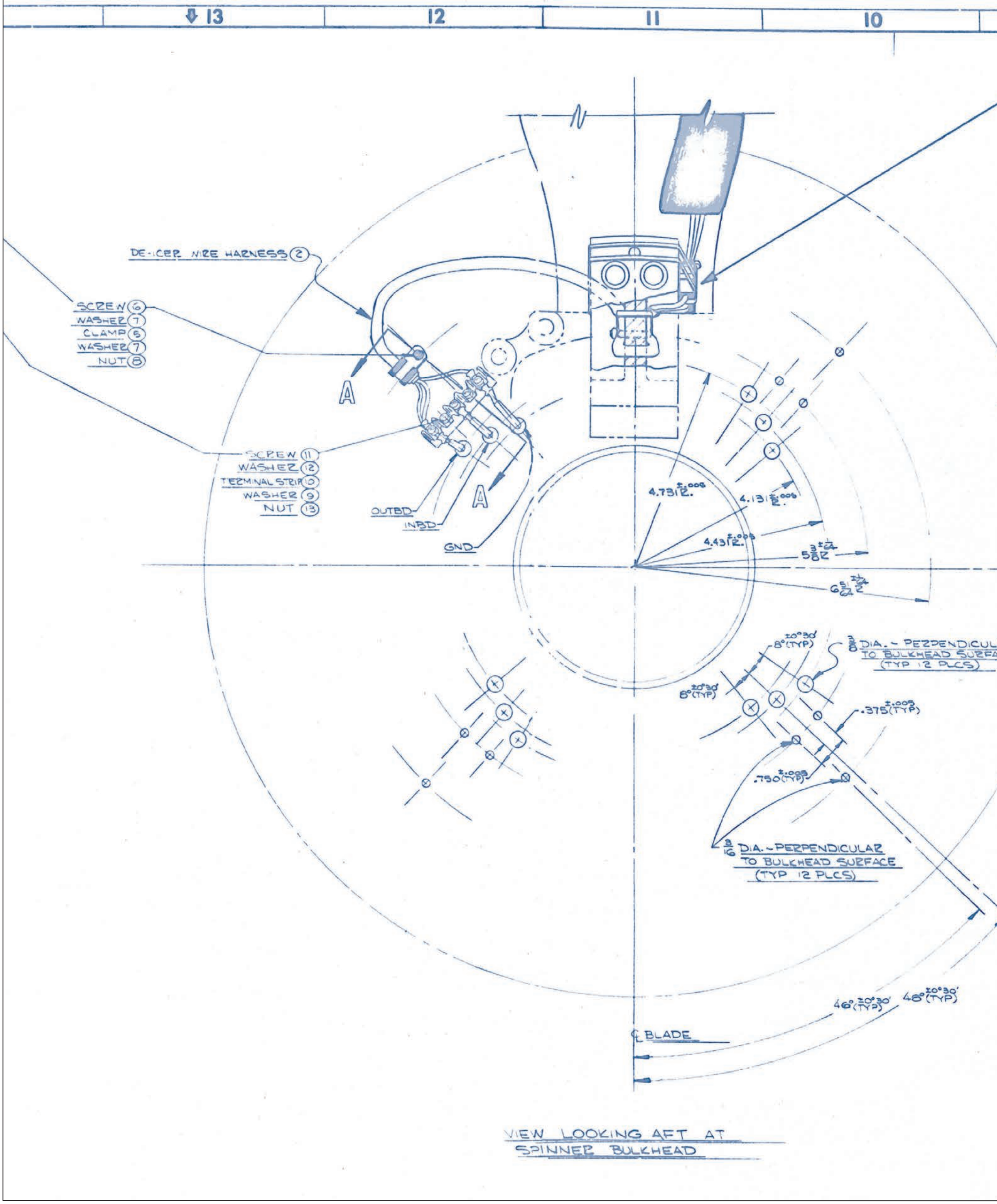
Table 1-23-4. Fractions, decimals, and millimeters.

No.	Square	Cube	Square root	Cube root	Circumference	Area
1	1	1	1.0000	1.0000	3.1416	0.7854
2	4	8	1.4142	1.2599	6.2832	3.1416
3	9	27	1.7321	1.4422	9.4248	7.0686
4	16	64	2.0000	1.5874	12.5664	12.5664
5	25	125	2.2361	1.7100	15.7080	19.635
6	36	216	2.4495	1.8171	18.850	28.274
7	49	343	2.6458	1.9129	21.991	38.485
8	64	512	2.8284	2.0000	25.133	50.266
9	81	729	3.0000	2.0801	28.274	63.617
10	100	1,000	3.1623	2.1544	31.416	78.540
11	121	1,331	3.3166	2.2240	34.558	95.033
12	144	1,728	3.4641	2.2894	37.699	113.10
13	169	2,197	3.6056	2.3513	40.841	132.73
14	196	2,744	3.7417	2.4101	43.982	153.94
15	225	3,375	3.8730	2.4662	47.124	176.72
16	256	4,096	4.0000	2.5198	50.266	201.06
17	289	4,913	4.1231	2.5713	53.407	226.98
18	324	5,832	4.2426	2.6207	56.549	254.47
19	361	6,859	4.3589	2.6684	59.690	283.53
20	400	8,000	4.4721	2.7144	62.832	314.16
21	441	9,261	4.5826	2.7589	65.974	346.36
22	484	10,648	4.6904	2.8020	69.115	380.13
23	529	12,167	4.7958	2.8439	72.257	415.48
24	576	13,824	4.8990	2.8845	75.398	452.39
25	625	15,625	5.0000	2.9240	78.540	490.88
26	676	17,576	5.0990	2.9625	81.682	530.93
27	729	19,683	5.1962	3.0000	84.823	572.56
28	784	21,952	5.2915	3.0366	87.965	615.75
29	841	24,389	5.3852	3.0723	91.106	660.52
30	900	27,000	5.4772	3.1072	94.248	706.86
31	961	29,791	5.5678	3.1414	97.390	754.77
32	1,024	32,768	5.6569	3.1748	100.53	804.25
33	1,089	35,937	5.7446	3.2075	103.67	855.30
34	1,156	39,304	5.8310	3.2396	106.81	907.92
35	1,225	42,875	5.9161	3.2711	109.96	962.12
36	1,296	46,656	6.0000	3.3019	113.10	1,017.88
37	1,369	50,653	6.0828	3.3322	116.24	1,075.21
38	1,444	54,872	6.1644	3.3620	119.38	1,134.12
39	1,521	59,319	6.2450	3.3912	122.52	1,194.59
40	1,600	64,000	6.3246	3.4200	125.66	1,256.64
41	1,681	68,921	6.4031	3.4482	128.81	1,320.26
42	1,764	74,088	6.4807	3.4760	131.95	1,385.45
43	1,849	79,507	6.5574	3.5034	135.09	1,452.20
44	1,936	85,184	6.6332	3.5303	138.23	1,520.53
45	2,025	91,125	6.7082	3.5569	141.37	1,590.44
46	2,116	97,336	6.7823	3.5830	144.51	1,661.91
47	2,209	103,823	6.8557	3.6088	147.66	1,734.95
48	2,304	110,592	6.9282	3.6342	150.80	1,809.56
49	2,401	117,649	7.0000	3.6593	153.94	1,885.75
50	2,500	125,000	7.0711	3.6840	157.08	1,963.50
51	2,601	132,651	7.1414	3.7084	160.22	2,042.83
52	2,704	140,608	7.2111	3.7325	163.36	2,123.72
53	2,809	148,877	7.2801	3.7563	166.50	2,206.19
54	2,916	157,464	7.3485	3.7798	169.65	2,290.23
55	3,025	166,375	7.4162	3.8030	172.79	2,375.84
56	3,136	175,616	7.4833	3.8259	175.93	2,463.01

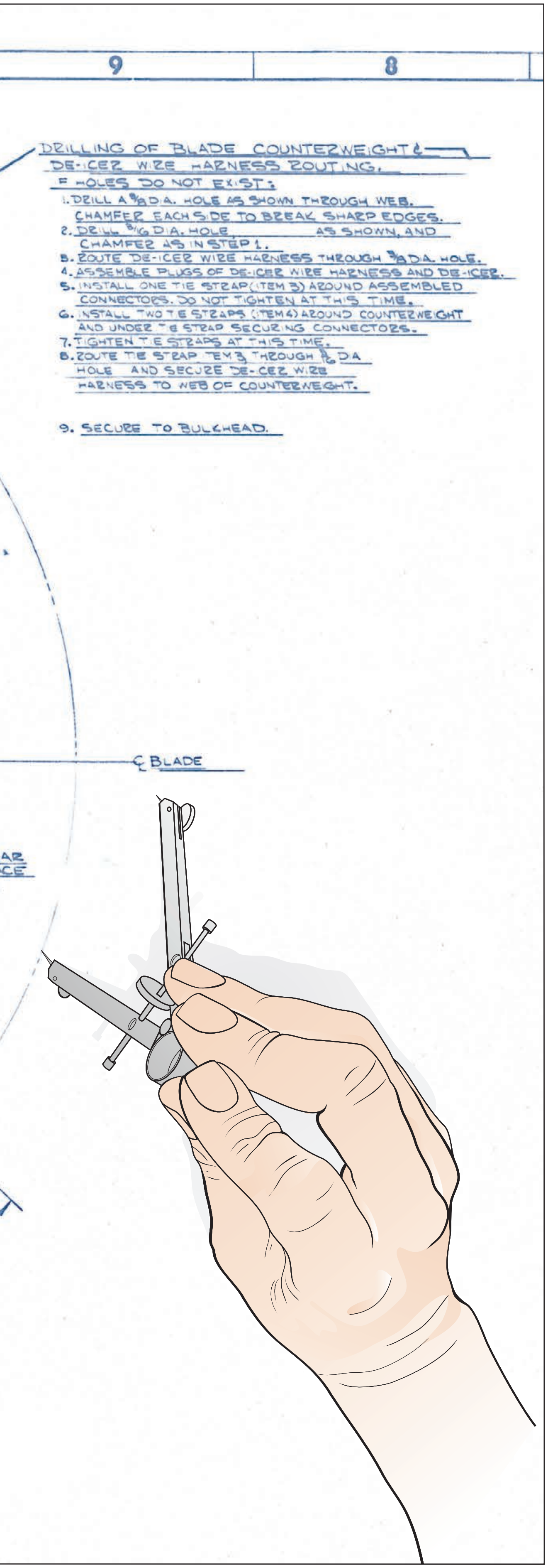
Table 1-24-1. Functions of numbers.

No.	Square	Cube	Square root	Cube root	Circumference	Area
57	3,249	185,193	7.5498	3.8485	179.07	2,551.76
58	3,364	195,112	7.6158	3.8709	182.21	2,642.09
59	3,481	205,379	7.6811	3.8930	185.35	2,733.98
60	3,600	216,000	7.7460	3.9149	188.50	2,827.44
61	3,721	226,981	7.8102	3.9365	191.64	2,922.47
62	3,844	238,328	7.8740	3.9579	194.78	3,019.08
63	3,969	250,047	7.9373	3.9791	197.92	3,117.25
64	4,096	262,144	8.0000	4.0000	201.06	3,216.99
65	4,225	274,625	8.0623	4.0207	204.20	3,318.32
66	4,356	287,496	8.1240	4.0412	207.35	3,421.20
67	4,489	300,763	8.1854	4.0615	210.49	3,525.66
68	4,624	314,432	8.2462	4.0817	231.63	3,631.69
69	4,761	328,509	8.3066	4.1016	216.77	3,739.29
70	4,900	343,000	8.3666	4.1213	219.91	3,848.46
71	5,041	357,911	8.4261	4.1408	223.05	3,959.20
72	5,184	373,248	8.4853	4.1602	226.20	4,071.51
73	5,329	389,017	8.5440	4.1793	229.34	4,185.40
74	5,476	405,224	8.6023	4.1983	232.48	4,300.85
75	5,625	421,875	8.6603	4.2172	235.62	4,417.88
76	5,776	438,976	8.7178	4.2358	238.76	4,536.47
77	5,929	456,533	8.7750	4.2543	241.90	4,656.64
78	6,084	474,552	8.8318	4.2727	245.05	4,778.37
79	6,241	493,039	8.8882	4.2908	248.19	4,901.68
80	6,400	512,000	8.9443	4.3089	251.33	5,026.56
81	6,561	531,441	9.0000	4.3267	254.47	5,153.01
82	6,724	551,368	9.0554	4.3445	257.61	5,281.03
83	6,889	571,787	9.1104	4.3621	260.75	5,410.62
84	7,056	592,704	9.1652	4.3795	263.89	5,541.78
85	7,225	614,125	9.2195	4.3968	267.04	5,674.52
86	7,396	636,056	9.2736	4.4140	270.18	5,808.82
87	7,569	658,503	9.3274	4.4310	273.32	5,944.69
88	7,744	681,472	9.3808	4.4480	276.46	6,082.14
89	7,921	704,969	9.4340	4.4647	279.60	6,221.15
90	8,100	729,000	9.4868	4.4814	282.74	6,361.74
91	8,281	753,571	9.5394	4.4979	285.89	6,503.90
92	8,464	778,688	9.5917	4.5144	289.03	6,647.63
93	8,649	804,357	9.6437	4.5307	292.17	6,792.92
94	8,836	830,584	9.6954	4.5468	295.31	6,939.79
95	9,025	857,375	9.7468	4.5629	298.45	7,088.24
96	9,216	884,736	9.7980	4.5789	301.59	7,238.25
97	9,409	912,673	9.8489	4.5947	304.74	7,389.83
98	9,604	941,192	9.8995	4.6104	307.88	7,542.98
99	9,801	970,299	9.9499	4.6261	311.02	7,697.71
100	10,000	1,000,000	10.0000	4.6416	314.16	7,854.00

Table 1-24-1. Functions of numbers, continued.



13
12
11
10
DE-ICER WIRE HARNESS (2)
SCREW (6)
WASHER (7)
CLAMP (5)
WASHER (7)
NUT (8)
A
SCREW (11)
WASHER (12)
TERMINAL STRIP (10)
WASHER (9)
NUT (13)
OUTBD
INBD
GND
A
4.731 R.
4.131 R.
4.431 R.
5 3/8 R
6 5/64 R
8° (TYP)
3/8 DIA. ~ PERPENDICUL
TO BULKHEAD SURFA
(TYP 12 PLCS)
8° (TYP)
.375 (TYP)
.750 (TYP)
3/16 DIA. ~ PERPENDICULAR
TO BULKHEAD SURFACE
(TYP 12 PLCS)
46° (TYP)
48° (TYP)
℄ BLADE
VIEW LOOKING AFT AT
SPINNER BULKHEAD



2

Blueprints and Drawings

Section 1

Purpose and Function of Aircraft Drawings

The exchange of ideas is essential to everyone, regardless of their vocation or position. Usually, this exchange is carried on by the oral or written word; but under some conditions the use of these alone is impractical. Industry discovered that it could not depend entirely upon written or spoken words for the exchange of ideas because misunderstanding and misinterpretation arose frequently.

Pictures were the earliest form of language used to communicate information and ideas. These pictures were drawn with lines and symbols. Drawing has since evolved along two different lines, artistic and technical. Artistic drawings use lines and forms in the creative expression of cultural things, whereas technical drawings use lines and symbols to express technical ideas and thoughts.

To express in written terms the information required to construct even a simple item would end in disaster. In the design and construction of complex items, drawings are the most accurate way to communicate the information. Each engineering field has made use of drawings. Each field uses standards in the production of drawings, but each has also evolved different symbols.

Drafting is the drawing of an engineering picture of an object. The drawing is a graphic presentation of a real thing. These pictures can be understood by anyone who knows the language of drafting. For this reason drafting is

Learning Objectives

REVIEW
- Types of aircraft drawings
- Uses of microfilm and microfiche
- Lines and their meanings
- Care of drafting instruments

DESCRIBE
- Methods of illustrating objects
- The components of aircraft production drawings

EXPLAIN
- Dimensioning
- Purpose and function of aircraft drawings
- Importance of the graphic presentation of information

APPLY
- Practice sketching techniques used in technical drawings
- Sketch types of repairs

Left. Installation drawing for electric propeller deice wiring block.

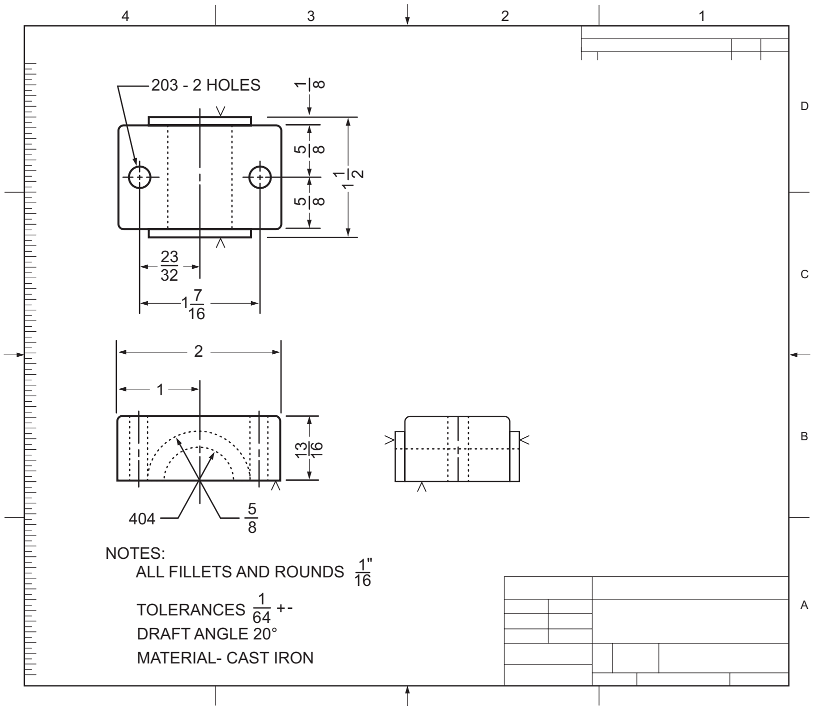


Figure 2-1-1. Single detail drawing.

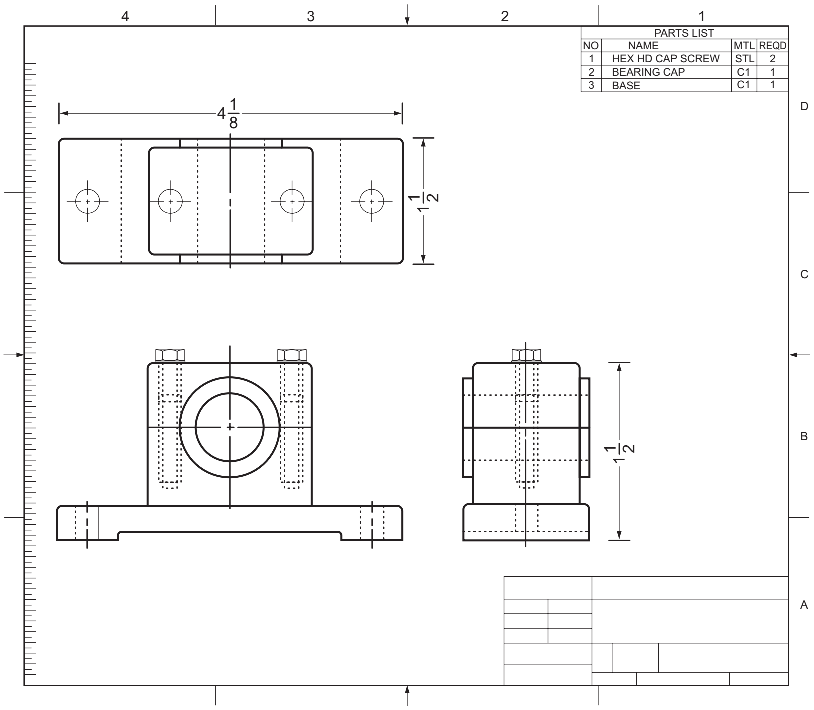


Figure 2-1-2. Assembly drawing.

referred to as the *universal language* (see the subsection Lines and Their Meanings, later in this chapter).

Aircraft drawings originate in the drafting section of the engineering office. These drawings are referred to as engineering drawings. There are many types of engineering drawings. Some of these types of drawings are discussed in the following paragraphs.

Prints are copies of the original engineering drawing, and are the link between the aircraft designers, manufacturers, and the mechanics that repair and maintain the aircraft. A print is a copy of the original working drawing for an aircraft part or group of parts, or for a design of a system or group of systems. It is made by placing a tracing of the drawing over a sheet of chemically treated paper and exposing it to a strong light for a short period of time. When the exposed paper is developed, it turns blue where the light has penetrated the transparent tracing. The inked lines of the tracing, having blocked out the light, show as white lines on a blue background. Other types of sensitized paper have been developed; prints may have a white background with colored lines or a colored background with white lines.

Because copies of prints can shrink, never make a layout directly from the drawing. Use the measurements.

With the introduction of Computer Aided Design (CAD), many engineering drawings today exist only in the computer. Many advanced designs are entirely CAD-drawn from inception to production.

Types of Drawings

Working drawings may be divided into three classes: detail drawings, assembly drawings, and installation drawings. Other types of drawings include sectional drawings, exploded views, block diagrams, logic flow charts, electrical wiring diagrams, schematic diagrams, and pictorial electrical diagrams.

Detail drawing. A detail drawing supplies complete information for the construction of a single part. The drawing shows the size, shape, material, method of manufacture, dimensions, tolerances, and/or specifications for material, finishes, and heat treating. Sectional views, auxiliary views, or enlarged views may be added for clearer understanding. Detail drawings may be either single-detail or multi-detail drawings. The single-detail drawing, Figure 2-1-1, shows the part and perhaps one detailed view of that part that emphasizes or helps to describe size, shape, or any of the other details previously mentioned. The multi-detail drawing is essentially the same as the single detail drawing except that more than one detailed view may be used to describe or emphasize the previously mentioned details.

Assembly drawing. An assembly drawing depicts the assembled relationships between two or more parts, a combination of parts, or a group of assemblies to form a larger assembly. Assembly drawings vary in the amount and

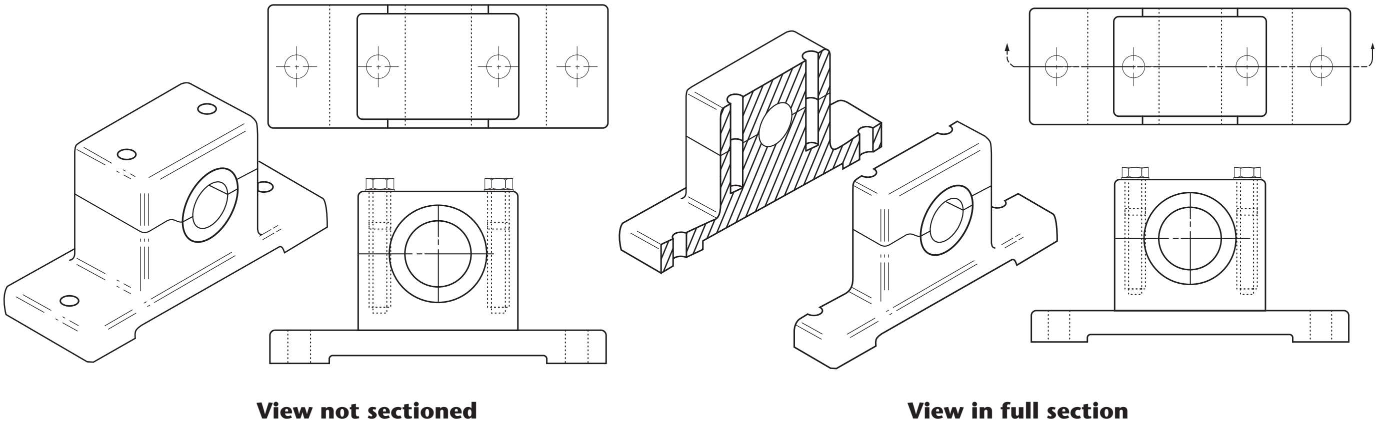


Figure 2-1-3. Sectional drawings.

type of information given depending on what the drawing depicts. The function of an assembly drawing is to show an item in its completed shape, to indicate relationships between parts or components, and to show the part number for the parts. Assembly drawings may also show overall dimensions capacities, information for assembly, and operating instructions (Figure 2-1-2).

Installation drawing. An installation drawing shows the general arrangement of the parts or their position and information to install the items. The information shown on an installation drawing is that needed to complete the installation. Depending on the type of installation, either electrical or mechanical, the information may vary. Generally, the information will give mounting directions, location and dimensions, and attaching hardware.

Sectional drawings. Sectional drawings are usually referred to as sectional views and are used to show internal detail more clearly than is possible in any other type of drawing. There are several types of view drawings available depending on what is to be shown. A cutting plane line is used to indicate what surface and where the surface is cut. The portion that is cut is indicated by the use of section lines. A viewing plane line is used to indicate what surface is being viewed and the direction from which it will be viewed.

A *full section view* indicates the object is cut or viewed as if it were cut in half (Figure 2-1-3). The cutting plane line passes completely through the object. The viewing plane line does not pass through the object.

In a *half section*, the cutting plane extends only halfway across the object, leaving the other half of the object as an exterior view. Half sections are used to advantage with symmetrical objects to show both the interior and exterior.

Exploded views. This type of drawing shows the relationship of parts and can be helpful in assembling components (Figure 2-1-4). Exploded views are also used to illustrate parts manuals.

Block diagrams. Block diagrams are used to show the relationship and function of each item in the diagram. This type of diagram can be used in electrical, electronic, or mechanical

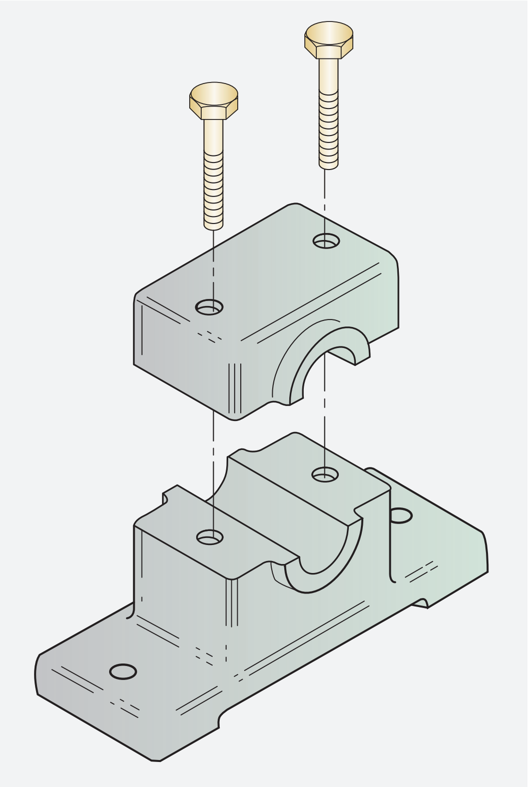


Figure 2-1-4. Exploded view.

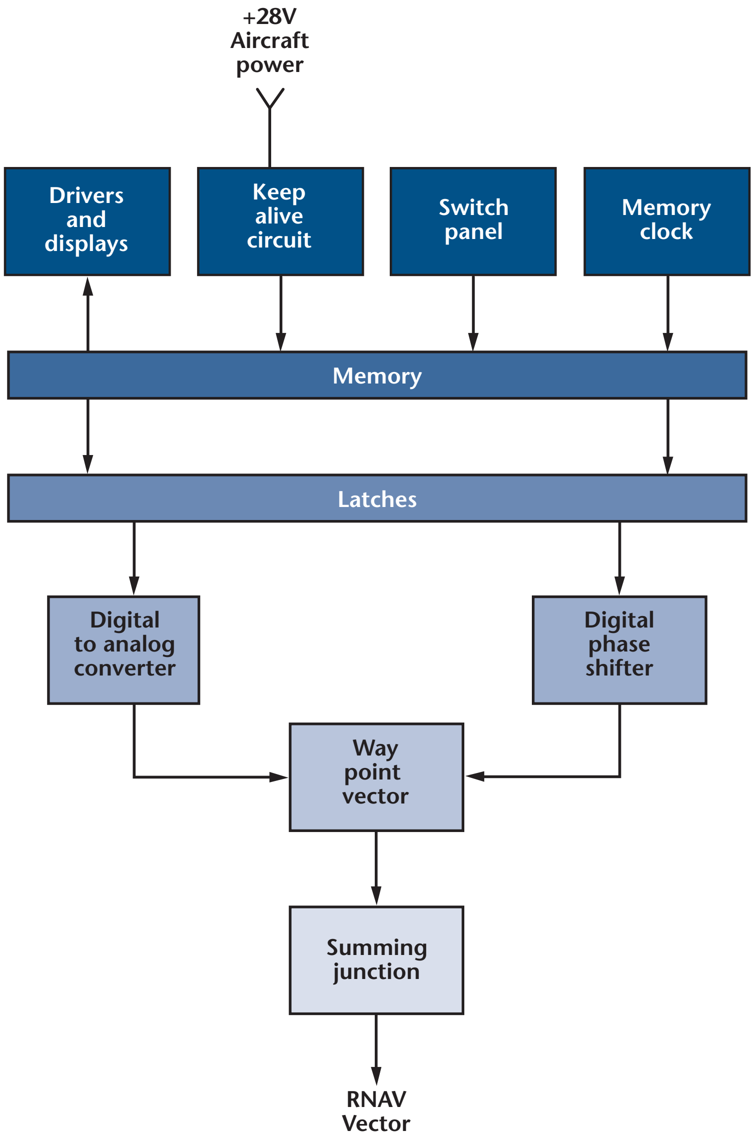


Figure 2-1-5. Block diagram.

applications. An electrical or electronic block diagram does not show electrical connections (Figure 2-1-5). Block diagrams are so called because each unit is identified by a block or square. Other types of symbols may also be used in block diagrams.

Logic flow charts. The logic flow chart represents the mechanical, electrical, or electronic action without necessarily expressing the construction or engineering information. An understanding of logic symbols is needed to interpret logic flow charts. Figure 2-1-6 shows a logic flow chart.

Electrical wiring diagram. Electrical wiring diagrams are divided into four types: single-

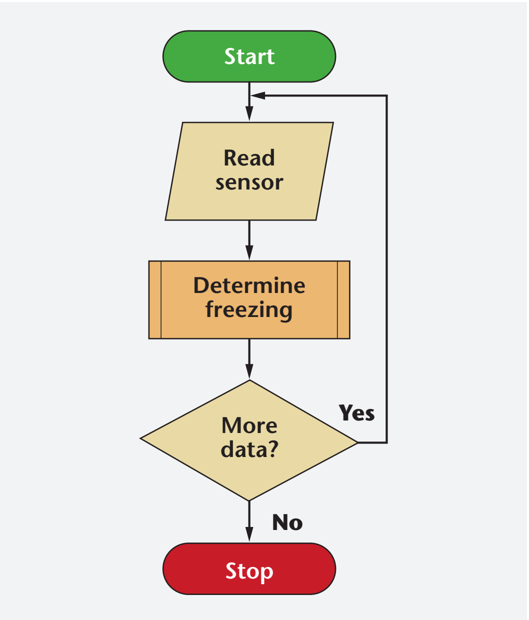


Figure 2-1-6. Logic flow chart.

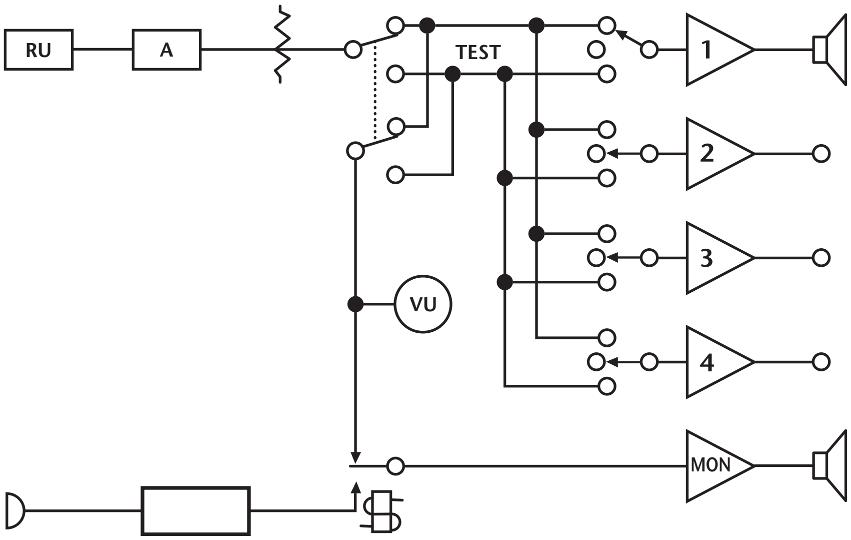


Figure 2-1-7. Single-line diagram.

line, schematic or elementary, connection or wiring, and interconnect. They will frequently show wire sizes.

A single-line diagram shows the path of an electrical circuit or system and components using graphic symbols as shown in Figure 2-1-7.

The connection or wiring diagram shows the general arrangement of parts and other information needed to trace or make internal or external connections (Figure 2-1-8).

The interconnect diagram shows only external connections between units (Figure 2-1-9).

Schematic diagrams, like installation diagrams, are used extensively in aircraft manuals and in the troubleshooting of aircraft systems.

Pictorial electrical diagrams. A pictorial electrical wiring diagram shows pictorial sketches of the parts and the electrical connections between them. This type of diagram can be used for learning system operation and troubleshooting. It does not show location of equipment (Figure 2-1-10).

Schematic diagrams. An electrical or electronic elementary schematic diagram indicates the electrical connection and function of electrical or electronic circuits. This type of diagram aids in the tracing, function, and troubleshooting of the circuit without regard to size, shape, or location of the components.

A mechanical schematic diagram depicts the relationship of parts, components, or flow of fluids in a system. For ease of reading and tracing the flow, each component is identified by name, and its location within the system can be ascertained by noting the lines that lead into and out of the unit.

CAD drawings. CAD software permits the user to switch between multiple drawings and diagrams within a single computer file. Composite views, which contain elements of multiple types of drawings are also available in some cases.

Methods of Illustrating Objects

The method used to illustrate an object depends on what is to be shown. Each type of drawing has advantages and disadvantages in presenting the desired information.

Orthographic projection drawings. In order to show the exact size and shape of all the parts of complex objects, a number of views are necessary. This is the system used in orthographic projection.

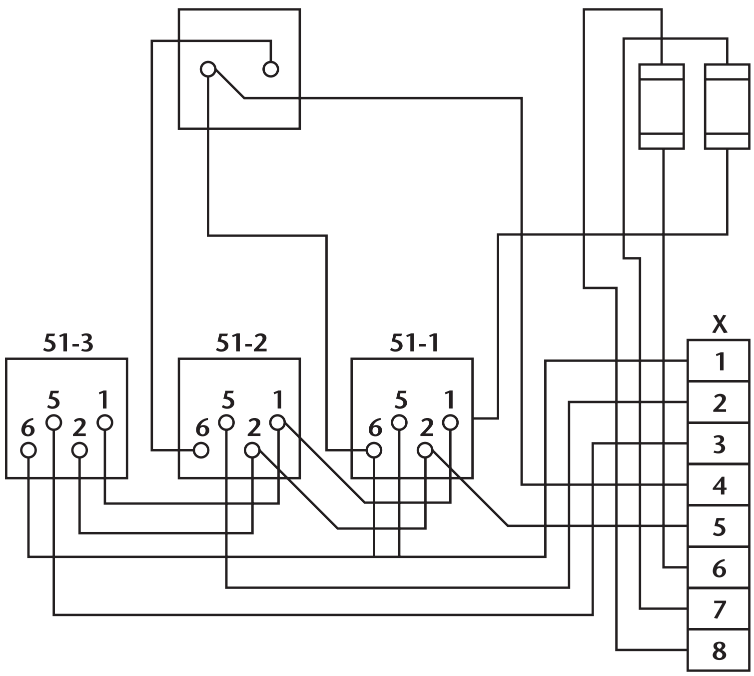


Figure 2-1-8. Connection or wiring diagram.

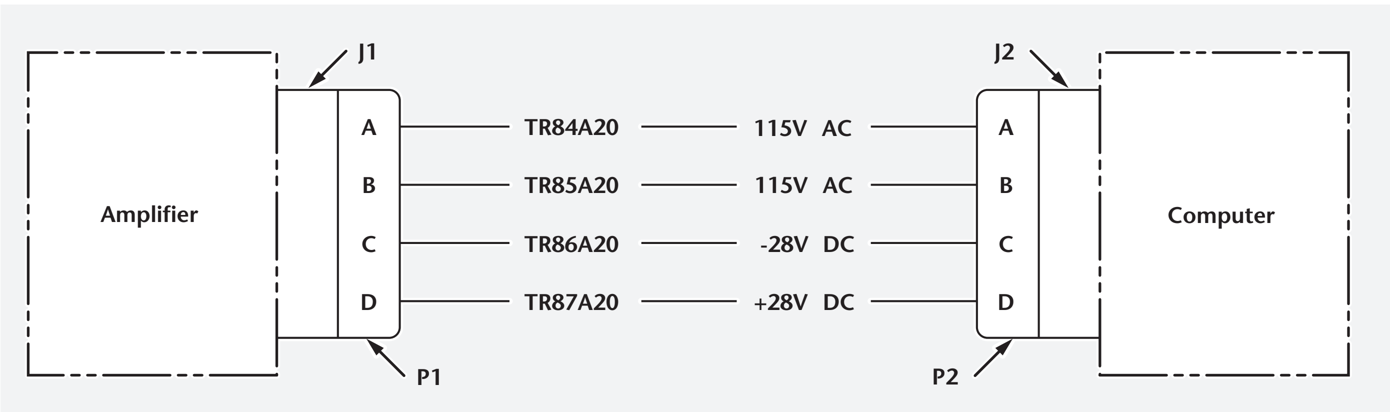


Figure 2-1-9. Interconnect diagram.

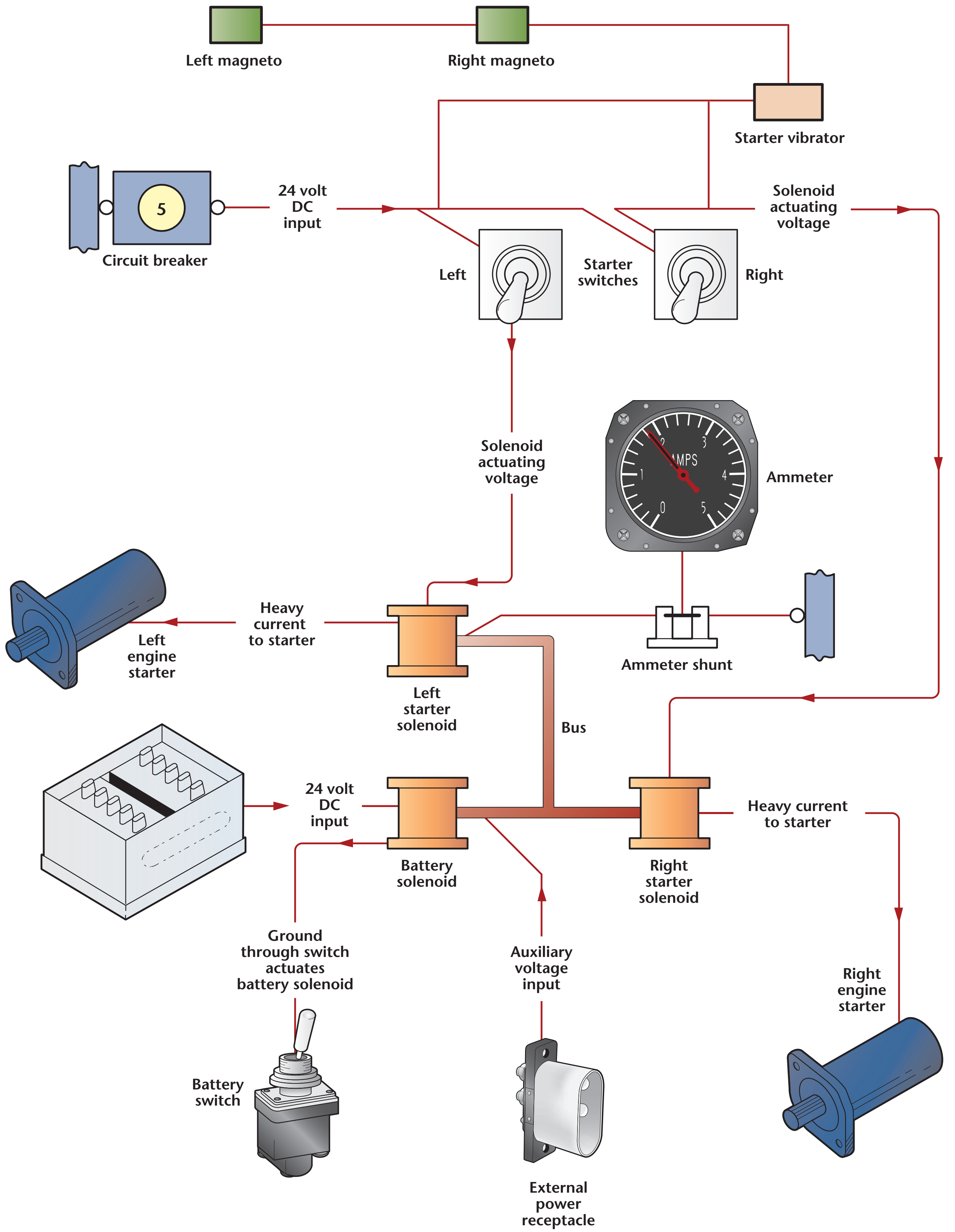


Figure 2-1-10. Pictorial electrical diagram.

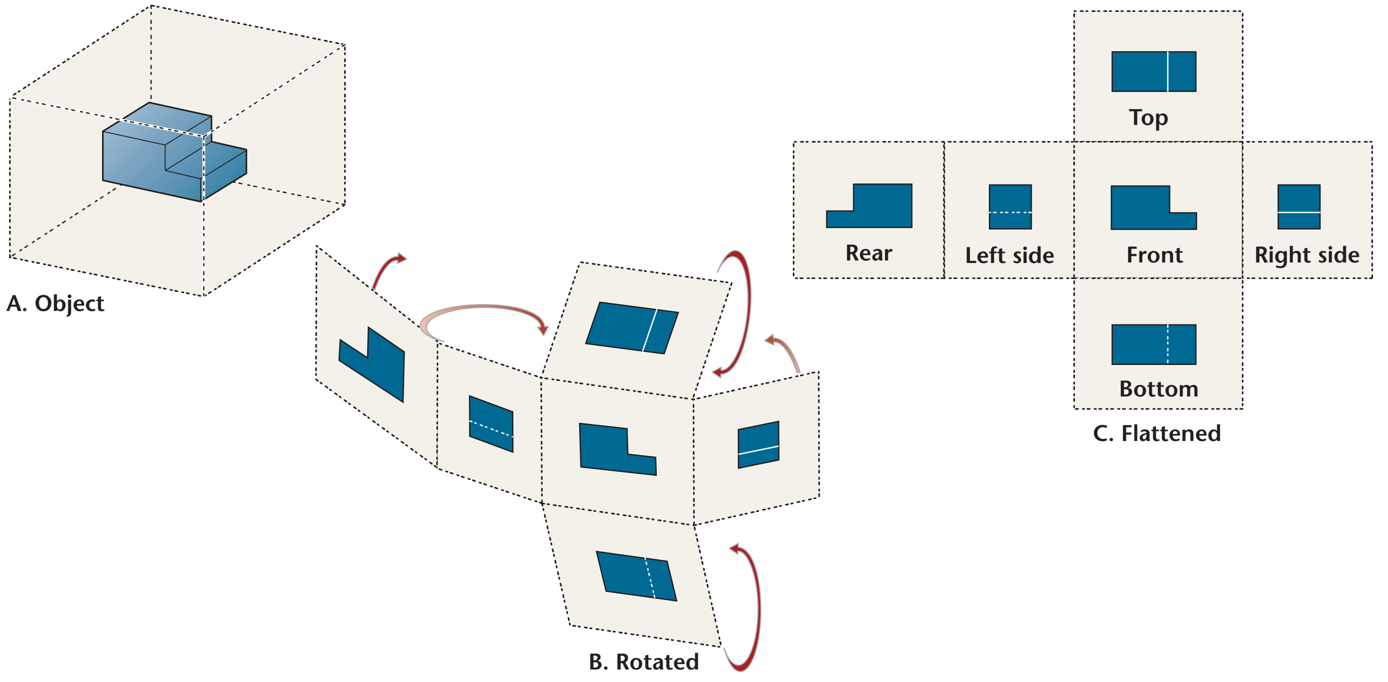


Figure 2-1-11. Orthographic projection.

In orthographic projection, there are six possible views of an object because all objects have six sides front, top, bottom, rear, right side, and left side. Figure 2-1-11A shows an object placed in a transparent box, hinged at the edges. The projections on the sides of the box are the views as seen looking straight at the object through each side. If the outlines of the object are drawn on each surface and the box opened as shown in Figure 2-1-11B, then laid flat as shown in Figure 2-1-11C, the result is a six-view orthographic projection.

It is seldom necessary to show all six views to portray an object clearly; therefore, only those views necessary to illustrate the required characteristics of the object are drawn. One-view, two-view, and three-view drawings are the most common. Regardless of the number of views used, the arrangement is generally, as shown in Figure 2-1-11, with the front view being the principal one. If the right-side view is shown, it will be to the right of the front view. If the left-side view is shown, it will be to the left of the front view. The top and bottom views, if included, will be shown in their respective positions relative to the front view. Should a rear view be necessary, it is customary to place it to the left of the left-hand view.

One-view drawings are commonly used for objects of uniform thickness, such as gaskets, shims, and plates. A dimensional note gives the thickness as shown in Figure 2-1-12. One-view drawings are also commonly used for cylindrical, spherical, or square parts, if all the necessary dimensions can be properly shown in one view.

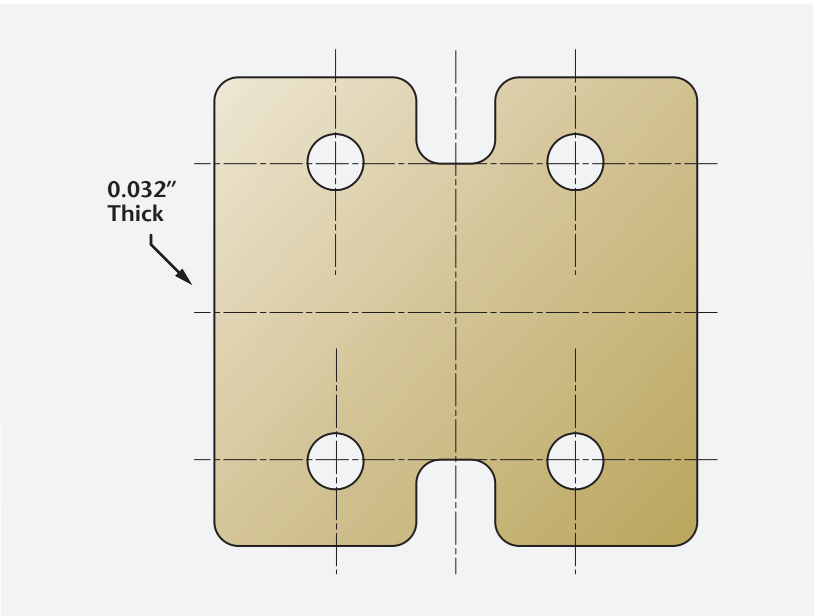


Figure 2-1-12. One-view drawing.

When space is limited and two views must be shown, symmetrical objects are often represented by half views. (Figure 2-1-13).

Isometric drawings. In an isometric drawing, all the lines that are parallel on the part being drawn are parallel on the drawing. Vertical lines on the part are shown vertical on the drawing, but horizontal lines are drawn at a 30° angle to the horizontal. This type of drawing cannot be

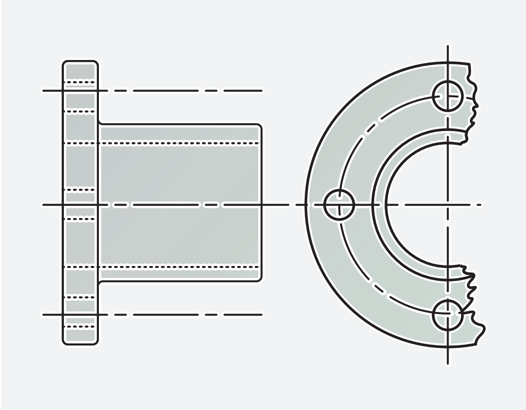


Figure 2-1-13. Symmetrical object with exterior half view.

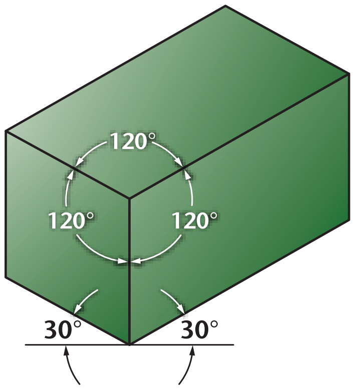


Figure 2-1-14. Isometric drawing.

used to express complex parts. It may be used to clarify orthographic drawings.

Unlike orthographic projection drawings which present three-dimensional objects on a flat plane with a number of views, isometric drawings present a three-dimensional object on a flat plane approximately the same way the eye views it (Figure 2-1-14). The three dimensions shown on an isometric drawing are height, width, and depth. They are also the three isometric axes and their point of intersection is called the point of origin. The angle between these axes is 120°,

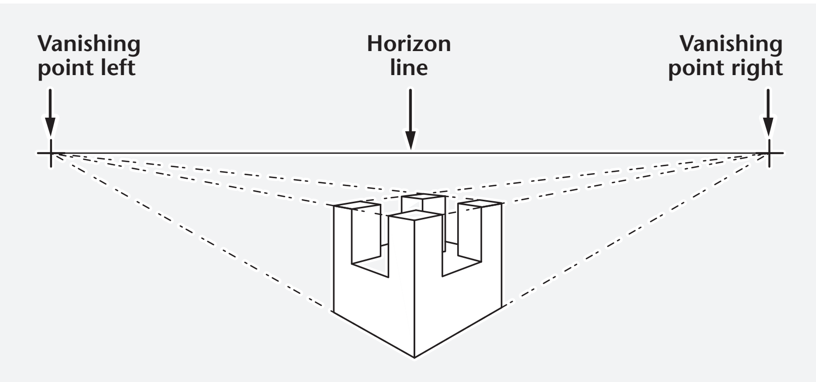


Figure 2-1-17. Perspective drawing.

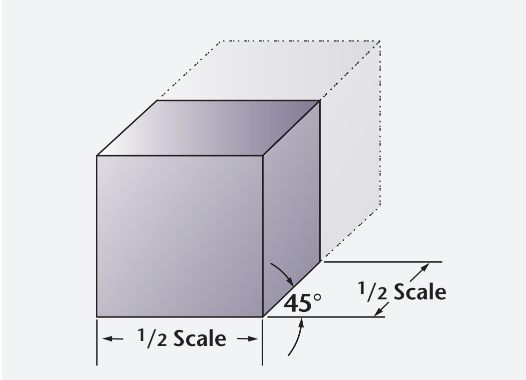


Figure 2-1-15. Cabinet drawing of a cube.

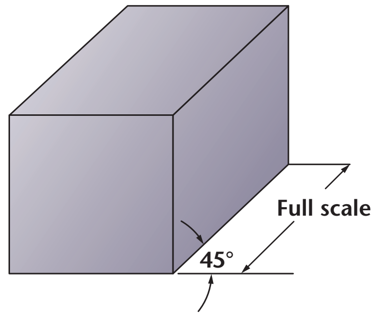


Figure 2-1-16. Cavalier oblique drawing.

as shown in Figure 2-1-14. Isometric drawings show external features only.

Oblique drawings. The front face of an oblique drawing is shown in true size and shape as if it were an orthographic drawing. The horizontal lines may be drawn at 30°, 45°, or 60° angles to the horizontal. The oblique sides are drawn to any scale to give a realistic depth.

Cabinet drawings. A cabinet drawing is a type of oblique drawing. It gets its name from drawings used for cabinet work. Cabinet drawings are drawn with the oblique side at a 30° or 45° angle to the horizontal and use 1/2 scale of the front view (Figure 2-1-15).

Cavalier drawings. The cavalier drawing uses the same scale of the front view on the oblique side lines. These lines are set at a 45° angle to the horizontal and create a distorted picture of the object's true proportions (Figure 2-1-16).

Perspective drawings. The perspective drawing is the truest representation of an object. This method of drawing allows objects to appear proportionally smaller the further the distance, just as they do when viewed.

A perspective drawing is not used in the manufacture or repair of aircraft. This type of drawing may be used effectively for technical illustrations (Figure 2-1-17).

CAD drawings. Computer Aided Design programs allow the user to select any one of many types of drawings for viewing on the computer screen or printout. They also often allow the user to freely rotate an object and obtain an isometric view or drawing from almost any angle.

Lines and Their Meanings

Every drawing is composed of lines. Lines mark the boundaries, edges, and intersections of surfaces. Lines are used to show dimensions and hidden surfaces, and to indicate centers. Obviously, if the same kind of line is used to show all of these things, a drawing becomes a meaningless collection of lines. For this reason, various kinds of standardized lines are used on aircraft drawings.

Most drawings use three widths or intensities of lines; thin, medium, or thick. These lines vary somewhat on different drawings, but there will always be a noticeable difference between a thin and thick line, with the width of the medium line somewhere between the two.

Visible lines. The visible line is used for all lines on the drawing representing visible lines on the object (Figure 2-1-18A).

Hidden lines. Hidden lines indicate invisible edges or contours. Hidden lines consist of short, evenly spaced dashes and are frequently referred to as dash lines (Figure 2-1-18B).

Center lines. Center lines are made up of alternate long and short dashes. They indicate the center of an object or part of an object. Where center lines cross, the short dashes intersect symmetrically. In the case of very small circles, the center lines may be shown unbroken (Figure 2-1-18C). Center lines may also be used to indicate the travel of a center and as extension lines.

Dimension lines. A dimension line (Figure 2-1-18D) is a light solid line, broken at the midpoint for insertion of measurement indications, and having opposite pointing arrowheads at each end to show origin and termination of a measurement. Dimension lines are generally parallel to the line for which the dimension is given, and are usually placed outside the outline of the object and between views if more than one view is shown. Dimension lines should not contact the outline of the object.

Extension lines. Extension lines are thin lines used to move the dimension from the surface of the object to a point where the dimension will not interfere with the other lines. Extension lines should not touch the outline of the object

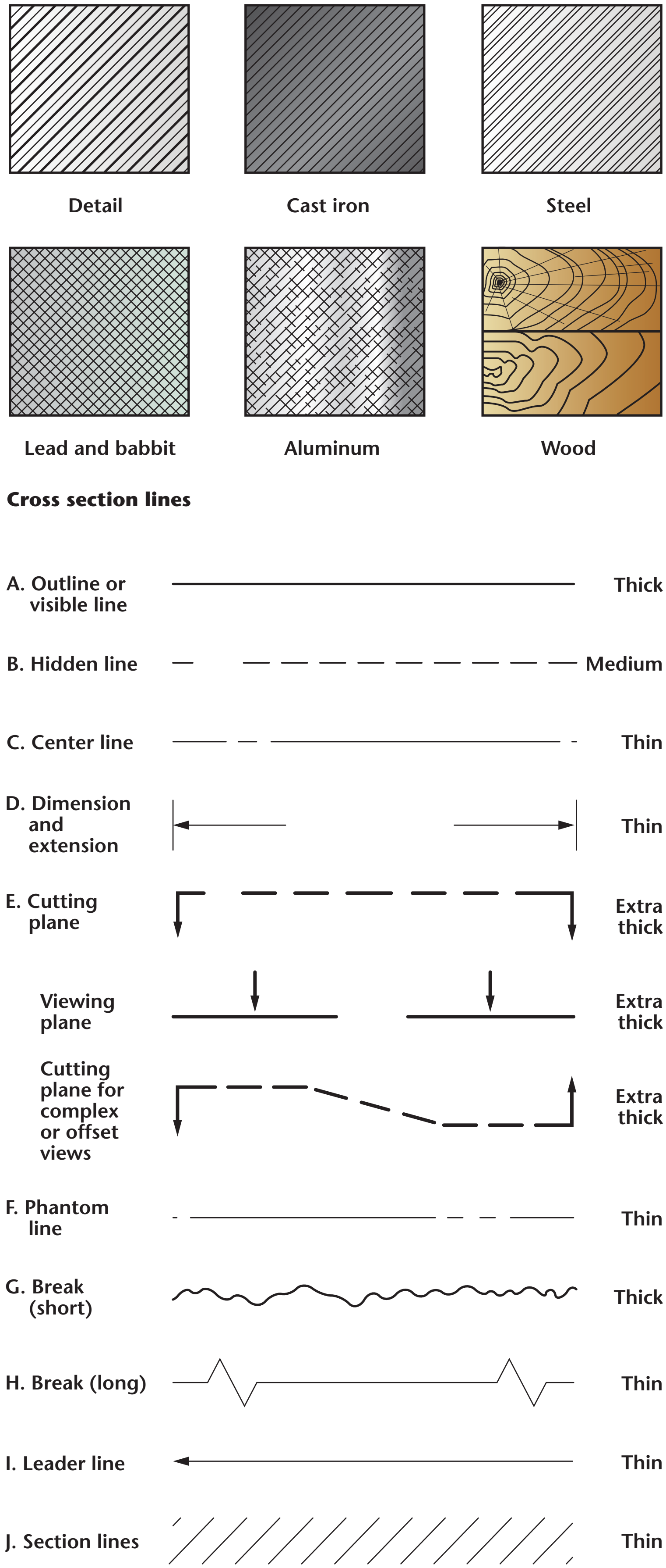


Figure 2-1-18. Lines and their meanings.

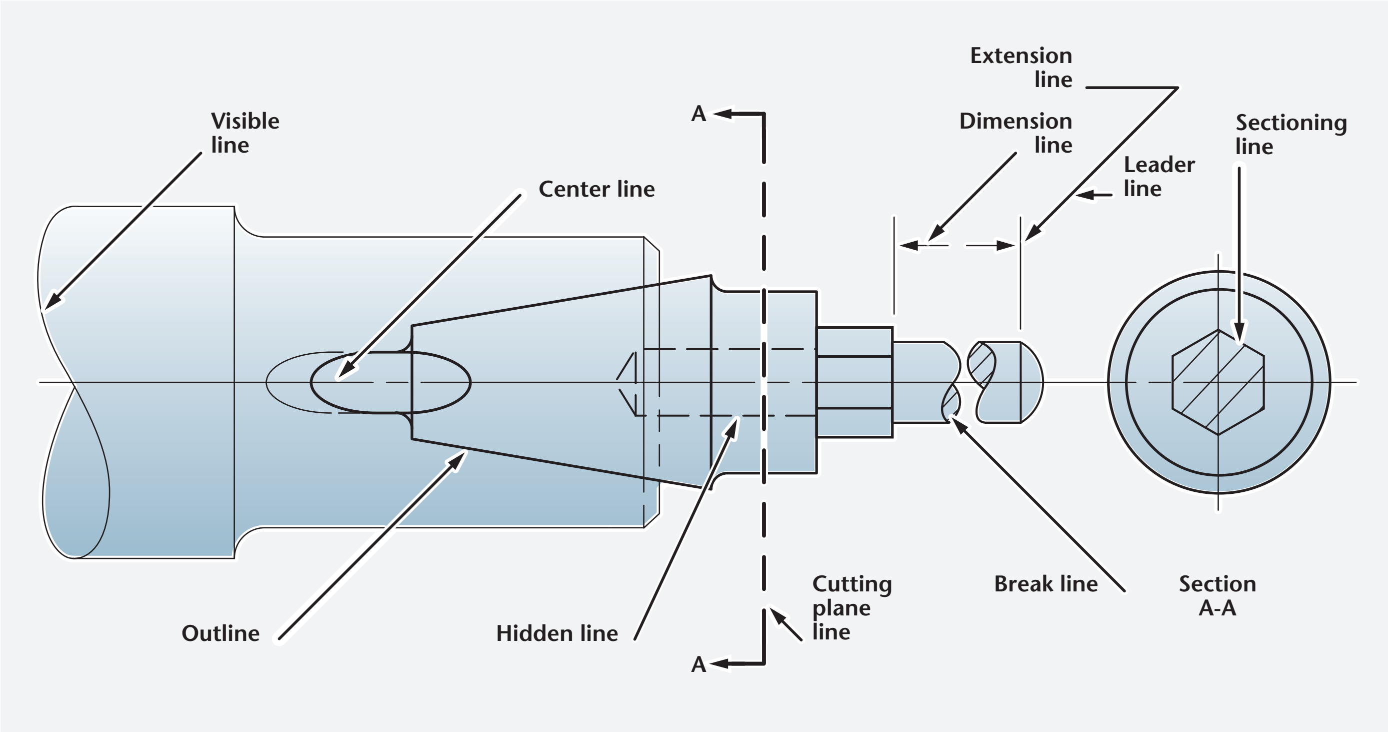


Figure 2-1-19. Correct uses of lines.

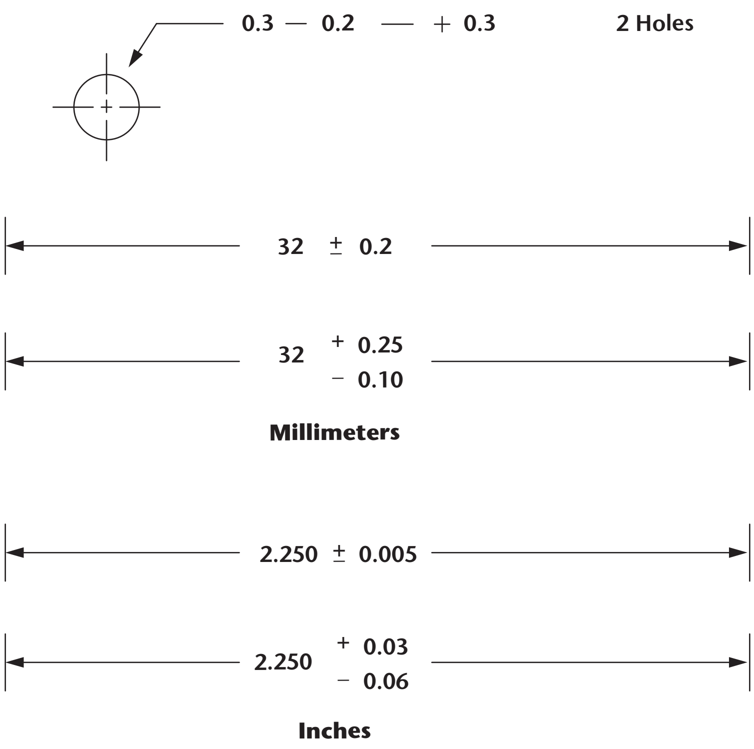


Figure 2-1-20. Bilateral tolerancing.

but may cross object lines. They should not begin or end on object lines (Figure 2-1-19).

Cutting plane lines. Cutting plane lines indicate the plane in which a sectional view of the object is taken. In Figure 2-1-19, plane line A-A indicates the plane in which section A-A is taken (Figure 2-1-18E).

Phantom lines. Phantom lines indicate the alternate position of parts of the object or the relative position of a missing part. Phantom lines are composed of one long and two short evenly spaced dashes (Figure 2-1-18F).

Break lines. Break lines indicate that a portion of the object is not shown on the drawing. Short breaks are made by solid, freehand lines (Figure 2-1-18G). For long breaks, solid ruled lines with zigzags are used (Figure 2-1-18H). Shafts, rods, tubes, and other such parts, which have a portion of their length broken out, have the ends of the break drawn as indicated in Figure 2-1-19.

Leader lines. Leaders are solid lines with one arrowhead and indicate a part or portion to which a note, number, or other reference applies (Figure 2-1-18I).

Sectioning lines. Sectioning lines are generally thin lines, and are sometimes referred to as cross-hatching. Section lines serve two purposes. The lines indicate the surface of an object that has been cut to make it stand out from the rest of the object. Section lines also indicate the type of material from which the object is made. The cast iron symbol is commonly used in drawings depicting all types of metals. The material description is then listed in the Bill of Materials block. Examples are shown at the top of Figure 2-1-18.

Removed sections. A removed section of a drawing is used to illustrate a particular part of a drawing. It is placed to the side of the drawing and shows pertinent details. These sections are normally drawn to a larger scale than the main view to provide increased detail.

Lettering. Good lettering gives a sketch a professional look. Sloppy lettering will make a good sketch look bad. Good lettering is essential for easy reading; therefore, it is important that you develop skill in lettering. Lettering is drawn, not written, so the standard forms and strokes can be learned through practice. Fancy, ornate lettering does not belong on a technical sketch.

The proportion of one letter to another and the order in which the strokes are drawn are as important as the shape of the individual letters. The proportion of the letters gives them style and character, and the order in which the strokes are drawn affects the ease and rapidity of lettering.

Numbers. The legibility of numbers and fractions on technical sketches is important. If the numbers on the sketch are hard to read, the wrong information may be communicated and time and material could be wasted.

Fractions. Fractions are always drawn with horizontal division lines. This will lessen the chance of misinterpretation with other numbers. Each figure is two-thirds the height of a whole number. To prevent the figures of a fraction from blending with the horizontal line when drawing fractions, leave space above and below the line. Lightly draw in the guide lines and erase them when you complete each set.

Dimensioning

Tolerance. Tolerance is the acceptable variation from the specific dimension given on a print or drawing. A tolerance is usually given in three decimals (0.010). The tolerance may be shown by one of the following ways:

- As a specific tolerance for a specified dimension.
- As a general tolerance note that indicates the tolerance for all dimensions not covered by specific tolerances. (This tolerance is usually found in the title block). Tolerances are shown on prints or drawings in two different ways: either by limit dimensioning or by plus and minus dimensioning.
- In limit dimensioning, Figure 2-1-20, the higher limit is placed above the lower limit. If the tolerance is expressed on a single line, the lower limit is expressed first, followed by the higher limit. A dash will separate the two limits.

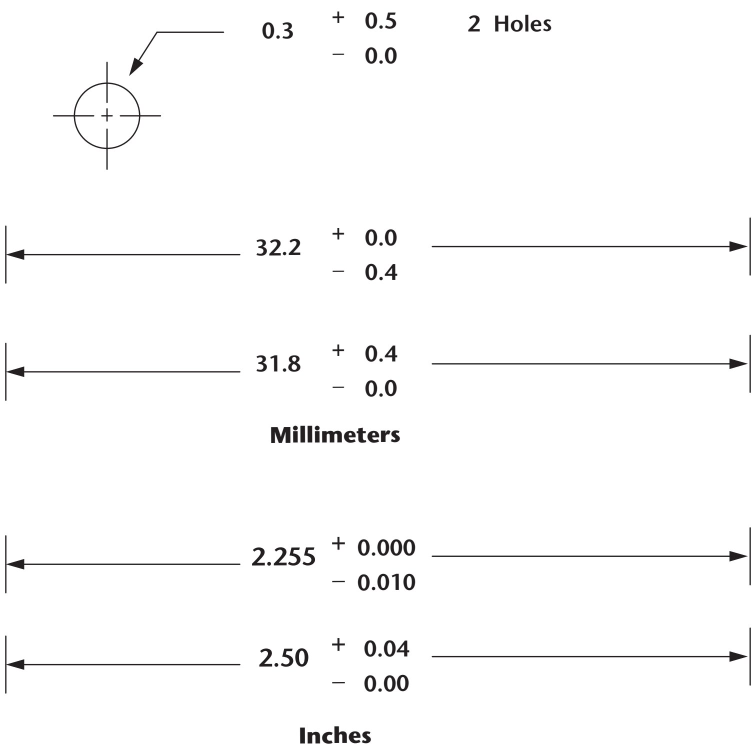


Figure 2-1-21. Unilateral tolerancing.

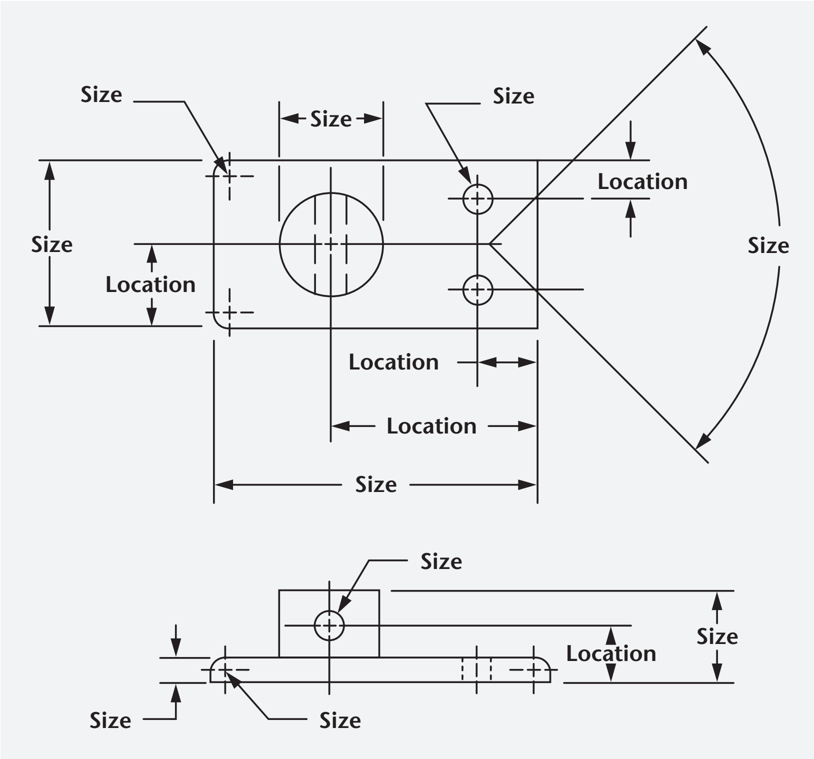


Figure 2-1-22. Size and location of dimension.

- Plus and minus dimensioning indicates the specific size dimension followed by the plus (high limit) and the minus (low limit). The plus limit is shown above the minus limit as shown in Figure 2-1-21.

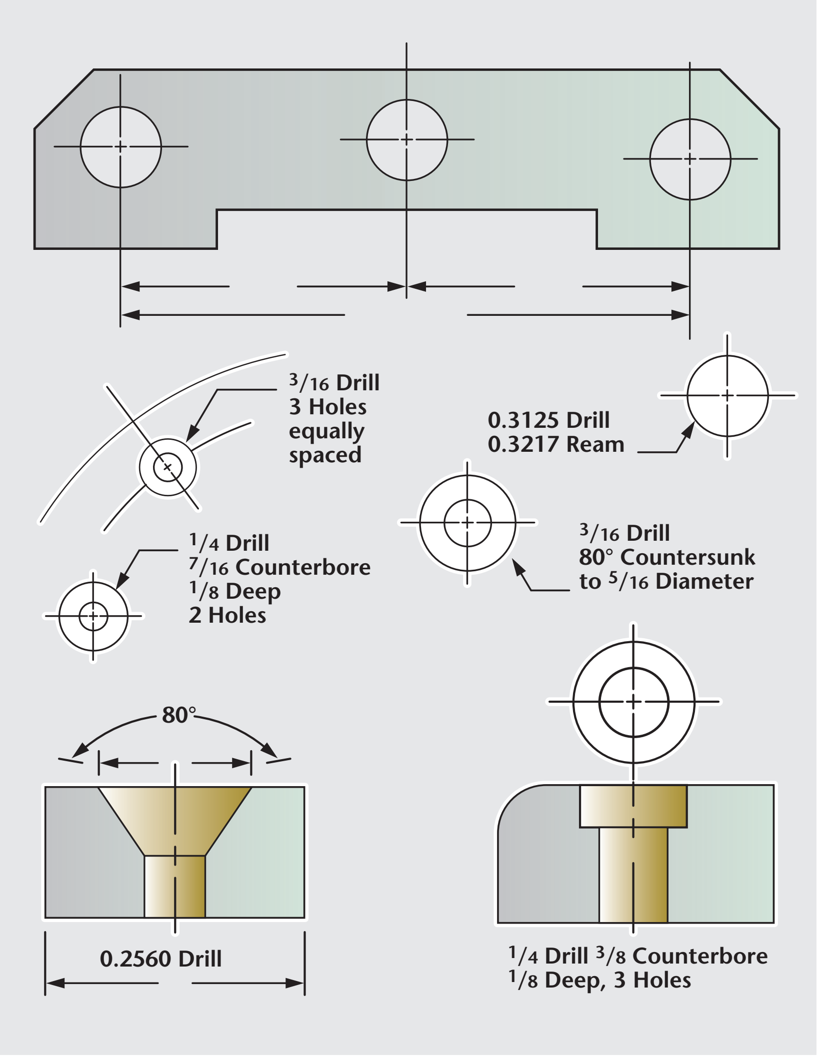


Figure 2-1-23. Dimensioning holes.

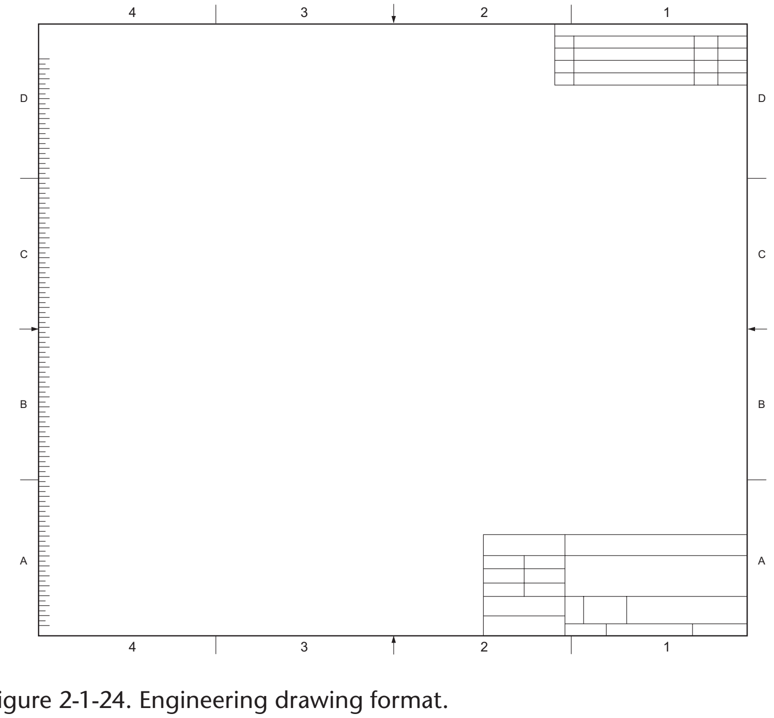


Figure 2-1-24. Engineering drawing format.

- Plus and minus tolerancing may be expressed as either bilateral or unilateral tolerances.
- In bilateral tolerancing, the plus and minus limits are generally equal, but designs may dictate unequal values as shown in Figure 2-1-20.
- Unilateral tolerancing is used when only a high or low limit of a tolerance is used, Figure 2-1-21.

Dimension lines. Dimensioning on a drawing or print is indicated by the use of extension lines, leader lines, dimension lines, figures, notes, or symbols. Dimensions on a drawing indicate length, angles, diameters, radius, or locations (Figure 2-1-22).

In dimensioning distances between holes in an object, dimensions are usually given from center to center rather than from outside to outside of the holes. When a number of holes of various sizes are shown, the desired diameters are given on a leader followed by notes indicating the machining operations for each hole. If a part is to have three holes of equal size, equally spaced, this information is given. For precision work, sizes are given in decimals. Diameters and depths are given for counterbored holes. For countersunk holes, the angle of countersinking and the diameters are given. Study the examples shown in Figure 2-1-23.

The dimensions given for fits signify the amount of clearance allowed between moving parts. A positive allowance is indicated for a part that is to slide or revolve upon another part. A negative allowance is one given for a force fit. Whenever possible, the tolerance and allowances for desired fits conform to those set up in the *American Standard for Tolerances, Allowances, and Gages for Metal Fits*. The classes of fits specified in the standard may be indicated on assembly drawings.

Aircraft Production Drawings

From the manufacturing design of an aircraft or part to the assembly, installation, and repair will require several types of engineering drawings. The engineering drawing is a document that pictorially shows the physical shape, function, or other information the designer wants to present.

To show all these requirements, it will normally take a number of different types of engineering drawings. As a rule, the combination of detail, assembly, installation, and diagrammatic drawings will provide the necessary information for a mechanic to complete the job. *Diagrammatic* is the description for usage of various diagrams.

It is plural and refers to no specific diagram, but any diagrams that may be required (used). The format for engineering drawings is shown in Figure 2-1-24.

Title blocks. Every print must have some means of identification. This is provided by a title block (Figure 2-1-25). The title block consists of a drawing number and certain other data concerning the drawing and the object it represents. This information is grouped in a prominent place on the print, usually in the lower right-hand corner. Sometimes the title block is in the form of a strip extending almost the entire distance across the bottom of the sheet.

Although title blocks do not follow a standard form insofar as layout is concerned, all of them will present essentially the following information:

- A drawing number to identify the print for filing purposes and to prevent confusing it with any other print
- The name of the part or assembly
- The scale to which it is drawn
- The date
- The name of the firm
- The name of the draftsperson, the checker, and the person approving the drawing

Size. The universal numbering system provides a means of identifying standard drawing sizes. In the universal numbering system, each drawing number consists of six or seven digits. The first digit is always A, B, C, D, E, or J (Figure 2-1-26), and indicates the size of the drawing. The remaining digits identify the drawing.

Many firms have modified this basic system to conform to their particular needs. Letters may be used instead of numbers. The letter or number depicting the standard drawing size may be prefixed to the number, separated from it by a dash. Other numbering systems provide a separate box preceding the drawing number for the drawing size identifier. In other modifications of this system, the part number of the depicted assembly is assigned as the drawing number.

Drawing numbers. All prints are identified by a number that appears in a number block in the lower right-hand corner of the title block. It may also be shown in other places, such as near the top border line in the upper right-hand corner or on the reverse side of the print at both ends, so that the number will show when the print is folded or rolled. The purpose of the number is for quick identification of a print.

<table>
<tr><td colspan="3">FEDERAL AVIATION ADMIN.
AERONAUTICAL CENTER OKLAHOMA CITY, OKLA.</td></tr>
<tr><td colspan="3">№ ADF "T" ANTENNA
LOCATION AND DETAILS</td></tr>
<tr><td colspan="3">SCALE: FULL SIZE</td></tr>
<tr><td colspan="2">APPROVED: MICHAEL KULP</td><td>SUBMITTED: B.B. GREENWELL</td></tr>
<tr><td>DR. BY: HBF
CK. BY: TDY</td><td>DATE: 05.02.2006</td><td>DR. # AC-A-735</td></tr>
</table>

Figure 2-1-25. Title block.

Size	A	B	C	J
Length	11″	17″	22″	Indefinite (roll)
Width	81/2	11″	27″	17, 22, 25, 50, 34, and 36 inches

Figure 2-1-26. Standard blueprint paper sizes.

If a print has more than one sheet and each sheet has the same number, this information is included in the number block, indicating the sheet number and the number of sheets in the series.

Reference numbers that appear in the title block refer a person to the numbers of other prints. When more than one detail is shown on a drawing, dash numbers are used. Both parts would have the same drawing number plus an individual number, such as 40267-1 and 40267-2.

In addition to appearing in the title block, dash numbers may appear on the face of the drawing near the parts they identify. Dash numbers are also used to identify right-hand and left-hand parts shown in the drawing. The right-hand part is called for in the title block. Above the title block will be found a notation such as "470204-1LH shown, 470204-2RH opposite". Both parts carry the same number, but the part called for is distinguished by a dash number. Some prints have odd numbers for left-hand parts and even numbers for right-hand parts.

Scale. The scale that is printed on the blueprint indicates the size of the part on the drawing as compared to the size of the actual part.

A scale may be indicated as 1 inch equals 2 inches; 1 inch equals 12 inches; 3/8 inch equals 1 foot, or full size, one-half size, or one-quarter size. The scale *1 inch = 2 inches* indicates that a 1-inch line on the drawing is actually 2 inches on the object. When the scale is shown as *3 inches = 1 inch*, the line on the drawing is 3 inches long and the line on the object is 1 inch long. This type of scale would be used when drawing a very small object.

BILL OF MATERIALS			
ITEM	PART NO.	REQUIRED	SOURCE
CONNECTOR	UG-21 D/U	2	STOCK

Figure 2-1-27. A typical bill of materials.

2	CHANGED PART NO. 5	E.O. 1	05/02/06	B.K.
1	REVISED DIMENSIONS	J.L.M.	07/01/06	E.K.P.
NO.	REVISION	AUTH.	DATE	SIGN

Figure 2-1-28. Revision block.

Never measure a drawing and use that dimension because the drawing may have been enlarged or reduced.

Page. The title block contains a place to number the pages of a drawing. If a drawing has more than one page, it will be indicated by 1 of 3 on the first page, 2 of 3 on the second page, and 3 of 3 on the third page. When drawings are in book form, this number may be used to indicate the page number of the book.

Responsibility. Within the title block is a space for the date and initials or signatures of the designer, draftsperson, checker, and supervisor. Each drawing may not have all of these positions, but each drawing will indicate the responsibility for the drawing.

Standards. There are standards by which all drawings are made. The purpose of these standards is for the uniformity of drawings among the manufacturers. The standards deal with all aspects of the drawing. These standards are set by organizations with an interest in producing uniform meaning of the information presented on the drawings.

Some of the organizations that set standards for drawings are the Department of Defense (DOD), Society of Automotive Engineers (SAE), American Welding Society (AWS), and the American National Standards Institute (ANSI).

Bill of materials. A list of the materials and parts necessary for the fabrication or assembly of a component or system is often included on the drawing. The list usually will be in ruled columns in which are listed the part number, name of the part, material from which the part is to be constructed, the quantity required, and the source of the part or material. A typical bill of materials is shown in Figure 2-1-27. On drawings that do not have a bill of materials, the data may be indicated directly on the drawing.

On assembly drawings, each item is identified by a number in a circle or square. An arrow connecting the number with the item assists in locating it in the bill of materials.

Revision block. Revisions to a drawing are necessitated by changes in dimensions, design, or materials. The changes are usually listed in ruled columns either adjacent to the title block or at one corner of the drawing. All changes to approved drawings must be carefully noted on all existing prints of the drawing.

When drawings contain such corrections, attention is directed to the changes by lettering or numbering them and listing those changes against the symbol in a revision block (Figure 2-1-28). The revision block contains the identification symbol, the date, the nature of the revision, the authority for the change, and the name of the draftsperson who made the change.

To distinguish the corrected drawing from its previous version, many firms are including, as part of the title block, a space for entering the appropriate symbol to designate that the drawing has been changed or revised.

Zone numbers. Zone numbers on drawings are similar to the numbers and letters printed on the borders of a map. They are there to help locate a particular point. To find a point, mentally draw horizontal and vertical lines from the letters and numerals specified; the point where these lines would intersect is the area sought.

Use the same method to locate parts, sections, or views on large drawings, particularly assembly drawings. Parts numbered in the title block can be located on the drawing by finding the numbers in squares along the lower border. Zone numbers read from right to left.

Station numbers. A numbering system is used in the design and manufacture of aircraft in order to identify any given point within the aircraft to within one cubic inch. This system utilizes fuselage stations, waterlines, buttock lines (commonly called butt lines), and wing stations. While each is described in detail in the following paragraphs, each one consists of a set of imaginary lines placed one inch apart, parallel to each other, and measured from a *0*, or reference datum line. In addition to using this station numbering system on drawings and in the design and manufacture of aircraft, once produced, the weight and balance of the aircraft is determined by utilizing these imaginary lines.

Fuselage stations. Fuselage stations (FS) are indicated in inches from the datum as set by the engineer. The datum can be at the nose of the aircraft, in front of the aircraft, aft of the nose of the aircraft, or any place the engineer designates. If the datum is aft of the nose of the aircraft, any station towards the nose of the aircraft will be a negative fuselage station. This will be indicated by a minus sign in front of the fuselage station number. For example, FS-15 indicates the station is 15 inches in front of the fuselage datum. When no sign precedes a number, it is positive and indicates that the fuselage station is between the fuselage datum and the tail of the aircraft.

Waterline stations. Waterline stations (WL) indicate, in inches, the vertical distance from the waterline datum to a location on the aircraft. The waterline datum has no set location. This datum may be a point above the ground, the ground itself, or below the ground. If the location of the datum allows any part of the aircraft to fall below the datum, those waterline stations will be negative.

Buttock line stations. Buttock line (BL) stations are measured in inches from the centerline of the aircraft. This is the only datum that is the same on all aircraft. Buttock line stations are measured to the left and right of the datum looking forward. This is indicated by right buttock line (RBL) and left buttock line (LBL). The right buttock line is given a positive value from 0 (zero) and the left buttock line is given a negative value from 0 (zero).

Some manufacturers use buttock line stations to indicate positions on the wings. Other manufacturers use wing stations.

Wing stations. Wing stations (WS) are measured in inches from the datum, which is the centerline of the aircraft. The wing stations are indicated by left or right. LWS indicates a left-wing station and RWS would indicate a right-wing station. When wing stations and buttock stations are used together, be careful not to confuse the numbers. Wing stations indicate positions on the wing structure only, not positions on the fuselage.

Section 2

Applied Geometry

To sketch an object or an idea, it may become necessary to draw geometric shapes, parallel lines, arcs, angles, or to bisect or divide lines into equal sections in order to communicate the needed information.

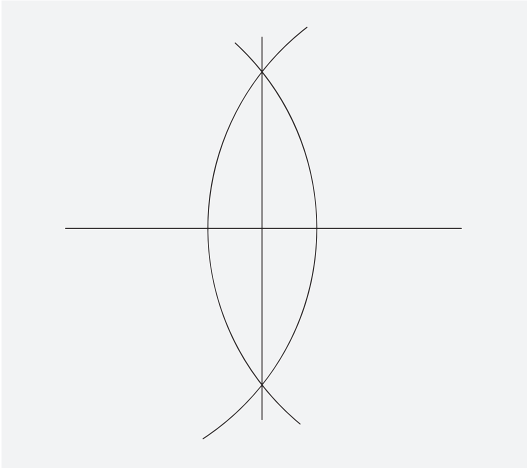


Figure 2-2-1. Bisecting a line.

Only a few simple tools are needed to perform many useful drawing functions. A pencil compass and ruler are all that is needed.

Figure 2-2-2. Compass.

Basics

Find the center of a line. To bisect a straight line (Figure 2-2-1) set the pencil compass (Figure 2-2-2) to a radius that is greater than half the line's length. Lightly swing an arc from both ends of the line. Connect the points where the arcs cross. The line will intersect the original line at 90° and divide the line in half. Erase the light lines.

Draw a line perpendicular to a baseline. To draw a line perpendicular from a point to a baseline, open the compass to a greater length than from the point to the baseline, then swing an arc across the baseline. Using the two points where the arc crosses the baseline as pivot points, swing an arc from each point on the opposite side of the baseline from the point where the perpendicular line is to start. Connect the point where these two arcs cross and the point where the perpendicular line is to start and draw a line from that point to the baseline (Figure 2-2-3).

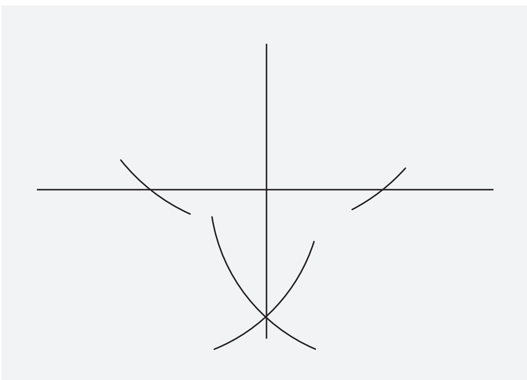


Figure 2-2-3. Drawing a perpendicular to the baseline.

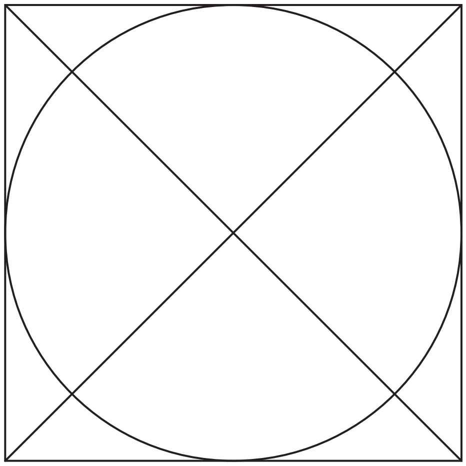


Figure 2-2-4. Finding the center of a circle by the square method.

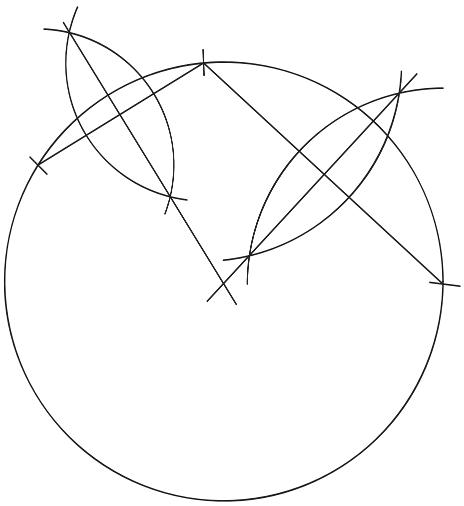


Figure 2-2-5. Finding the center of a circle by the bisection method.

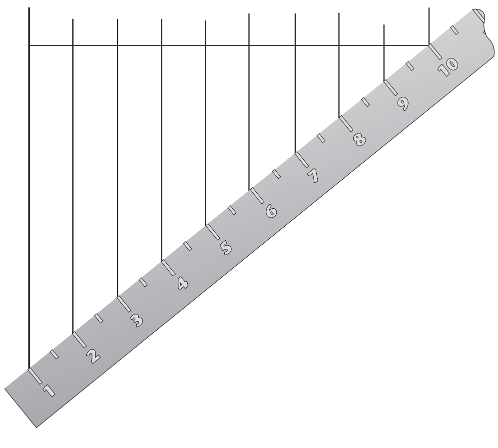


Figure 2-2-6. Dividing a straight line into equal lengths.

Find the center of a circle. One method of finding the center of a circle is to draw a square around the circle. Then draw diagonal lines from the corners. Where the diagonal lines cross is the center of the circle (Figure 2-2-4).

Another method is to draw two lines from one point on the circle to opposite sides of the circle, then bisect each line. Extend the bisecting if necessary for the lines to cross. Where they cross is the center of the circle (Figure 2-2-5).

Divide a line into an equal number of parts. Divide a straight line into equal sections, Figure 2-2-6, by using a ruler that has the correct divisions of measurement. Lightly draw a diagonal line perpendicular below the line to be divided. With the high numbered end at the right side of the line, rotate the other end until the zero or one crosses the perpendicular line. Then mark the divisions on the paper and draw parallel vertical lines to the line being divided. The line will be divided into equal segments.

Bisect an angle. To bisect an angle, Figure 2-2-7, set the pencil compass to a radius at least half the length of one of the lines that form the angle. Swing a light arc that crosses both line AB and BC. Then set the compass on these points (D, E) and swing short arcs from both points toward the opening of the angle. Connect point B where the arcs cross. The angle is bisected.

Sketching

The aviation maintenance technician should possess the ability to communicate in the form of technical drawings. The technician should be able to pass on ideas, information, and major repair information in the form of technical drawings. This does not mean that maintenance technicians should be able to produce sets of finished blueprints, but they should be able to present clear, concise, factual, and accurate information on the drawing.

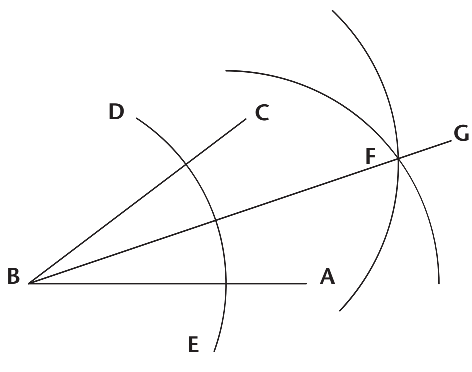


Figure 2-2-7. Bisecting an angle.

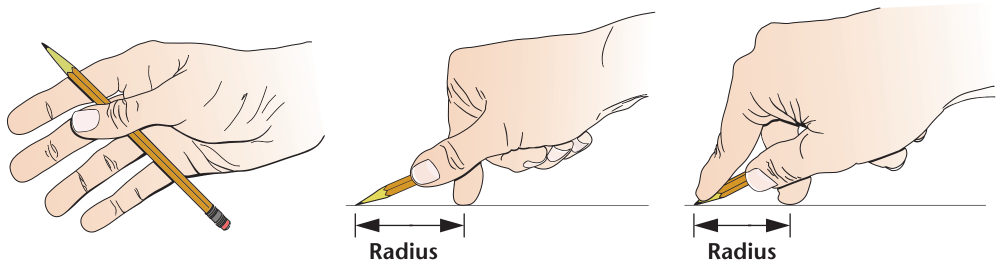


Figure 2-2-8. Freehand arcs and circles.

The individual style or method of drawing is not important. The choice of presentation is up to the technician. The only requirement is that the drawing shows what the technician needs and wants to show, as accurately as possible.

Almost all objects are composed of one or a combination of six basic shapes: triangles, circles, cubes, cylinders, cones, or spheres. Therefore, being an artist, or having special talents is not necessary to produce good technical sketches. Through practice and use of the basic skills, anyone can develop their drawing skills to an acceptable level.

Sketching techniques. To produce accurate and usable drawings, there are a few basic techniques that have to be learned, mastered, and practiced. Drafting instruments are not usually needed to draw a sketch, however, the use of graph paper can make sketching easier.

Try to find a well lighted area with enough room to place the drawing paper and drawing equipment and to support your arms while working. The proper support for the arms is needed to help with the free and easy movement of wrists and fingers. Do not hold the pencil so tightly that your fingers become cramped.

When drawing lines, use short strokes. This allows for control of the pencil's movement, and provides for better control of the pencil point pressure on the paper. Make the pencil marks light while drawing. When the outline is finished, darken only the lines needed to show the object and erase the rest. Lightly drawn lines are easily erased.

Lines, arcs, and circles. To make clear, accurate drawings, the sketcher must be able to sketch lines, circles, and arcs that will intersect lines. These types of lines are done best with drawing tools. Because these tools may not be available when a drawing needs to be made, it is important to be able to sketch freehand.

Freehand lines. When drawing freehand lines, it is a good practice to place dots lightly on the paper as guides, with one at the beginning and one at the end of the line. If the line is long, a few intermediate dots may be used. Before drawing the line, swing the drawing arm along the dots to relax the arm and to get the feel for the length of the line. With a well sharpened, soft lead pencil, use a light touch and short strokes. The short strokes will help make the line straighter, and the light touch will make erasure easier if it is needed. After drawing a line, examine it for straightness and neatness. Additional practice may be needed, but vertical and slanted lines are drawn in the same way as horizontal lines.

Freehand arcs and circles. Drawing a freehand arc or circle requires no more skill than straight lines, but it does require a bit more practice. With the pencil held as shown in Figure 2-2-8, the first or second finger (based on the size desired) is used as a pivot point for the arc. A circle is drawn as a series of connected arcs. As with straight lines, use a light touch and short strokes.

Repair Sketches

When the completion of a repair requires a sketch of the repair, the sketch must be drawn clearly and contain enough information so someone could duplicate the repair.

To sketch a repair, follow the four steps that are listed below and demonstrated in Figure 2-2-9:

1. Determine the views necessary to portray the object.
2. Block in the views using light construction lines.
3. Complete details, darken the object outline, and sketch extension and dimension lines and dimensions.
4. Complete the drawing with repair details, such as the type of material used, the types of fasteners, the location of the repair, and any additional information necessary to duplicate the repair. Also include a title, date, and, if necessary, the name of the sketcher.

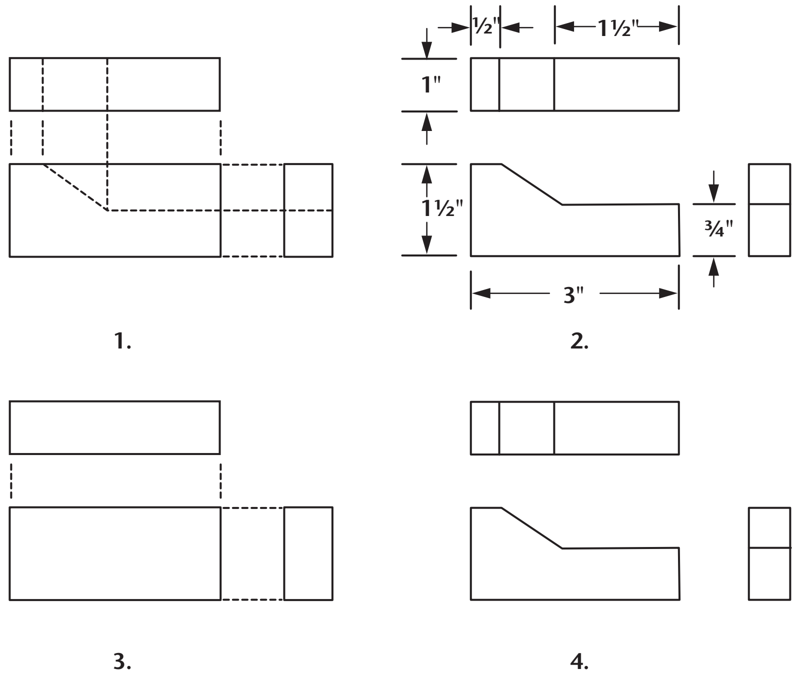


Figure 2-2-9. Sample repair sketch.

Graphic Presentation of Information

Some of the technical information used in maintaining aircraft can best be understood by presenting the information in the form of charts or graphs. They can be divided into those that present technical relationships or mathematical relationships and those used to express nontechnical data.

The type of chart or graph used depends on what information is to be presented. Care must be taken to select the right type of chart or graph, or the information presented could be misinterpreted. See examples in the Graphs and Charts section in this book's General Mathematics chapter.

A nomograph is used to show specific relationships between three variables. When the values of the two variables are known, set a ruler between the two and the third variable can be found.

A rectilinear graph shows the relationship between variables. One variable is shown on the vertical and the other is on the horizontal.

Circular charts and bar charts are used to give a visual presentation of the parts to the whole.

Care of Drafting Instruments

Good drawing instruments are expensive, precision tools. Reasonable care given to them during use and storage will prolong their service life.

T-squares, triangles, and scales should not be used, or placed, where their surfaces or edges may be damaged. Use a drawing board only for its intended purpose, and not in a manner that will mar the working surface.

Compasses, dividers, and pens will provide better results with less annoyance if they are correctly shaped and sharpened and are not damaged by careless handling.

Store drawing instruments in a place where they are not likely to be damaged by contact with other tools or equipment. Protect compass and divider points by inserting them into a piece of soft rubber or similar material. Never store ink pens without first cleaning and drying them thoroughly.

Microfilm and Microfiche

Everyone in aviation has a space problem. Space is needed to hangar aircraft, to perform maintenance, for offices and storage, and the need for space goes on and on. The aviation technician who can honestly say that they don't need additional space is rare indeed.

One of the objects that traditionally takes up extraordinary amounts of space is the paperwork necessary to conduct the business of aircraft maintenance. This paperwork includes regulations, instructions, drawings, and other records. While regulations and records are addressed in greater detail in other chapters of this book, it is necessary to mention them at this time since they too, along with drawings and instructions, have been reduced to microfilm, microfiche, and stored in computer data banks in order to alleviate storage and space problems encountered by everyone in aircraft maintenance.

Microfilm. The practice of recording drawings, parts catalogs, and maintenance and overhaul manuals on microfilm was introduced a number of years ago. Microfilm is regular 16-mm or 35-mm film. Since 35-mm film is larger, it provides a better reproduction of drawings. Depending on the size of the drawing to be reproduced, a varying number of drawings can be photographed on one reel of 35-mm film. To view or read drawings or manuals on a reel of film, you need either a portable 35-mm film projector or a microfilm reader or viewer.

The advantage of microfilm is that several reels, which represent perhaps hundreds of drawings, require only a small amount of storage space. Too, a person working on an aircraft may need to refer to a specific dimension. They can place the reel of microfilm in a projector, locate the drawing or desired information, and read the dimension. If they need to study a detail of the drawing or work with the drawing for a long period of time, an enlarged photographic reproduction can be made, using the microfilm as a negative.

Microfilm of drawings has many other uses and advantages. However, microfilm is not intended to replace the need for original drawings, especially where the originals are modified and kept current over a long period of time.

When drawings are filmed on continuous reels, corrections can be made by cutting out superseded drawings and splicing in the revised ones. When these corrections become numerous, the procedure becomes impractical and is discarded in favor of again filming all the related drawings.

A method that allows corrections to be made easily is to photograph the drawings and then cut up the film into individual slides. This has one disadvantage; it requires considerable time to convert the film into slides, insert them into transparent protective envelopes, and arrange them in sequence so that desired drawings can be located quickly.

A 70-mm microfilm has been developed to replace the older and less versatile 16-mm and 35-mm films. With it, larger size drawings can be reproduced as individual frames or slides, and these can be inserted in regular paper envelopes and kept in an ordinary file. When held to the light, this large microfilm can be read with the naked eye.

Microfiche. A variation of microfilm is microfiche, which uses a sheet of film, typically 4 inches by 6 inches, on which the information is recorded. Literally thousands of pages of written material can be kept in one three-ring binder or in a small file box (Figure 2-2-10).

The microfiche is divided into grids that are used to identify and locate information in much the same way that grid lines are used to find locations on a road map. The size of the grids is based on the size of the document being reproduced onto the microfiche. As an example, if standard 8-1/2 × 11 inch paper is reproduced on microfiche, most microfiche will accommodate 24 grids across and 12 or 13 grids down. That means each fiche can contain at least 288 pages on information.

Microfiche is read on a reader which consists of a plate to hold the film, a light source which illuminates the film, a lens which enlarges the image and allows for focusing, a mirror to deflect the image to the viewing screen, and the viewing screen. Some microfiche readers have the capability to copy the selected image onto paper, which allows the user to have a *hard copy* of the information or drawing.

NOTE: Hard copies should be destroyed immediately after use to avoid using material that has changed or been superseded since the hard copy was made.

Computers

While the computer is by no means new, many ways of using them are. Today, the computer is utilized by the aircraft maintenance technician to assist in the design and maintenance of aircraft parts and components. The Boeing 777 is the first commercial airplane that was designed on, and exclusively drawn on, a computer.

Computer-Assisted Design (CAD). Most modern aircraft are at least partially designed by engineers and designers using computers to assist them. In addition to assistance in solving complex design formulas, computers can be used to draw the designer's idea or concept on the screen, and transfer it to paper via a printer. By formulating the design on a computer screen, mirror images, corrections, and adjustments are simple key strokes, as compared to manual design, which requires extensive erasure or redrawing.

Computer-assisted Maintenance (CAM). Through the use of the computer, today's aircraft technician can record performed maintenance, find repair procedures, locate illustrations, track equipment performance, account for time, order parts, and much more. Programs and software available to the technician allow access to more information in less time, with more accuracy and less error than ever before. As technology improves the computer and its software, and because computers are becoming ever more affordable and easy to use, the future of CAM is basically unlimited.

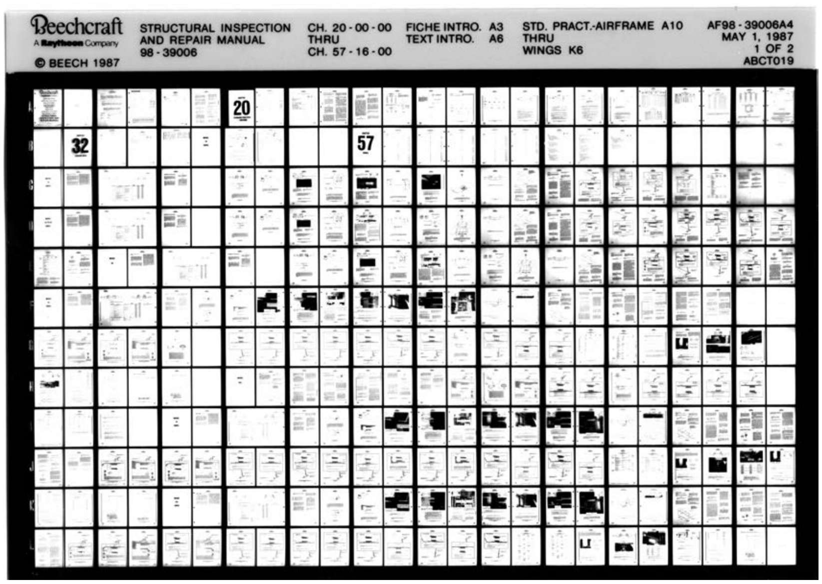
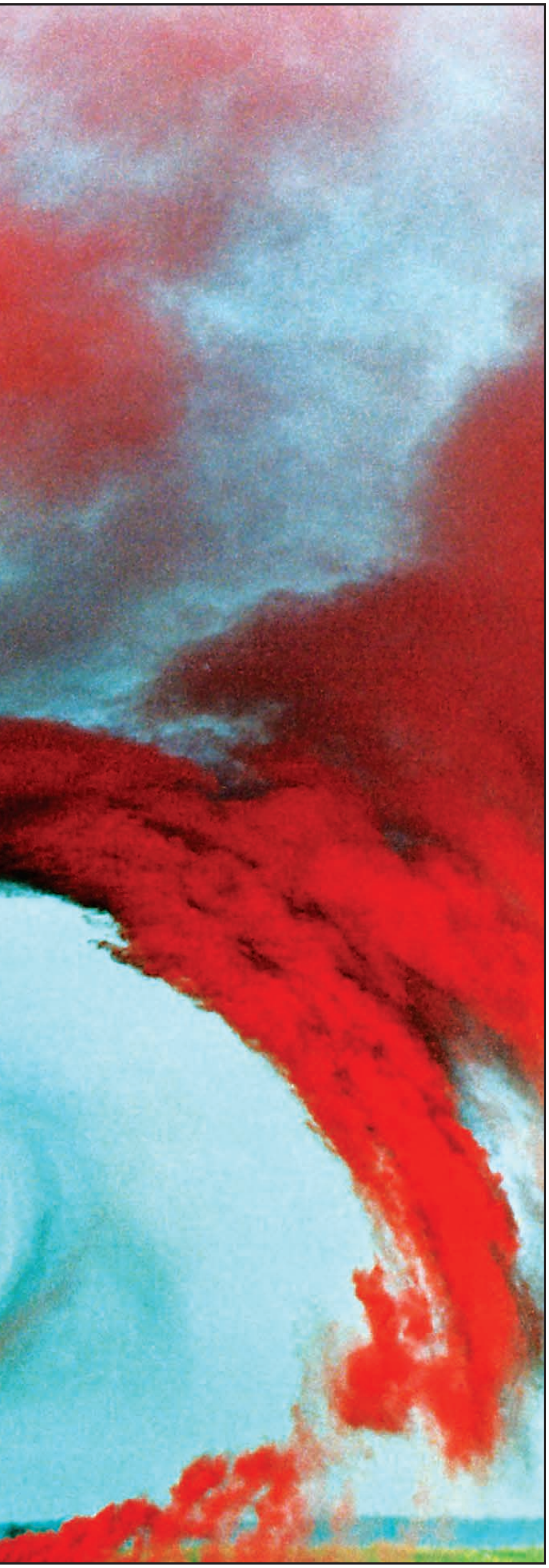


Figure 2-2-10. Microfiche sheet.



3

Principles of Aviation Physics

Section 1

Introduction to Physics

Physics is the term applied to that area of knowledge regarding the basic and fundamental nature of matter and energy. It does not attempt to determine *why* matter and energy behave as they do in their relation to physical phenomena, but rather *how* they behave.

People who maintain and repair aircraft should have a knowledge of physics, because these basic laws apply to all the mechanical, electrical, and hydraulic systems of the airframe and powerplant. With this basic knowledge, the technician is better able to understand and identify the problems that occur and determine methods of repair and preventive measures to ensure the safe operation of the aircraft.

Matter. Matter is the most basic of all things related to physics and the material world, yet it is one of the most difficult things to define. Matter itself cannot be destroyed, but it can be changed from one state to another by chemical or physical means. It is often considered in terms of the energy that it contains, absorbs, or gives off. Under certain controlled conditions, matter can be of great benefit to man. For lack of a better definition, matter is any substance that occupies space and has weight.

Chemical nature of matter. The smallest particle of any substance is the molecule. This can be broken down to elemental particles called atoms. It is these atoms, or combination of atoms, that form the molecules of matter. In nature only 92 of these elements exist. Others have been produced by laboratory means, but, for our purposes, we will only consider the 92 natural elements.

Learning Objectives

REVIEW
- Basic principles of physics
- Types of energy

DESCRIBE
- The laws of fluid mechanics

EXPLAIN
- How the laws of physics apply to gases
- The principles of:
  - stress
  - pressure
  - sound
  - heat
  - motion

Left. Wake vortex study at Wallops Island.

Photo courtesy of NASA Langley Research Center

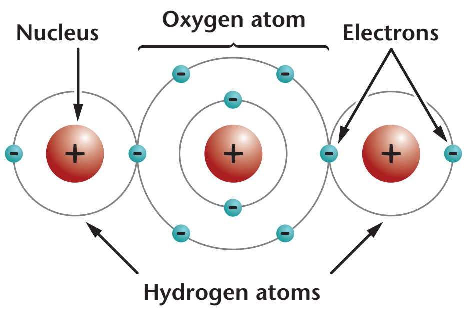


Figure 3-1-1. A water molecule.

These atoms are combined in various manners to form molecules of matter. Most of these molecules are made up of two or more atoms. A few are made of a single atom, such as many of our inert gases like argon, helium, and neon.

If two or more molecules are grouped together and keep their chemical identity, they are referred to as a legion. An example of this would be soil that could contain various amounts of elements.

In other cases, two or more atoms could be combined and result in a chemically different substance, which is called a compound. Water is one of these compounds. It is made of hydrogen and oxygen and is chemically referred to as H_2O, meaning that two atoms of hydrogen have formed with one atom of oxygen to form one molecule of water (Figure 3-1-1).

By using different combinations of atoms, different compounds may be formed. For example, the same elements are found in both alcohol and sugar, but the molecules are not the same. All of our various metal alloys are formed of compounds in order to obtain the characteristics most desirable for a particular function.

Physical nature of matter. It has been determined that matter is composed of tiny particles called molecules. The molecules are so small that they cannot be seen even with the use of an optical microscope, and their masses are so small that they cannot be detected on the most sensitive analytical balances. However, there is indirect physical and chemical evidence to establish the fact that molecules exist in matter. One of the methods of establishing these facts is the *kinetic-molecular theory*. It theorizes that all matter, regardless of its state, is comprised of molecules. These molecules are the smallest particle of a substance that still retains the physical and chemical properties of that substance. All of the molecules in one substance are exactly alike and unique to that substance. This means that the molecules in one substance are not like those found in any other substance.

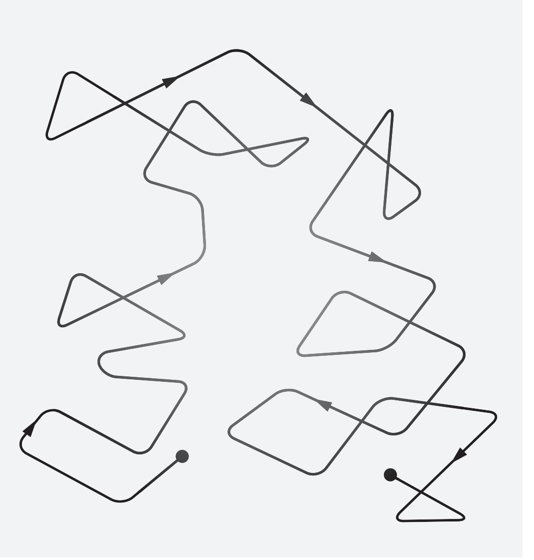


Figure 3-1-2. Darting smoke.

In this theory, the molecules are in constant motion with varying speeds. This theory is often shown by observing through a microscope the action of smoke in a box. In this experiment, the particles of smoke appear to dart in one direction and then another, as shown in Figure 3-1-2.

The reason for this action is quite simple: The particles of smoke are considerably larger than the molecules of the air in which they are suspended; therefore, they constantly collide. When more collisions occur on one side than the other, the smoke particles change direction.

When the molecules are close together, they attract each other until they get too close, and then they repel each other. This attraction and repulsion is one of the determining factors in the state of the matter.

Physical states. Basically, all matter falls into three states: solids, liquids, and gases. The same type of matter may exist in all three forms. These three forms will all contain the same identical molecules. The most common example of this is water. When it is water, it is a liquid. If we freeze it, the water becomes a solid. If we heat it above the boiling point, it becomes a gas. These different states of matter are explained by the relative position of the molecules and the freedom of their motions.

Solids. In a solid state, matter has a definite shape and volume. This shape may be changed by outside forces, such as forging, rolling, or milling — common processes with metals — or it may be changed by chemical processes. It is thought that, in the solid state, the molecules oscillate about fixed points and are held together by a strong molecular force called

	Metric system	English system	Equivalents
Length (distance)	**Centimeter**	**Foot**	
	1 centimeter = 10 millimeters		1 inch = 2.54 centimeters
	1 decimeter = 10 centimeters	1 foot = 12 inches	1 foot = 30.5 centimeters
	1 meter = 100 centimeters	1 yard = 3 ft.	1 meter = 39.37 inches
	1 kilometer = 1,000 meters	1 mile = 5,280 ft.	1 kilometer = 0.62 miles
Weight (mass)	**Gram**	**Pound**	
	1 gram = 1,000 milligrams	1 pound = 16 ounces	1 pound = 453.6 grams
	1 kilogram = 1,000 grams	1 ton = 2,000 lbs.	1 kilogram = 2.2 lbs.
Time	**Second**	**Second**	
	Same as for English system	1 second = 1/86,400 of average solar day	Time same for both systems

Table 3-1-1. Comparison of metric and English systems of measurement.

cohesion. It is cohesion that causes solids to retain their shape and volume.

Liquids. Liquids have a definite volume but an indefinite shape. In other words, the liquid takes the shape of its container. Another characteristic of liquids is that, for all practical purposes, the liquids are incompressible. This element is extremely important regarding the use of hydraulic power.

The molecules in liquids are not held together in rigid patterns, as are those of solids. However, liquid molecules are almost as close together as those of solids, without fixed positions. This can be easily shown by adding a few drops of a colored liquid dye to a clear liquid. Soon the clear liquid will take the color of the few drops of dye. This is caused by the molecules of dye passing between the spaces between the molecules of the clear liquid.

Gases. Gases differ from solids and liquids in that they have neither a definite shape nor a definite volume. This is demonstrated by the fact that, regardless of the shape of the container, the gas will fill the whole container.

The molecules of gases have no cohesive forces upon each other. This, coupled with the fact that the molecules travel rapidly, accounts for the ability of gaseous materials to fill a container very shortly after being released.

Two other molecular properties of gases are its elasticity and compressibility. These properties are continually in use in aviation, as shown with the use of pneumatic tires, accumulators, hydraulic systems, and landing gear struts, to name a few.

Weight and mass. All matter has weight and mass. These two terms are often considered to be similar terms, but, in reality, they are not. *Weight* is a function of gravity. For this reason, the weight of an object may vary from one place to another, while mass does not. *Mass* is the amount of matter in a body and can be determined by the following formula:

$$\text{mass} = \frac{\text{weight}}{\text{acceleration due to gravity}}$$

To measure these characteristics of matter, a system of measurement must be used. The two most commonly used systems of measurement are the English system, which is still in general use in the United States, and the metric system, used in most European countries and now adopted by the Armed Forces of the United States. The metric system is normally used in all scientific applications.

The three basic quantities that require units of measurement are length (distance), weight (mass) and time.

The English system uses different units for the measurement of mass and length. The pound is the unit of weight, the foot is used to measure length. The second is used to measure time, the same as in the metric system.

The units of one system can be converted to units in the other system by using a conversion factor, or by referring to a chart similar to the one shown in Table 3-1-1. In this table, the English and the metric systems are compared; in addition, a column of equivalents is included, which can be used to convert units from one system to the other.

Solids	Specific gravity	Liquids (room temperature)	Specific gravity	Gases (air standard at 0 °C, and 76.0 centimeters of mercury)	Specific gravity
Aluminum	2.7	Alcohol, ethyl	0.789	Air	1.000
Bronze	8.8	Gasoline	0.68 0.72	Hydrogen	0.0695
Copper	8.9	Oil (paraffin)	0.8	Nitrogen	0.967
Ice	0.917	Water	1.00	Oxygen	1.105
Titanium	4.4	JP4	0.785	Acetylene	0.898
Iron	7.9	JP5	0.871	Carbon dioxide	1.528

Table 3-1-2. Typical values of specific gravity.

Density. The density of a substance is its weight per unit volume. The unit volume selected for use in the English system of measurement is 1 cubic foot (ft^3). In the metric system, it is 1 cubic centimeter (cm^3). Therefore, density is expressed in pounds per cubic foot (lb/ft^3) or in grams per cubic centimeter (g/cm^3).

To find the density of a substance, its weight and volume must be known. Its weight is divided by its volume to find the weight per unit volume.

For example, the liquid that fills a certain container weighs 1,497.6 lbs. The container is 4 feet long, 3 feet wide, and 2 feet deep. Its volume is 24 ft^3 (4 feet× 3 feet× 2 feet). If 24 ft^3 of this liquid weighs 1,497.6 lbs., then 1 ft^3 weighs 1,497.6/24, or 62.4 lbs. Therefore, the density of the liquid is 62.4 lb/ft^3.

This is the density of water at 4°C, and that is usually used as the standard for comparing densities of other substances. (In the metric system, the density of water is 1 g/cm^3.) The standard temperature of 4°C is used when measuring the density of liquids and solids. Changes in temperature will not change the weight of a substance but will change the volume of the substance by expansion or contraction, thus changing its *weight per unit of volume*.

The procedure for finding density applies to all substances; however, it is necessary to consider the pressure when finding the density of gases. Temperature is more critical when measuring the density of gases than it is for other substances. The density of a gas increases in direct proportion to the pressure exerted on it. Standard conditions for the measurement of the densities of gases have been established at 0°C for temperature and a pressure of 76 centimeters (cm) of mercury. This is the average pressure of the atmosphere at sea level. Density is computed based on these conditions for all gases.

Specific gravity. It is often necessary to compare the density of one substance with that of another. For this purpose, a standard is needed. Water is the standard that physicists have chosen to use when comparing the densities of all liquids and solids. For gases, air is most commonly used. However, hydrogen is sometimes used as a standard for gases.

In physics, the word *specific* implies a ratio. Thus, specific gravity is calculated by comparing the weight of a definite volume of the given substance with the weight of an equal volume of water. The terms *specific weight* or *specific density* are sometimes used to express this ratio.

The following formulas are used to find the specific gravity (sp. gr.) of liquids and solids:

$$\text{sp.gr.} = \frac{\text{weight of the substance}}{\text{weight of an equal volume of water}}$$

or

$$\text{sp.gr.} = \frac{\text{density of substance}}{\text{density of water}}$$

The same formulas are used to find the density of gases by substituting air or hydrogen for water.

Specific gravity is not expressed in units, but as pure numbers. For example, if a certain hydraulic fluid has a specific gravity of 0.8, 1 ft^3 of the liquid weighs 0.8 times as much as 1 ft^3 of water: 62.4 times 0.8, or 49.92 lbs. In the metric system, cm^3 of a substance with a specific gravity of 0.8 weighs 1 times 0.8, or 0.8 g. (Note that, in the metric system, the specific gravity of a liquid or solid has the same numerical value as its density.) Since air weighs 1.293 grams per liter (g/L), the specific gravity of gases does not equal the metric densities.

Specific gravity and density are independent of the size of the sample under consideration, and depend only upon the substance of which it is made. See Table 3-1-2 for typical values of specific gravity for various substances.

A device called a *hydrometer* is used for measuring specific gravity of liquids. It consists of a tubular-shaped glass float contained in a larger glass tube (Figure 3-1-3). The larger glass tube provides the container for the liquid. A rubber suction bulb draws the liquid up into the container. There must be enough liquid to raise the float and prevent it from touching the bottom. The float is weighted and has a vertically graduated scale.

To determine specific gravity, the scale is read at the surface of the liquid in which the float is immersed. An indication of 1.000 is read when the float is immersed in pure water. When immersed in a liquid of greater density, the float rises, indicating a greater specific gravity. For liquids of lesser density, the float sinks, indicating a lower specific gravity.

An example of the use of the hydrometer is its use in determining the specific gravity of the electrolyte (battery liquid) in a lead-acid aircraft battery. When a battery is discharged, the calibrated float immersed in the electrolyte will indicate approximately 1.150. The indication of a charged battery is between 1.275 and 1.310.

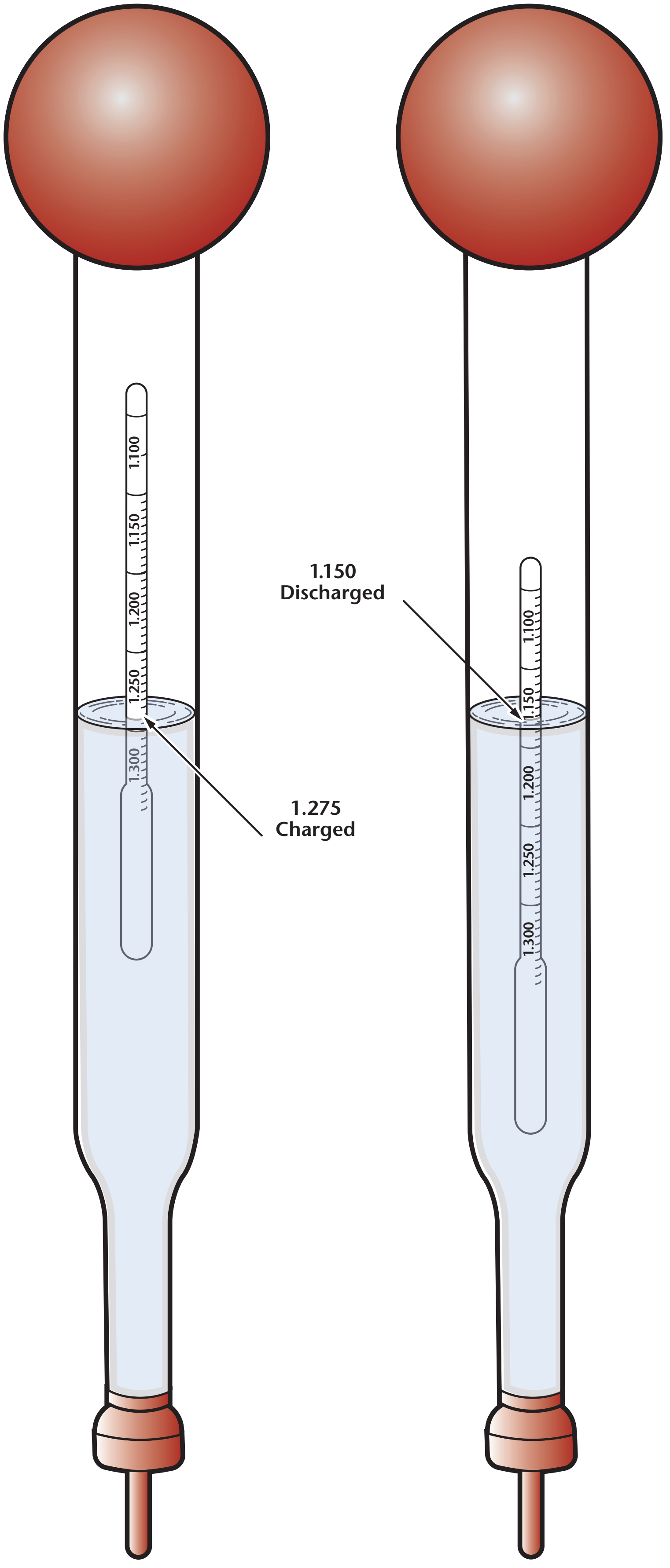


Figure 3-1-3. A hydrometer measures specific gravity of liquids.

Section 2

Types of Energy

Under certain conditions, matter has the ability to do work, even though none is being done at the present time. There are many examples in our everyday life. For example, a battery has power but no current is being drawn from it. A gallon of jet fuel, if burned in the engine, will produce work. These are all examples of matter that could produce work. Energy is simply the capacity to do work. This capacity breaks down into two classifications of energy: potential and kinetic energy.

Potential energy. Potential energy is energy that is stored. It may be classified into three groups:

- Energy due to position
- Energy due to distortion of an elastic body
- Energy which produces work through chemical action

Water in an elevated reservoir and the lifted weight of a pile driver are examples of the first group. A stretched rubber band and compressed spring are examples of the second group. Energy in coal, food, and storage batteries are examples of the third group.

Kinetic energy. Kinetic energy occurs when bodies in motion require work to put them in motion. Thus, they possess energy of motion. Energy due to motion is known as kinetic energy. A moving vehicle, a rotating flywheel, and a hammer in motion are examples of kinetic energy.

Energy is expressed in the same units as those used to express work. The quantity of potential energy possessed by an elevated weight may be computed by the following equation:

Potential Energy = Weight × Height

If weight is given in pounds and height in feet, the final unit of energy will be foot-pounds (ft. lbs.).

Example: An aircraft with a gross weight of 110,000 lbs. is flying at an altitude of 15,000 ft. above the surface of the earth. How much potential energy does the aircraft possess with respect to the earth?

Potential Energy = Weight × Height

PE = 110,000 × 15,000

PE = 1,650,000,000 ft-lb

The most common forms of energy are: heat, mechanical, electrical, and chemical. The various forms of energy can be changed, or transformed, into another form in many different ways. For example, in the case of mechanical energy, the energy of work done against friction is always converted into heat energy, and the mechanical energy that turns an electric generator develops electrical energy at the output of the generator.

Work

The study of machines, both simple and complex, is in one sense a study of the energy of mechanical work. This is true because all machines transfer input energy (the work done on the machine) to output energy (the work done by the machine).

Work, in the mechanical sense of the term, is done when a resistance is overcome by a force acting through a measurable distance. Two factors are involved;

- Force
- Movement through a distance

As an example, suppose a small aircraft is stuck in the snow. Two people push against it for a period of time, but the aircraft does not move. According to the technical definition, no work was done in pushing against the aircraft. By definition, work is accomplished only when an object is displaced some distance against a resistive force. In equation form:

Work = Force (F) × Distance (D)

The physicist defines work as *force times displacement*. Work done by a force acting upon a body is equal to the magnitude of the force multiplied by the distance through which the force acts.

In the metric system, the unit of work is the *joule*, where one joule is the amount of work done by a force of one Newton when it acts through a distance of one meter.

1 joule = 1 Newton x meter

Hence, we can write the definition in the form:

W (joules) = F (Newtons) × D (meters)

EXAMPLE: If we push a box for 8 meters (m) across a floor with a force of 100 Newtons, the work we perform is:

W = FD = 100 Newtons × 8m = 800 joules

EXAMPLE: How much work is done in raising a 500-kilogram (kg) elevator cab from the ground floor of a building to its tenth floor, 30m higher? We note that the force needed is equal to the weight of the cab, which is Mg.

In the metric system, mass, rather than weight, is normally specified. To find the weight in Newtons (the metric unit of force) of something whose mass in kilograms is known, we simply turn to F = Mg and set G = 9.8 m/sec^2

F (Newtons) = M (kilograms) x G (9.8 m/sec^2)

W (joules) = M (kilograms) x G (9.8 m/sec^2) x D (meters)

FD = MGD = 500 kg x 9.8 m/sec^2 x 30m

= 147,000 joules

= 1.47 × 10^5 joules

Power

Power is a badly abused term. In speaking of power-driven equipment, people often confuse the term *power* with the ability to move heavy loads. This is not the meaning of power. A sewing machine motor is powerful enough to rotate an aircraft engine propeller, providing it is connected to the crankshaft through a suitable mechanism. It could not rotate the propeller at 2,000 revolutions per minute (r.p.m.), however, for it is not powerful enough to move a large load at a high speed. Therefore, power means the rate of doing work. It is measured in terms of work accomplished per unit of time. In equation form, it reads:

$$\text{Power} = \frac{\text{Force} \times \text{Distance}}{\text{time}} \quad \text{or} \quad P = \frac{FD}{t}$$

If force is expressed in pounds, distance in feet, and time in seconds, then power is given in foot-pounds per second. Time may also be given in minutes. If time in minutes is used in this equation, then power will be expressed in foot-pounds per minute.

$$\text{Power} = \frac{\text{pounds x feet}}{\text{seconds}} = \text{ft-lbs/sec}$$

or

$$\text{Power} = \frac{\text{pounds x feet}}{\text{minutes}} = \text{ft-lbs/min}$$

EXAMPLE: An aircraft engine weighing 3,500 lbs. was hoisted a vertical height of 7 ft. in order to install it on an aircraft. The hoist was hand-powered and required 3 minutes of cranking to raise the engine. How much power is developed by the man cranking the hoist? (Do not include the friction in the hoist.)

$$P = \frac{FD}{t}$$

$$\text{Power} = \frac{\text{3,500 pounds x 7 feet}}{\text{3 minutes}}$$

$$= \text{8,167 ft-lb/min}$$

Power is often expressed in units of *horsepower.* One horsepower is equal to 550 ft-lb./sec, or 33,000 ft-lb./min. (Example: In the hoist example above, calculate the horsepower developed by the man.)

$$\text{Horsepower} = \frac{\text{Power in ft. - lb/min}}{33{,}000}$$

$$\text{hp} = \frac{\frac{FD}{t}}{33{,}000}$$

$$= \frac{8{,}167}{33{,}000} = 0.247\text{, or about 1/4 hp}$$

Power is rate of doing work:

$$P = \frac{W}{t}$$

In the metric system, the unit of power is the *watt*, where:

1 watt = 1 joule/sec
1hp=746 watts

Thus, a motor with an output of 5,000 watts is capable of doing 5,000 joules of work per second. A kilowatt (kw) is equal to 1,000 watts. Hence, the motor has a power output of 5 kw.

How much time does a 500 kg elevator cab need to ascend 30 meters if it is being lifted by a 5 kw motor? We rewrite P = W/t into the formula:

$$t = \frac{W}{P}$$

and then substitute $W = 1.47 \times 10^5$ joules and $P = \times\ 5.10^3$ watts to find that:

$$t = \frac{W}{P} = \frac{1.47 \times 10^5 \text{ joules}}{5 \times 10^5 \text{ watts}} = 29.4 \text{ sec}$$

Force

Force may simply be defined as a push or pull that causes a change in motion. This could start a body at rest into motion, or stop a body in motion. It can also accelerate the body or decelerate it. All machines, regardless of how simple or complex, depend upon force and interaction of forces to perform their various operations. Force may be applied parallel to displacement or at angles.

The Lever

The simplest machine, and perhaps the most familiar one, is the lever. A seesaw is a familiar example of a lever in which one weight balances the other.

There are three basic parts in all levers: namely, the fulcrum, *F*; a force or effort, *E;* and a resistance, *R*. Shown in Figure 3-2-1 are the pivotal point (*F*) fulcrum, the effort (*E*), which is applied at a distance (*A*) from the fulcrum and resistance (*R*), which acts at a distance (*a*) from the fulcrum. Distances (*A*) and (*a*) are the lever arms.

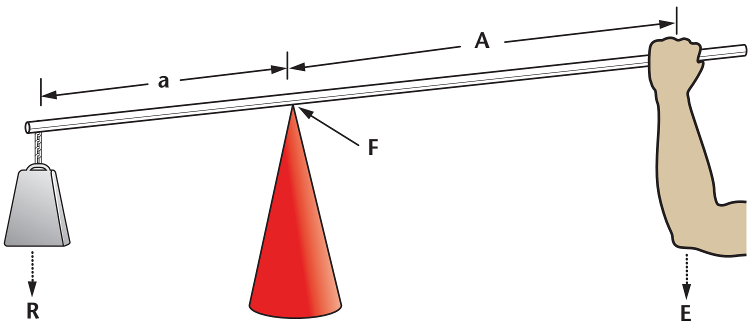


Figure 3-2-1. A simple lever.

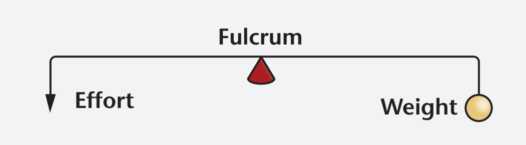


Figure 3-2-2A. First-class lever.

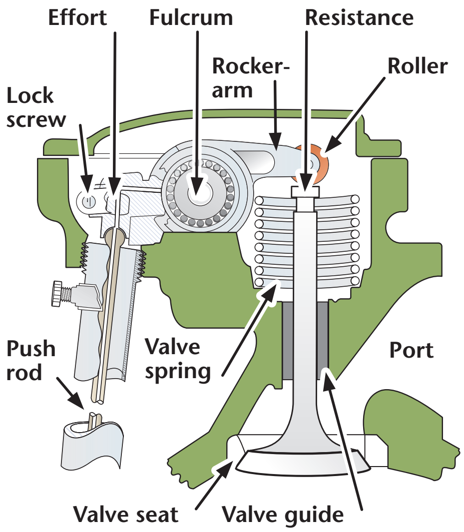


Figure 3-2-2B. A rocker arm is one example of a first-class lever.

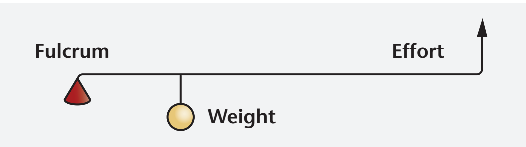


Figure 3-2-3A. Second-class lever.

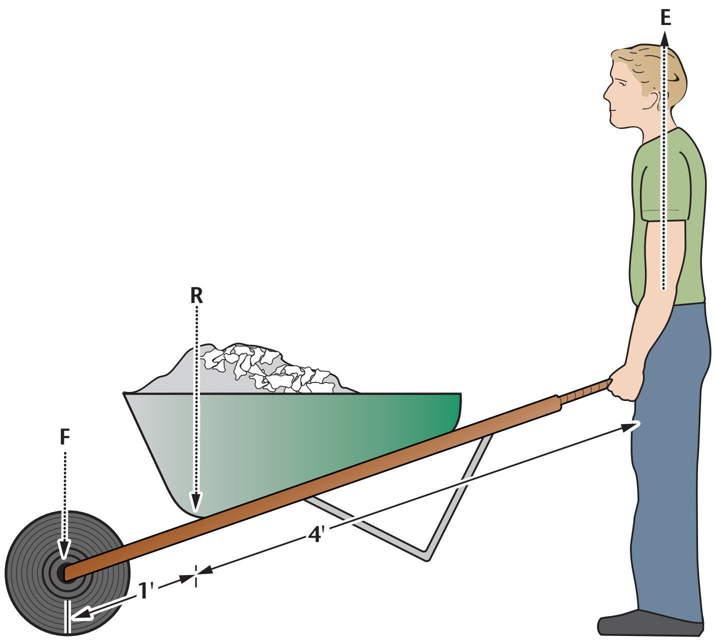


Figure 3-2-3B. A wheelbarrow is a second-class lever. Effort is applied opposite the fulcrum and the load (resistance) located in between the two.

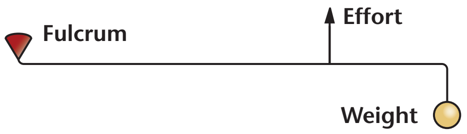


Figure 3-2-4A. Third-class lever.

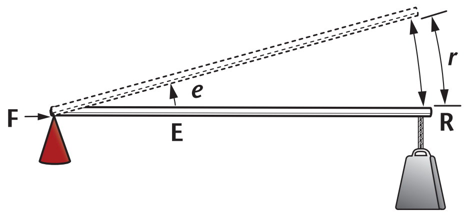


Figure 3-2-4B. A third-class lever, with the effort applied between the fulcrum and the resistance.

First-class levers. In the first-class lever, Figure 3-2-2A, the fulcrum is located between the effort and the resistance. As mentioned earlier, the seesaw is a good example of a first-class lever. The amount of weight and the distance from the fulcrum can be varied to suit the need. Another good example of a first-class lever is the rocker arm used to move the valve in an engine, as shown in Figure 3-2-2B. The fulcrum is the rocker arm pin. The push rod is the force applied, and the valve and spring are the resistance. There are hundreds of other examples of first-class levers, which include shears, pliers, and pry bars, to name a few.

Second-class levers. The second-class lever (Figure 3-2-3A) has the fulcrum at one end; the effort is applied at the other end. The resistance is somewhere between these points. The wheelbarrow in Figure 3-2-3B is a good example of a second-class lever.

Third-class levers. There are occasions when it is desirable to speed up the movement of the resistance, even though a large amount of effort must be used. Levers that help accomplish this are third-class levers. As shown in Figure 3-2-4A, the fulcrum is at one end of the lever, and the weight or resistance to be overcome is at the other end, with the effort applied at some point between.

Third-class levers are easily recognized because the effort is applied between the fulcrum and the resistance. This is illustrated by the diagram in Figure 3-2-4B. While point *E* is moving the short distance *e*, the resistance *R* must be greater than that of *E*, since R covers a greater distance in the same length of time.

The landing gear shown in Figure 3-2-4C is a good example of a third-class lever. In this

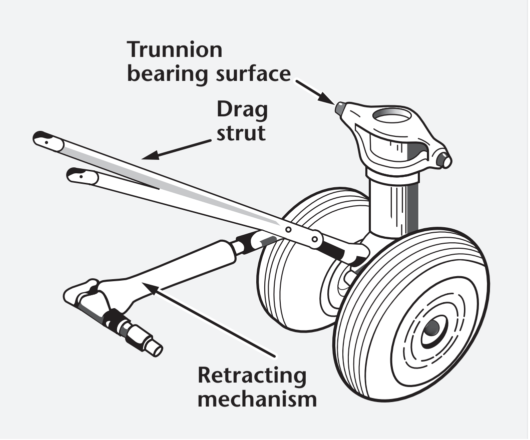


Figure 3-2-4C. A landing gear is an example of a third-class lever.

case, the strut is the lever, the hydraulic cylinder is the force and the wheel is the weight. This third-class lever is a method to gain speed in raising the weight.

Inclined Plane

The inclined plane is a simple machine that facilitates the raising or lowering of heavy objects by application of a small force over a relatively long distance. Some familiar examples of the inclined plane are a mountain highway and loading ramps.

The inclined plane permits a large resistance to be overcome by application of a small force through a longer distance than the load is to be raised. In Figure 3-2-5, a 300-lb. barrel is being rolled up a ramp to the bed of a truck, three feet. above the sidewalk. The ramp is nine feet. long.

Without the ramp, a force of 300 lbs., applied straight up through the three foot distance, would be required to load the barrel. With the ramp, a force can be applied over the entire nine feet. of the ramp as the barrel is rolled slowly up to a height of three feet. It can be determined, by observation, that a force of only three-ninths of the 300 lbs., or 100 lbs., will be required to raise the barrel by using an inclined plane. This can also be determined mathematically, using the following formula:

$$\frac{L}{H} = \frac{R}{E}$$

where:

L = Length of the ramp, measured along the slope

H = Height of the ramp

R = Weight of object to be raised or lowered

E = Force required to raise or lower object

In this case, L = 9 ft.; H = 3 ft.; and R = 300 lb. Substituting these values in the formula:

$$\frac{9}{3} = \frac{300}{E}$$

$$9E = 900$$

$$E = 100\text{lb}$$

Since the ramp is three times as long as its height, the mechanical advantage is three. The theoretical mechanical advantage is found by dividing the total distance through which the effort is exerted by the vertical distance through which the load is raised or lowered.

Pulley

A single fixed pulley is really a first-class lever with equal arms. The arms *EF* and *FR* in Figure 3-2-6 are equal; hence, the mechanical advantage is one. Thus, the force of the pull on the rope must be equal to the weight of the object being lifted. The only advantage of a single fixed pulley is to change the direction of the force.

With some modification, a single pulley can also be used to magnify the force exerted. In

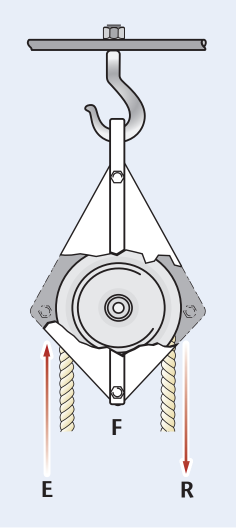


Figure 3-2-6. A single fixed pulley.

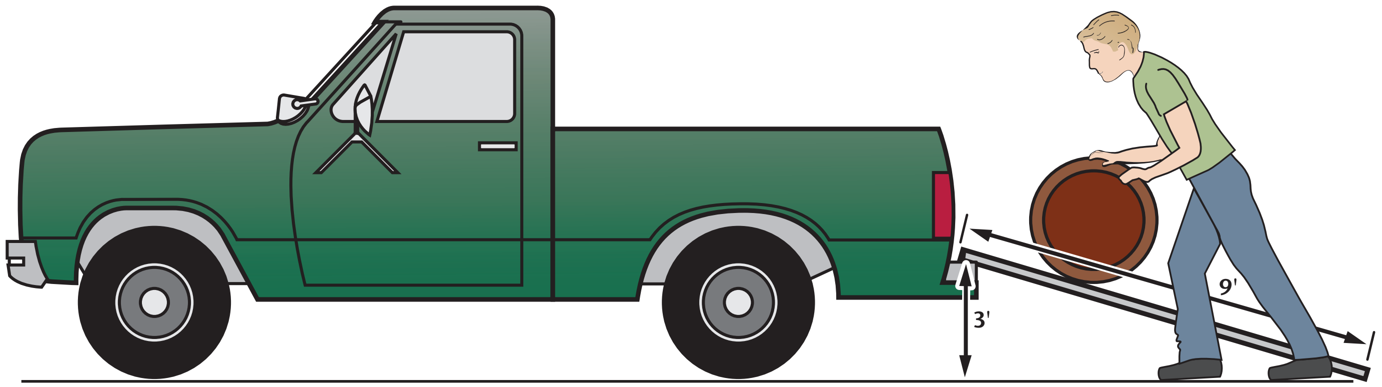


Figure 3-2-5. An inclined plane.

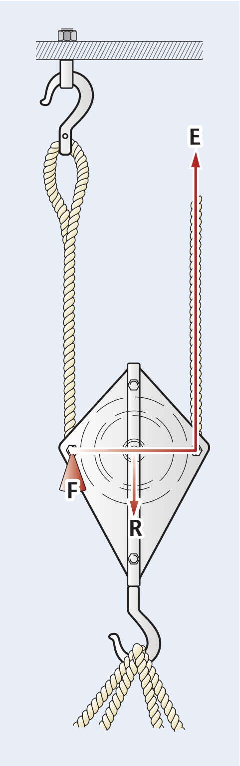


Figure 3-2-8. A single moveable pulley as a second-class lever.

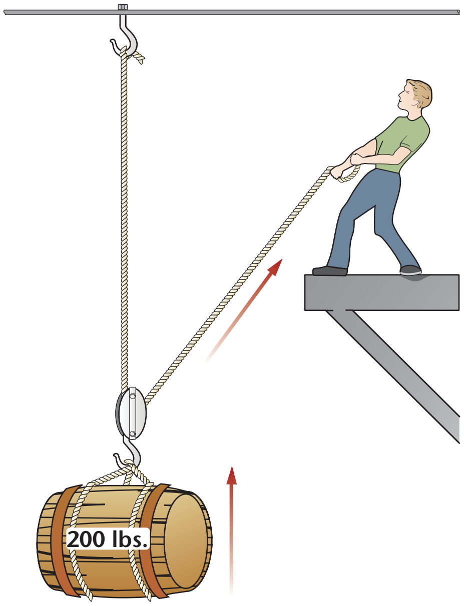


Figure 3-2-7. A single movable pulley.

Figure 3-2-7, the pulley is not fixed, and the rope is doubled because it supports a 200-lb. weight. Used in this manner, a single block-and-tackle can lift the 200-lb. weight with a 100-lb. pull, since each half of the rope (tackle) carries one-half the total load. The mechanical advantage is two, which can be verified by using the following formula:

$$MA = \frac{R}{E} = \frac{200}{100} = 2$$

E = Effort

R = Weight of object to be raised or lowered

MA = Mechanical advantage

The single movable pulley used in the manner shown in Figure 3-2-7 is a second-class lever. To see this, refer to Figure 3-2-8. The effort *E* acts upward on the arm *EF*, which is the diameter of the pulley. The resistance *R* acts downward on the arm *FR*, which is the radius of the pulley. Since the diameter is twice the radius, the mechanical advantage is two.

When the effort at *E* moves up two feet., the load at *R* is raised only one foot. This is true of all systems of block-and-tackle, for if a mechanical advantage is obtained, the length of rope passed through the hands is greater than the distance that the load is raised.

The mechanical advantage of a pulley system is found by measuring the resistance and the effort, then dividing the amount of resistance by the effort. A shorthand method often used is simply to count the number of rope strands that move or support the movable block.

Gears

The gear is used in most complex mechanical machinery today. Gears can be used to increase mechanical advantage, increase speeds, or change directions. There are four basic types of gears. They are the spur gear, bevel gear, worm gear, and the helical gear. Myriad sizes and variations can be used to perform hundreds of tasks. A few of these applications seen on aircraft include reducing engine r.p.m., driving engine accessories, deploying and retracting flaps, and driving helicopter rotors.

Spur gears. Spur gears are used to drive two parallel shafts as shown in Figure 3-2-9. The ratio of the two gears is in proportion to the number

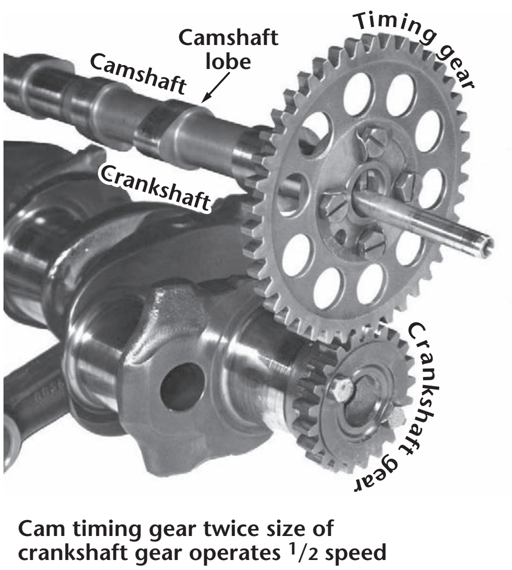


Figure 3-2-9. An example of spur gears.

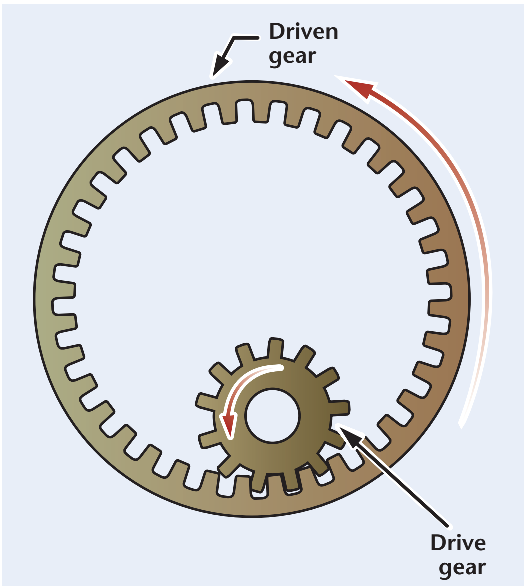


Figure 3-2-10. Gears rotating in the same plane.

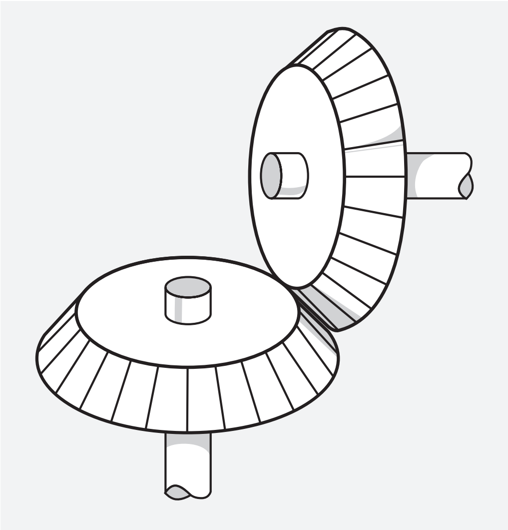


Figure 3-2-11. An example of bevel gears.

of teeth on each gear. If a 2 to 1 ratio was desired, then one gear would have twice the number of teeth as the other gear. However, most applications will place odd numbers of teeth on one gear so the same teeth do not continuously pass over each other. This spreads wear evenly among the teeth of the gear. This is why ratios are normally 2.11:1 or some other odd number. In some instances, an even ratio is required, such as timing gears on an engine. It might also be noted that gears change direction of rotation unless a variation is used. Commonly, if the same direction must be maintained, internal teeth are placed on the driven gear, as shown in Figure 3-2-10.

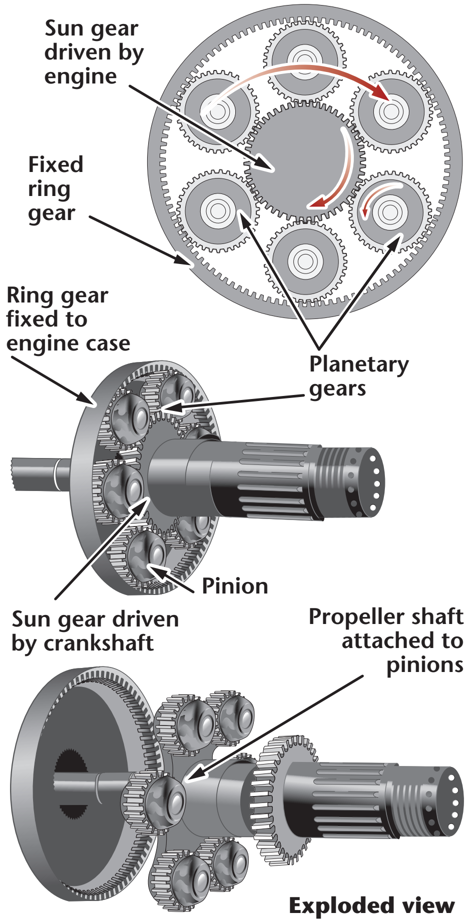


Figure 3-2-12. Spur-planetary gears.

Bevel gears. Bevel gears can be used to change direction and change speed, as shown in Figure 3-2-11. A common application is a tail rotor gear box used on a helicopter to drive the tail rotor.

Worm gear. The worm gear is used in applications where a high mechanical advantage is necessary, generally at low speed. Such devices are often used to drive flaps. With this device, the drive or driven shaft has a ridge that meshes with the gear. One revolution of the shaft will rotate the gear one tooth.

Planetary gearing. Planetary gearing is used in several aviation applications. The two most widely used areas are propeller reductions on reciprocating or turbine engines and helicopter transmissions. In this system, r.p.m. can be reduced in a fairly compact unit.

The spur-planetary gear reduction consists of a *sun gear* splined to the crankshaft, a large *stationary gear* called a *bell gear* or *ring gear*, and a set of small planetary gears mounted to a carrier. This carrier is fastened to the propeller shaft, and the planetary gears mesh with both the sun gear and the bell gear.

The stationary gear, or bell gear, is attached to the front case. When the sun gear rotates, the planetary gears will also rotate, because they are meshed with a ring as well. As they rotate, or walk, around the bell gear, they will rotate the propeller shaft as shown in Figure 3-2-12.

Section 3

Principles of Stress

Whenever a solid body is deformed by external forces, there are internal molecular forces that resist this change. This internal resistance is called stress. Stress can be shown as a ratio as follows:

$$\text{Stress} = \frac{\text{External Force}}{\text{Area over the applied force}}$$

The common unit of stress in the United States is *pounds per square foot* or *pounds per square inch*.

There are two basic types of stress: tension and compression. The three other forms, torsion, bending, and shear, are applications of these two.

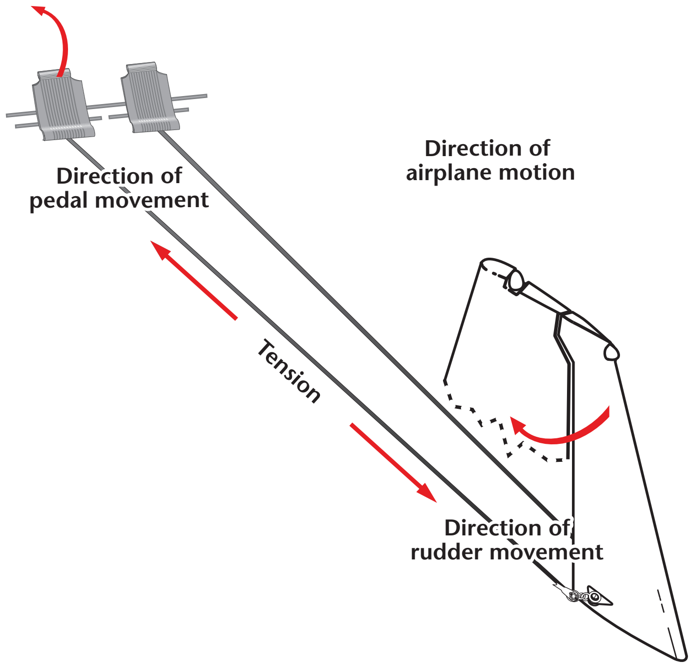


Figure 3-3-1. Control cables under tension.

These forces are commonly applied to the aircraft structure and components in normal flight. For this reason, the design of the aircraft and its components must account for these normal stresses. Any repairs or alterations to the aircraft must be made so that it can be ensured that they will also withstand the stresses applied during flight.

Tension

Tension occurs when a force tends to pull a body apart. Tension occurs in many parts of an aircraft and may often occur with other forces on the same component. In one of the purest forms, tension is applied to a control cable every time the control is moved, as shown in Figure 3-3-1. In Figure 3-3-2 the cable is in tension while the bullet is pulled through the tube to remove the dent. Another example of tension would be the helicopter transmission mount each time the helicopter lifts off the ground (Figure 3-3-4).

Compression

Compression is the resistance to any external force that tends to push the body together. This also occurs on an aircraft structure or components. In fact, many times a part which has tension applied at one point may have compression applied at another point in the flight. An example of this is shown in Figure 3-3-3. This is an aircraft seat leg. When the pilot sits in the seat, compression is applied to the leg due to the pilot's body weight. This load may be increased by flight maneuvers by twice the normal weight in a loop, or by landing the aircraft. In the example of the transmission mount carrying a tension load in flight, it should be noted that it will carry a compression load in landing. This will be quite typical of much of the structure of the aircraft.

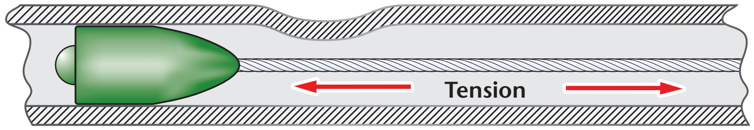


Figure 3-3-2. Tension is applied to the cable used to pull a "bullet" through a tube while removing a dent.

Torsion

Torsion is a combination force that has both tension and compression acting on the component at the same time. This torsional force is often referred to as a twisting force. This type of force is usually placed upon driveshafts, crankshafts, or propshafts that are common to aircraft.

It should be noted that most parts of the aircraft are placed under more than one stress at a time and must be designed to withstand these stresses. While one stress may be most evident, others may occur at the same time or at different modes of operation. This is quite evident in the example in Figure 3-3-4. This is a helicopter mast used to drive the main rotor. When the mast is first rotated, it is subject to torsion; as the helicopter lifts, a tension load is added; and when it lands, a compression load is placed on the mast.

Bending

Bending is another combination force that is applied to many components of the aircraft. This force may be applied with one force being greater

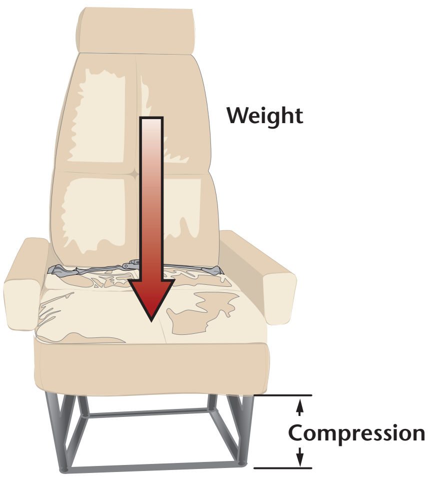


Figure 3-3-3. An example of compression.

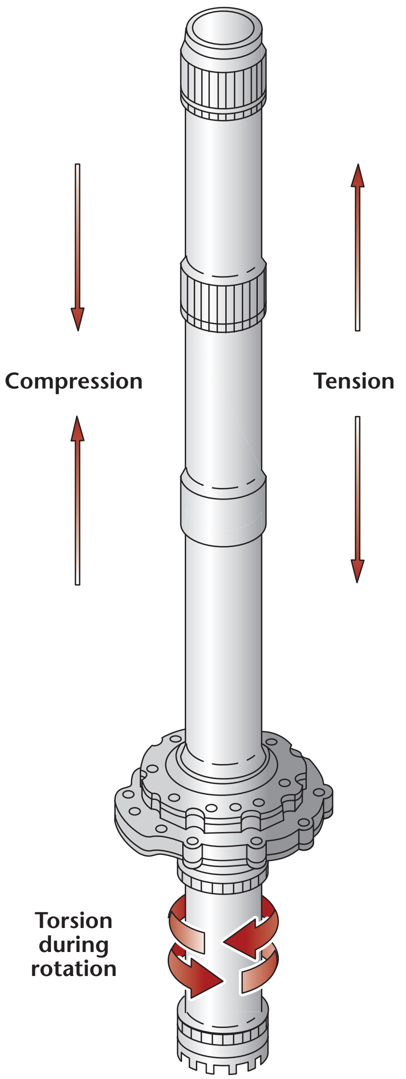


Figure 3-3-4. Examples of torsion, tension and compression.

than the other, or they may be equal. An example of this force is shown on an aircraft wing when the aircraft is in flight. The skin on the top of the wing is subject to compression, while the bottom of the wing is subject to tension, as shown in Figure 3-3-5. When the aircraft is on the ground these forces are reversed with the top skin now in tension and the bottom in compression,

Shear

Shear is a force that tends to pull a component apart. This is a common force applied to rivets used to join sheet metal on aircraft. When the sheet metal is stressed with either a tension or compression load, the rivet is placed in a shear load, as shown in Figure 3-3-6. The combination is not uncommon, since the sheet metal may be stressed differently and at different times during flight and landings.

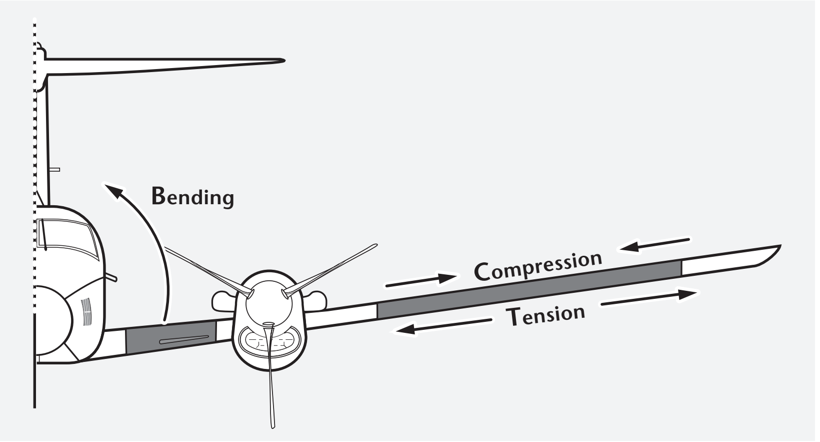


Figure 3-3-5. An example of bending.

Strain

Strain is the consequence of stress. When stress is applied to any body, strain is the result. If strain does not exceed the elastic limit of the body, there will be no visible change. However, over a period of time a change will take place. For example, if we bend a piece of wire back and forth, it will eventually yield or break. This will take place with any solid body. In aircraft structures, this may take place by pressurizing and depressurizing the fuselage or it may be the result of landing. Often highly stressed parts are assigned a time life, or a finite life, to eliminate the possibility of failure of the component.

Section 4

Principles of Motion

Newton's Law of Motion

When a magician snatches a tablecloth from a table and leaves a full setting of dishes undisturbed, this is not a mystic art, but a demonstration of the principle of inertia. Inertia is responsible for the discomfort felt when an airplane is brought to a sudden halt in the parking area and the passengers are thrown forward in their seats. Inertia is a property of matter. This property of matter is described by Newton's First Law of Motion.

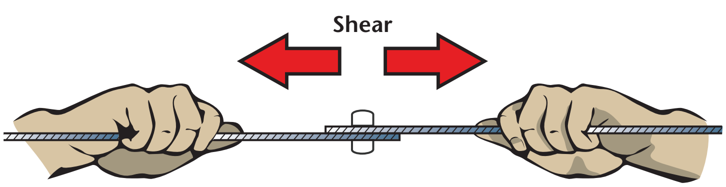


Figure 3-3-6. An example of shear.

Newton's First Law of Motion. Objects at rest tend to remain at rest; objects in motion tend to remain in motion at the same speed and in the same direction.

Bodies in motion have the property called *momentum*. A body that has great momentum has a strong tendency to remain in motion and is therefore hard to stop. For example, a train moving at even low velocity is difficult to stop because of its large mass.

Newton's Second Law of Motion. Newton's Second Law applies to this property. It states: When a force acts upon a body, the momentum of that body is changed. The rate of change of momentum is proportional to the applied force.

The momentum of a body is defined as the product of its mass and its velocity. Thus,

$$\text{Momentum} = \text{mass} \times \text{Velocity}$$

or

$$M = mV$$

Now if a force is applied, the momentum changes at a rate equal to the force or:

$$F = \text{rate of change of momentum}$$

$$= \frac{M_f - M_i}{t}$$

Substituting mV for M:

$$F = \frac{m_f V_f - m_i V_i}{t}$$

where:

m_f = Final mass

m_i = Initial mass

t = Elapsed time

V_f = Final velocity

V_i = Initial velocity

Since the mass does not usually change, $m_f = m_i = m$. Then:

$$F = \frac{mV_f - mV_i}{t}$$

$$= m\frac{(V_f - V_i)}{t}$$

From the previous section the second term is recognized as acceleration. Then the second law becomes:

$$F = ma$$

On Earth, gravity exerts a force on each body, causing an acceleration of 32 feet/sec^2, usually designated as *g force*. The force is commonly called weight, *W*. Using the formula above:

$$W = mg$$

and

$$m = \frac{W}{g}$$

On Earth, the second law becomes:

$$F = ma$$

$$= \frac{W}{g}(a)$$

The following examples illustrate the use of this formula.

EXAMPLE: A truck weighs 32,000 lbs. and is traveling at 10 ft./sec. What force is required to bring it to rest in 10 seconds?

$$F = \frac{W}{g}(a)$$

$$F = \frac{W}{g}\frac{(V_f - V_i)}{t}$$

$$= \frac{32{,}000 \text{ lbs}}{32 \text{ ft/sec}^2}\frac{(0\text{-}10 \text{ ft/sec})}{10 \text{ sec}}$$

$$= \frac{32{,}000 \text{ lbs} \times (-10 \text{ ft./sec})}{32 \text{ ft/sec}^2 \times 10 \text{ sec}}$$

$$= -1{,}000 \text{ lb}$$

The negative sign means that the force must be applied against the truck's motion.

EXAMPLE: An aircraft weighs 6,400 lbs. How much force is needed to give it an acceleration of 6 ft./sec^2?

$$F = \frac{W}{g}(a)$$

$$= \frac{6{,}400 \text{ lbs} \times 6 \text{ ft/sec}^2}{32 \text{ ft/sec}^2}$$

$$= 1{,}200 \text{ lb}$$

Newton's Third Law of Motion. Newton's Third Law is often called the law of action and reaction. It states that *for every action, there is an equal and opposite reaction*. This means that if a force is applied to an object, the object will supply a resistive force exactly equal to and in the opposite direction of the force applied. It is easy to see how this might apply to objects at rest. For example, as a person stands on the floor, the floor exerts a force against their feet exactly equal to their weight. But this force is also applicable when a force is applied to an object in motion.

When the force applied to an object is more than sufficient to produce and sustain uniform motion, inertia of the object will cause such a resistive force that the force opposing the motion of the object equals the force producing the motion. This resistance to change in velocity due to inertia is usually referred to as internal force. When several forces act upon an object to produce accelerated motion, the sums of the external forces are in a state of unbalance; however, the sums of the external and the internal forces are always in a state of balance, whether motion is being sustained or produced.

Forces always occur in pairs. The term *acting force* means the force one body exerts on a second body, and *reacting force* means the force the second body exerts on the first.

When an aircraft propeller pushes a stream of air backward with a force of 500 lbs., the air pushes the blades forward with a force of 500 lbs. This forward force causes the aircraft to move forward. In like manner, the discharge of exhaust gases from the tailpipe of a turbine engine is the action that causes the aircraft to move forward.

The three laws of motion that have been discussed here are closely related. In many cases, all three laws may be operating on a body at the same time.

Motion of Bodies

The study of the relationship between the motion of bodies or objects and the forces acting on them is often called the study of *force and motion*. In a more specific sense, the relationship between velocity, acceleration, and distance is known as *kinematics*.

Speed and velocity. In everyday usage, speed and velocity often mean the same thing. In physics, they have definite and distinct meanings. *Speed* refers to how fast an object is moving, or how far the object will travel in a specific time. The speed of an object tells nothing about the direction an object is moving. For example, if information is given that an aircraft leaves St. Louis and travels at a speed of 200 miles per hour (m.p.h.) for 4 hours, nothing is known of the direction in which the aircraft is moving. At the end of the 4 hours, it could be in Denver, Colorado, or Syracuse, New York, or, if it had traveled a circular route, it could be back in St. Louis. In aviation, speed is measured in nautical miles per hour, also known as knots.

Velocity is that quantity in physics that denotes both the speed of an object and the direction in which the object moves. Velocity may be defined as the rate of motion in a particular direction.

The average velocity of an object can be calculated using the formula:

$$V_A = \frac{V_S}{t}$$

where:

V_A = the average velocity

V_S = the rate of motion or average speed

t = the elapsed time

Acceleration. Acceleration is defined by physicists as the rate of change of velocity, or change in velocity divided by the amount of time over which that change took place.

The velocity of an object is increased from 20 m.p.h. to 30 m.p.h., the object has been accelerated. If the increase in velocity is 10 m.p.h. in 5 seconds, then the example used can be expressed as follows:

$$A = \frac{V_S}{t}$$

$$V_S = V_f - V_i \text{ (for constant acceleration)}$$

where:

A = Acceleration

V_f = the final velocity (30 m.p.h.)

V_i = the initial velocity (20 m.p.h.)

t = the elapsed time

$$A = \frac{30 \text{ m.p.h.} - 20 \text{ m.p.h.}}{5 \text{ sec}}$$

$$A = \frac{2 \text{ m.p.h.}}{\text{sec}}$$

If the object accelerated to 22 m.p.h. in the first second, 24 m.p.h. in the next second and 26 m.p.h. in the third second, the change in velocity is 2 m.p.h. each second. The acceleration is said to be constant, and the motion is described as uniformly accelerated motion.

If a body has a velocity of 3 m.p.h. at the end of the first second of its motion, 5 m.p.h. at the end of the next second, and 8 m.p.h. at the end of the third second, its motion is described as acceleration, but is called variable accelerated motion.

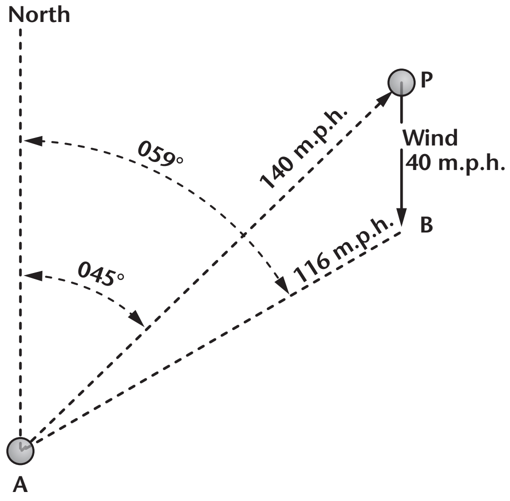


Figure 3-4-1. Vectors, when drawn to scale, can be used to solve tough mathematical problems.

Vectors. Often the solving of a problem is very difficult mathematically. This is basically because we cannot see what is going on. This is especially true in problems dealing with length, time, direction, and speed. These types of problems can be much better understood graphically than by algebra and trigonometry.

The solution of these problems is called vector analysis. This study often involves college courses in engineering. However, simple vectors drawn to scale may solve many problems, especially those dealing with travel by air.

An example of vector analysis can be shown in this manner. A pilot flies on a compass heading of 045° at an airspeed of 140 m.p.h. The wind is blowing due south at 40 m.p.h. The vector diagram will show where the aircraft is traveling over the ground and, if it is drawn to scale, the speed can be computed (Figure 3-4-1).

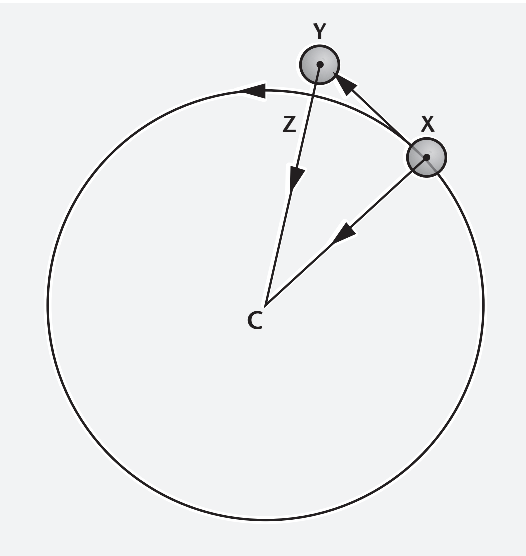


Figure 3-4-2. Examples of both centripetal force and centrifugal force.

Circular motion. Circular motion is the motion of an object along a curved path that has a constant radius. For example, if one end of a string is tied to an object and the other end is held in the hand, the object can be swung in a circle. The object is constantly deflected from a straight (linear) path by the pull exerted on the string, as shown in Figure 3-4-2.

If an object in Figure 3-4-2 travels along the circumference from X to Y, the pull, or force, on the string deflects it from Y toward Z. This pull is called *centripetal force*, which deflects an object from a straight path and forces it to travel in a curved path. Thus, the string exerts a centripetal force on the object, and the object exerts an equal but opposite force on the string, obeying Newton's Third Law of Motion.

The force that is equal to centripetal force, but acts in an opposite direction, is called *centrifugal force*. In the example in Figure 3-4-2, it is the force exerted by the object on the string. Without a centripetal force, there is no centrifugal force.

Centripetal force is always directly proportional to the mass of the objects in circular motion. Thus, if the radius of the object in Figure 3-4-2 is shortened, the mass remains the same and the speed remains constant, then the pull on the string must be increased since the radius is decreased, and the string must pull the object from its linear path more rapidly.

Using the same reasoning, the pull on the string must be increased if the object is swung more rapidly in its orbit. Centripetal force is thus directly proportional to the square of the velocity of the object. The formula for centripetal force is:

$$CP = \frac{MV^2}{R}$$

where:

M = the mass of the object

V = Velocity

R = Radius of the object's path

Section 5

Principles of Heat

Heat is a form of energy on Earth. It is produced only by the conversion of one of the other forms of energy. Heat may also be defined as the total kinetic energy of molecules of any substance.

Some forms of energy, which can be converted into heat energy, are as follows:

Mechanical energy. This includes all methods of producing increased motion of molecules such as friction, impact of bodies or compression of gases.

Electrical energy. Electrical energy is converted to heat energy when an electric current flows through any form of resistance. This might be an electric iron, electric light, or electric blanket.

Chemical energy. Most forms of chemical reaction convert stored potential energy into heat. Some examples are the explosive effects of gunpowder, the burning of oil or wood, and the combining of oxygen and grease.

Radiant energy. Electromagnetic waves of certain frequencies produce heat when they are absorbed by the bodies they strike. Included are X-rays, light rays, and infrared rays.

Nuclear energy. Energy stored in the nucleus of atoms is released during the process of nuclear fission in a nuclear reactor or atomic explosion.

The sun. All heat energy can be directly or indirectly traced to the nuclear reactions occurring in the sun.

Transfer of Heat and Sensible Heat

Heat may be transferred from one substance to another. For example, the sun may heat the water in a lake or sea. This heat is then stored and released when the outside air temperature is less than the water temperature. Other examples include household heating, water-cooled engines, and liquid-cooled transformers.

When heat is applied to any substance that causes the temperature to rise, it is known as sensible heat. An example would be when heat is applied to water. The temperature of the water will rise until 212°F (100°C) is reached.

Latent Heat

Using the example above, when the temperature of 212°F (100°C) is reached, the water temperature will remain at 212°F (100°C) regardless of how much more heat is added. This is known as latent heat, or hidden heat. What is actually happening is that the additional heat is being used to transfer the water to steam.

Dimensional Changes Caused By Heat

Thermal expansion. Thermal expansion takes place in solids, liquids, or gases when they are heated. With few exceptions, solids will expand when heated and contract when cooled. Because the molecules of solids are much closer together and are more strongly attracted to each other, the expansion of solids when heated is very slight in comparison to the expansion in liquids and gases. The expansion of fluids is discussed in the study of Boyle's law. Thermal expansion in solids must be explained in some detail because of its close relationship to aircraft metals and materials.

Expansion in solids. Solid materials expand in length, width, and thickness when they are heated.

An example of the expansion and contraction of substances is the ball and ring illustrated in Figure 3-5-1. The ball and ring are made of iron. When both are at the same temperature, the ball will barely slip through the ring. When the ball is heated or the ring is cooled, the ball cannot slip through the ring.

Because some substances expand more than others, it is necessary to measure experimentally the exact rate of expansion of each one. The amount that a unit length of any substance expands for a 1° rise in temperature is known as the *coefficient of linear expansion* for that substance.

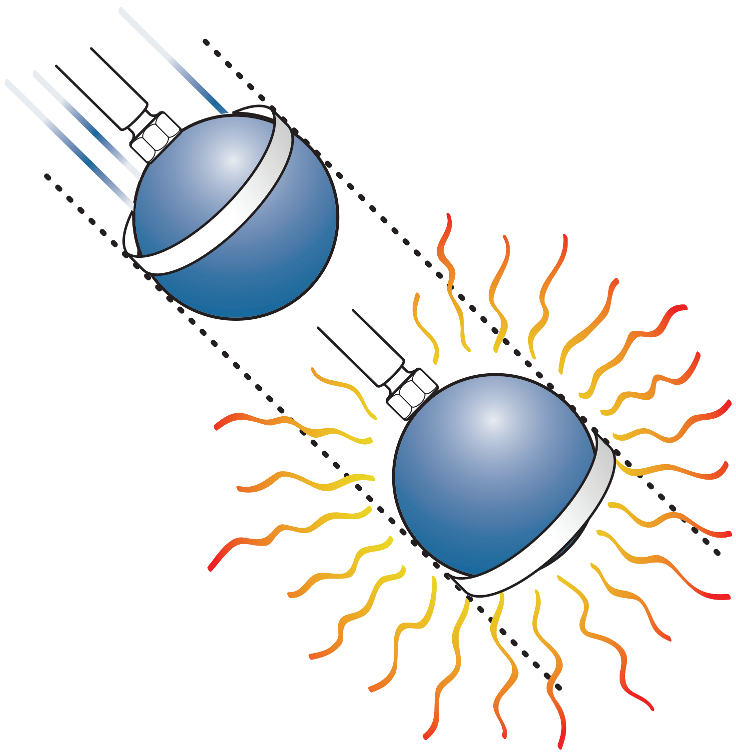


Figure 3-5-1. An example of expansion using a ball and ring.

Coefficients of expansion. To estimate the expansion of any object, such as a steel rail, it is necessary to know three things about it, namely: its length, the rise in temperature to which it is subjected, and its coefficient of expansion. This relationship is expressed by this equation:

Expansion = coefficient × length
× rise in temperature

$e = kL(t_2 - t_1)$

Where:

e = Expansion

k = Coefficient of expansion

L = Length

t_2 = Final temperature

t_1 = Initial temperature

In this equation, the letter *k* represents the coefficient of expansion for the particular substance. In some instances, the Greek letter α (alpha) is used to indicate the coefficient of linear expansion.

If a steel rod measures exactly 9 ft. at 21°C, what is its length at 55°C? The value of k for steel is 11×10^{-6}. If the equation $e = kL(t_2 - t_1)$,

then:

$e = (11 \times 10^{-6}) \times 9 \text{ feet} \times (55^\circ C - 21^\circ C)$

$e = 0.000011 \times 9 \text{ feet} \times 34^\circ C$

$e = 0.003366$

This amount, when added to the original length of the rod, makes the rod 9.003366 ft. long.

The increase in the length of the rod is relatively small, but if the rod were placed where it could not expand freely, there would be a tremendous force exerted due to thermal expansion. Thus, thermal expansion must be taken into consideration when designing airframes, powerplants, or related equipment.

Substance	Coefficient of linear expansion (per °C)
Aluminum	24×10^{-6}
Brass	19×10^{-6}
Copper	17×10^{-6}
Glass	$4 \text{ to } 9 \times 10^{-6}$
Quartz	0.4×10^{-6}
Steel	11×10^{-6}
Zinc	26×10^{-6}

Table 3-5-1. Expansion coefficients of some common substances.

Table 3-5-1 contains the coefficients of linear expansion for some common substances.

Specific Heat

One important way in which substances differ is in the requirement of different quantities of heat to produce the same temperature change in a given mass of the substance. Each substance requires a quantity of heat, called its *specific heat capacity*, to increase the temperature of a unit of its mass 1°C. The specific heat of a substance is the ratio of its specific heat capacity to the specific heat capacity of water. Specific heat is expressed as a number that, because it is a ratio, has no units and applies to both the English and the metric systems.

It is fortunate that water has a high specific heat capacity. The larger bodies of water on Earth keep the air and solid matter on or near the surface of the planet at a fairly constant temperature. A great quantity of heat is required to change the temperature of a large lake or river. When the temperature of the atmosphere falls below the temperature of these bodies of water, the water gives off large quantities of heat. This process keeps the atmospheric temperature at the surface of the Earth from changing rapidly.

The specific heat values of some common materials are listed in Table 3-5-2.

Material	Specific heat
Mercury	0.033
Copper	0.095
Iron and steel	0.113
Glass	0.200
Alcohol	0.500
Water	1.000

Table 3-5-2. Specific heat values for some common materials.

Methods of Heat Transfer

There are three methods by which heat is transferred from one location to another or from one substance to another. These three methods are conduction, convection, and radiation.

Conduction. Everyone knows from experience that the metal handle of a heated pan can burn the hand. A plastic or wood handle, however, remains relatively cool, even though it is in direct contact with the pan. The metal transmits the heat more easily than the wood because it is a better *conductor* of heat. Different materials conduct heat at different rates. Some metals are much better conductors of heat than others. Aluminum and copper are used in pots and pans because they conduct heat very rapidly. Woods and plastics are used for handles because they conduct heat very slowly.

The different rates of conduction in various metals are illustrated in Figure 3-5-2. There is a wide variation in thermal conductivity between different metals. In some cases, the ability of a metal to conduct heat may be a major factor in choosing one metal over another. It is interesting to note that the thermal conductivity of a certain metal has no relationship to its coefficient of thermal expansion.

Liquids are poorer conductors of heat than metals. Notice that the ice in the test tube shown in Figure 3-5-3 is not melting rapidly, even though the water at the top is boiling. The water conducts heat so poorly that not enough heat reaches the ice to melt it.

Gases are even poorer conductors of heat than liquids. It is possible to stand quite close to a stove without being burned, because air is such a poor conductor.

At the point of application of the heat source, the molecules become violently agitated. These molecules strike adjacent molecules, causing them to become agitated. This process continues until the heat energy is distributed evenly throughout the substance. Because molecules are farther apart in gases than in solids, the gases are much poorer conductors of heat.

Materials that are poor conductors are used to prevent the transfer of heat and are called *heat insulators*. A wooden handle on a pot or a soldering iron serves as a heat insulator. Certain material, such as finely spun glass, is a particularly poor heat conductor. These materials are therefore used for many types of insulation.

Convection. Convection is the process by which heat is transferred by movement of a heated fluid (gas or liquid). For example, an electronic tube will, when heated, become increasingly hotter until the air surrounding it begins to move. The motion of the air is upward. This upward motion of the heated air carries the heat away from the hot tube by convection.

Transfer of heat by convection may be hastened by using a ventilating fan to move the air surrounding a hot object. The rate of cooling of a hot vacuum tube can be increased if it is provided with copper fins that conduct heat away from the hot tube. The fins provide large surfaces against which cool air can be blown.

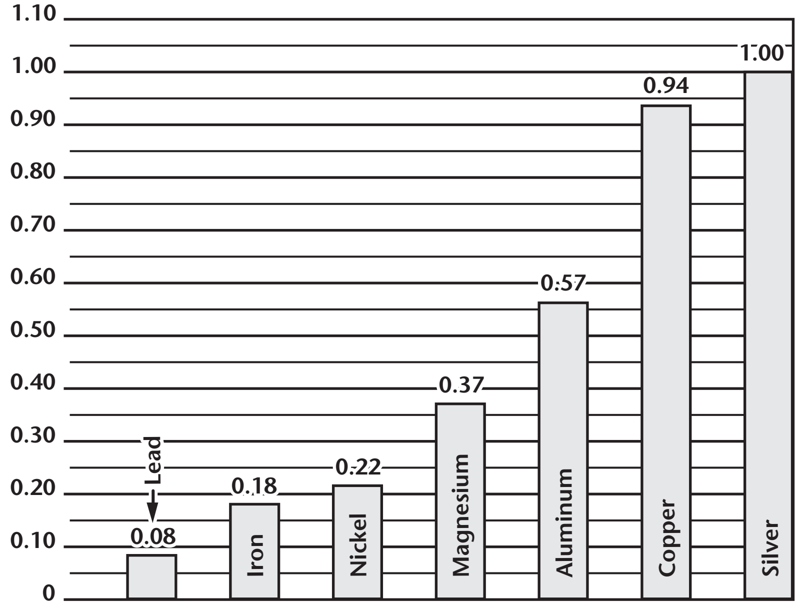


Figure 3-5-2. The different rates at which various metals conduct heat.

When the circulation of gas or liquid is not rapid enough to remove sufficient heat, fans or pumps are used to accelerate the motion of the cooling material. In some installations, pumps are used to circulate water or oil to help cool large equipment. In airborne installations, electric fans and blowers are used to aid convection.

Radiation. Conduction and convection cannot wholly account for some of the phenomena associated with heat transfer. For example, the heat one feels when sitting in front of an open fire cannot be transferred by convection, because the air currents are moving toward the fire. It cannot be transferred through

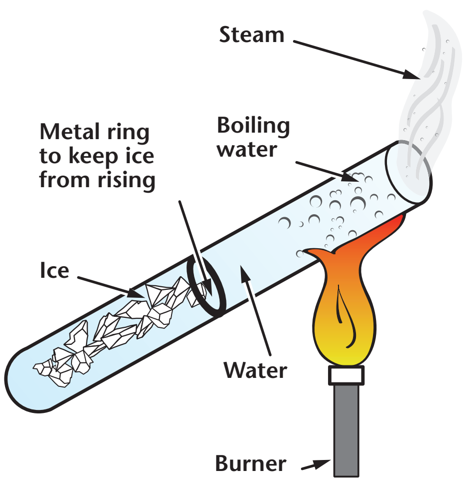


Figure 3-5-3. Water is a poor conductor of heat.

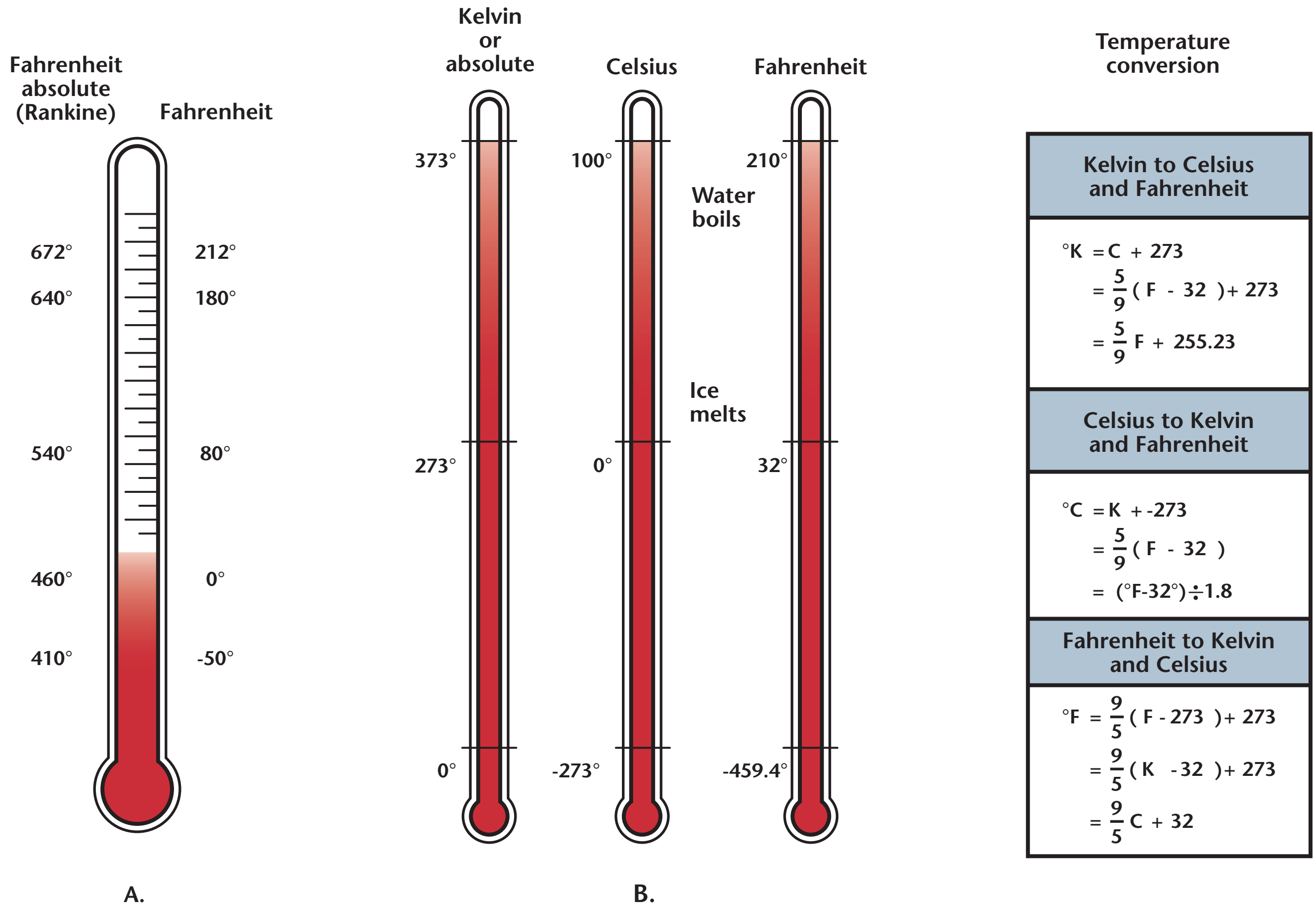


Figure 3-5-4. (A) Rankine scale used to convert Fahrenheit to absolute temperature; (B) Comparison of Fahrenheit, Celsius, and Kelvin temperatures.

conduction because the conductivity of the air is very small, and the cooler currents of air moving toward the fire would more than overcome the transfer of heat outward. Therefore, there must be some way for heat to travel across space other than by convection.

The existence of another process of heat transfer is still more evident when the heat from the sun is considered. Since conduction and convection take place only through some medium, such as a gas or a liquid, heat from the sun must reach the Earth by another method, since space is an almost perfect vacuum. Radiation is the name given to this third method of heat transference.

The term radiation refers to the continual emission of energy from the surface of all bodies. This energy is known as *radiant energy*. It is in the form of electromagnetic waves, radio waves, or X-rays, which are all alike except for a difference in wavelengths. These waves travel at the velocity of light and are transmitted through a vacuum more easily than through air, because air absorbs some of them. Most forms of energy can be traced back to the energy of sunlight. Sunlight is a form of radiant heat energy that travels through space to reach the Earth. These electromagnetic heat waves are absorbed when they come in contact with nontransparent bodies. The result is that the motion of the molecules in the body is increased, as indicated by an increase in the temperature of the body.

The differences between conduction, convection, and radiation may now be considered. First, while conduction and convection are extremely slow, radiation takes place with the speed of light. This fact is evident at the time of an eclipse of the sun, when the shutting off of the heat from the sun takes place at the same time as the shutting off of the light. Second, radiant heat may pass through a medium without heating it. For example, the air inside a greenhouse may be much warmer than the glass through which the sun's rays pass. Third, although conducted or convected heat may travel in roundabout routes, radiant heat always travels in a straight line. For example, radiation can be cut off with a screen placed between the source of heat and the body to be protected.

The sun, a fire, and an electric light bulb all radiate energy, but a body need not glow to give off heat. A kettle of hot water or a hot soldering iron radiates heat. If the surface is polished or light in color, less heat is radiated. Bodies that do not reflect are good radiators and good absorbers, and bodies that reflect are poor radiators and poor absorbers. For this reason, light-colored clothing is preferable in the summer season.

A practical example of the control of loss of heat is the Thermos bottle. The flask itself is made of two walls of glass separated by a vacuum. The vacuum prevents the loss of heat by conduction and convection, and a silver coating on the walls prevents the loss of heat by radiation.

Temperature

Temperature is a dominant factor affecting the physical properties of fluids. It is of particular concern when calculating changes in the state of gases.

The three temperature scales used extensively are the Celsius, the Fahrenheit, and the absolute, or Kelvin, scales. The Celsius scale is constructed by using the freezing and boiling points of water under standard conditions as fixed points of 0° and 100°, respectively, with 100 equal divisions between. The Fahrenheit scale uses 32° as the freezing point of water and 212° as the boiling point, and has 180 equal divisions between. The Kelvin scale is constructed with absolute 0°C, or -459.4°F, as its starting point. The relationships of the other fixed points of the scales are shown in Figure 3-5-4(B).

Absolute zero, one of the fundamental constants of physics, is commonly used in the study of gases. It is usually expressed in terms of the Celsius scale. If the heat energy of a given gas sample could be progressively reduced, some temperature would be reached at which the motion of the molecules would cease entirely. If accurately determined, this temperature could then be taken as a natural reference, or as a true *absolute zero* value.

Experiments with hydrogen indicated that if a gas were cooled to -273.16°C (used as -273° for most calculations), all molecular motion would cease and no additional heat could be extracted from the substance.

When temperatures are measured with respect to the absolute zero reference, they are expressed as zero or may be expressed as 0°K, as -273°C or as -459.4°F (used as -460° for most calculations).

When working with temperatures, always make sure which system of measurement is being used, and know how to convert from one to another. The conversion formulas are shown in Figure 3-5-4. For purposes of calculations, the Rankine scale, illustrated in Figure 3-5-4(A), is commonly used to convert Fahrenheit to absolute. For Fahrenheit readings above zero, 460° is added. Thus, 72°F equals 460° plus 72°, or 532° absolute. If the Fahrenheit reading is below zero, it is subtracted from 460°. Thus 40°F equals 460° minus 40°, or -420° absolute. It should be stressed that the Rankine scale does not indicate absolute temperature readings in accordance with the Kelvin scale, but these conversions may be used for the calculations of changes in the state of gases.

The Kelvin and Celsius scales are used more extensively in scientific work; therefore, some technical manuals may use these scales in giving directions and operating instructions. The Fahrenheit scale is commonly used in the United States, and most people are familiar with it. Therefore, the Fahrenheit scale is used in most areas of this text.

Section 6

Principles of Pressure

The term *pressure*, as used throughout this chapter, is defined as a force per unit area. Pressure is usually measured in pounds per square inch (p.s.i.). Sometimes pressure is measured in inches of mercury or, for very low pressure, inches of water.

Pressure may be in one direction, several directions, or in all directions (Figure 3-6-1). Ice, a solid, exerts pressure downward only. Water, a fluid, exerts pressure on all surfaces with which it comes in contact. Gas, a fluid, exerts pressure in all directions, because it completely fills the container.

Absolute pressure. As stated previously, absolute temperature is used in the calculation of changes in the state of gas. It is also necessary to use absolute pressure for these calculations.

Absolute pressure is measured from absolute zero pressure, rather than from normal or atmospheric pressure (approximately 14.7 p.s.i.). Gauge pressure is used on all ordinary gauges and it indicates pressure in excess of atmospheric. Therefore, absolute pressure is equal to atmospheric pressure plus gauge pressure. For example, 100 lbs. per square-inch gauge (p.s.i.g.) equals 100 p.s.i. plus 14.7 p.s.i. or 114.7 lbs. per square-inch absolute (p.s.i.a.).

Absolute pressure is often measured in inches of mercury or millibars of mercury. Basically, a column of mercury in a tube will be 29.92 inches, or 1,013 millibars or 760 mm Hg, at sea level. This would be equal to 14.7 p.s.i.a.

One of the uses of an absolute pressure gauge is manifold pressure. This gauge reads in inches of mercury. During idle, the gauge will read at

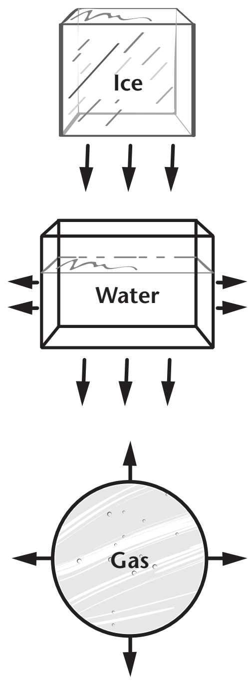


Figure 3-6-1. Exertion of pressure.

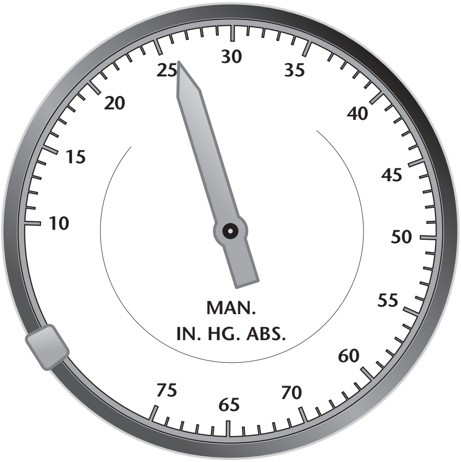


Figure 3-6-2. Manifold pressure gauge.

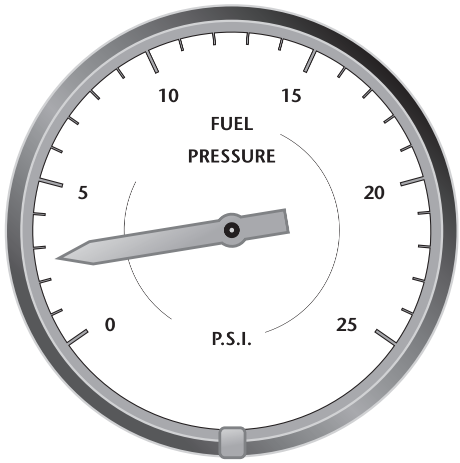


Figure 3-6-3. Fuel pressure gauge.

its lowest point. When the engine is shut down, the gauge will read the atmospheric pressure of the field (Figure 3-6-2).

Another example of an absolute pressure gauge is the altimeter. This gauge will read feet of altitude based on absolute pressure.

Gauge pressure. Most pressure instruments used in the aircraft read in what is commonly known as gauge pressure. This indication starts at zero from the present atmospheric pressure. Such indications as oil pressure, hydraulic pressure and fuel pressure are all read in p.s.i.g. (Figure 3-6-3).

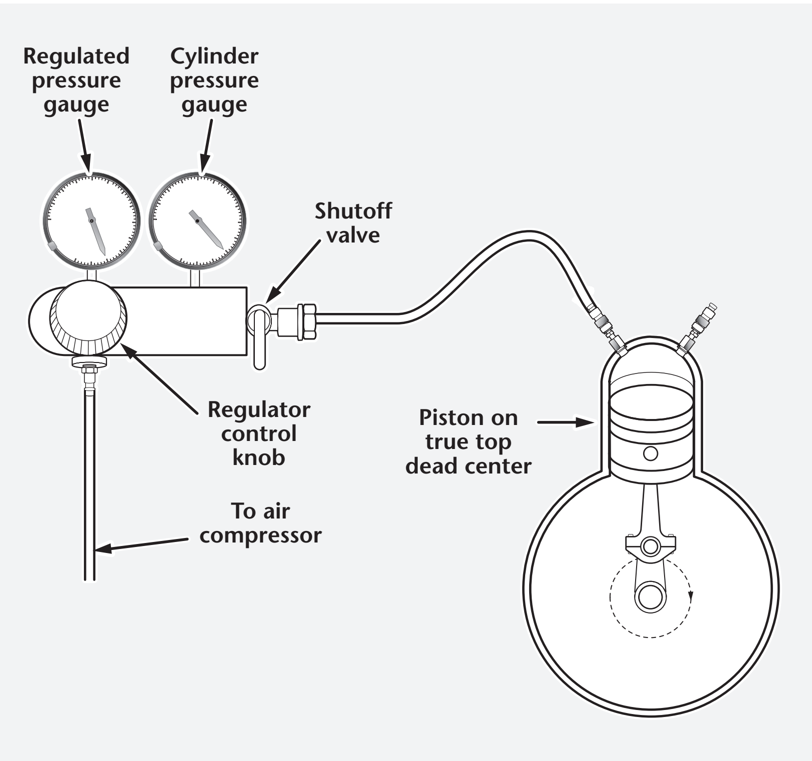


Figure 3-6-4. Cylinder leak-down tester.

Differential pressure. Differential pressure is used to compare one pressure to another, as the name implies. This type of reading may be on one gauge, or it may require two. It is common practice to take a differential pressure reading on reciprocating engine cylinders. In this case, 80 p.s.i.g. is applied to the cylinder through the spark plug hole on the compression stroke of the cylinder, and the loss of air is measured. Readings are shown as 70/80 (Figure 3-6-4).

In other instances, the gauge could read something else. An example of this is the *airspeed indicator*. This measures the difference of ram air pressure and static, or atmospheric, pressure. This gauge may be read in m.p.h. or knots.

Section 7

Gas Laws

Liquids and gases are both classified as fluids, and some laws of physics apply to both. Some of the differences concerning the two are compressibility and volume of gases due to temperature and pressure.

Incompressibility and expansion of liquids. Liquids can be compressed only slightly, that is, the reduction of the volume that they occupy, even under extreme pressure, is very small. If a pressure of 100 p.s.i. is applied to a body of water, the volume will decrease only 3/10,000 of its original volume. It would take a force of 64,000 p.s.i. to reduce its volume 10 percent. Since other liquids behave in about the same manner, liquids are usually considered incompressible.

In some applications of hydraulics where extremely close tolerances are required, the compressibility of liquids must be considered in the design of the system. In this study, however, liquids are considered to be incompressible.

Liquids usually expand when heated. This action is normally referred to as *thermal expansion*. All liquids do not expand the same amount for a certain increase in temperature. If two flasks are placed in a heated vessel, and if one of these flasks is filled with water and the other with alcohol, it will be found that alcohol expands much more than the water for the same rise in temperature. Most oils expand more than water. Aircraft hydraulic systems contain provisions for compensating for this increase of volume in order to prevent breakage of equipment.

Compressibility and expansion of gases. The two major differences between gases and liquids are their compressibility and expansion characteristics. Although liquids are practically incompressible, gases are highly compressible. Gases completely fill any closed vessel in which they are contained, but liquids fill a container only to the extent of their normal volume.

Boyle's law. As previously stated, compressibility is an outstanding characteristic of gases. The English scientist Robert Boyle was among the first to study this characteristic, which he called the *springiness of air*. By direct measurement, he discovered that when the temperature of a combined sample of gas was kept constant and the pressure doubled, the volume was reduced to half the former value; as the applied pressure was decreased, the resulting volume increased. From these observations, he concluded that for a constant temperature, the product of the volume and pressure of an enclosed gas remains constant. Boyle's law is normally stated: *The volume of an enclosed dry gas varies inversely with its pressure, provided the temperature remains constant.*

This law can be demonstrated by confining a quantity of gas in a cylinder that has a tightly fitted piston. A force is then applied to the piston so as to compress the gas in the cylinder to a specific volume. When the force applied to the piston is doubled, the gas is compressed to one-half its original volume, as indicated in Figure 3-7-1.

In equation form, this relationship may be expressed in either of two ways:

$$V_1P_1 = V_2P_2$$

or

$$\frac{V_1}{V_2} = \frac{P_2}{P_1}$$

where V_1 and P_1 are the original volume and pressure and V_2 and P_2 are the revised volume and pressure.

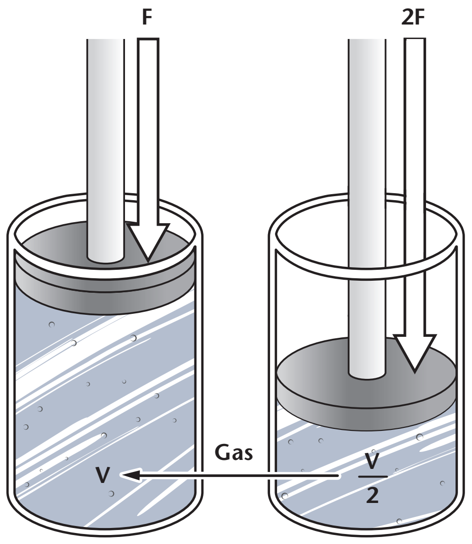


Figure 3-7-1. Gas compressed to half its original volume by a double in force.

EXAMPLE OF BOYLE'S LAW: 4 ft^3 of nitrogen are under a pressure of 100 p.s.i.g. The nitrogen is allowed to expand to a volume of 6 ft^3. What is the new gauge pressure? Formula or equation:

$$V_1P_1 = V_2P_2$$

Substituting:

$$4\ ft^3 \times (100\ p.s.i.g.) = 6\ ft^3 \times P_2$$

$$= P_2\ \frac{4\ ft^3 \times 100\ p.s.i.g.}{6\ ft^3}$$

$$P_2 = 66.6\ p.s.i.g.$$

A gas that conforms to Boyle's law is termed an *ideal gas*. When pressure is increased upon such a gas, its volume decreases proportionally and its density is increased. Thus, the density of the gas varies directly with the pressure, if the temperature remains constant. Density also varies with temperature, since gases expand when heated and contract when cooled.

The useful applications of Boyle's law are many and varied. Some applications more common to aviation are:

- The carbon dioxide (CO_2) bottle used to inflate life rafts and life vests
- The compressed oxygen and the acetylene tanks used in welding
- The compressed air brakes and shock absorbers
- The use of oxygen tanks for high-altitude flying and emergency use

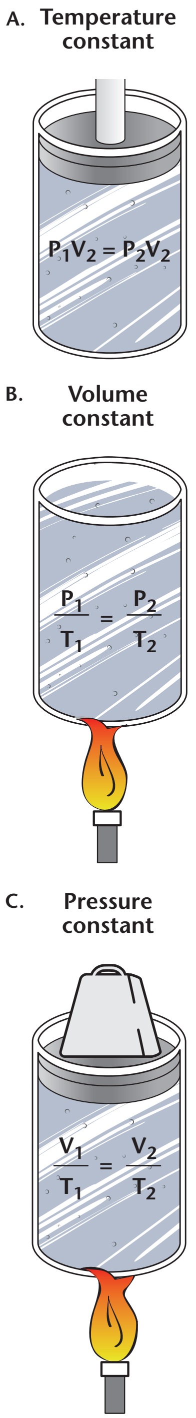


Figure 3-7-2. The general gas law.

Charles's law. French physicist Jacques Charles (1746-1823) provided much of the foundation for the modern kinetic theory of gases. He found that all gases expand and contract in direct proportion to the change in the absolute temperature, provided the pressure is held constant. In equation form, this part of the law may be expressed:

$$V_1T_2 = V_2T_1$$

or:

$$\frac{V_1}{T_1}=\frac{V_2}{T_2}$$

This equation means that with a constant volume, the absolute pressure of a gas varies directly with the absolute temperature.

EXAMPLES OF CHARLES'S LAW: A cylinder of gas under a pressure of 1,800 p.s.i.g. at 70°F (21.1°C) is left out in the sun in the tropics and heats up to a temperature of 130°F 54.4°C). What is the new pressure within the cylinder? The pressure and temperature must be converted to absolute pressure and temperature by using this formula or equation:

$$\frac{P_1}{P_2}=\frac{T_1}{T_2}$$

Using the Rankine system:

70°F (21°C) = 530° absolute
130°F (54°C) = 590° absolute

$$= \frac{1{,}800 + 14.7}{P_2} = \frac{530}{590}$$

Substituting:

$$P_2 = \frac{(590)(1{,}814.7)}{530}$$

Then:

P_2 = 2,020 p.s.i.a.

Converting absolute pressure to gauge pressure:

2,020.0
-14.7
2,005.3 p.s.i.g.

Free balloon flights into the stratosphere, the expanding gases of jet-propelled aircraft, and the effects of clouds and weather on instrument recordings may be explained by Charles's law. Here are practical applications of a law of physics that aid the pilot, air controller, and aerographer in their work. Flying is made safer when humans are able to apply this law in handling weather data so vital to aviation.

General gas law. The facts concerning gases discussed in the preceding sections are summed up and illustrated in Figure 3-7-2. Boyle's law is expressed in view (A), and the effects of temperature changes on pressure and volume (Charles' law) are illustrated in views (B) and (C), respectively.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

By combining Boyle's and Charles's laws, a single expression may be derived that states all the information contained in both. This expression is called the general gas law, a very useful form of which is given in the following equation, where P and T signify absolute pressure and temperature, respectively.

An examination of Figure 3-7-2 reveals that the three equations are special cases of the general equation. Thus, if the temperature remains constant, T_1 equals V_2, and both can be eliminated from the general formula, which then reduces to the form shown in view (A). When the volume remains constant, V_1 equals V_2, reducing the general equation to the form given in view (B). Similarly, P_1 is equated to P_2 for constant pressure, and the equation then takes the form given in view (C).

The general gas law applies with exactness only to *ideal* gases, in which the molecules are assumed to be perfectly elastic. However, it describes the behavior of actual gases with sufficient accuracy for most practical purposes.

EXAMPLE: 2 ft^3 of a gas at 75 p.s.i.g. and 80°F (26.7°C) are compressed to a volume of 1 ft^3 and then heated to a temperature of 300°F (148.9°C). What is the new gauge pressure? Using the following formula or equation:

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

and the Rankine system:

80°F (27°C) = 540° absolute
300°F (149°C) = 760° absolute

$$\frac{(75 \text{ p.s.i.g.} + 14.7 \text{ p.s.i. a.})\ (2)}{540° \text{ a}} = \frac{P_2(1 \text{ ft}^3)}{760° \text{ a}}$$

substituting:

$$\frac{179.4 \text{ p.s.i.g}}{540° \text{ a}} = \frac{P_2}{760° \text{ a}}$$

$$P_2 = \frac{(179.4 \text{ p.s.i.g})(760° \text{ a})}{540° \text{ a}}$$

then:

$P_2 = 252.5$ p.s.i.a.

Converting absolute pressure to gauge pressure

$$\begin{array}{r} 252.5 \\ -14.7 \\ \hline 237.8 \text{ p.s.i.a.} \end{array}$$

EXAMPLE: 4 ft^3 of a gas at 75 p.s.i.g. and 80°F (26.7°C) are compressed to 237.8 p.s.i.g. and heated to a temperature of 300°F (148.9°C). What is the volume of the gas resulting from these changes? Using the following formula or equation:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

and the Rankine system:

80°F (27°C) = 540° absolute
300°F (149°C) = 760° absolute

substituting:

$$\frac{(75 \text{ p.s.i.g.} + 14.7 \text{ p.s.i.a.})(4 \text{ ft}^3)}{540° \text{ a}} = \frac{(237.8 \text{ p.s.i.g.} + 14.7 \text{ p.s.i.a.})V_2}{760° \text{ a}}$$

then:

$$\frac{(89.7 \text{ p.s.i.g.})(4 \text{ p.s.i.g.})}{540° \text{ a}} = \frac{(237.8 \text{ p.s.i.g.} + 14.7 \text{ p.s.i.a.})V_2}{760° \text{ a}}$$

$$V_2 = \frac{358.8 \text{ p.s.i.g.} \times 760° \text{ a}}{540° \text{ a} \times 252.5 \text{ p.s.i.a.}}$$

$$V_2 = 2\text{ft}^3$$

Dalton's law. If a mixture of two or more gases which do not combine chemically is placed in a container, each gas expands throughout the total space and the absolute pressure of each gas is reduced to a lower value, called its *partial pressure*. This reduction is in accordance with Boyle's law. The pressure of the mixed gases is equal to the sum of the partial pressures. This fact was discovered by John Dalton, an English physicist (1766-1844), and is set forth in Dalton's law:

> A mixture of several gases which do not react chemically exerts a pressure equal to the sum of the pressures which the several gases would exert separately if each were allowed to occupy the entire space alone at the given temperature.

Avogadro's hypothesis. Italian physicist Amedeo Avogadro (1776-1856) conceived the theory that, at the same temperature and pressure, equal volumes of different gases contain equal numbers of molecules. This theory was proven by experiment and found to agree with the kinetic theory, so it has come to be known as Avogadro's law.

Section 8

Fluid Mechanics

Many of the physics laws concerning gases also pertain to liquids, in that both areas are involved in fluid mechanics. We will see that many of these principles will apply to aerodynamics as well as hydraulics.

Transmission of forces through solids. When the end of a bar is struck, the main force of the blow is carried straight through the bar to the other end, as illustrated in Figure 3-8-1A. This happens because the bar is rigid. The direction of the blow almost entirely determines the direction of the transmitted force. The more rigid the bar, the less force is lost inside the bar or transmitted outward at right angles to the direction of the blow.

Transmission of forces through a confined liquid. When a force is applied to the end of a column of confined liquid, as in Figure 3-8-1B, it is transmitted straight through to the other end, also equally undiminished in every direction throughout the column—forward, backward, and sideways—so that the containing vessel is literally filled with pressure.

Transmission of forces through a gas. If a gas is used instead of a liquid, the force is transmitted in the same manner. The one difference is that gas, being compressible, provides a much less rigid force than the liquid, which is incompressible. This is the main difference in the action of liquids and gases in fluid power systems.

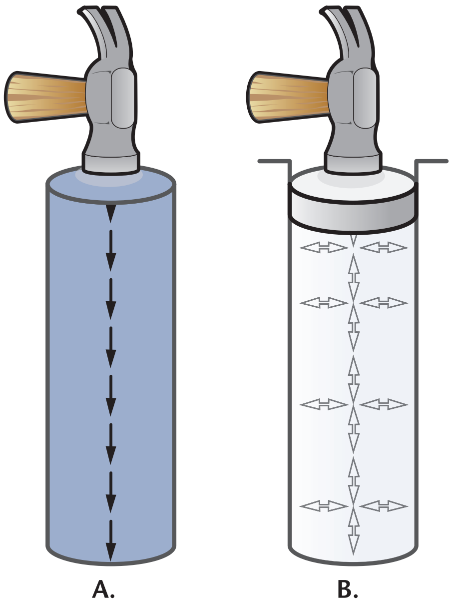


Figure 3-8-1. Transmission of force: (A) solid and (B) fluid.

Force and Pressure

In order to understand how the laws of fluid mechanics apply to fluid power, a distinction must be made between the terms force and pressure. Force may be defined as a push or pull. It is the push or pull exerted against the total area of a particular surface, and it is expressed in pounds. As previously stated, pressure is the amount of force on a unit area of the surface acted upon. In hydraulics and pneumatics, pressure is expressed in p.s.i.a. Thus, pressure is the amount of force acting upon 1 square inch of area.

Buoyancy. A solid body submerged in a liquid or a gas weighs less than when weighed in free space. This is because of the upward force, called *buoyant force*, which any fluid exerts on a body submerged in it. An object will float if this upward force of the fluid is greater than the weight of the object. Objects denser than the fluid, even though they sink readily, appear to lose a part of their weight when submerged. A person can lift a larger weight under water than what can possibly be lifted into the air.

The following experiment is illustrated in Figure 3-8-2. The overflow can is filled up to the spout with water. The heavy metal cylinder is first weighed in still air and then is weighed while completely submerged in the water. The difference between the two weights is the buoyant force of the water. As the cylinder is lowered into the overflow can, the water is caught in the catch bucket. The volume of water that overflows equals the volume of the cylinder. The volume of irregularly shaped objects can be measured by this method. If this experiment is performed carefully, the weight of the water displaced by the metal cylinder exactly equals the buoyant force of the water.

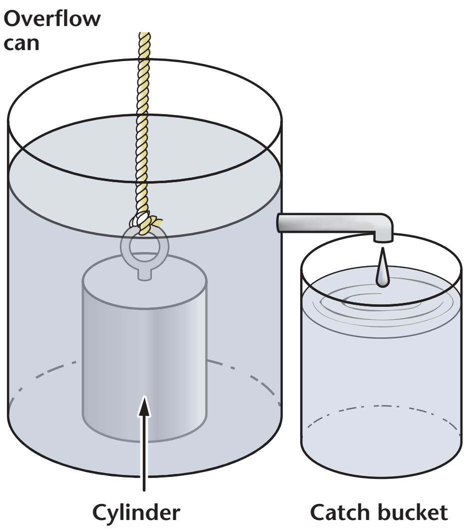


Figure 3-8-2. Measurement of a buoyant force.

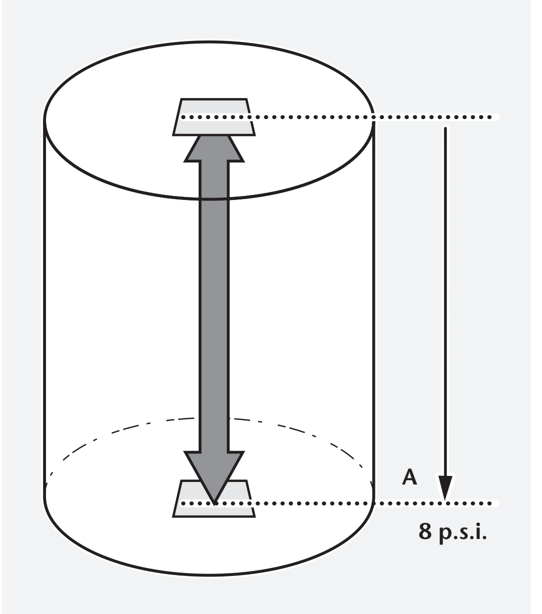


Figure 3-8-3. Pressure acting on a cylinder.

Similar experiments were performed by Greek mathematician Archimedes (287-212 B.C.). As a result of his experiments, he discovered that the buoyant force that a fluid exerts upon a submerged body is equal to the weight of the fluid the body displaces. This statement is referred to as *Archimedes' principle*. This principle applies to all fluids or gases, as well as liquids. Just as water exerts a buoyant force on submerged objects, air exerts a buoyant force on objects submerged in it.

Pascal's law. The foundations of modern hydraulics and pneumatics were established in 1653, when French philosopher and mathematician Blaise Pascal (1623-1662) discovered that pressure set up in a fluid acts equally in all directions. This pressure acts at right angles to containing surfaces. Thus, in Figure 3-8-3, if the liquid standing on a square inch (A) at the bottom of the tank weighs 8 lbs., a pressure of 8 p.s.i. is exerted in every direction at (A). The liquid resting on (A) pushes equally downward and outward. The liquid on every square inch of the bottom surface is pushing downward and outward in the same way, so that the pressures on different areas are in balance.

At the edge of the tank bottom, the pressures act against the wall of the tank, which must be strong enough to resist them with a force exactly equal to the push. Every square inch of the bottom of the tank must also be strong enough to resist the downward pressure of the liquid resting on it. The same balance of pressures exists at every other level in the tank, though the pressure lessens as one approaches the surface. Therefore, the liquid remains at rest; it does not leak out and the tank does not collapse.

One of the consequences of Pascal's law is that the shape of the container in no way alters pressure relations. Thus, in Figure 3-8-4, if the pressure due to the weight of the liquid at one point on the horizontal line (H) is 8 p.s.i., the pressure is 8 p.s.i. everywhere at level (H) in the system.

Pressure due to the weight of a fluid depends, at any level, on the height of the fluid from the level to the surface of the fluid. The vertical distance between two horizontal levels in a fluid is known as the head of the fluid. In Figure 3-8-4, the liquid head of all points on level (H) with respect to the surface is indicated.

Pressure due to fluid head also depends on the density of the fluid. Water, for example, weighs 62.4 lb/ft^3 or 0.036 lb/in^3, but a certain oil might weigh 55 lb/ft^3, or 0.032 lb/in^3. To produce a pressure of 8 p.s.i., it would take 222 inches of head using water and 252 inches of head using the oil (Figure 3-8-5).

Bernoulli's principle. The Bernoulli effect, named for Swiss mathematician Daniel Bernoulli (1700-1782), was originally stated to explain the action of a liquid flowing through the varying cross sectional areas of tubes. In Figure 3-8-6, a tube is shown in which the cross-sectional area gradually decreases to a minimum diameter in its center section. A tube constructed in this manner is called a *venturi*, named for Italian physicist G.B. Venturi (1746-1822), whose study inspired the tube's invention.

As a liquid (fluid) flows through the venturi tube, the three vertical tubes act as pressure gauges, filling with liquid until the pressure of the liquid in each tube equals the pressure of the moving liquid in the venturi.

The venturi in Figure 3-8-6 can be used to illustrate Bernoulli's principle, which states that: The pressure of a fluid (liquid or gas) decreases at points where the velocity of the fluid increases.

In the wide section of the venturi — points (A) and (C) of Figure 3-8-6 — the liquid moves at low velocity, producing a high pressure, as indicated by the height of the liquid in the vertical tubes at these two points. As the tube narrows in the center, it must contain the same volume of fluid as the two end areas. In this narrow section, the liquid moves at a higher velocity, producing a lower pressure than that at points A and C, as indicated by the height of the column of liquid in the vertical tube above point (B) of Figure 3-8-6.

The venturi principle, in any of a number of shapes and sizes, is used in aircraft systems. They may be referred to as restrictions or orifices. For example, an orifice is generally installed in a hydraulic line to limit the rate of fluid flow. A hydraulically operated aircraft landing gear, when being extended, will tend to drop with great speed because of the weight of the mechanism. If a restrictor is installed in the hydraulic return line, the extension of the gear will be slowed, thus preventing possible structural damage.

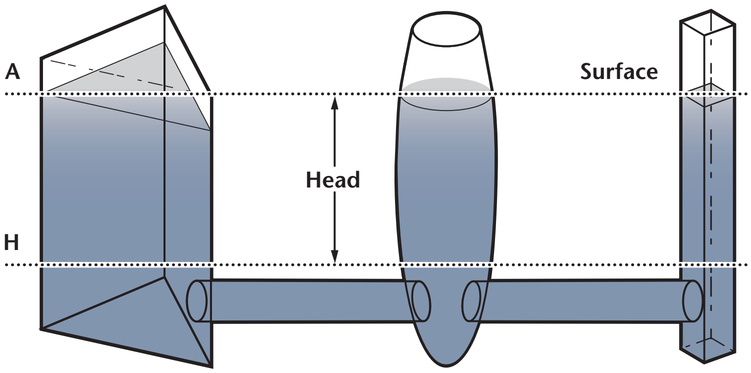


Figure 3-8-4. Pressure relationship with the shape of the container.

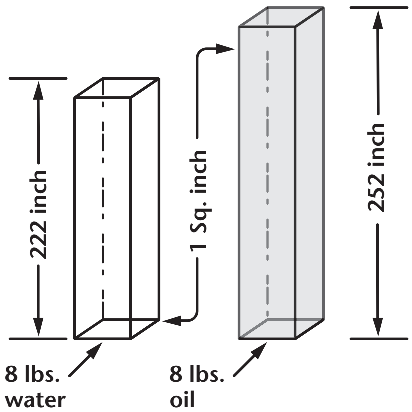


Figure 3-8-5. The relationship of pressure and density.

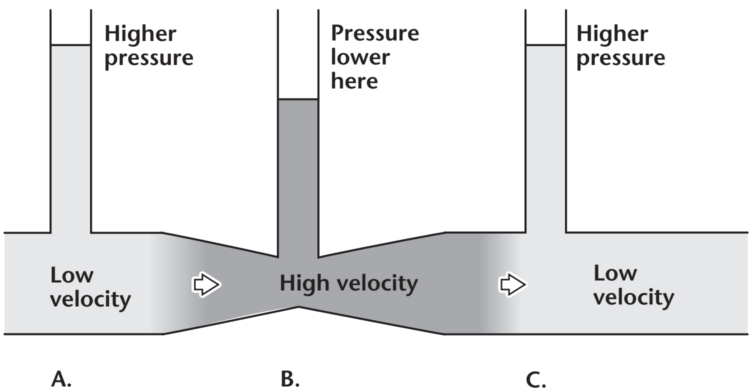


Figure 3-8-6. The relationship of pressure and velocity in a venturi tube.

Section 9

Principles of Sound

Sound has been defined as a series of disturbances in matter that the human ear can detect. This definition may also be applied to disturbances that are beyond the range of human hearing.

Sound Propagation

There are three elements that are necessary for the transmission and reception of sound. These are the *source*, a *medium* for carrying the sound, and the *detector*. Anything that moves back and forth (vibrates) and disturbs the medium around it may be considered a sound source.

An example of the production and transmission of sound is the ring of a bell. When the bell is struck and begins to vibrate, the particles of the medium (the surrounding air) in contact with the bell also vibrate. The vibrational disturbance is transmitted from one particle of the medium to the next, and the vibrations travel in a *wave* through the medium until they reach the ear. The eardrum, acting as detector, is set in motion by the vibrating particles of air, and the brain interprets the eardrum's vibrations as the characteristic sound associated with a bell.

Wave motion. Since sound is a wave motion in matter, it can best be understood by first considering water waves. When a stone is thrown into a pool, a series of circular waves travel away from the disturbance. In Figure 3-9-1, such waves are diagrammed as though seen in cross-section, from the side. Notice that water waves are a succession of crests and troughs. The *wavelength* is the distance from the crest of one wave to the crest of the next. Water waves are known as transverse waves, because the motion of the water molecules is up and down, or at right angles to the direction in which the waves are traveling. This can be seen by observing a cork on the water, bobbing up and down as the waves pass by. The cork moves very little from side to side.

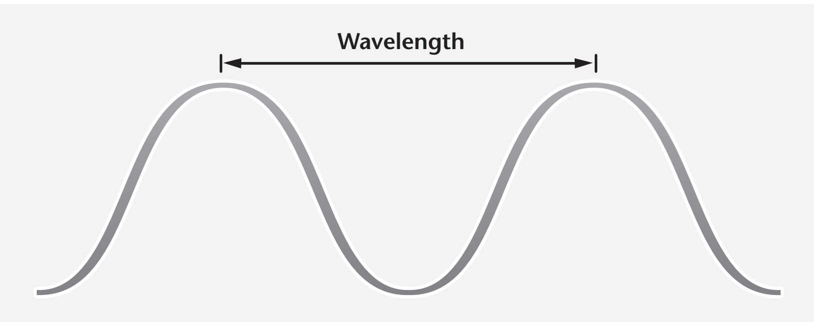


Figure 3-9-1. A transverse wave.

Sound travels through matter in the form of longitudinal wave motions. These waves are called longitudinal waves because the particles of the medium vibrate back and forth longitudinally in the direction of propagation, as shown in Figure 3-9-2.

When the tine of a tuning fork (Figure 3-9-2) moves in an outward direction, the air immediately in front of the tine is compressed so that its momentary pressure is raised above that at other points in the surrounding medium. Because air is elastic, this disturbance is transmitted progressively in an outward direction from the tine in the form of a *compression wave*.

When the tine returns and moves in an inward direction, the air in front of the tine is rarefied so that its momentary pressure is reduced below that at other points in the surrounding medium. This disturbance is transmitted in the form of a *rarefaction wave*, or expansion wave, and follows the compression wave through the medium.

The progress of any wave involves two distinct motions: The wave itself moves forward with constant speed; simultaneously, the particles of the medium that convey the wave vibrate harmonically. Examples of harmonic motion are the motion of a clock pendulum, the balance wheel in a watch and the piston in a reciprocating engine.

The period of a vibrating particle is the time (t), in seconds, required for the particle to complete one vibration.

The frequency (f) is the number of vibrations completed per second and may be expressed in cycles per second (Hz). When expressed in this unit, the word cycles means vibrations. The period is the reciprocal of the frequency:

$$t = 1/f$$

The velocity of a wave is equal to the wavelength (λ, lambda) divided by the period of time. Since the period is the reciprocal of the frequency, the velocity is $v = f\lambda$.

v = Velocity in ft./sec.

f = Frequency in Hz.

λ = Wavelength in ft.

The amplitude of vibration is the maximum displacement of the particle from its equilibrium position.

Two particles are *in phase* when they are vibrating with the same frequency and continually pass through corresponding points of their paths at the same time. For any other condition, the particles are out of phase. The two particles are *in phase*

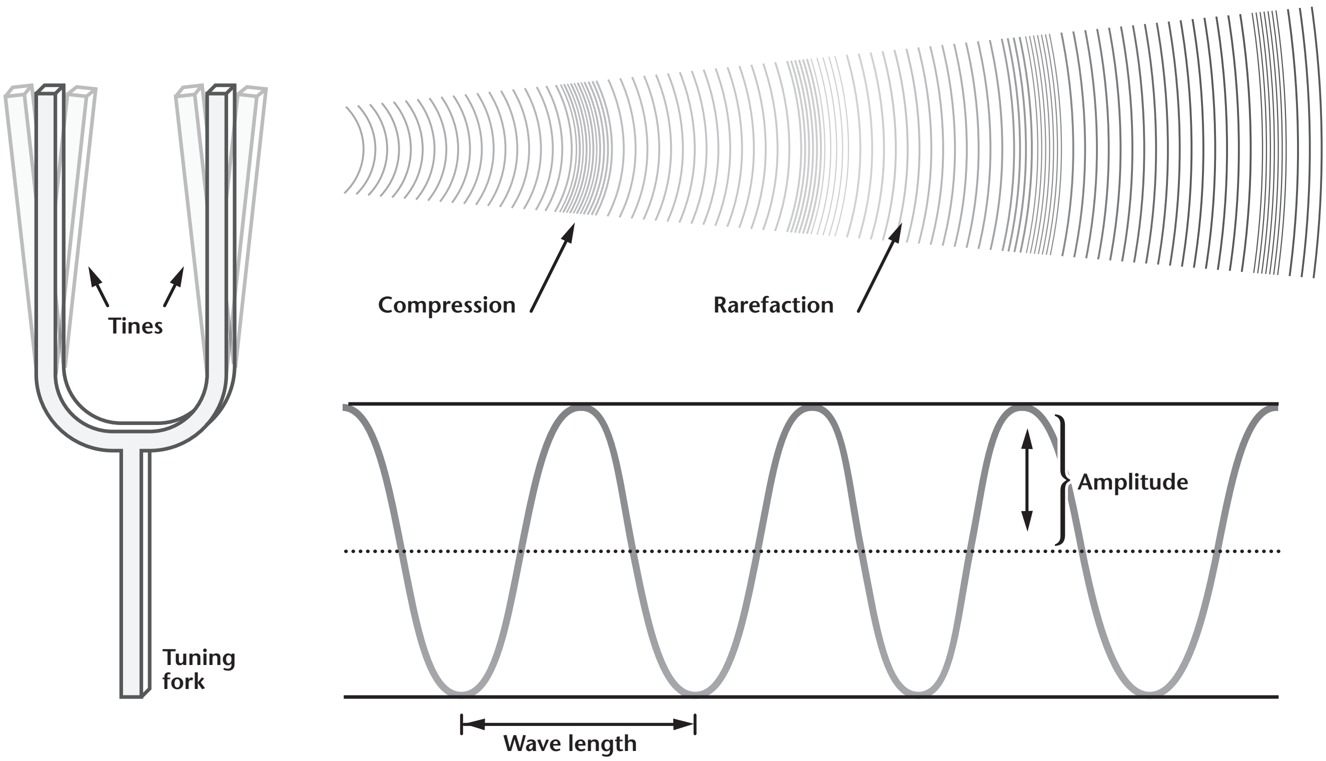


Figure 3-9-2. This shows sound propagation by a tuning fork.

opposition when they reach their maximum displacement in opposite directions at the same time.

The wavelength is the distance measured along the direction of propagation between two corresponding points of equal intensity that are in phase on adjacent waves. This length can be represented by the distance between the adjacent maximum rarefaction points in the traveling sound wave (Figure 3-9-2). When referring to Figure 3-9-2, keep in mind that the transverse wave drawn below the compressional wave is merely a device for simplifying the concept and relating it to the type of wave illustration commonly used in discussions of electromagnetic waves.

When an advancing wave encounters a medium of different character, some of its energy is reflected back into the initial medium, and some is transmitted into the second medium.

Reflection of sound waves. To understand wave reflection, it is helpful to think of the wave as a ray. A ray is a line that indicates the direction the wave is traveling. In a uniform medium, a ray will travel in a straight line. Only at the boundary of two media or in an area where the medium is changing do the rays change their direction.

If a line, called a *normal*, is drawn perpendicular to a boundary, the angle between an incoming ray and this normal is called the *angle of incidence*, or *i*, as shown in Figure 3-9-3. The angle which the reflected ray makes with the normal is called the *angle of reflection*, or *r*. Any wave being reflected is reflected in such a way that the angle of incidence equals the angle of reflection.

Light is often thought of first when reflection is discussed, however, reflection is equally common in other types of waves. As an example, echoes are caused by reflection of sound waves.

When a hard surface is situated so that a sound reflection from it is outstanding, it appears as a distinct echo and is heard an appreciable interval later than the direct sound. If the surface is concave, it may have a focusing effect and concentrate the reflected sound energy at one locality. Such a reflection may be several levels higher in intensity than the direct sound, and its arrival at a later time may have particular significance in such applications as sonar.

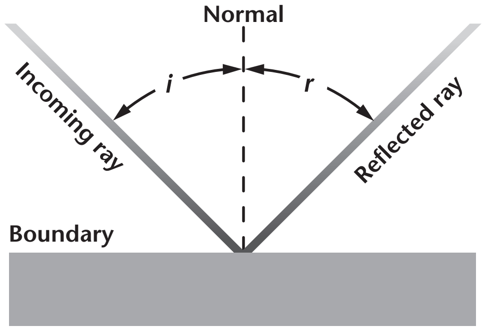


Figure 3-9-3. The reflection of a ray.

Intensity of Sound

Frequency of sound. The term *pitch* is used to describe the frequency of a sound. The outstanding recognizable difference between the tones produced by two different keys on a piano is a difference in pitch. The pitch of a tone is proportional to the number of compressions and rarefactions received per second, which in turn is determined by the vibration frequency of the sounding source.

Frequency, or pitch, is usually measured by comparison with a standard. The standard tone may be produced by a tuning fork of known frequency or by a siren whose frequency is computed for a particular speed of rotation. By regulating the speed, the pitch of the siren is made equal to that of the tone being measured.

Intensity. When a bell rings, the sound waves spread out in all directions, and the sound is heard in all directions. When a bell is struck lightly, the vibrations are of small amplitude and the sound is weak. A stronger blow produces vibrations of greater amplitude in the bell, and the sound is louder. It is evident that the amplitude of the air vibrations is greater when the amplitude of the vibrations of the source is increased. Hence, the loudness of the sound depends on the amplitude of the vibrations of the sound waves. As the distance from the source increases, the energy in each wave spreads out, and the sound becomes weaker.

The intensity of sound is the energy per unit area, per second. In a sound wave of simple harmonic motion, the energy is half kinetic and half potential; half is due to the speed of the particles, and half is due to the compression and rarefaction of the medium. These two energies are 90° out of phase at any given instant. That is, when the speed of particle motion is at a maximum, the pressure is normal; when the pressure is at a maximum or a minimum, the speed of the particles is zero.

The loudness of sound depends on both intensity and frequency. The intensity of a sound wave in a given medium is proportional to the following quantities:

- Square of the frequency of vibration
- Square of the amplitude
- Density of the medium
- Velocity of propagation

At any distance from a source of sound (point), the intensity of the wave varies inversely as the square of the distance from the source. As the sound wave advances, variations in pressure occur at all points in the transmitting medium. The greater the pressure variations, the more intense the sound wave will be. It can be shown that the intensity is proportional to the square of the pressure variation, regardless of the frequency. Thus, by measuring pressure changes, the intensities of sounds having different frequencies can be compared directly.

Measurement of sound intensity. The loudness (intensity) of sound is not measured by the same type of scale used to measure length. The human ear has a nonlinear response pattern, and units of sound measurement are used that vary logarithmically with the amplitude of the sound variations. These units are the *bel (B)* and *decibel (dB)*, which refer to the difference between sounds of unequal intensity or sound levels. The decibel, which is one-tenth of a bel, is the minimum change of sound level perceptible to the human ear. Hence, the decibel merely describes the ratio of two sound levels. For example, 5 decibels may represent almost any volume of sound, depending on the intensity of the reference level or the sound level on which the ratio is based.

On the decibel scale, the smallest audible sound (near total silence) is 0dB. A sound 10 times more powerful is 10dB. A sound 100 times more powerful than total silence is 20dB. Some common sounds and their ratings are:

- Near total silence – 0dB
- A whisper – 15dB
- Normal conversation – 60dB
- A lawn mower - 90dB
- A jet engine – 120dB
- A gunshot – 140dB

Any sound above 85dB can cause hearing loss, and the loss is related both to the power of the sound as well as the length of exposure. You know that you are listening to an 85dB sound if you have to raise your voice to be heard. Eight hours of 90dB sound can cause damage to your ears, and exposure to 140dB causes immediate damage and actual pain.

The dB is also used as a unit in electrical engineering and acoustics to express on a logarithmic scale the ratio between two values with the dimensions. The quantities compared may be two voltages, two power levels, two sound pressure levels, and so on. For instance, 1 dBm is the reference level is 1 milliwatt across an impedance of 600 ohms. The “m” stands for milliwatt.

Doppler effect. Doppler effect is experienced by many people without really realizing the cause. Many of us have heard an aircraft noise and noticed that the sound dropped appreciably as the aircraft passed over us. This change of pitch is due to an apparent change in frequency, or frequency shift. The principle for this shift was developed by Austrian physicist Christian Johann Doppler (1803-1853). The principle states that *the frequency of waves from a source that reach an observer, when both the source and observer are in motion, increases or decreases relative to the speed at which the distance between the observer and the source increases or decreases*. The sound waves in front of the moving aircraft are closer together than other sound waves around the aircraft. This principle, though developed in regard to sound, has much greater emphasis in radar, where speed and range are determined rather than sound.

Speed of Sound

In any uniform medium, under given physical conditions, sound travels at a definite speed. In some substances, the velocity of sound is higher than in others. Even in the same medium under different conditions of temperature, pressure, etc., the velocity of sound varies. Density and elasticity of a medium are the two basic physical properties that govern the velocity of sound.

In general, a difference in density between two substances is sufficient to indicate which one will be the faster transmission medium for sound. For example, sound travels faster through water than it does through air at the same temperature. However, there are some surprising exceptions to this rule of thumb. An outstanding example among these exceptions involves comparison of the speed of sound in lead and aluminum at the same temperature. Sound travels at 16,700 ft./s in aluminum at 20°C, and only 4,030 ft./s in lead at 20°C, despite the fact that lead is much more dense than aluminum. The reason for such exceptions is found in the fact, as mentioned above, that sound velocity depends on elasticity as well as density.

Using density as a rough indication of the speed of sound in a given substance, it can be stated as a general rule that sound travels fastest in solid materials, slower in liquids, and slowest in gases.

For a fixed temperature, the velocity of sound is constant for any medium and is independent of the period, frequency or amplitude of the disturbance. Thus, the velocity of sound in air at 0°C (32°F) is 1,087 ft./s and increases by 2 ft./s for each Celsius degree of temperature rise (1.1 ft./s for each degree Fahrenheit). For practical purposes, the speed of sound in air may be considered 1,100 ft./s.

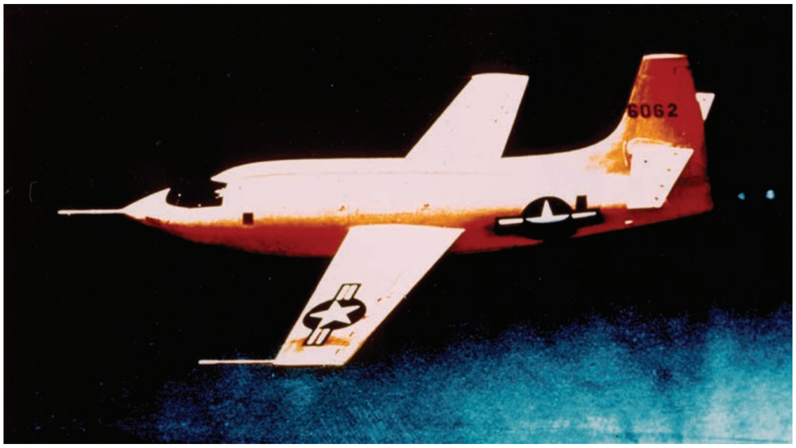


Figure 3-9-4. Flying the Bell X-1 for 20 seconds at sustained, level flight at an altitude of 42,000 ft., Air Force Capt. Chuck Yeager broke the sound barrier over southern California on October 14, 1947. Yeager reached speeds of nearly 700 m.p.h. — more than Mach 1. The X-1 was powered by a rocket-propulsion system and was air-launched from a modified B-29 bomber.

Mach number. In the study of aircraft that fly at supersonic speeds, it is customary to discuss aircraft speed in relation to the velocity of sound (approximately 760 m.p.h.). The term *Mach number* has been given to the ratio of the speed of an aircraft to the speed of sound, in honor of Austrian physicist and philosopher Ernst Mach (1836-1916). Thus, if the speed of sound at sea level on a 59˚F day (15˚C) is 760 m.p.h., an aircraft flying at a Mach number of 2.2 would be traveling at a speed of 760 m.p.h. × 2.2 = 1,672 m.p.h. Refer to Figure 3-9-4. The speed of sound decreases with altitude. Mach numbers are used as a common reference that automatically adjusts for the pressure and density of the air.

Resonance

When a body vibrates unhampered by any other body, it is said to be executing free vibrations. This frequency is said to be its natural frequency. When another body vibrates with a frequency other than its own natural frequency, it is referred to as a *forced vibration*. If two bodies that have the same frequency of natural vibration are set next to each other, the vibration of one can transfer its wave energy to the other. This transferring is called *resonance*. This phenomenon is used in all reed instruments.

In mechanical equipment, resonance is not desirable. It is possible to have portions of an aircraft that will vibrate in resonance to engine speed or rotor r.p.m. These vibrations may become violent enough to cause structural failure over a period of time.

4

Principles of Aerodynamics

Section 1

Theory of Flight

Even though modern computer-based design programs have taken the place of many years of struggle by design teams, a human brain still has to be in control. The design principles that control heavier-than-air flight exist in the mind; the computer just makes assumptions based on human input.

In order to properly maintain any aircraft, the technician must make assumptions based on human input. In the process, understanding the relationship of the various control surfaces to each other, as well as the complete airplane, is essential. As you read this chapter, remember that, in aviation, nothing exists and operates alone.

Aerodynamics. Aerodynamics is the science of the action of air on an object. It is further defined as that branch of dynamics that deals with the motion (current) of air and with the forces acting upon an object in the current of air. In effect, aerodynamics is concerned with three distinct parts: the atmosphere, the relative wind, and the aircraft.

The atmosphere. Obviously, an aircraft operates in the air; therefore, the properties of air that affect aircraft control and performance must be understood to actually know what an airplane is doing when it flies.

Since air is a combination of gases, it adheres to the laws of gases. Air is considered a fluid because it answers the definition of a fluid; namely, a substance that may be made to flow or change its shape by the application of

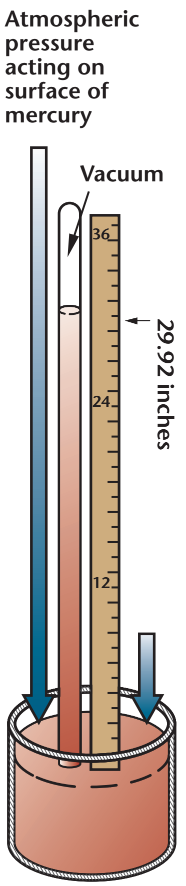
Learning Objectives

DESCRIBE
- The design principles behind the theory of flight
- Characteristics of airfoils
- The function of aircraft control systems
- Components of transport aircraft control surfaces
- The influences on and principles of aircraft stability

EXPLAIN
- The forces of thrust and drag and how they influence flight
- Aircraft surfaces and axes and how these affect control
- The characteristics of high-speed aerodynamics

Left. Full-span model in wind tunnel.

Photo courtesy of NASA Langley Research Center



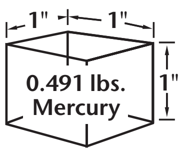


Figure 4-1-1. Measurement of atmospheric pressure using a column of mercury.

moderate pressure. Air has weight, therefore something lighter than air, such as a balloon filled with helium, will rise in the air.

Pressure. If a 1-inch^2 column of air extending from sea level to the top of the atmosphere could be weighed, it would be found to weigh about 14.69 lbs. Thus, atmospheric pressure at sea level is 14.69 p.s.i. (pounds per square inch). However, p.s.i. is rather a crude unit for the measurement of a light substance such as air. Therefore, atmospheric pressure is usually measured in terms of inches of mercury.

The apparatus for measuring atmospheric pressure is shown in Figure 4-1-1. A glass tube, 36 inches long, open at one end and closed at the other, is filled with mercury. The open end is sealed temporarily and then submerged into a small container partly filled with mercury, after which the end is unsealed. This allows the mercury in the tube to descend, leaving a vacuum at the top of the tube. Some of the mercury flows into the container, while a portion of it remains in the tube. The weight of the atmosphere pressing on the mercury in the open container exactly balances the weight of the mercury in the tube, which has no atmospheric pressure pushing down on it due to the vacuum in the top of the tube. As the pressure of the surrounding air decreases or increases, the mercury column lowers or rises correspondingly. At sea level, the height of the mercury in the tube measures approximately 29.92 inches and varies slightly with atmospheric conditions.

Another unit of measure for barometric pressure is *millibars* which is defined as 1000 dyne/cm^2. The most common usage is in weather maps, which use millibars to show levels of barometric pressure. At sea level, the pressure is 1,013.25 millibars (mb).

An important consideration is that atmospheric pressure varies with altitude. The higher an object rises above sea level, the shorter the column of air above it. This means the lower the pressure. On a normal day, the pressure drop can be calculated and charted for each altitude. At the same time, temperature changes with a change in altitude. This temperature change with a change in altitude is called a *lapse rate*. When all things are equal, it changes at a predictable rate. This is called the *adiabatic lapse rate*.

There are some other specific changes, brought about by various atmospheric conditions that have a definite relation to flying. The effect of temperature, combined with altitude, affects the density of the air and affects aircraft performance.

Temperature. Temperature is a dominant factor affecting the physical properties of fluids. It is of particular concern when calculating changes in the state of gases.

There are three temperature scales used extensively. They are:

- Celsius
- Fahrenheit
- Kelvin, or absolute

The Celsius scale is constructed by using the freezing and boiling points of water under standard conditions, as fixed points of 0° and 100°, respectively, with 100 equal divisions between.

The Fahrenheit scale uses 32°F as the freezing point of water and 212°F as the boiling point, with 180 equal divisions between.

The absolute, or Kelvin, scale is constructed with its zero point established as -273°C, or -459°F, below the freezing point of water. The relationships of all the fixed points of the scales are shown in Figure 4-1-2.

Absolute zero, one of the fundamental constants of physics, is commonly used in the study of gases. It is usually expressed in terms of the Celsius scale. If the heat energy of a given gas sample could be progressively reduced, some temperature would be reached at which the motion of the molecules would cease entirely. If accurately determined, this temperature could then be taken as a natural reference, or as a true *absolute zero* value.

Experiments with hydrogen indicated that if a gas were cooled to -273.16°C (used as -273°C for most calculations), all molecular motion would cease, and no additional heat could be extracted from the substance.

When temperatures are measured with respect to the absolute zero reference, they are expressed as 0 in the absolute, or Kelvin, scale. Thus, absolute zero may be expressed as 0°K, as –273°C, or as –459.4°F (used as –460°F for most calculations).

When working with temperatures, always make sure which system of measurement is being used and know how to convert from one to another. The conversion formulas are shown in Figure 4-1-2.

For purposes of calculations, the Rankine scale, illustrated in Figure 4-1-2, is commonly used to convert Fahrenheit to absolute.

For Fahrenheit readings above zero, 460° is added. Thus, 72°F equals 460° plus 72°, or 532°F absolute. If the Fahrenheit reading is below zero, it is subtracted from 460°. Thus, -40°F equals 460° minus 40°, or 420° absolute.

Kelvin to Celsius and Fahrenheit

$$°K = C + 273$$
$$= \frac{5}{9}(F - 32) + 273$$
$$= \frac{5}{9}F + 255.23$$

Celsius to Kelvin and Fahrenheit

$$°C = \frac{5}{9}(F - 32)$$
$$= (°F - 32°) \div 1.8$$
$$= °K + -273$$

Fahrenheit to Kelvin and Celsius

$$°F = \frac{9}{5}(F - 273) + 273$$
$$= \frac{9}{5}(K - 32) + 273$$
$$= \frac{9}{5}C + 32$$

Rankine to Fahrenheit

$$°R = °F + 460$$

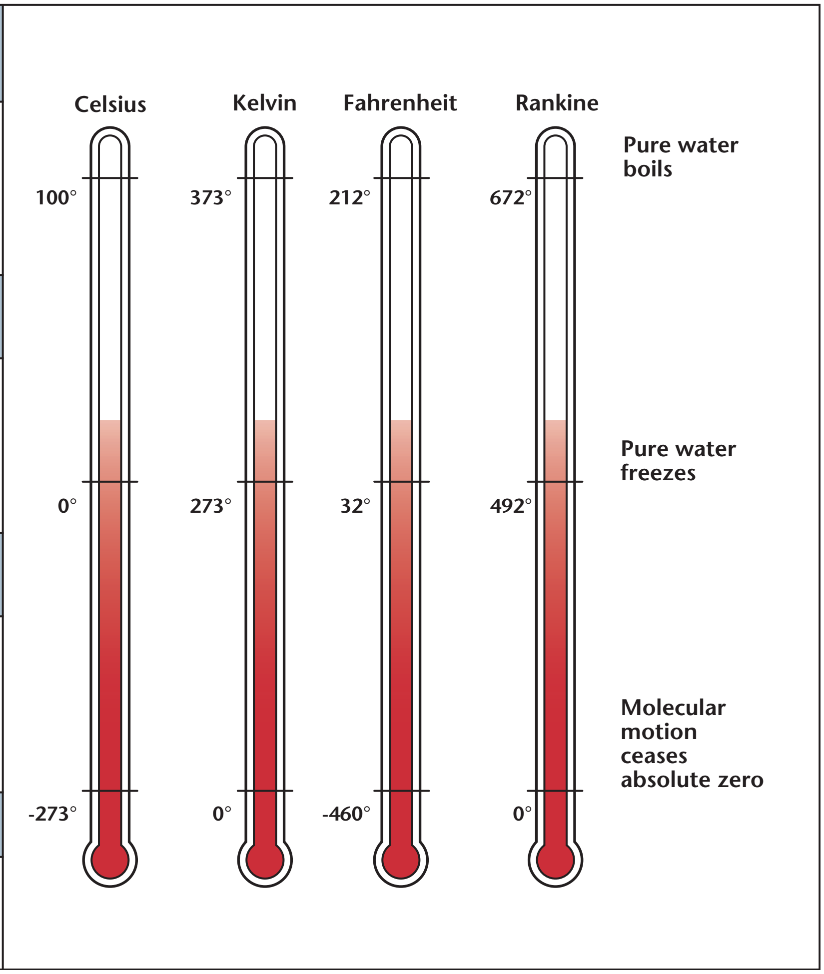


Figure 4-1-2. Common temperatures compared in the temperature measurement systems normally encountered. The Rankine scale is used to convert Fahrenheit to absolute.

The Rankine scale does not indicate absolute temperature readings in accordance with the Kelvin scale, but these conversions may be used for the calculations of changes in the state of gases.

The Kelvin and Celsius scales are used more extensively in scientific work; therefore, some technical manuals may use these scales in giving directions and operating instructions. The Fahrenheit scale is commonly used in the United States, and most people are familiar with it. Therefore, the Fahrenheit scale is used in most areas of this text.

Density. Density is a term that means weight per unit volume. Since air is a mixture of gases, it can be compressed. If the air in one container is under one-half as much pressure as the air in another identical container, the air under the greater pressure weighs twice as much as that in the container under lower pressure. The air under greater pressure is twice as dense as that in the other container. Additionally, for equal weights of air, that which is under the greater pressure will only occupy half the volume.

The density of gases is governed by the following rules:

- Density varies in direct proportion with the pressure.
- Density varies inversely with the temperature.

Thus, air at high altitudes is less dense than air at low altitudes, and a mass of hot air is less dense than a mass of cool air.

Changes in density affect the aerodynamic performance of aircraft. With the same horsepower, an aircraft can fly faster at a high altitude, where the density is low, than at a low altitude, where the density is great. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit volume.

Humidity. Humidity is the amount of *water vapor* in the air. The maximum amount of water vapor that air can hold varies with the temperature. The higher the temperature of the air, the more water vapor air can absorb.

By itself, water vapor weighs approximately five-eighths as much as an equal amount of perfectly dry air. Therefore, when air contains water vapor, it is not as heavy as air containing no moisture at all. An airplane will not perform as well in high humidity conditions, because they produce a higher density altitude.

Absolute humidity. Absolute humidity is the actual amount of the water vapor in a mixture of air and water. It is sometimes expressed in grams per cubic meter (g/m^3), sometimes in pounds per cubic feet (lb/ft^3). The amount of water vapor that can be present in the air is dependent upon the temperature and pressure. The higher the temperature, the more water vapor the air is capable of holding, assuming constant pressure. When air has all the water vapor it can hold at the prevailing temperature and pressure, it is considered saturated.

Relative humidity. Relative humidity is the ratio of the amount of water vapor actually present in the atmosphere to the amount that would be present if the air were saturated at the prevailing temperature and pressure. This ratio is usually multiplied by 100 and expressed as a percentage. Suppose, for example, that a weather report says that the temperature is 75°F (24°C) and the relative humidity is 56 percent. This indicates that the air holds 56 percent of the water vapor required to saturate it at 75°F. (24°C) If the temperature drops and the absolute humidity remains constant, the relative humidity will increase. This is because less water vapor is required to saturate the air at the lower temperature.

Standard Day

While all the above may be interesting, it also has a very important purpose. It is the basis for defining a *standard day*. A standard day is a derived set of parameters that are used for many things, including designing airplanes and measuring their performance. It is also used in weather forecasting.

A standard day is defined as being 29.92 inches of mercury (1,013.25 mb), 14.7 p.s.i. at mean sea level altitude with a temperature of 59°F (15°C).

Law of Conservation of Energy

Energy is required for all forms of work. It is possible for man to convert one form of energy to another, but we cannot destroy it. However, it normally appears that a portion of the energy is lost during transformation. What actually happens is that some of the energy used transfers to different types of energy, and that is our primary concern.

For instance, an electric motor is a means of changing electrical energy to mechanical energy. A loss of 6 percent is common. This energy cannot be accounted for in friction or power. However, it has become heat. The same processes must be considered in flight. In flight, we change chemical energy into heat energy through combustion. This, in turn, is converted into mechanical energy, which powers the aircraft. During each of these processes, some of this energy becomes a byproduct of the transformation. Because of this, we must do whatever is possible to obtain the best flight characteristics for the energy consumed.

Velocity and acceleration. The terms *speed* and *velocity* are often used interchangeably, but they do not mean the same thing. Speed is the rate of motion, and velocity is the rate of motion in a particular direction in relation to time.

An aircraft starts from New York City and flies 10 hours at an average speed of 260 m.p.h. At the end of this time, the aircraft may be over the Atlantic Ocean, the Pacific Ocean, the Gulf of Mexico, or, if its flight were in a circular path, it may even be back over New York. If this same aircraft flew at a velocity of 260 m.p.h. in a southwestward direction, it would arrive in Los Angeles in about 10 hours. Only the rate of motion is indicated in the first example, denoting the speed of the aircraft. In the last example, the particular direction is included with the rate of motion, thus denoting the velocity of the aircraft.

Acceleration is defined as the rate of change of velocity. An aircraft increasing in velocity is an example of positive acceleration, while an aircraft reducing its velocity is an example of *negative acceleration*. Positive acceleration is commonly referred to simply as acceleration and negative acceleration as deceleration.

Motion. Motion is the act or process of changing place or position. An object may be in motion with respect to one object and motionless with respect to another. For example, a person sitting quietly in an aircraft flying at 200 knots is at rest, or motionless, with respect to the aircraft. However, the person is in motion with respect to the air or the Earth, the same as is the aircraft.

Air has no force or power, except pressure, unless it is in motion. When it is moving, however, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect then, whether an object is moving with respect to the air or the air is moving with respect to the object. The result is the same.

The flow of air around an object caused by the movement of either the air or the object, or both, is called the *relative wind*.

Newton's laws of motion. The fundamental laws governing the action of air around an airfoil are Newton's laws of motion.

Newton's First Law of Motion is normally referred to as the law of inertia. It simply means that a body at rest will not move unless force is applied to it. If it is moving at uniform speed in a straight line, additional force must be applied to increase or decrease that speed.

Since air has mass, it is a *body* in the meaning of the law. When an aircraft is on the ground with its engines stopped, inertia keeps the aircraft at rest. An aircraft is moved from its state of rest by the thrust force created by the propeller, by the expanding exhaust gases, or both. When it is flying at uniform speed in a straight line, inertia tends to keep the aircraft moving. Some external force is required to change the aircraft from its path of flight.

Newton's Second Law of Motion, that of force, also applies to objects. This law states, *"if a body moving with uniform speed is acted upon by an external force, the change of motion will be proportional to the amount of the force, and motion will take place in the direction in which the force acts."* This law may be stated mathematically as follows:

Force = mass × acceleration or $F = ma$

Newton's Third Law of Motion is the law of action and reaction. This law states that *"for every action* (force) *there is an equal and opposite reaction"* or (force). This law is well illustrated by someone rowing a boat. As the oars push the water aft, it propels the boat forward, since the water resists the action of the oars. When the force of lift on an aircraft's wing equals the force of gravity, the aircraft maintains level flight.

The three laws of motion are closely related and apply to the theory of flight. In many cases, all three laws may be operating on an aircraft at the same time.

Bernoulli's Principle and Subsonic Flow

Bernoulli's principle states that when a fluid (air) flowing through a tube reaches a constriction, or narrowing of the tube, the speed of the fluid flowing through that constriction is increased and its pressure is decreased. This is the principle of a *venturi* and is what makes a carburetor work. The *cambered* (curved) surface of an airfoil (wing) affects the airflow exactly as constriction in a tube affects airflow; in essence, half of a venturi. This is illustrated in Figure 4-1-3.

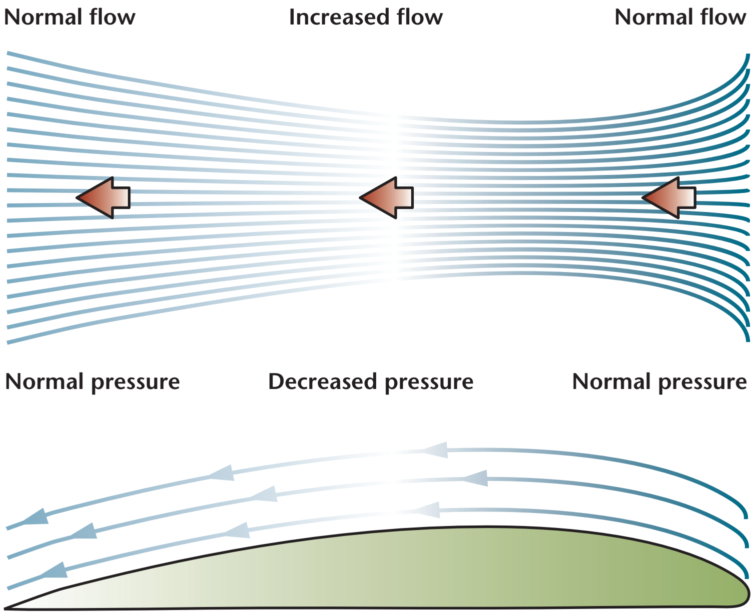


Figure 4-1-3. Bernoulli's principle is best explained by examining the actions of a venturi.

The top portion of Figure 4-1-3 illustrates the effect of air passing through a constriction in a tube. In the bottom illustration on Figure 4-1-3, the air is flowing past a cambered surface, such as an airfoil, and the effect is similar to that of air passing through a restriction.

As the air flows over the upper surface of an airfoil, its speed, or velocity, increases and its pressure decreases. An area of low pressure is thus formed. There is an area of greater pressure on the lower surface of the airfoil, and this greater pressure tends to move the wing upward. This difference in pressure between the upper and lower surfaces of the wing is called *lift*. Three-fourths of the total lift of an airfoil is the result of the decrease in pressure over the upper surface. The impact of air on the under surface produces the other one-fourth of the lift generated by the airfoil. At the trailing edge of the airfoil, the upper air, traveling faster, will strike the slower air passing under the airfoil and force it downward at an angle, producing a *downwash*. The downwash produced will extend the full width of the wing and add significantly to the total lift.

An aircraft in flight is acted upon by four forces:

- *Gravity* (or weight) — the force that pulls the aircraft toward the Earth
- *Lift* — the force that pushes the aircraft upward

- *Thrust* — the force that moves the aircraft forward
- *Drag* — the force that exerts a braking action

Figure 4-2-2. Fineness ratio of chord to thickness.

Section 2

Airfoils

An *airfoil* is a surface designed to obtain a desirable reaction from the air through which it moves. Thus, we can say that any part of the aircraft that converts air resistance into a force useful for flight is an airfoil. The blades of a propeller are so designed that when they rotate, their shape and position cause a higher pressure to be built up behind them than in front of them so that they will pull the aircraft forward. The profile of a conventional wing, shown in Figure 4-2-1, is an excellent example of an airfoil. Notice that the top surface of the wing profile has greater curvature than the lower surface.

The difference in curvature of the upper and lower surfaces of the wing builds up the lift force. When a fluid, in this case air, flows over an object, the air molecules, because they are not tightly bound to each other are free to move around the object. Because of this ability there is a velocity associated with the air and this velocity has dissimilar values at various locations near the object.

Bernoulli's equation relates the pressure in a fluid to the local velocity; as the velocity increases the pressure decreases by an inverse proportion. By adding all the pressure variations and multiplying by the area of the object, the aerodynamic force on the body is determined. Lift is the component of the aerodynamic force which is perpendicular to the original air flow direction, while the drag is parallel to the flow direction. When the velocity variations are added up it can be seen that the velocity of the fluid also determine the aerodynamic force. The sum of all these variations results in a turning of the airflow. When Newton's third law, of action and reaction, is applied to this turning, a reaction force behind the object is the result. This turning of the airflow is sometimes called the downwash. So it can be seen that lift is a combination of Bernoulli's theory and Newton's laws of motion.

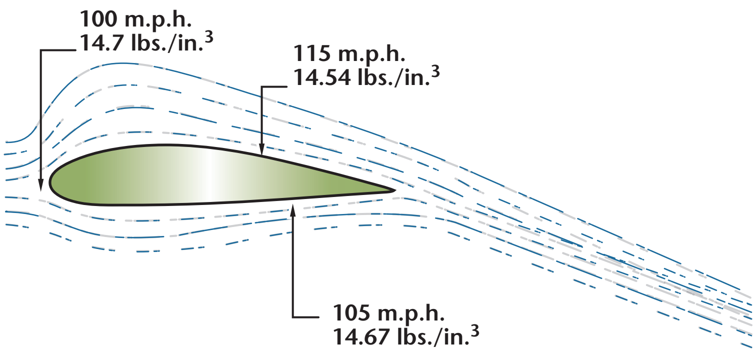


Figure 4-2-1. Airflow over a wing section, showing the various velocities, pressures, and the downwash angle.

The theoretical amount of lift of the airfoil at a velocity of 100 m.p.h. can be determined by sampling the pressure above and below the airfoil at the point of greatest air velocity. As shown in Figure 4-2-1, this pressure is 14.54 p.s.i. above the airfoil. Subtracting this pressure from the pressure below the airfoil, 14.67 p.s.i., gives a difference in pressure of 0.13 p.s.i. Multiplying 0.13 by 144 (number of square inches in a square foot) shows that each square foot of this wing will lift 18.72 lbs. The equation for figuring lift — when P_1 is the air pressure at the point of greatest velocity above the airfoil, P_2 is the air pressure under the airfoil, D is the difference between the two pressures, and L is the lift per square foot — is as follows:

$$P_2 - P_1 = D$$

$$D / 144 = L$$

Thus, a small pressure differential across an airfoil section can produce a large lifting force. Within limits, lift can be increased by increasing the angle of attack, the wing area, the free stream velocity, the density of the air, or by changing the shape of the airfoil.

Shape of the Airfoil

The shape of the airfoil determines the amount of turbulence, or *skin friction*, that it will produce. The shape of a wing consequently affects its efficiency.

Airfoil section properties differ from wing or aircraft properties because of the effect of the wing *planform*. A wing may have various airfoil sections from root to tip, with taper, twist and sweepback. The resulting aerodynamic properties of the wing are determined by the action of each section along the span.

Turbulence and skin friction are controlled mainly by the *fineness ratio*, which is defined as the ratio of the chord of the airfoil to the maximum thickness (Figure 4-2-2).

If the wing has a high fineness ratio, it is a very thin wing and produces a large amount of skin friction. A thick wing has a low fineness ratio, producing a large amount of turbulence. The best wing is a compromise between these two extremes to hold both turbulence and skin friction to a minimum.

Efficiency of a wing is measured in terms of the *lift-over-drag (L/D) ratio*. This ratio varies with the angle of attack but reaches a definite maximum value for a particular angle of attack. At this angle, the wing has reached its maximum efficiency. The shape of the airfoil is the factor that determines the angle of attack at which the wing is most efficient; it also determines the degree of efficiency.

Research has shown that the most efficient airfoils for general use have the maximum thickness occurring about one-third of the way back from the leading edge of the wing.

Some modern airliners use a wing with the maximum thickness further back. This provides a better lift to drag ratio at higher speeds, improving fuel efficiency at cruising speeds.

High-lift wings, as well as high-lift devices for wings, have been developed by shaping the airfoils to produce the desired effect. The amount of lift produced by an airfoil will increase with an increase in wing *camber*.

Camber refers to the curvature of an airfoil above and below the *chord line* surface. Upper camber refers to the upper surface, lower camber to the lower surface, and *mean camber* to the *mean line* of the section. Camber is positive when departure from the chord line is outward and negative when it is inward (Figure 4-2-3). Thus, high-lift wings have a large positive camber on the upper surface and a slight negative camber on the lower surface. Wing flaps cause an ordinary wing to approximate this same condition by increasing the upper camber and by creating a negative lower camber.

Aspect ratio. It is also known that the longer the wingspan compared to the chord, the greater the lift obtained. This comparison is called *aspect ratio*. The higher the aspect ratio, the greater the lift. Despite benefits from an increase in aspect ratio, there are limitations where the structural and drag considerations outweigh the gain from a high aspect ratio (Figure 4-2-4).

Modern aircraft have airfoils that strike a medium between extremes, with the shape varying according to the aircraft for which it is designed.

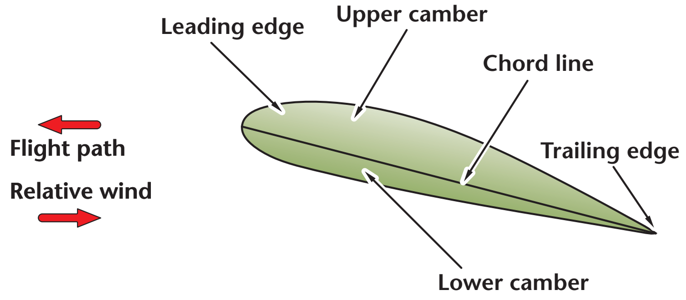


Figure 4-2-3. Wing terminology.

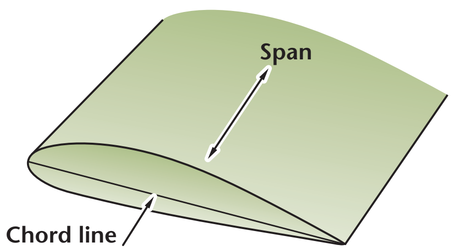


Figure 4-2-4. Aspect ratio; span to chord.

Angle of incidence. The acute angle that the wing chord makes with the longitudinal axis of the aircraft is called the *angle of incidence* (Figure 4-2-5), or the angle of wing setting. The angle of incidence in most cases is a fixed, built-in angle. When the leading edge of the wing is higher than the trailing edge, the angle of incidence is said to be positive. The angle of incidence is negative when the leading edge is lower than the trailing edge of the wing.

Do not confuse the angle of incidence with the angle of attack, which is the angle between the chord line of the wing and the relative wind. A good way to keep the two separated in your mind is to remember that the angle of incidence is established by the attachment of the wing to the airframe.

Angle of attack. Before beginning the discussion on *angle of attack* (Figure 4-2-6) and its effect on airfoils, we first need to consider the terms chord and center of pressure.

The *chord* of an airfoil or wing section is an imaginary straight line passing through the section from the leading edge to the trailing edge, as shown in Figure 4-2-6. The chord line provides one side of an angle that ultimately forms the *angle of attack*. The other side of the angle is formed by a line indicating the direction of the *relative wind*. The relative wind is opposite to the direction in which the wing is moving. Thus, angle of attack is defined as the angle between the chord line of the wing and the direction of the relative wind.

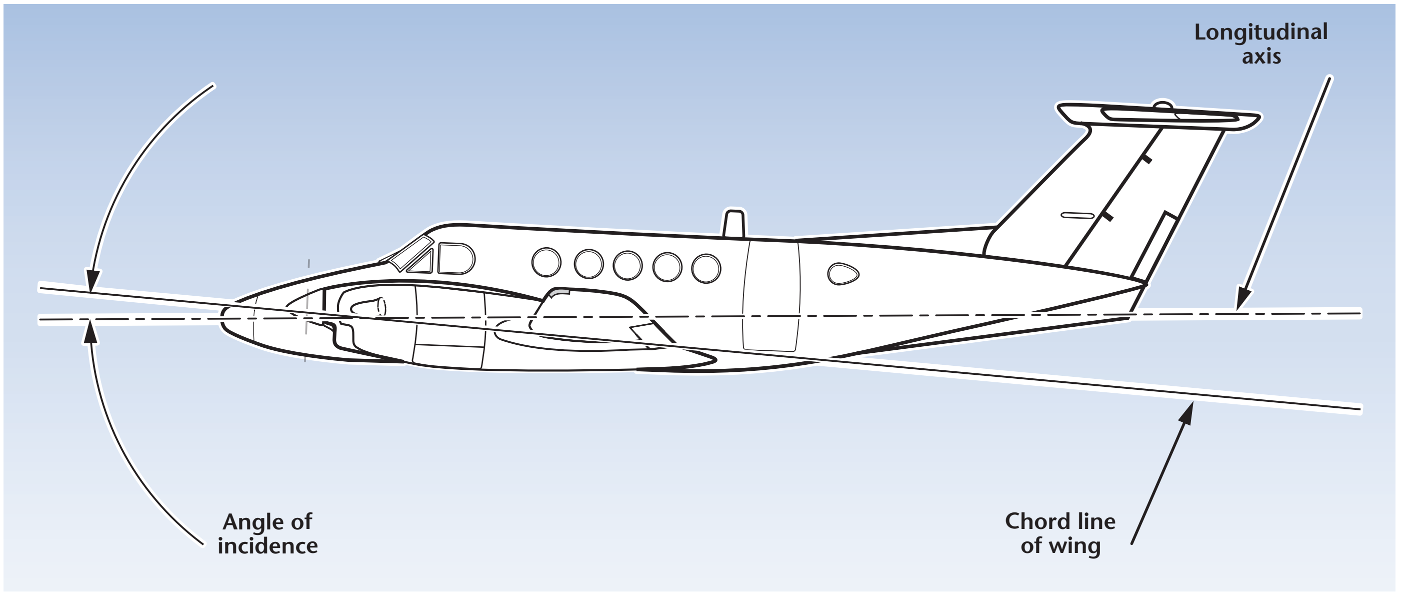


Figure 4-2-5. The angle of incidence is the angle between the centerline of the airplane and the bottom of the wing. For rigging purposes, the angle of incidence is adjustable through a very small range on some aircraft.

On each minute part of an airfoil or wing surface, a small force is present. This force is different in magnitude and direction from any forces acting on other areas forward or rearward from this point. It is possible to add all of these small forces mathematically, and the sum is called the *resultant force,* or *lift*. This resultant force has magnitude, direction, and location, and can be represented as a *vector*, as shown in Figure 4-2-6. The point of intersection of the resultant force line with the chord line of the airfoil is called the *center of pressure*. The center of pressure moves along the airfoil chord as the angle of attack changes. Throughout most of the flight range, the center of pressure moves forward with the increasing angle of attack and rearward as the angle decreases. The effect of increasing the angle of attack on the center of pressure is shown in Figure 4-2-7.

The angle of attack changes as the aircraft's attitude changes. Since the angle of attack has a great deal to do with determining lift, it is of primary consideration when designing airfoils. In a properly designed airfoil, the lift increases as the angle of attack is increased.

When the angle of attack is increased gradually toward a positive angle of attack, the lift component increases rapidly up to a certain point and then suddenly drops off. During this action, the *drag component* increases slowly at first, and then rapidly, as lift begins to drop off.

When the angle of attack increases to the angle of maximum lift, the *burble point* is reached. This is known as the *critical angle*. When the critical angle is reached, the air ceases to flow smoothly over the top surface of the airfoil and begins to burble, or eddy. This means that air breaks away from the upper camber line of the wing. What was formerly an area of decreased pressure is now filled by this burbling air. When this occurs, the amount of lift drops, downwash is reduced, and drag becomes excessive. The force of gravity exerts itself and the nose of the aircraft drops. Thus, we see that the burble point is the *stalling angle*.

The distribution of the pressure forces over the airfoil varies with the angle of attack. The application of the *resultant force*, the center of pressure, varies correspondingly. As this angle increases, the center of pressure moves forward. As the angle decreases, the center of pressure moves back. The instability of the center of pressure is characteristic of most airfoils.

Boundary layer and stall. The ideal situation would be for the air to flow over the airfoil smoothly in layers. This does not occur for two reasons: the air is *viscous* and the airfoil is not perfectly smooth.

Because air is viscous, it has a tendency to stick to the airfoil surface. Because the airfoil is not

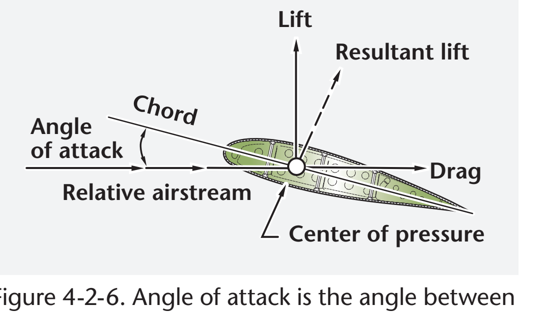


Figure 4-2-6. Angle of attack is the angle between the relative wind and the chordline of the airfoil.

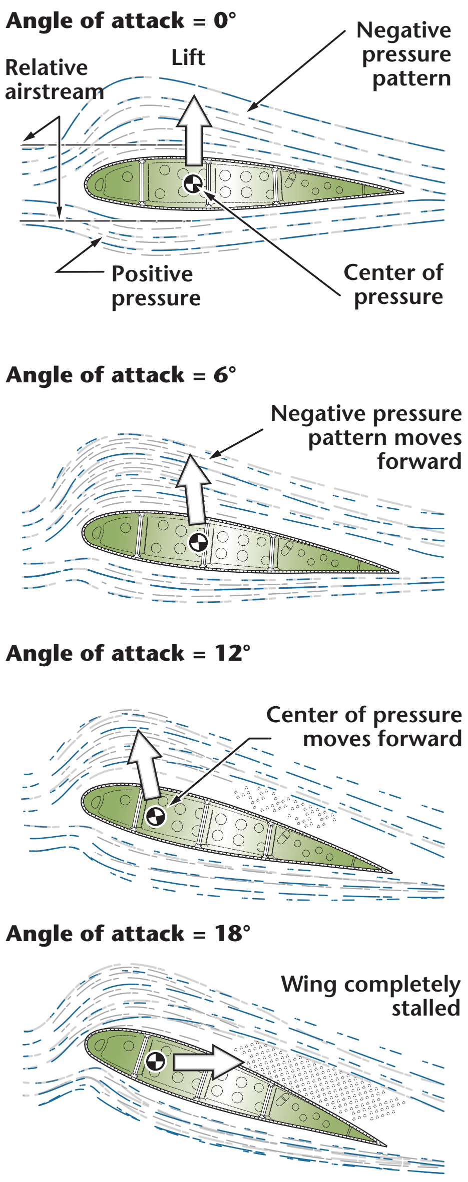


Figure 4-2-7. Angle of attack is extremely important to the safe operation of the aircraft.

perfectly smooth, turbulence is created where the surface is rough. These two factors result in what is referred to as the *boundary layer.*

In the design of a wing, it is desirable to keep this boundary layer as thin as possible. As the boundary layer becomes thicker, more turbulence is created. This turbulence will lead to stall. Under normal circumstances, the boundary layer becomes thicker when the angle of attack is increased. The airflow will eventually break away, and stall will occur. This is why the surface of the airfoil should remain as smooth as possible.

Downwash. For many years, lift was explained using just the Bernoulli principle. Indeed, many textbooks still rely solely on it. What is ignored is the effect of the downwash coming

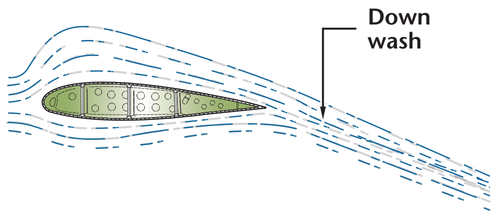


Figure 4-2-8. The downwash is an example of Newton's third law.

off the trailing edge of the surface. Created by the airflow around an airfoil, the downwash is a classic example of Newton's third law. Many aerodynamicists now believe that the actual lift is created by the downwash, and the airflow around an airfoil is for the purpose of creating the downwash (Figure 4-2-8).

Obviously, designers must adhere closely to the Bernoulli principle, because any disruption of airflow causes a change in both the lift of the airfoil and the reaction of the downwash. Careful observation of a modern, high-performance airplane, like a jet fighter, shows that all efforts have been made to preserve both principles.

Section 3

Thrust and Drag

An aircraft in flight is the center of a continuous battle of forces. Actually, this conflict is not as violent as it sounds, but it is the key to all maneuvers performed in the air. There is nothing mysterious about these forces; they are definite and known. The directions in which they act can be calculated, and the aircraft itself is designed to take advantage of each of them. In all types of flying, flight calculations are based on the magnitude and direction of four forces: weight, lift, drag, and thrust (Figure 4-3-1).

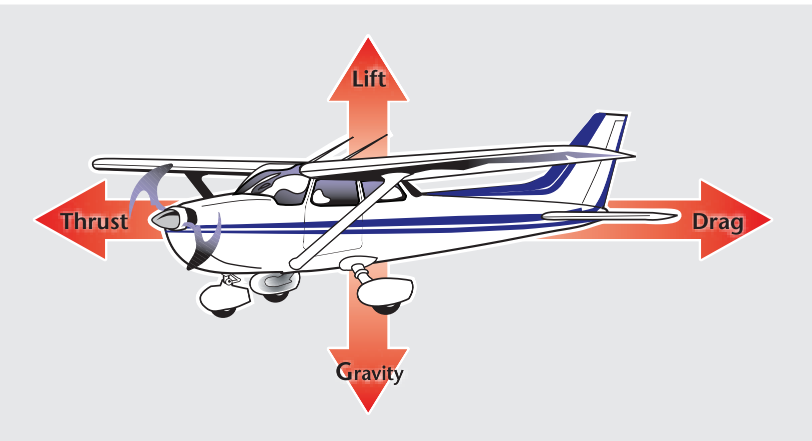


Figure 4-3-1. The four forces of flight in action.

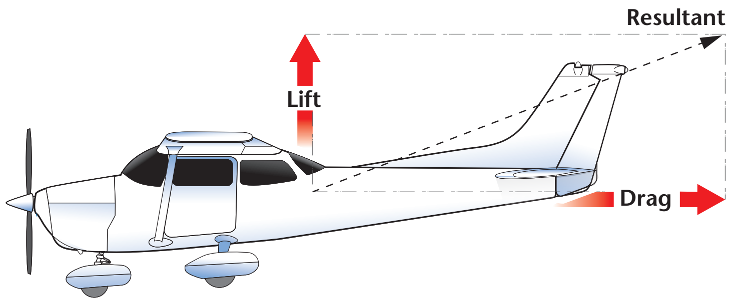


Figure 4-3-2. The resultant of lift and drag.

Weight is the force of gravity acting downward upon everything that goes into the aircraft, such as the aircraft itself, the crew, the fuel, and the cargo.

Lift acts vertically and by so doing counteracts the effects of weight.

Drag is a backward deterrent force and is caused by the disruption of the airflow by the wings, fuselage, and protruding objects.

Thrust produced by the powerplant is the forward force that overcomes the force of drag.

Notice that these four forces are only in perfect balance when the aircraft is in straight and level unaccelerated flight.

The force of lift and drag are the direct result of the relationship between the relative wind and the aircraft. *The force of lift always acts perpendicular to the relative wind, and the force of drag always acts parallel to the relative wind and in the same direction.* These forces are actually the components that produced a resultant lift force on the wing, as shown in Figure 4-3-2.

Weight has a definite relationship with lift, as has thrust with drag. This relationship is quite simple, but very important in understanding the aerodynamics of flying. Remember that lift is the upward force on the wing acting perpendicular to the relative wind. Lift is required to counteract the aircraft's weight, caused by the force of gravity acting on the mass of the aircraft. This weight force acts downward through a point called the *center of gravity*; the point at which all the weight of the aircraft is considered to be concentrated. When the lift force is in equilibrium with the weight force, the aircraft neither gains nor loses altitude.

If lift becomes less than weight, the aircraft loses altitude. When the lift is greater than weight, the aircraft gains altitude.

Drag must be overcome in order for the aircraft to move, and movement is essential to obtain lift. To overcome the drag and move the aircraft forward, another force is essential. This force is thrust. Thrust is derived from jet propulsion or from a propeller-and-engine combination. Jet propulsion theory is based on Newton's third law of motion, which states, "*for every action there is an equal and opposite reaction*." For example, in firing a gun, the action is the bullet going forward, while the reaction is the gun recoiling backward. The turbine engine causes a mass of air to be moved backward at high velocity, resulting in a forward reaction that moves the aircraft.

In a propeller/engine combination, the propeller is actually two or more revolving airfoils mounted on a horizontal shaft. The motion of the blades through the air produces lift and downwash similar to a wing, but it acts in a horizontal direction, pulling the aircraft forward.

We have seen that increasing the lift means that the aircraft moves upward, whereas decreasing the lift so it is less than the weight causes the aircraft to lose altitude. A similar rule applies to the two forces of thrust and drag. If the r.p.m. of the engine is reduced, the thrust is lessened, and the aircraft slows down. As long as the thrust is less than the drag, the aircraft travels more and more slowly until its speed is insufficient to support it in the air.

Likewise, if the r.p.m. of the engine is increased, thrust becomes greater than drag, and the speed of the aircraft increases. As long as the thrust continues to be greater than the drag, the aircraft continues to accelerate. When drag equals thrust, the aircraft flies at a steady speed.

To make things a bit more complicated, an airplane has a design cruising speed. Design cruising speed is where a specific power setting produces a speed where all forces are equal and the airplane flies at a steady speed and altitude. Trimmed for level flight and left to its own devices, this is where the airplane wants to fly.

Increased thrust means more speed, which equals greater airflow over the wings, which in turn equals more lift. With lift becoming greater, the aircraft will increase in altitude. It will continue to increase in altitude until the excess engine power is used up and all the forces reach a balance again. With the forces in balance, the airplane will now resume its design cruising speed at the new altitude. The opposite is true for a reduction in power. The speed will decrease and drag will now be greater than lift. The nose of the airplane will drop and the airplane will descend. Descent will result in an increase in speed. Once the increase in speed produces enough lift to balance the forces again, the design cruise speed will resume.

The pilot can change the results somewhat by manipulating the controls. When the airplane starts to descend, he can raise the nose somewhat to counteract the decent. The result will be a slower speed at the same altitude. The reverse is also true. To increase speed, the pilot adds power, the airplane tries to climb, and the pilot must lower the nose to maintain the same altitude at a higher speed.

Unlike an automobile, where more power means more speed, airplanes behave differently. In an airplane, *power controls altitude and pitch controls speed*. Step on the gas and you go up; let off the gas and you go down. Pull the nose up and you go slower; push the nose down and you go faster.

The relative motion of the air over an object that produces lift also produces drag. Drag is the resistance of the air to objects moving through it. If an aircraft is flying in level flight, the lift force acts vertically to support it while the drag force acts horizontally to hold it back. The total amount of drag on an aircraft is made up of many drag forces, but for our purposes, we will only consider three:

- Parasite drag
- Profile drag
- Induced drag

Parasite drag is made up of a combination of many different drag forces. Any exposed object on an aircraft offers some resistance to the air, and the more objects in the airstream, the more parasite drag. While parasite drag can be minimized by reducing the number of exposed parts and streamlining their shape, *skin friction* is the type of parasite drag most difficult to reduce. No surface is perfectly smooth. Even machined surfaces when inspected under magnification have a ragged, uneven appearance. These ragged surfaces deflect the air near the surface causing resistance to smooth airflow. Skin friction can be reduced by using glossy, smooth finishes and eliminating protruding rivet heads, roughness, and other irregularities.

Profile drag may be considered the parasite drag of the airfoil itself. The various components of parasite drag are all of the same nature as profile drag.

The action of the airfoil that gives us lift also causes *induced drag*. Remember that the pressure above the wing is less than atmospheric, and the pressure below the wing is equal to or greater than atmospheric pressure. Since fluids always move from high pressure toward low pressure, there is a spanwise movement of air from the bottom of the wing outward from the fuselage and upward around the wing tip. This flow of air results in *spillage* up and over the wing tip. The spilled air is then pulled downward into the low-pressure air flowing above the wing. This sets up a whirlpool of disturbed air called a *vortex* (Figure 4-3-3). When viewed from the rear of the airplane, a tip vortex spirals clockwise off the left tip and counterclockwise off the right tip. The spiraling air contains a large amount of energy and can be a danger to other airplanes flying too close behind.

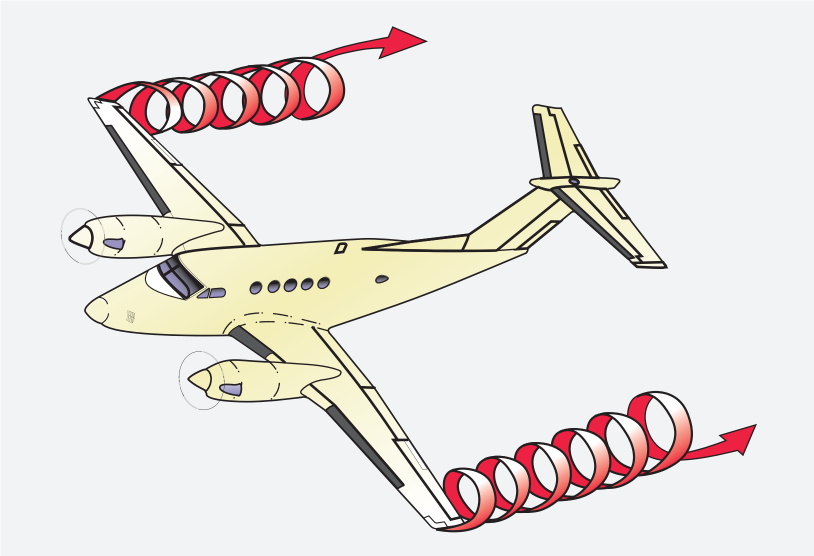


Figure 4-3-3. Wing tip vortices grow larger the further away from the airplane they progress.

The air on the upper surface has a tendency to move in toward the fuselage and off the trailing edge. This air current forms a similar vortex at the inner portion of the trailing edge of the wing. Inner vortex control is the prime reason for wing fillets and fairings. Control of the inner vortex reduces drag and reduces interference with the tail surfaces. These vortices increase drag because of the turbulence produced and constitute-induced drag. Additionally, a wing tip vortex has a major effect on the downwash pattern. Any disruption caused to the downwash also constitutes a reduction in lift or an increase in induced drag.

Section 4

Aircraft Stability

Center of gravity. Gravity is the pulling force that draws all things toward the center of the earth. The center of gravity may be considered as a point at which all the weight of the aircraft is concentrated. If the aircraft were supported at its exact center of gravity, it would balance in any position. Center of gravity is of major importance in an aircraft, for its position has a great bearing upon *stability*.

The center of gravity is determined by the general design of the aircraft. The designer

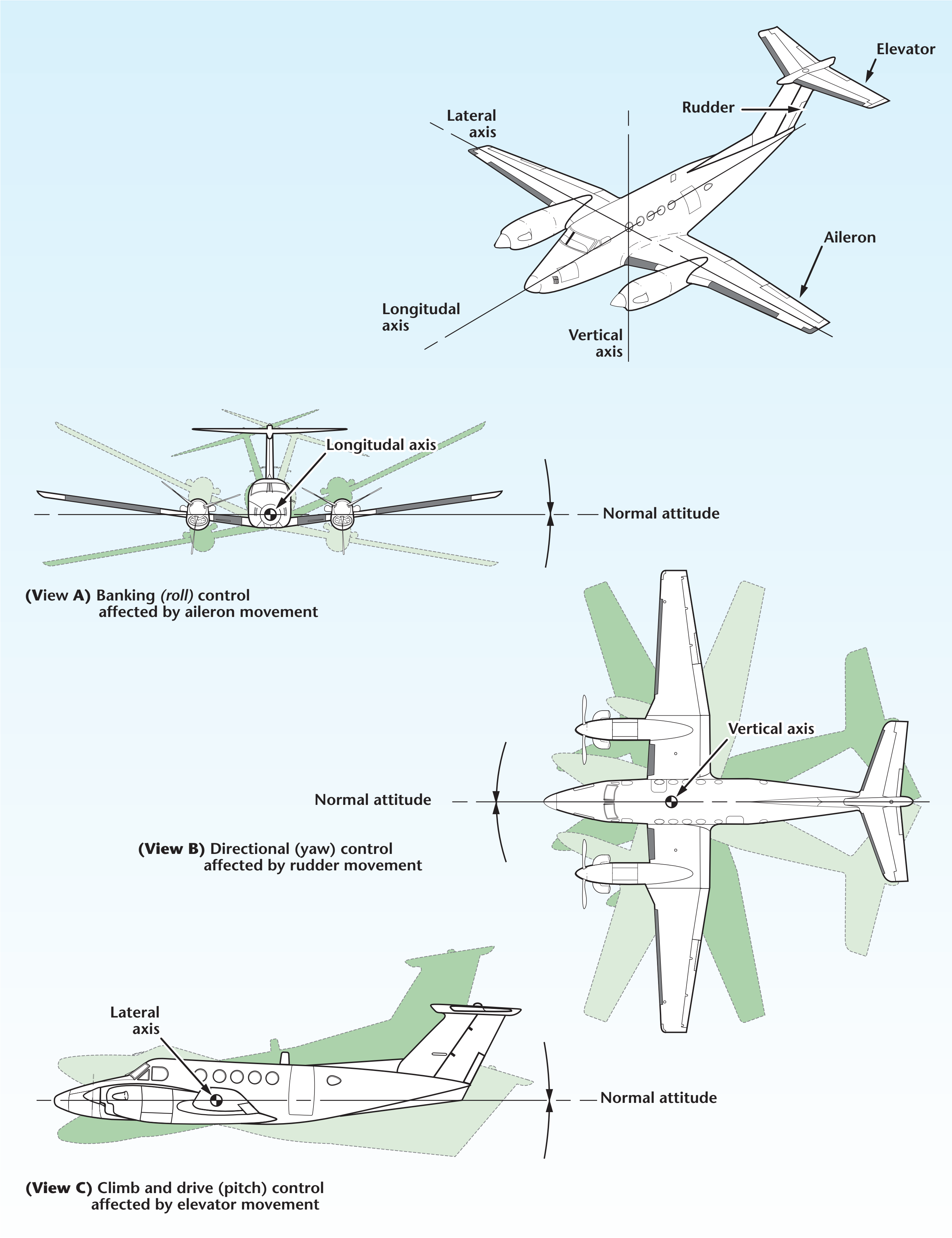


Figure 4-4-1. Motion of an aircraft around its axes.

estimates how far the *center of pressure* will travel. He then fixes the center of gravity in front of the center of pressure for the corresponding design cruise speed in order to provide an adequate *restoring moment* for flight equilibrium.

Axes of an aircraft. Whenever an aircraft changes its attitude in flight, it must turn from one or more of three *axes*. Figure 4-4-1 shows the three axes, which are imaginary lines passing through the center of the aircraft. The axes of an aircraft can be considered as imaginary axles around which the aircraft turns like a wheel. At the center, where all three axes intersect, each is perpendicular to the other two. The *axis* that extends lengthwise through the fuselage from the nose to the tail is called the *longitudinal axis*. The axis that extends crosswise, from wing tip to wing tip, is the *lateral axis*. The axis that passes through the center, from top to bottom, is called the *vertical axis*.

Motion around the longitudinal axis resembles the roll of a ship from side to side. In fact, the names used in describing the motion about an aircraft's three axes were originally nautical terms. They have been adapted to aeronautical terminology because of the similarity of motion between an aircraft and a ship.

The motion around the longitudinal axis is called *roll*; motion around the lateral (crosswing) axis is called *pitch*. Finally, an aircraft moves around its vertical axis in a motion termed *yaw*. This is a horizontal movement of the nose of the aircraft.

Roll, pitch, and yaw, the motions an aircraft makes around its longitudinal, lateral, and vertical axes, are controlled by three control surfaces. Roll is produced by the *ailerons*, which are located at the trailing edges of the wings. Pitch is affected by the *elevators*, the rear portion of the horizontal tail assembly. Yaw is controlled by the *rudder*, the rear portion of the vertical tail assembly.

Stability and control. An aircraft must have sufficient stability to maintain a uniform flight path and recover from the various upsetting forces. Also, to achieve the best performance, the aircraft must have the proper response to the movement of the controls.

Three terms that appear in any discussion of stability and control are:

- Stability
- Maneuverability
- Controllability

Stability is the characteristic of an aircraft that causes it to fly (hands off) in a straight and level flight path. *Maneuverability* is the ability of an aircraft to be directed along a desired flight path and to withstand the stresses imposed. *Controllability* is the quality of the response of an aircraft to the pilot's commands while maneuvering the aircraft.

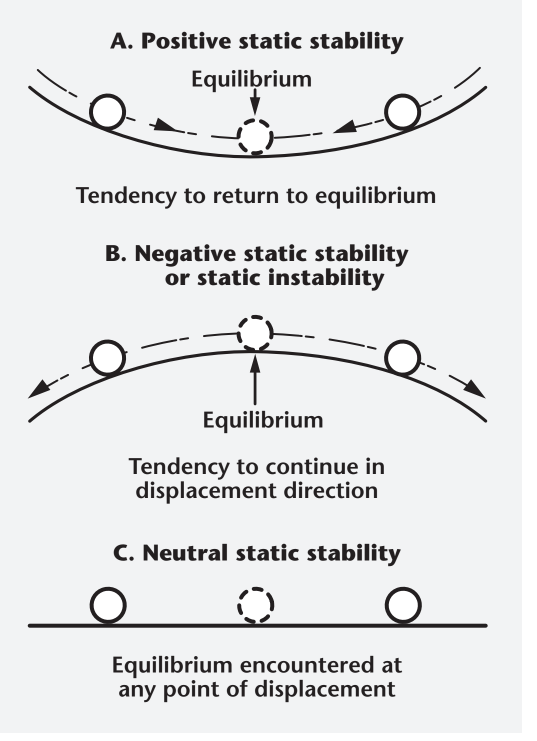


Figure 4-4-2. This illustration shows the three types of stability: positive, negative, and static.

Stability. An aircraft is in a state of equilibrium when the sum of all the forces acting upon the aircraft and all the moments are equal to zero. (A *moment* is equal to the weight multiplied by the distance from the pivot point or center of gravity.) An aircraft in equilibrium experiences no accelerations, and the aircraft continues in a steady flight. A gust of wind or a deflection of the controls disturbs the equilibrium, and the aircraft experiences acceleration due to the unbalance of moment or force.

The three types of *static stability* are defined by the character of the movements following some disturbance from equilibrium. *Positive static stability* exists when the disturbed object tends to return to equilibrium. *Negative static stability* or *static instability* exists when the disturbed object tends to continue in the direction of disturbance. *Neutral static stability* exists when the disturbed object has neither the tendency to return nor continue in the displacement direction, but remains in equilibrium in the direction of disturbance. These three types of stability are illustrated in Figure 4-4-2.

Dynamic stability. While static stability deals with the tendency of a displaced body to return to equilibrium, *dynamic stability* deals with the resulting motion with time. If an object is disturbed from equilibrium, the time history of the

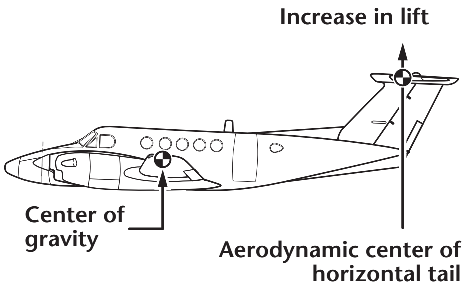


Figure 4-4-3. The majority of horizontal tail surfaces are designed to produce lift.

resulting motion defines the dynamic stability of the object. In general, an object demonstrates positive dynamic stability if the amplitude of motion decreases with time. If the amplitude of motion increases with time, the object is said to possess dynamic instability.

Any aircraft must demonstrate the required degrees of static and dynamic stability. If an aircraft were designed with static instability and a rapid rate of dynamic instability, the aircraft would be very difficult, if not impossible, to fly. Usually, positive dynamic stability is required in an aircraft design to prevent objectionable continued oscillations.

Longitudinal stability. When an aircraft has a tendency to keep a constant angle of attack with reference to the relative wind, that is, when it does not put its nose down and dive or lift its nose and stall, it is said to have *longitudinal stability*. Longitudinal stability refers to motion in pitch. The *horizontal stabilizer* is the primary surface that controls longitudinal stability. The action of the stabilizer depends upon the speed and angle of attack of the aircraft. Figure 4-4-3 illustrates the contribution of tail lift to stability. If the aircraft changes its angle of attack, a change in lift takes place at the aerodynamic center (center of pressure) of the horizontal stabilizer.

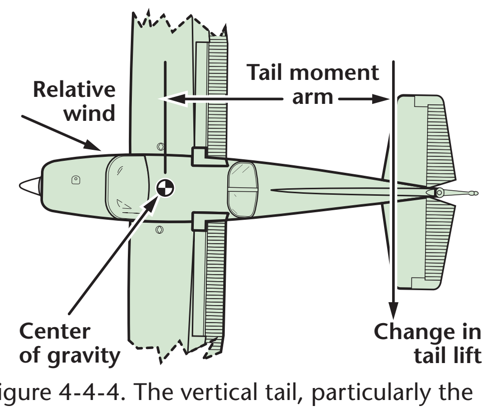


Figure 4-4-4. The vertical tail, particularly the fin portion, is a major contributor to directional stability.

Under certain conditions of speed, load, and angle of attack, the flow of air over the horizontal stabilizer creates a force that pushes the tail up or down. When conditions are such that the airflow creates equal forces up and down, the forces are said to be in equilibrium. This condition is usually found in level flight in calm air.

Directional stability. Stability around the vertical axis is referred to as *directional stability*. The aircraft should be designed so that when it is in straight and level flight it remains on its course heading, even though the pilot takes his hands and feet off the controls. If an aircraft recovers automatically from a skid, it has been well designed and possesses good directional balance. The *vertical stabilizer* is the primary surface controlling directional stability.

As shown in Figure 4-4-4, when an aircraft is in a sideslip, or yawing, the vertical tail experiences a change in angle of attack with a resulting change in lift (not to be confused with the lift created by the wing). The change in lift, or side force, on the vertical tail creates a yawing moment about the center of gravity that tends to return the aircraft to its original flight path.

Sweepback wings aid in directional stability. If the aircraft yaws from its direction of flight, the wing which is farther ahead presents more leading edge surface to the apparent wind, offering more drag than the wing which is aft and presents less surface to the apparent wind. The effect of this drag is to hold back the wing that is farther ahead and to let the other wing catch up.

In subsonic flight, directional stability is also aided by using a large *dorsal fin* and a long fuselage.

The high Mach numbers of supersonic flight reduce the contribution of the vertical tail to directional stability. To produce the required directional stability at high Mach numbers, a very large vertical tail area may be necessary. *Ventral* (belly) fins may be added as an additional contribution to directional stability.

Lateral stability. We have seen that pitching is motion around the aircraft's lateral axis, and yawing is motion around its vertical axis. Motion around its longitudinal (fore and aft) axis is a lateral, or rolling, motion. The tendency to return to the original attitude from such motion is called *lateral stability*.

The lateral stability of an airplane involves consideration of rolling moments due to *sideslip*. A sideslip tends to produce both a rolling and a yawing motion. If an airplane has a favorable rolling moment, a sideslip will tend to return the airplane to a level flight attitude.

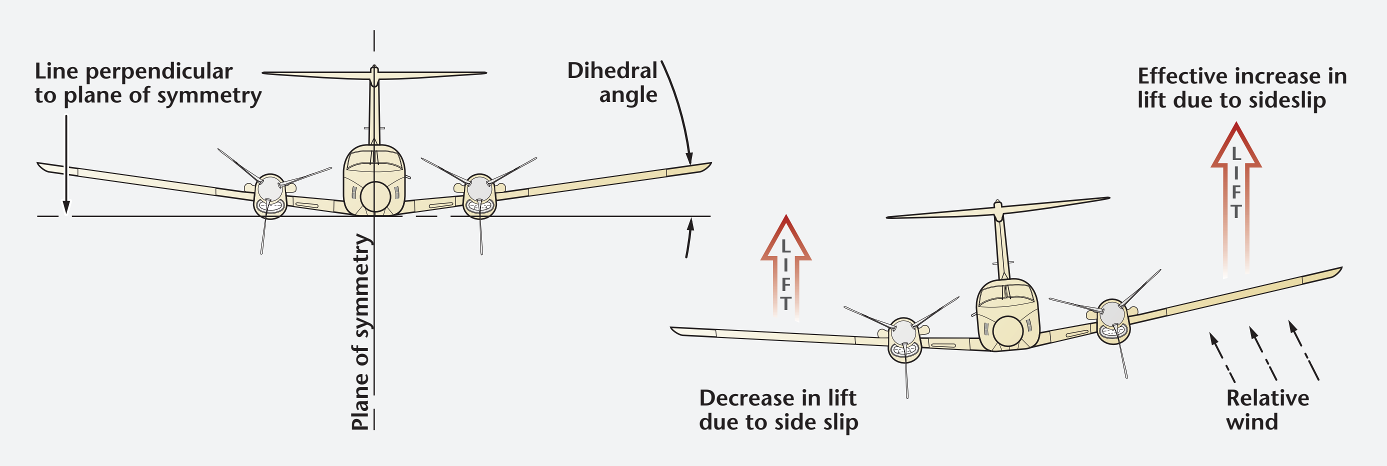


Figure 4-4-5. Dihedral is a major contributor to lateral stability. It helps an airplane hold its course without constant control.

The principal surface contributing to the lateral stability of an airplane is the wing. The effect of the *geometric dihedral* of a wing is a powerful contribution to lateral stability. As shown in Figure 4-4-5, a wing with dihedral develops stable rolling moments with sideslip. With the relative wind from the side, the wing into the wind is subject to an increase in angle of attack and develops an increase in lift. The wing away from the wind is subject to a decrease in angle of attack and develops less lift. The changes in lift effect a rolling moment tending to raise the windward wing.

When a wing is swept back, the effective dihedral increases rapidly with a change in the lift coefficient of the wing. *Sweepback* is the angle between a line perpendicular to the fuselage centerline and the quarter chord of each wing airfoil section. Sweepback in combination with dihedral causes the dihedral effect to be excessive. As shown in Figure 4-4-6, the swept-wing aircraft in a sideslip has the wing that is into the wind operating with an effective decrease in sweepback, while the wing out of the wind is operating with an effective increase in sweepback. The wing into the wind develops more lift, and the wing out of the wind develops less. This tends to restore the aircraft to a level flight attitude.

Dutch roll. The amount of effective dihedral necessary to produce satisfactory flying qualities varies greatly with the type and purpose of the aircraft. Generally, the effective dihedral is kept low, since high roll due to sideslip can create problems. Excessive dihedral effect can lead to *Dutch roll*, a yaw and roll combination that makes rudder coordination more difficult in rolling maneuvers, or place extreme demands for lateral control of power during crosswind takeoff and landing. Transport and larger executive aircraft provide an automatic control system for the rudder, called a *yaw damper*, to reduce this tendency. Dutch roll can be a very unpleasant experience for passengers (Figure 4-4-7). Yaw damper systems are designed to correct for Dutch roll.

Section 5

Aircraft Control

Control is the action taken to make the aircraft follow any desired flight path. When an aircraft is said to be controllable, it means that the craft responds easily and promptly to movement of the controls. Different control surfaces are used to control the aircraft about each of the three axes. Moving the control surfaces on an aircraft changes the airflow over the aircraft's surface. This, in turn, creates changes in the balance of forces acting to keep the aircraft flying straight and level.

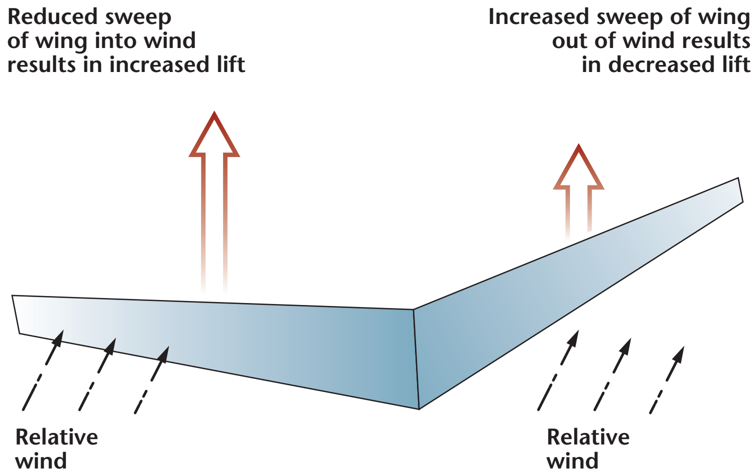


Figure 4-4-6. Sweepback is also important to lateral stability. It helps maintain a heading.

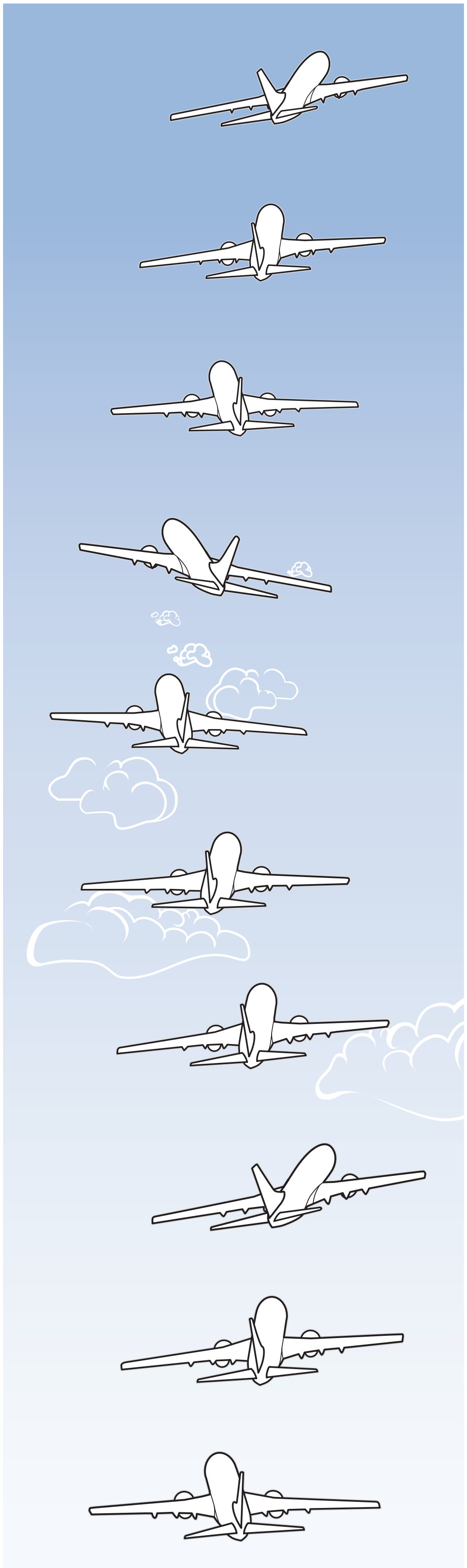


Figure 4-4-7. Dutch Roll is a lateral oscillation with both rolling and yawing components at the same time.

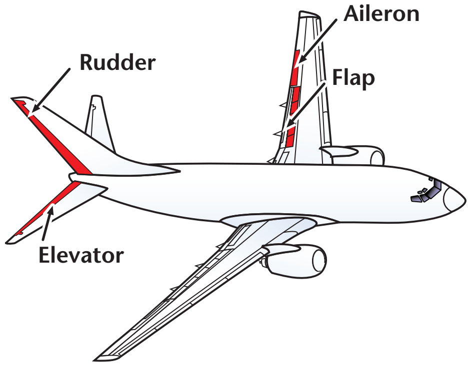


Figure 4-5-1. Primary flight controls on a conventional airplane.

Flight control surfaces. The flight control surfaces are hinged or movable airfoils designed to change the attitude of the aircraft during flight.

The primary group includes the ailerons, elevators, and rudder (Figure 4-5-1). These surfaces are used for moving the aircraft around its three axes. The concepts of these three control systems and their interaction were developed by the Wright brothers. It is the prime reason they were successful in establishing powered flight and controllability.

Ailerons and elevators are operated from the cockpit by a wheel-and-yoke assembly. Rudders are operated by foot pedals.

Control around the longitudinal axis. The motion of the aircraft around the longitudinal axis is called *rolling* or *banking*. The ailerons (Figure 4-5-2) are used to control this movement. The ailerons form a part of the wing and are located in the trailing edge of the wing toward the tips. Ailerons are the movable surfaces of an otherwise fixed-surface wing. The aileron is in neutral position when it is streamlined with the trailing edge of the wing.

Ailerons respond to side pressure applied to the control wheel. Pressure applied to move the wheel toward the right raises the right aileron and lowers the left aileron, causing the aircraft to bank to the right. Ailerons are linked together by control cables so that when one aileron is down, the opposite aileron is up. The function of the lowered aileron is to increase the lift by increasing the wing camber, thereby raising the wing. The up aileron, on the opposite end of the wing, decreases lift on that end of the wing and subsequently lowers that wing. This causes the aircraft to roll around its longitudinal axis.

As a result of the increased lift on the wing with the lowered aileron, drag on that side is also increased. This drag attempts to pull the nose in the direction of the drag. Since the ailerons are

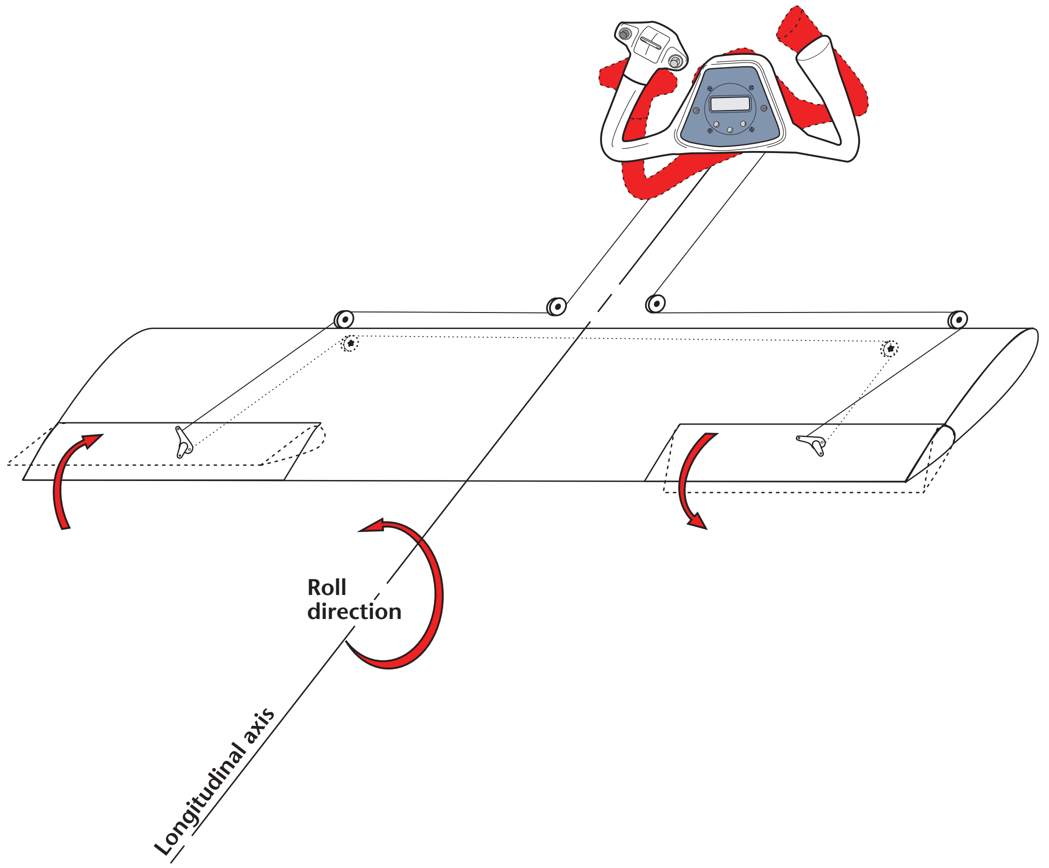


Figure 4-5-2. The aileron is the control surface that controls rolling or banking around the longitudinal axis.

used with the rudder when making turns, the increased drag tries to turn the aircraft in the direction opposite to that desired. To avoid this undesirable effect called adverse yaw, aircraft are designed with *differential travel* of the ailerons.

Differential aileron travel provides more aileron up travel than down travel for a given movement of the control wheel in the cockpit.

In modern transport aircraft, the action of the ailerons is supplemented by the use of *spoilers.*

The spoilers are plates hinged to the upper surface of the wing. They are usually deflected upward by hydraulic actuators in response to control-wheel movement in the cockpit. The purpose of the spoilers is to disturb the smooth airflow across the top of the airfoil, thereby creating an increased amount of drag and a decreased amount of lift on that airfoil.

Spoilers are used primarily for lateral control. When banking the airplane, the spoilers function with the ailerons. The spoilers on the up aileron side raise with that aileron to further decrease the lift on that wing. The spoiler on the opposite side remains in the faired position.

During lateral control at high speed, use of the ailerons would cause a large amount of bending pressure to be applied to the wing and excessive loads on the ailerons themselves. Therefore, the ailerons are automatically disconnected from the system at high speed. Lateral control is then by action of the spoilers only.

When the spoilers are used as a *speed brake*, they are all deflected upward simultaneously. A separate control is provided for operating the spoilers as speed brakes.

Control around the lateral axis. When the nose of an aircraft is raised or lowered, it is rotated around its lateral axis. Elevators are the movable control surfaces that cause this rotation (Figure 4-5-3). They are normally hinged to the trailing edge of the horizontal stabilizer.

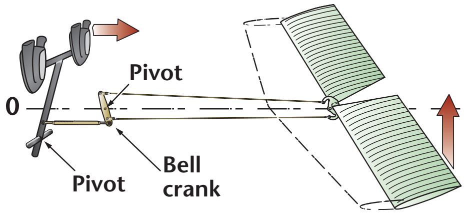


Figure 4-5-3. An up or down motion of the elevators causes the nose of the aircraft to move up or down in relation to the lateral axis.

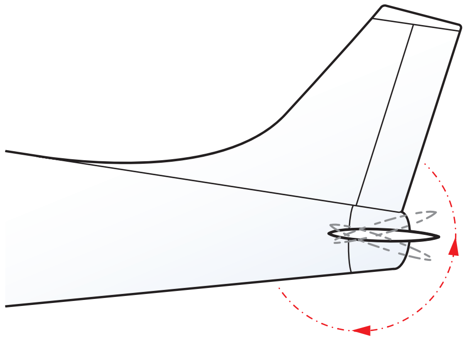


Figure 4-5-4. A stabilator acts as a horizontal stabilizer-and-elevator in one. Pivoting as a unit, the stabilator portion ahead of the pivot point serves as an aerodynamic balance.

The elevators can be moved either up or down and are used to make the aircraft pitch nose up or nose down.

If the elevator is rotated up, it decreases the lift force on the tail, causing the tail to lower and the nose to rise. If the elevator is rotated downward, it increases the lift force on the tail, causing it to rise and the nose to lower. Lowering the aircraft's nose increases forward speed, and raising the nose decreases forward speed.

Some aircraft use a movable horizontal surface called a *stabilator* (Figure 4-5-4). The stabilator serves the same purpose as the horizontal stabilizer and elevator combined. When the cockpit control is moved, the complete stabilator is moved to raise or lower the leading edge, thus changing the angle of attack and the amount of lift on the tail surfaces.

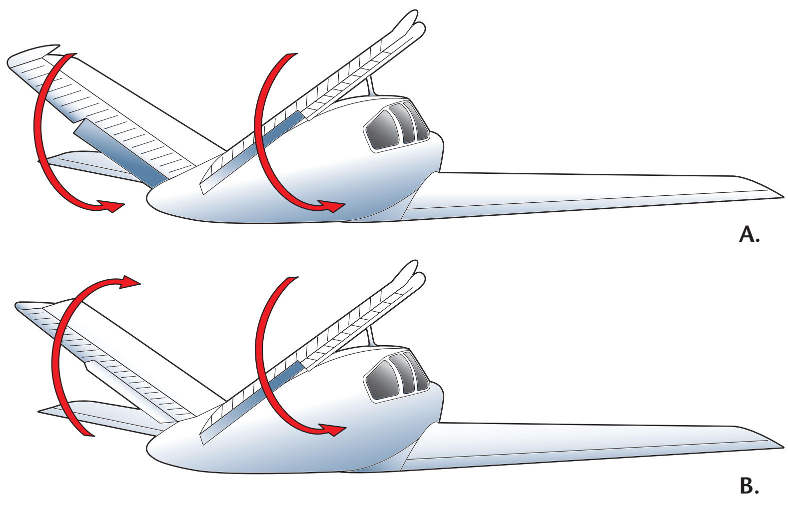


Figure 4-5-5. The vee-tail configuration was first popularized by the Beechcraft Bonanza. In this configuration the controls are called ruddervators. They combine the elevator and rudder inputs.

Control around the vertical axis. Turning the nose of the aircraft causes the aircraft to rotate around its vertical axis. Rotation of the aircraft around the vertical axis is called *yawing*. This motion is controlled by using the rudder, as illustrated in Figure 4-4-1B.

The rudder is a movable control surface attached to the trailing edge of the vertical stabilizer. The main function of the rudder is to turn the nose of the aircraft in flight. A turn is maintained by the side pressure of the air moving past the vertical surfaces. To turn the aircraft to the right, the rudder is moved to the right. The rudder protrudes into the airstream, causing a force to act upon it. This is the force necessary to give a turning movement around the center of gravity, which turns the aircraft to the right. If the rudder is moved to the left, it induces a counterclockwise rotation and the aircraft similarly turns to the left. Rudder-only turns produce a skidding turn that is not very effective. To be effective, a turn must be a coordinated effort involving the rudder, ailerons, and the elevator.

To make a coordinated turn, first the pilot applies a little rudder to get the nose swinging, then establishes a bank with the ailerons. The nose will start swinging in the desired direction, but the airplane still needs some help to make a good turn. Because of the lift lost by banking, the nose will start to drop a bit, which is corrected by a little up-elevator pressure. At the same time, the rudder pressure is relaxed, and the airplane starts making a coordinated turn. Rudder is then used to keep the nose of the airplane on the horizon so the turn can be made without losing altitude. To roll out of the turn requires the exact opposite control movements, in reverse order.

Making smooth coordinated turns takes a bit of practice. Some airplanes even have a control interconnect between the rudder and the ailerons in an attempt to help the pilot make coordinated turns. When an aircraft begins to slip or skid, rudder pressure is applied to keep the aircraft balanced or headed in the desired direction.

Slip, or *side-slipping*, refers to any motion of the aircraft to the side and downward toward the inside of a turn. *Skid*, or *skidding*, refers to any movement upward and outward away from the center of a turn.

Vee tails. Aircraft *empennages*, or tail sections, that combine the vertical and horizontal stabilizers have been designed. Such empennages have the stabilizers set at an angle, as shown in

Figure 4-5-6. This Beechcraft Bonanza is one example of a vee-tailed aircraft.

Figure 4-5-5. This arrangement is referred to as a butterfly-, or *vee-, tail*. The Bonanza in Figure 4-5-6 is an illustration of a modern vee-tailed aircraft.

The control surfaces are hinged to the stabilizers at the trailing edges. The stabilizing portion of this arrangement is called a stabilator, and the control portion is called the *ruddervator*. The ruddervators can be operated both up or both down at the same time.

When used in synchronization in this manner, as shown in Figure 4-5-5A, the result is the same as with any other type of elevator. This action is controlled by the control column.

The ruddervators can be made to move opposite each other by pushing the left or right rudder pedal. If the right rudder pedal is pushed, the right ruddervator moves down and the left ruddervator moves up. As seen in illustration B of Figure 4-5-5, this produces turning moments to move the nose of the aircraft to the right.

The newer vee-tailed military aircraft are frequently fly-by-wire control systems, therefore controlled by computer. The older civil aircraft use a mechanical mixer box to combine different inputs. Without the mixer, a pilot couldn't apply elevator and rudder at the same time.

Section 6

Transport Aircraft Control Surfaces

On most light aircraft, the longitudinal control is accomplished by the *elevator system*. This system uses a fixed horizontal stabilizer with a moveable elevator hinged to the rear of the stabilizer. In most instances, the elevator is equipped with a moveable trim tab so that minor corrections in the pitch of the aircraft can be made. This enables the pilot to fly without having to hold fore or aft pressure on the control column; in essence, *hands off*.

A typical light aircraft elevator control system is shown in Figure 4-5-3. This system is strictly a mechanical system, using cables and bellcranks to transfer motion. An airplane featuring a *canard* system would work in the same manner, only the canard would be in the front and travel in the opposite direction.

Two control columns are present in such a system. The fore and aft movement of the column moves the elevator. The two columns move in unison to move a bellcrank in the lower section of the floor. This bellcrank has a cable attached to the top and bottom of the arm. These, in turn, lead to a second bellcrank in the empennage of the aircraft.

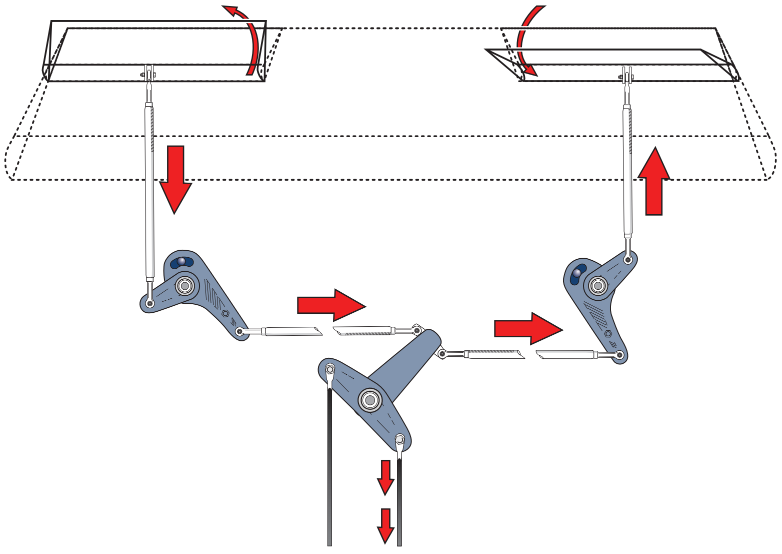


Figure 4-6-1. Aileron systems are connected in a closed loop system. Each wing bellcrank is connected to its opposite side by linkage.

The second bellcrank attaches to a push-pull tube and horn that attaches to the elevator. When the elevator down-cable is pulled, the bottom of the bellcrank moves forward. This causes the push-pull tube to pull the elevator down. This operation is reversed when the up-cable is pulled.

Lateral and directional controls. As we already discussed, the ailerons control bank and the rudder controls direction. In order to turn the aircraft, a coordinated turn requires both aileron and rudder. Figure 4-6-1 is a view of a typical light aircraft aileron system.

The aileron system connects the control column to the two ailerons. This, again, is accomplished with the use of a *cable*, *bellcranks*, and *push-pull tubes*.

The movement of the control wheel is a rotating movement for the ailerons. This is accomplished by a chain-and-sprocket arrangement behind the instrument panel. The chain is attached to a cable that rotates a bellcrank. This bellcrank changes the rotary motion to linear motion. Cables go out each side from the bellcrank to the aileron bellcranks. Running between the two bellcranks is an additional cable that is often referred to as the *balance cable*. This completes the closed loop and ensures that one aileron movement is transferred to the other aileron. Attached to the wing bellcrank is a push-pull tube that connects to a fitting near the leading edge of the aileron.

The rudder system is quite simple, as shown in Figure 4-6-2. This system operates the rudder pedals by pushing with the foot. A *torque tube* attached at the base of the pedals transfers the pedal motion to pull on the cables, which in turn are attached to horns on the base of the rudder. As the pedals are depressed left or right, the rudder is deflected in the same direction.

The rudder pedals are often connected to the nose gear for steering on light aircraft, which may be a either rigid connection or spring connection. Even in advanced aircraft that use hydraulic or electrical control actuators instead of control cables, the same basic process applies.

Tabs. Even though an aircraft has inherent stability, it does not always tend to fly straight and level. The weight of the load and its distribution affect stability. Various speeds also

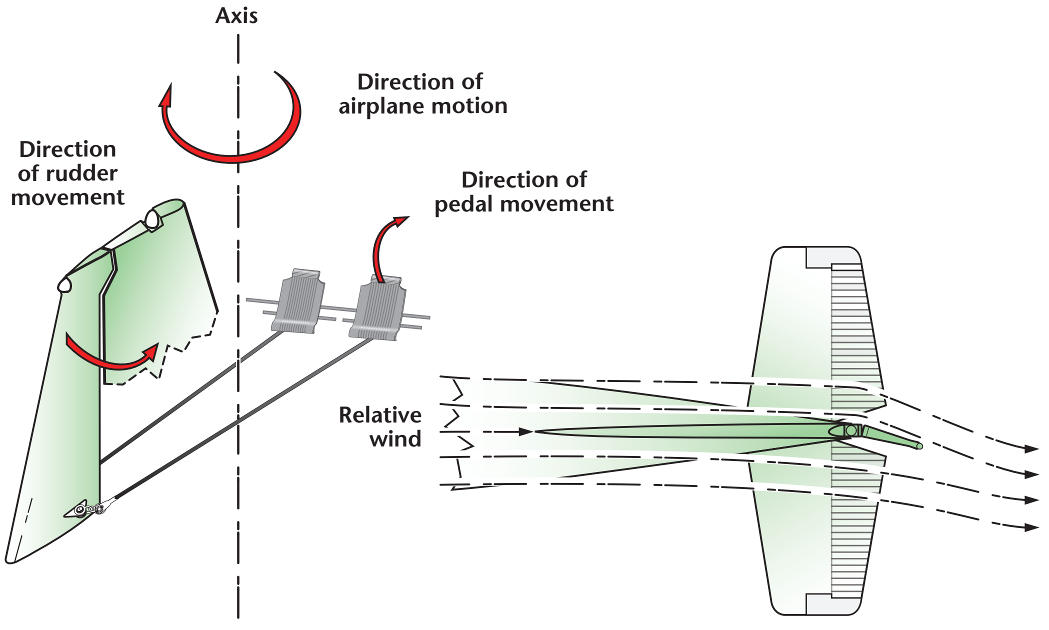


Figure 4-6-2. Moving the nose/tail left or right, yawing, is controlled by the rudder.

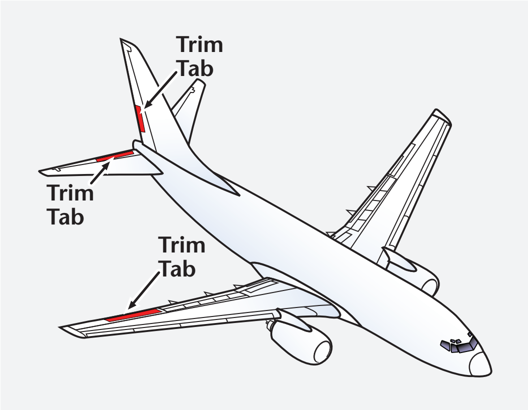


Figure 4-6-3. Trim tabs.

affect its flight characteristics. If the fuel in one wing tank is used before that in the other wing tank, the aircraft tends to roll toward the full tank. All of these variations require constant exertion of pressure on the controls for correction. While climbing or descending, it is necessary to apply pressure on the controls to keep the aircraft in the desired attitude.

To offset the forces that tend to unbalance an aircraft in flight, ailerons, elevators, and rudders are provided with auxiliary controls known as *trim tabs*. These are small, hinged control surfaces (Figure 4-6-3) on the trailing edge of the primary control surfaces. Tabs can be moved up or down by means of a control or moved electrically from the cockpit. These tabs can be used to balance the forces on the controls so that the aircraft flies hands-off straight and level, or may be set so that the aircraft maintains either a climbing or descending attitude (Figure 4-6-4A).

Servo tabs. *Servo tabs* (Figure 4-6-4B) are very similar in operation and appearance to the trim tabs just discussed. Servo tabs, sometimes referred to as flight tabs, are used primarily on the large main control surfaces. They aid in moving the control surface and holding it in the desired position. Only the servo tab moves in response to movement of the cockpit control. (The servo tab horn is free to pivot to the main control surface hinge axis.) The force of the airflow on the servo tab then moves the primary control surface. With the use of a servo tab, less force is needed to move the main control surface.

Balance tabs. A *balance tab*, also called a leading tab, is shown in Figure 4-6-4C. The linkage is designed in such a way that when the main control surface is moved, the tab moves in the opposite direction. Thus, aerodynamic forces acting on the tab assists in moving the main control surface.

Spring tabs. *Spring tabs* (Figure 4-6-4D) are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used

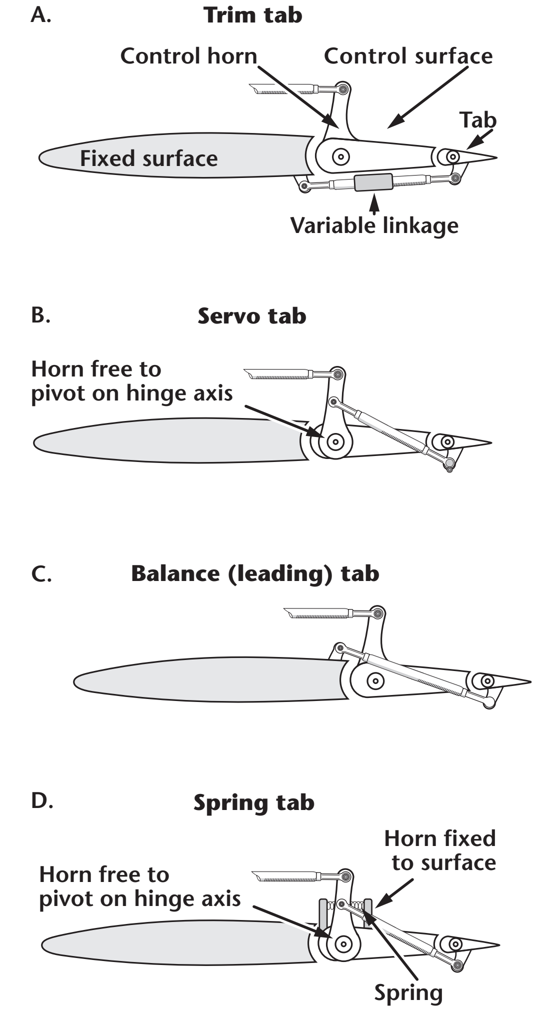


Figure 4-6-4. Trim and control tabs can come in a bewildering array of types and operating principles. Almost all use air pressure exerted by the slipstream to help move the surface.

for the same purpose as hydraulic actuators: that is, to aid in moving a primary control surface. There are various spring arrangements used in the linkage of the spring tab.

On some aircraft, a spring tab is hinged to the trailing edge of each aileron and is actuated by a spring-loaded push-pull rod assembly that is also linked to the aileron control linkage. The linkage is connected in such a way that movement of the aileron in one direction causes the spring tab to be deflected in the opposite direction. This provides a balanced condition, thus reducing the amount of force required to move the ailerons.

Anti–servo tabs. The anti–servo tab is used on stabilators to help dampen out a tendency for the surface to move abruptly in the direction of deflection. The abrupt movement occurs when the nose of the stabilator is moved out of the airstream by the pilot and is forced to continue in the direction of the movement by the action of the air pushing against the front of the control

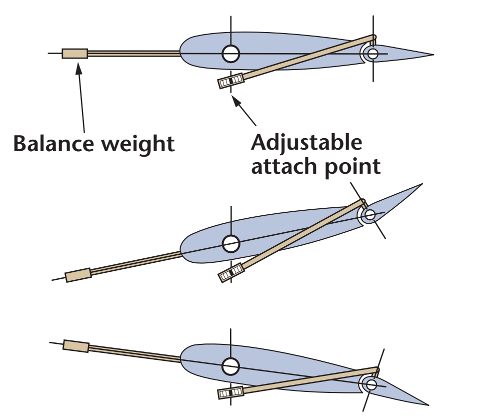


Figure 4-6-5. Anti-servo tab on an all-movable tail surface.

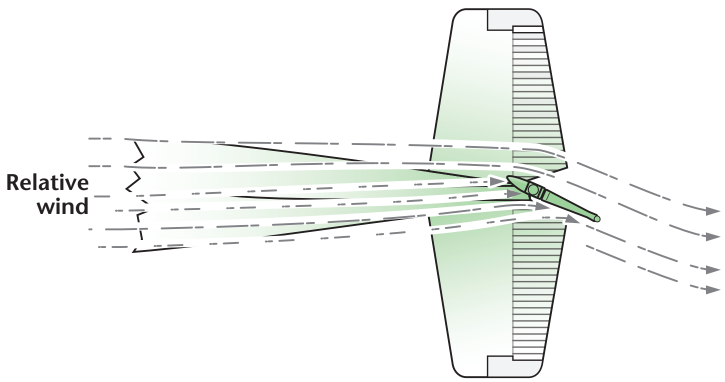


Figure 4-6-6. In many aerodynamic balances, additional weight is used to also create a static balance. If repairs or refinishing disturbs the static balance, the surface will have to be rebalanced.

surface. The anti-servo tab moves up when the nose of the control moves down and acts to dampen out the tendency of the stabilator to continue in the direction of the deflection. The anti-servo tab can also be used as a trim tab with a control in the cockpit and a drum and jackscrew mechanism (Figure 4-6-5).

Ground-adjustable tabs. Ground-adjustable trim tabs are adjusted on the ground before taking off. Their purpose is to compensate for minor differences between different airplanes and allow the airplane to be trimmed for hands-off at a specific speed (usually cruising). This will allow a full range of movement of the regular trim tabs to be available to the pilot to compensate for varying loads and conditions.

Control surface balance. To lessen the force required to operate the control surfaces, they are usually balanced statically and aerodynamically. *Aerodynamic balance* is usually achieved by extending a portion of the control surface ahead of the hinge line. This utilizes the airflow around the aircraft to aid in moving the surface. This method, applied to a rudder, is shown in Figure 4-6-6.

Static balance is accomplished by adding weight to the section forward of the hinge line until it weighs the same as the section aft of it. Some designs use a small aerodynamic balance to provide a longer arm, lessening the amount of weight needed to achieve balance. When repairing a control surface, use care to prevent upsetting or disturbing the static balance. An unbalanced surface has a tendency to flutter as air passes over it. Flutter increases the pressure on the surface attach points and control system. It is possible for a fluttering surface to depart the airplane, resulting in an accident. Should a repair or refinishing operation cause an imbalance to a surface, check the maintenance manual for the correct rebalancing procedure for the specific surface. NEVER allow a statically balanced control surface to be installed in an out of balance condition.

An *adjustable stabilizer* is used on some aircraft rather than using a tab for the elevator. This device generally uses the *jackscrew* and a hinge point, as shown in Figure 4-6-7, which can be raised or lowered by an electric motor running a jackscrew. Normally, a switch is used on the control column for its operation. On some aircraft, this is controlled by a manually operated trim wheel.

High-lift devices. High-lift devices are used in combination with airfoils in order to reduce the takeoff or landing speed by changing the lift characteristics of an airfoil during the landing or takeoff phases. When these devices are no longer needed, they are retracted to a position within the wing to regain the normal characteristics of the airfoil.

The most common high-lift device is known as a *flap*. It is a hinged surface on the trailing edge of the wing. It is controlled from the cockpit and, when not in use, fits smoothly into the lower surface of the wing. The use of flaps increases the camber of a wing and, therefore, the lift of the wing, making it possible for aircraft speed to be decreased without stalling. This also permits a steeper gliding angle to be obtained in the landing approach without increasing speed.

Flaps. Flaps are primarily used during takeoff and landing. As the two uses are opposite, each has their own settings. On a large airplane, if not enough flap is used for takeoff, the airplane will be short on lift. If the flaps are set in the landing range, there will be too much drag. A wrong flap setting will not allow the airplane to perform correctly.

The types of flaps in use on aircraft include:

- Plain
- Split
- Fowler
- Slotted

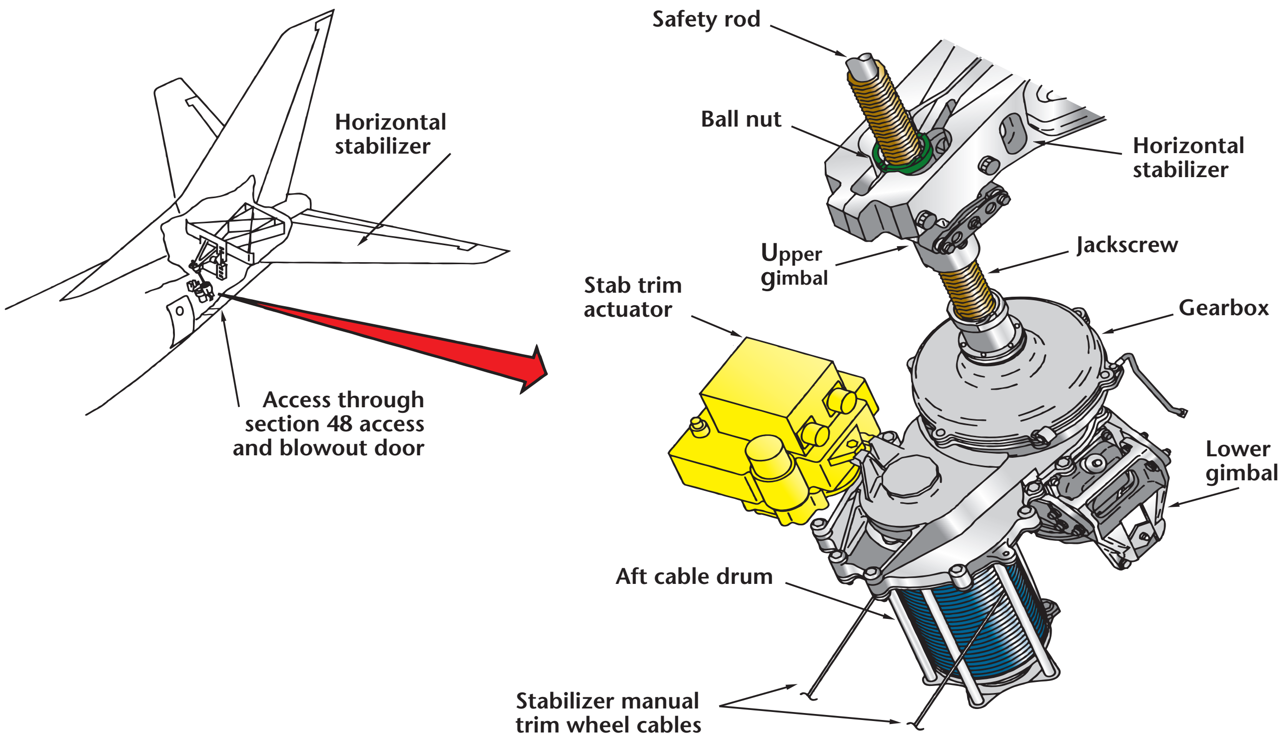


Figure 4-6-7. Many transport category airplanes use a jackscrew system to raise or lower the stabilizer. Most are hydraulic, operated by either cable or electrical inputs.

The *plain flap* (Figure 4-6-8A) is simply hinged to the wing and forms a part of the wing surface when raised.

The *split flap* (Figure 4-6-8B**)** gets its name from the hinge at the bottom part of the wing near the trailing edge, permitting it to be lowered from the fixed top surface.

The *Fowler flap* (Figure 4-6-8C) fits into the lower part of the wing, flush with the surface. In operation, it slides backward on tracks and tilts downward at the same time. In addition to increasing wing camber, Fowler flaps also increase the wing area, thus providing added lift without unduly increasing drag.

The *slotted flap* (Figure 4-6-8D) is like the Fowler flap in operation, but it is similar to a plain flap in appearance. This flap is equipped with either tracks and rollers or hinges of a special design. During operation, the flap moves downward and rearward away from the position of the wing. The *slot*, thus opened, allows a flow of air over the upper surface of the flap. The effect is to streamline the airflow and to improve the efficiency of the flap. Often, more than one panel is used with the slotted flap.

Boundary layer control devices. The layer of air over the surface that is slower-moving in relation to the rest of the slipstream is called the *boundary layer*. The initial airflow on a smooth surface (Figure 4-6-8) gives evidence of a very

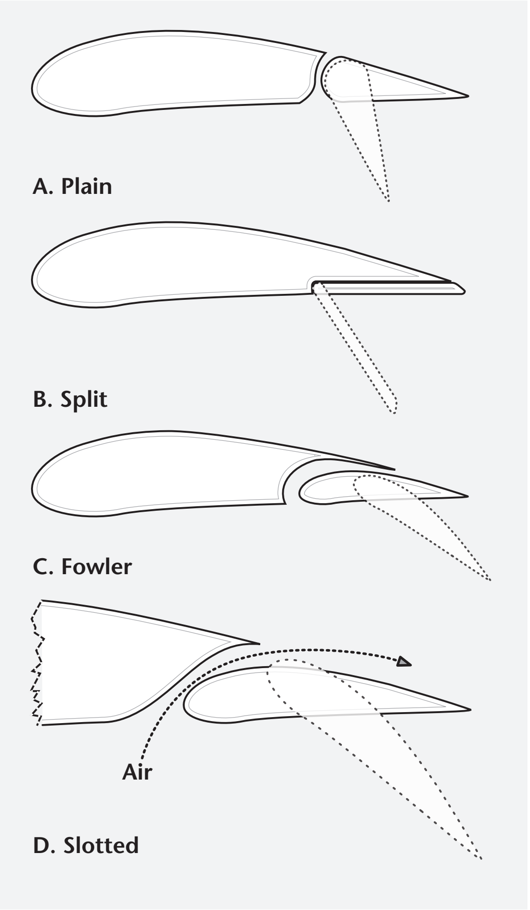


Figure 4-6-8. Principal flap systems with common usage. The transport category “split flap” is a modified fowler flap.

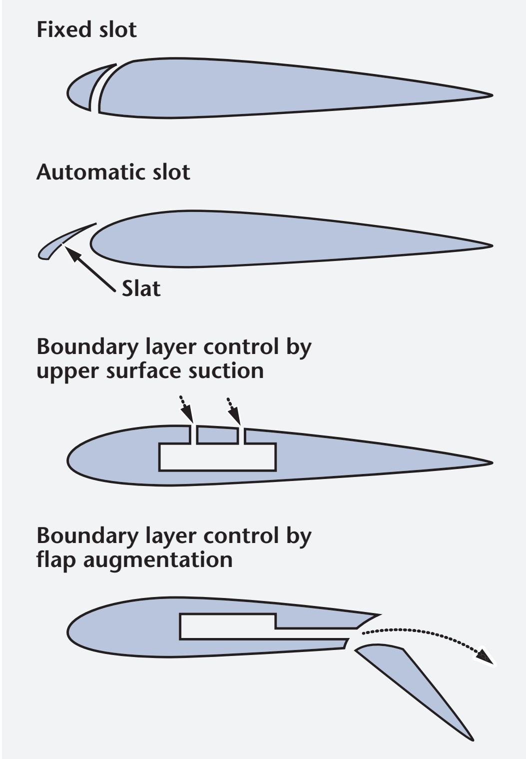


Figure 4-6-9. Methods of controlling boundary layer air.

Figure 4-6-10. Leading-edge flaps on large transport airplanes can be quite complicated. By clever linkage design, this leading edge flap can unfold and extend, as in this view of a Kruger flap on a Boeing 747.

thin boundary layer, with the flow occurring in smooth laminations of air sliding smoothly over one another. Therefore, the term for this type of flow is the *laminar boundary layer.*

As the flow continues back from the leading edge, friction forces in the boundary layer continue to dissipate the energy of the airstream, slowing it down. The laminar boundary layer increases in thickness with increased distance from the wing's leading edge. Some distance from the leading edge, the laminar flow begins an oscillatory disturbance that is unstable. A waviness occurs in the laminar boundary layer that ultimately grows larger and more severe and destroys the smooth laminar flow. Thus, a transition takes place in which the laminar boundary layer decays into a turbulent boundary layer. The same sort of transition can be noticed in the smoke from a burning cigarette. At first, the smoke ribbon is smooth and laminar, then develops a definite waviness and decays into a random turbulent smoke pattern.

Boundary layer control devices are additional means of increasing the maximum lift coefficient of a section. The thin layer of air adjacent to the surface of an airfoil shows reduced local velocities from the effect of skin friction. At high angles of attack, the boundary layer on the upper surface tends to *stagnate*, or come to a stop. When this happens, the airflow separates from the surface and stall occurs.

Boundary layer control for high-lift applications features various devices to maintain high velocity in the boundary layer and delay separation of the airflow. Control of the boundary layer's kinetic energy can be accomplished using slats and the application of suction to draw off the stagnant air and replace it with high-velocity air from outside the boundary layer.

One of the simplest of these devices is the *slot*. The device is simply an opening aft of the forward edge of the wing. When the angle of attack is increased, the air passing through the slot prevents the boundary layer from thickening by increasing the airflow. This will retard the point where stall will occur. On some high-performance Short Takeoff and Landing (STOL) airplanes, the slots are forward of the ailerons. This allows positive airflow over the ailerons, providing control during a stall.

Slats. (Figure 4-6-9) are movable control surfaces attached to the leading edge of the wing. When the slat is closed, it forms the leading edge of the wing. When in the open position (extended forward), a slot is created between the slat and the wing leading edge. Thus, high-energy air is introduced into the boundary layer over the top of the wing. This is a form of *boundary layer control*. At low airspeeds this improves handling characteristics, allowing the aircraft to be controlled laterally at airspeeds below the otherwise normal landing speed.

Controlling boundary layer air by surface suction allows the wing to operate at higher angles of attack. The effect on lift characteristics is similar to that of a slot, because the slot is essentially a boundary layer control device, ducting high-energy air to the upper surface. This type of boundary layer control is normally reserved for military airplane designs.

Boundary layer control can also be accomplished by directing high-pressure engine bleed air through a narrow orifice located just forward of the wing flap leading edge. This directs a *laminar flow* (air in layers) over the wing and flaps when opened sufficiently to expose the orifice. The high-temperature, high-velocity laminar air passing over the wing and flaps delays *flow separation* (when the airstream over an airfoil no longer follows the contour of the airfoil), hence reducing turbulence and drag (Figure 4-6-9). This results in a lower stall speed and allows slower landing speeds. The first application of *blown flaps* was on the Grumman F9F jet fighter in the 1950s.

Some leading-edge flaps actually change the camber of the leading edge of the wing. These are normally made of composite material and are driven hydraulically or electrically. In most cases, both systems are used, with one as primary and the other as a back-up. An excellent example is the *Kruger flap* (Figure 4-6-10).

Aerodynamic twist. Most aircraft produced today have an aerodynamic twist designed into the wing structure (Figure 4-6-11). Normally, the outer section of the wing is twisted down, or has a lower angle of attack, than the wing root. When the wing stalls, the root section will reach the critical angle of attack first and will thus stall first. With the root stalling first, the pilot should have time to push the nose down, increase speed, and have some degree of aileron control still available.

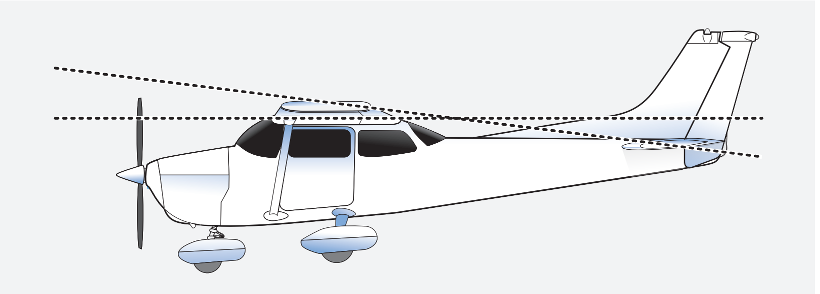


Figure 4-6-11. Aerodynamic twist in a wing is easy to observe. Stand opposite the tip. Move your eye up or down until the trailing edge lines up at both the tip and root.

Many older aircraft have wing designs that do not allow the root of the wing to stall before the outer portion of the wing. This feature is undesirable, since the ailerons should aid in control when the stall occurs. Ideally, a small triangular strip, called a *stall strip*, is added to the root portion of the wing. This creates enough disturbance to stall the root before the tip at high angles of attack. The result is a much more gentle stall with some aileron control. If the stall strips were removed, a complete wing stalling would result. In that scenario, the only control surface with some positive reaction is the rudder. Trying to use any other surface would result in a spin (Figure 4-6-12).

Winglets. One major method of controlling wingtip vortices is the design of the wingtip itself. The current trend toward the installation of *winglets* on the tips of wings is an example of attempting to control the vortex by design.

Because air is viscous, it has a tendency to slide off the wingtip at right angles to the chord of the wing. The higher pressure air then flows, or curls, into the low-pressure area formed on top of the wing. A whirlwind effect is created.

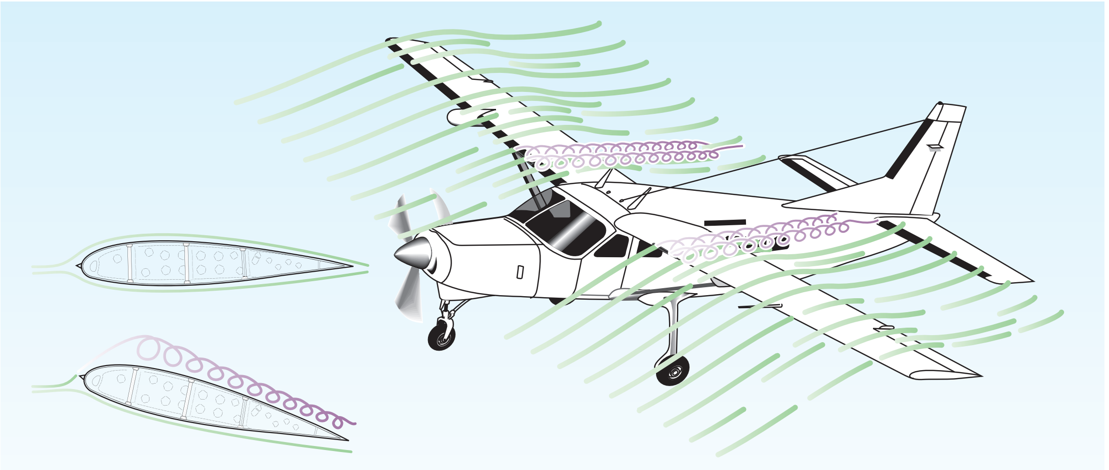


Figure 4-6-12. Stall strips are an important part of aerodynamics and should not be removed.

Figure 4-6-13. Winglets add considerable weight and structural complexity but do provide excellent drag reduction.

Figure 4-6-14. The Cozy series of homebuilt airplanes is currently one of the most popular examples of a canard design.

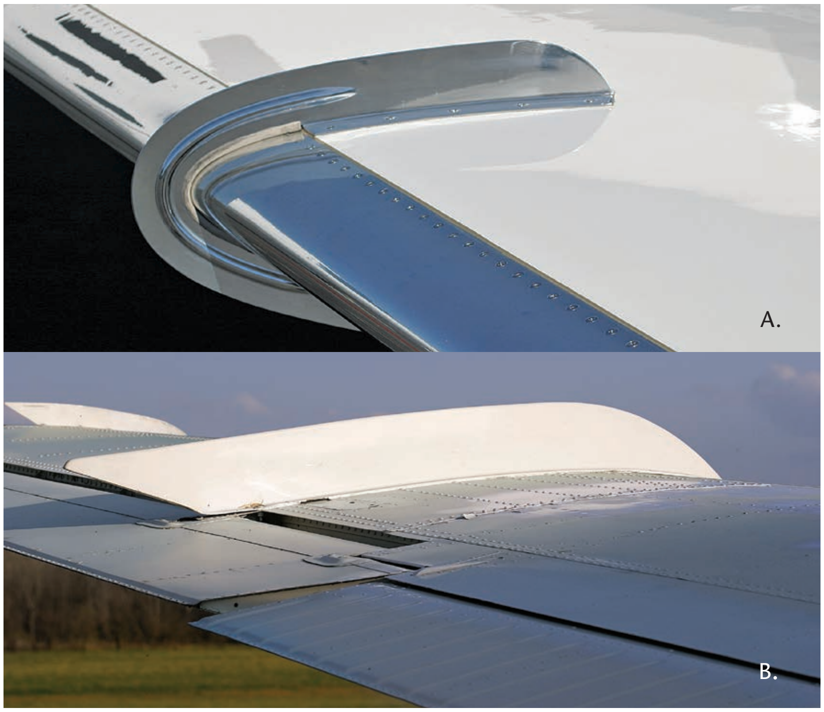


Figure 4-6-15. The purpose of a wing fence is to keep the air flowing chordwise across the wing. Some span little more than the leading edge of the wing (A), while others reach all the way back to the trailing edge (B).

The "whirlwind" continues to grow in size and plays out behind the wing tip as the airplane flies on. This causes a great deal of turbulence and reduces the effectiveness of the wing by destroying downwash. Additionally, the turbulence can remain organized for some time, producing a danger to following aircraft.

In its simplest form, a winglet is a vertical extension of the wing. It keeps the air from sliding off the wing and combining with the air on top. The actual tip of the winglet can now be a symmetrical airfoil. This reduces and relocates the wing tip vortice, thus reducing loss of downwash caused by the disturbance. Additionally, a winglet increases the aspect ratio of the wing. Increasing the aspect ratio always produces an increase in lift (Figure 4-6-13 for an example of a winglet).

Winglets are not a cure-all for induced drag. As with all other factors aircraft designers consider, there are trade-offs. Winglets require more structural strength, and many wings would need complete redesign to accommodate them. There is also a trade-off between the gain they produce and the cost and complexity they add to the manufacture of the airplane.

Just as lift increases with an increase in angle of attack, induced drag also increases as the angle of attack becomes greater. This occurs because, as the angle of attack is increased, there is a greater pressure difference between the top and bottom of the wing. This causes more violent vortices to be set up, resulting in more turbulence and more induced drag.

Canard. A *canard* is a fixed or moveable surface mounted on the forward fuselage, much as a horizontal stabilizer is placed on the rear of the fuselage. The canard is a very old idea. The Wright brothers placed their elevator on the front of their aircraft. A fixed canard adds to the lift of the forward portion of the fuselage. This allows the wing to be placed further aft on the fuselage. A fixed canard also reduces the size requirement of the horizontal stabilizer. In some designs, a canard actually eliminates the need for a horizontal stabilizer; in effect, it becomes a horizontal stabilizer located in front. The best current example of a fixed canard is on jet fighter aircraft, while the Varieze homebuilt series is an example of a canard used in place of tail surfaces (Figure 4-6-14).

To understand the operation of a moveable canard requires some further explanation. On a conventional tail assembly, the horizontal stabilizer provides a down force, or reverse lift, on the aft of the fuselage. At design cruise speed, this down force balances the fuselage nose's down force from weight ahead of the center of gravity. A reduction of power causes the horizontal stabilizer to lose some lift, or down pressure, and the nose drops in response. As speed increases from the nose-down attitude, the lift will increase faster on the horizontal stabilizer than on the wings, pushing the tail down and raising the nose, with the aircraft resuming level flight.

A canard works in reverse. The canard provides lift, or upward pressure, on the forward fuselage. At design cruise speed, this upward pressure balances the lift of the wings, and the airplane flies straight and level. When power is reduced, lift is lost more quickly on the canard than on the wings and the nose drops. As speed builds, the canard builds lift faster than the wings, raising the nose to level flight. It is possible to design an airplane with a canard planform that, for practical purposes, will not stall.

Wing fences. Wing fences have been used for many years with the advent of the swept-back wing. The purpose of the fence is to direct the airflow over the chord of the wing rather than at the angle of the sweepback, and to stop the movement of air towards the wingtip (Figure 4-6-15).

Section 7

Control Systems

Control systems in modern transports can quickly become complicated. Transport aircraft use several control surfaces in conjunction with each other in most flight configurations.

The input commands for each flight control are generally managed by an electronic device that will provide the commands to the various systems simultaneously. Most of these controls are hydraulically assisted, generally from two or more hydraulic systems. This redundancy in the flight controls is a safety measure to ensure the operation of the system in an emergency.

Some aircraft have electrical backup control mechanisms on some of the hydraulic controls, while others may have a mechanical backup system.

An aircraft may have control surfaces that are moved electrically with electrical backup systems — called *fly-by-wire* systems. Because of all the various systems and variations in use, it is easiest to follow one particular system through its operation, rather than portions of several unrelated systems. Our example aircraft, in Figure 4-7-1, has control surfaces of this type.

The primary control surfaces are the ailerons, elevator, and the rudder. These surfaces are operated by control cables running from the flight deck to the hydraulic-control actuators. For reliability, they utilize the two hydraulic systems of the aircraft.

The secondary controls include the spoilers, speed brakes, stabilizer, slats, and flaps.

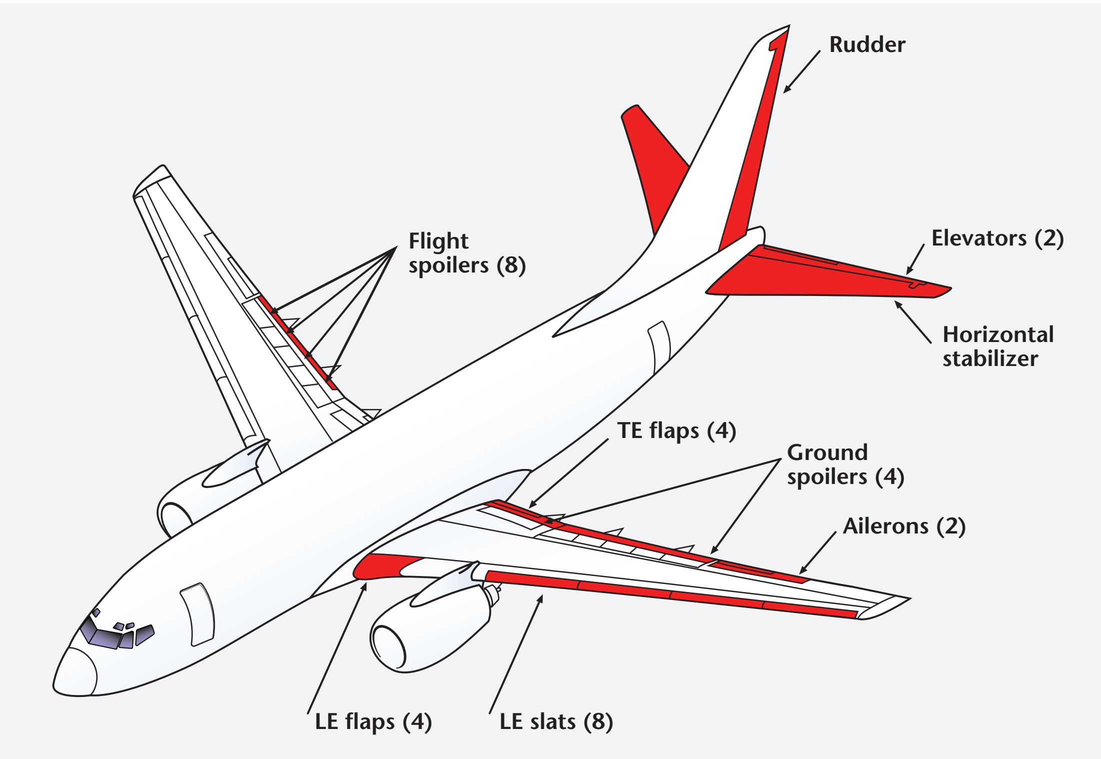


Figure 4-7-1. Primary control surfaces on a transport aircraft are the same rudder, elevator, and ailerons as used on any other conventional airplane.

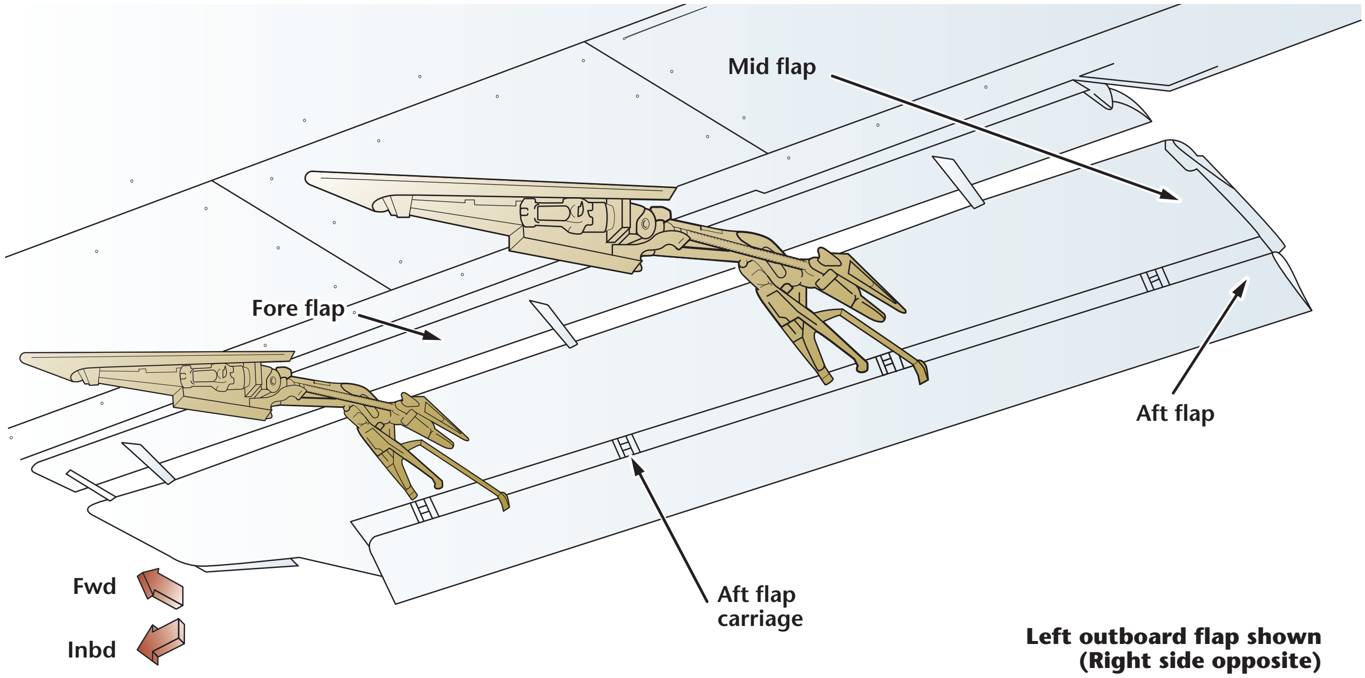


Figure 4-7-2. Inboard trailing edge flaps extended.

The spoilers consist of six units on the top of each wing. The four center panels are used for roll control, while all six panels are used for flight and ground-speed brakes. The autospeed brakes are for landing and are refused activation by the computer system for takeoff. The spoilers are hydraulically powered and electronically controlled.

The stabilizer is moved up and down by the use of cable linkages controlling the hydraulic power output to a mechanical jackscrew. Again, two hydraulic systems are used to ensure reliability.

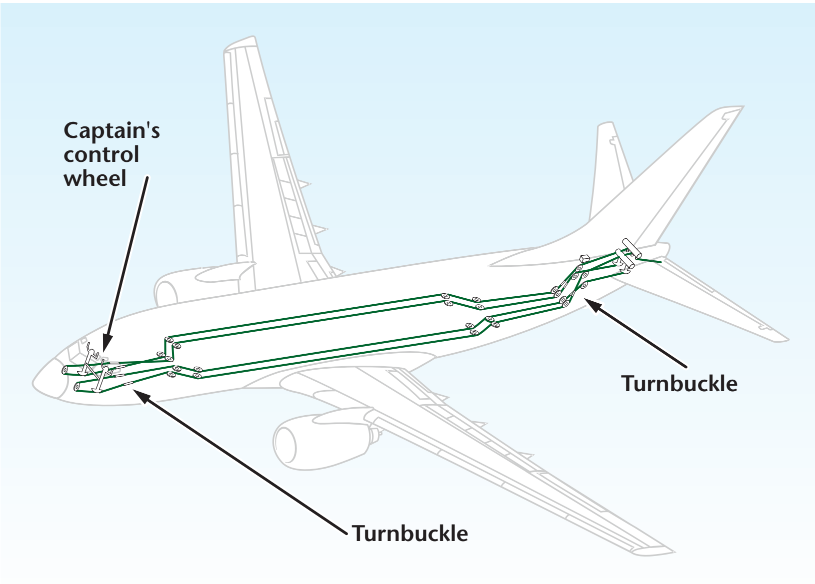


Figure 4-7-3. Stabilizer cable-operated trim system.

The system of slats consists of eight units, four on each wing. These have three programmed positions: cruise, landing, and takeoff. They are hydraulically powered, with torque tube drives and electric power backup.

This aircraft utilizes an outboard and inboard flap on each wing. The outboard flap is a single-slotted flap. The inboard flap is single-slotted for takeoff and double-slotted for landing. These are lowered by a hydraulically powered torque tube and have electric power backup for reliability.

During landings, the inboard ailerons are lowered, or drooped, 10°. This improves the lift and reduces drag by filling in the gap between the inboard and outboard flaps.

The droop is controlled mechanically by the flap-drive angle gearbox. The droop begins as the trailing edge flaps extend beyond 5° down. The droop is completed at 10° down. This cycle is reversed when the trailing edge flaps are retracted. The wing cable system is not affected by the aileron droop.

The outboard aileron becomes inoperative when 235 knots of airspeed is reached, with roll control being provided by the spoiler system. This greatly reduces the bending stresses placed on the wing structure. This is accomplished through an automatic lockout system.

The spoiler system assists in aileron control by raising the flight spoilers on one wing to destroy lift. In addition to this function, the spoiler may be deployed as speed brakes, both in the air and on the ground.

The operation of the speed brakes on the ground may be accomplished by the speed brake lever or automatically by an electrical actuator after the aircraft is on the ground.

Flaps and slats are used for high-lift systems. The flap system is made up of two double-slotted flaps (shown in Figure 4-7-2) on the inboard and two single-slotted flaps on the outboard wing. There are a total of twelve slats. These have a small seal flap between the inboard slat and the engine strut. The flap and slats are operated by a single lever.

The horizontal stabilizer is movable and used to trim the aircraft. To accomplish this, the stabilizer is pivoted at the rear attachments. It is raised and lowered by a hydraulically powered ball screw actuator assembly.

Control switches on each cockpit control wheel horn provide manual electric trim. The flight control computers provide autopilot trim. Manual control of the stabilizer is accomplished with a manual lever cable system. Figure 4-7-3 is an illustration of a stabilizer trim system.

The elevator system consists of an inboard and outboard elevator on each side. The inboard and outboard elevators are connected by links that move the elevators as a single unit. The two systems normally operate as one. However, if a problem developed in one of the systems, the other would be sufficient to operate the plane.

Other features of the (dual-path) elevator control system include *artificial feel*, *autopilot input* and a *stick nudger*. The stick nudger is used to reproduce the feel of a conventional control system when it approaches a stall.

The rudder system consists of two pedal systems that mechanically drive a pair of quadrants. The quadrants are tied together, enabling either set of pedals to control the rudder.

The directional autopilot servos receive control inputs from the flight control computer and provide directional control in *auto-land mode* on final approach and runway rollout.

The feel centering unit provides a feel force to the pedal input and a centering force to return the pedals to neutral when the input is removed.

The *yaw damper* provides control input to the rudder actuators (Figure 4-7-4). Two yaw-damper servos receive inputs from control modules and provide turn coordination and protection against uncommanded yaw inputs.

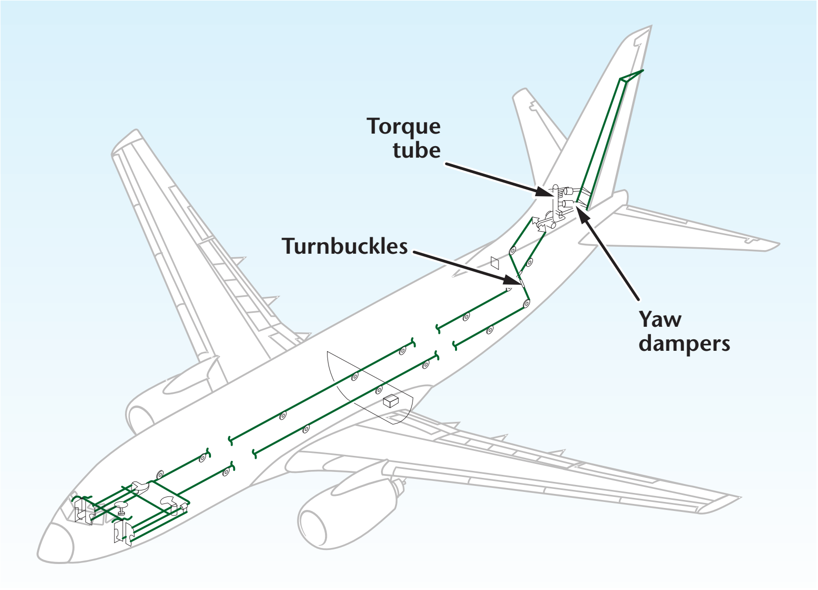


Figure 4-7-4. Although they appear conventional, large aircraft include additional control inputs, including automatic yaw dampers.

Section 8

High-Speed Aerodynamics

Developments in aircraft and powerplants are yielding high-performance transports with capabilities for very high-speed flight. Many significant differences arise in the study of high-speed aerodynamics when compared with low-speed aerodynamics. The differences are enough that a technician needs to be familiar with the nature of high-speed airflow and the peculiarities of high-performance airplanes.

General concepts of supersonic flow patterns. At low flight speeds, air experiences small changes in pressure, which are negligible variations in density, greatly simplifying the study of low-speed aerodynamics. The flow is called *incompressible* since the air undergoes small changes in pressure without significant changes in density. At high flight speeds, however, the pressure changes that take place are quite large and significant changes in air density occur. The study of airflow at high speeds must account for these changes in air density and must consider that the air is *compressible*, or that there are compressibility effects.

The speed of sound is very important in the study of high-speed airflow. The speed of sound varies with the ambient temperature. At sea level, on a standard day, the speed of sound is about 661.7 knots (760 m.p.h.).

As a wing moves through the air, local velocity changes occur which create pressure disturbances in the airflow around the wing. These

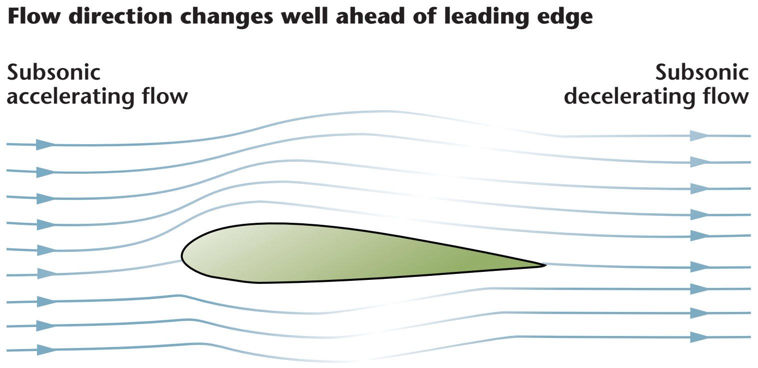


Figure 4-8-1. Typical subsonic flow pattern, subsonic wing.

pressure disturbances are transmitted through the air at the speed of sound. If the wing is traveling at low speed, the pressure disturbances are transmitted and extend indefinitely in all directions. Evidence of these pressure disturbances is seen in the typical subsonic flow pattern illustrated in Figure 4-8-1, where upwash and flow direction change well ahead of the wing leading edge.

When the wing is traveling supersonically, the airflow ahead of the wing is not influenced by the pressure field of the wing, since pressure disturbances cannot be propagated faster than the speed of sound. As the flight speed nears the speed of sound, a compression wave forms at the leading edge, and all changes in velocity and pressure take place quite sharply and suddenly. The airflow ahead of the wing is not influenced until the air molecules are suddenly forced out of the way by the wing. Evidence of this phenomenon is seen in the typical supersonic flow pattern shown in Figure 4-8-2.

Compressibility effects depend not on airspeed but rather on the relationship of airspeed to the speed of sound. This relationship is called the *Mach number,* the ratio of true airspeed to the speed of sound at a particular altitude.

Compressibility effects are not limited to flight speeds at and above the speed of sound. Since an airplane is made up of aerodynamic shapes, air accelerates and decelerates around these shapes and attains local speeds above the flight speed. Thus, an aircraft can experience compressibility effects at flight speeds well below the speed of sound. Since it is possible to have both subsonic and supersonic flows on the airplane at the same time, it is best to define certain regimes of flight. These approximate regimes are defined as follows:

Subsonic: flight Mach numbers below 0.75

Transonic: flight Mach numbers from 0.75 to 1.20

Supersonic: flight Mach numbers from 1.20 to 5.00

Hypersonic: flight Mach numbers above 5.00

While the flight Mach numbers used to define these regimes are approximate, it is important to appreciate the types of flow existing in each area. In the subsonic regime, subsonic airflow exists on all parts of the aircraft. In the transonic regime, the flow over the aircraft components is partly subsonic and partly supersonic.

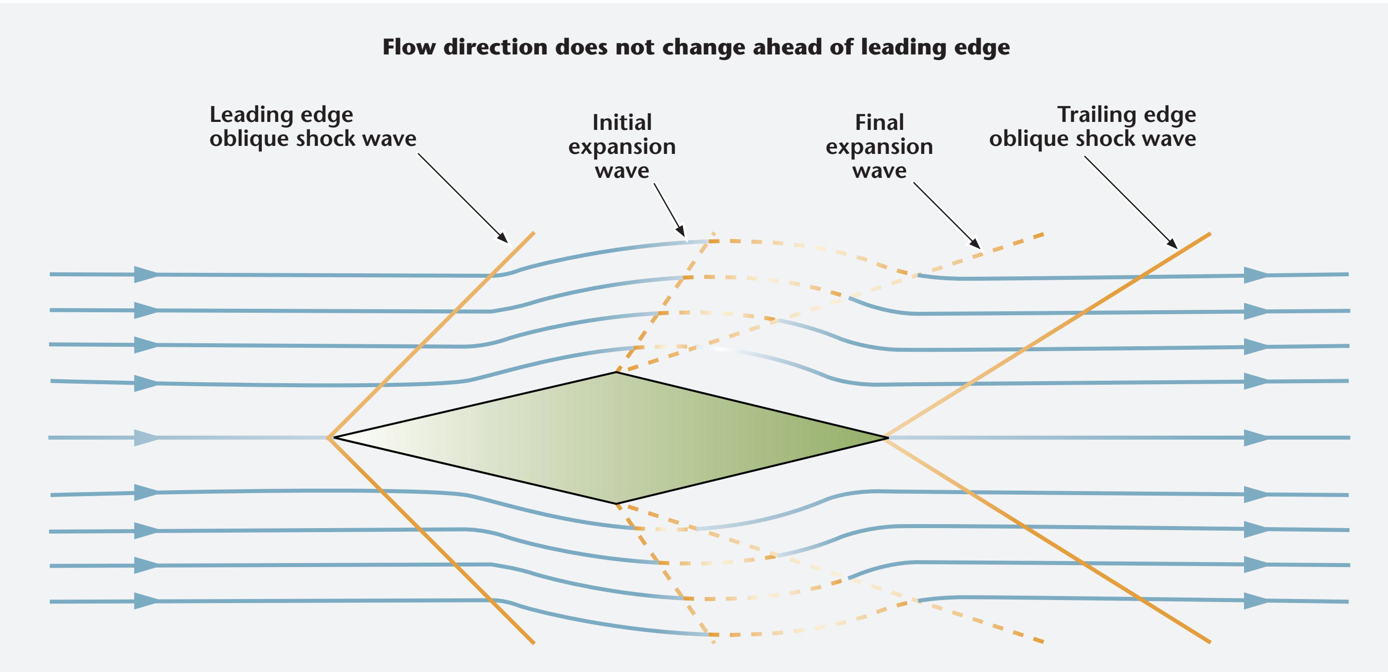
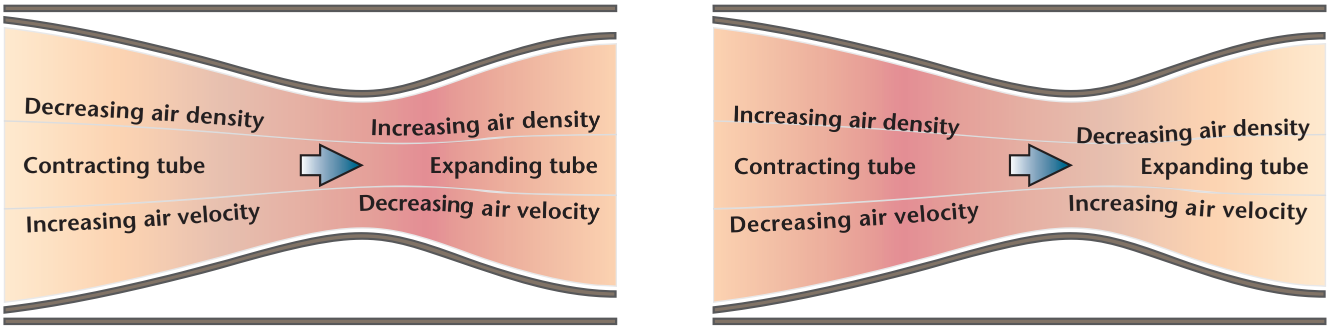


Figure 4-8-2. Typical supersonic flow pattern, supersonic wing.



A. Subsonic flow **B. Supersonic flow**

Figure 4-8-3. Comparison of subsonic and supersonic airflow through a closed tube.

In the supersonic and hypersonic regimes, supersonic flow exists over all parts of the aircraft. In super- and hypersonic flight, some portions of the boundary layer are subsonic, but the predominating flow is still supersonic.

Difference between subsonic and supersonic flow. In a subsonic flow, every molecule is affected more or less by the motion of every other molecule in the whole field of flow. At supersonic speeds, an air molecule can influence only that part of the flow contained in the Mach cone formed behind that molecule.

The peculiar differences between subsonic flow and supersonic flow can best be seen by considering airflow in a closed contracting/expanding tube, as depicted in Figure 4-8-3.

Unlike supersonic flow, a subsonic airstream accelerates along an expanding tube, causing the air density to decrease rapidly to compensate for the combined effects of increased speed and increased cross-sectional area.

Unlike subsonic flow, a supersonic airstream decelerates along a contracting tube, causing the air density to increase rapidly to compensate for the combined effects of decreased speed and decreased cross sectional area.

In order to clarify these fundamental points, Table 4-8-1 lists the nature of the two types of tubes. An understanding of Figures 4-8-1 through 4-8-3 and Table 4-8-1 is essential in order to grasp the fundamentals of supersonic flow.

Typical supersonic flow patterns. With supersonic flow, all changes in velocity, pressure, temperature, density, and flow direction take place suddenly and over a short distance. The areas of flow change are distinct, and the phenomena causing the flow change are called *wave formations*. All *compression waves* occur abruptly and are wasteful of energy. Compression waves are more familiarly known as shock waves. *Expansion waves* result in smoother flow transition and are not wasteful of energy like shock waves. Three types of waves can take place in supersonic flow: the *oblique* (inclined angle); the *shock wave* (compression); and the *expansion wave* (no shock). The nature of the wave depends on the Mach number, the shape of the object causing the flow change, and the direction of flow.

A supersonic airstream passing through the oblique shock wave experiences these changes:

- The airstream is slowed down. The velocity and the Mach number behind the wave are reduced, but flow is still supersonic.
- The flow direction is changed so that the airstream runs parallel to the new surface.
- Static pressure behind the wave is increased.
- The static temperature behind the wave goes up, so the local speed of sound is increased.
- The density of the airstream behind the wave is increased.
- Some of the available energy of the airstream (indicated by the sum of dynamic and static pressure) is dissipated by conversion into unavailable heat energy. Therefore, the shock wave wastes energy.

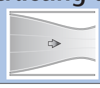
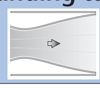
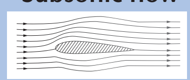
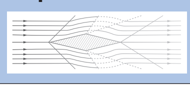
	Contracting tube 	**Expanding tube** 
Subsonic flow 	Accelerates and rarefies slightly	Decelerates and compresses slightly
Supersonic flow 	Decelerates and compresses slightly	Accelerates and rarefies slightly

Table 4-8-1. High-speed flows.

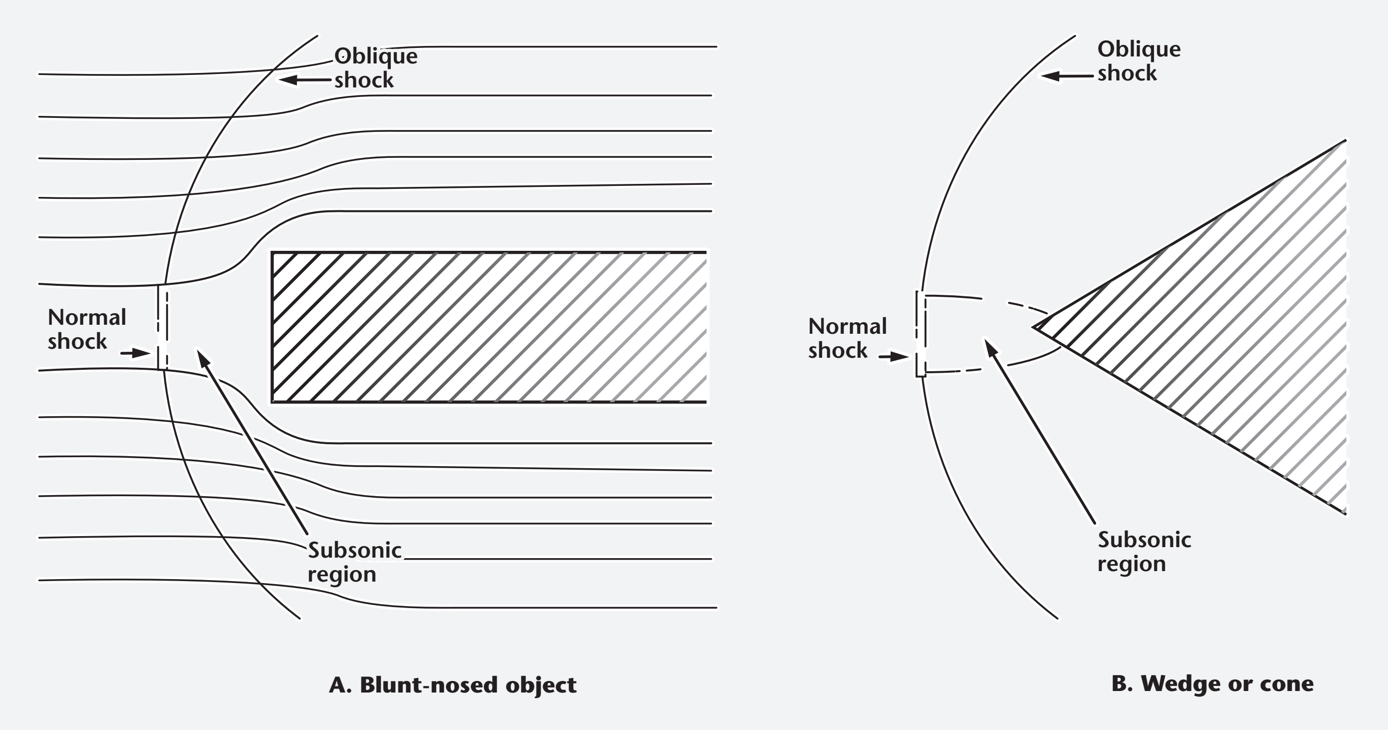


Figure 4-8-4. Normal shock-wave formation with a detached wave.

The normal shock wave. If a blunt-nosed object is placed in a supersonic airstream, the shock wave that is formed is detached from the leading edge. The detached wave also occurs when a wedge or cone half-angle exceeds some critical value. Figure 4-8-4 shows the formation of a normal shock wave in the above two cases. Whenever a shock wave forms perpendicular to the free stream flow, the shock wave is termed a *normal shock wave*, or a *right-angle shock wave*, and the flow immediately behind the wave is subsonic. No matter how high the free-stream Mach number may be, the flow directly behind a normal shock is always subsonic. In fact, the higher the supersonic free-stream Mach number (M) is in front of the normal shock wave, the lower the subsonic Mach number is aft of the wave. For example, if M1 is 1.5, M2 is 0.7; if M1 is 2.6, M2 is only 0.5.

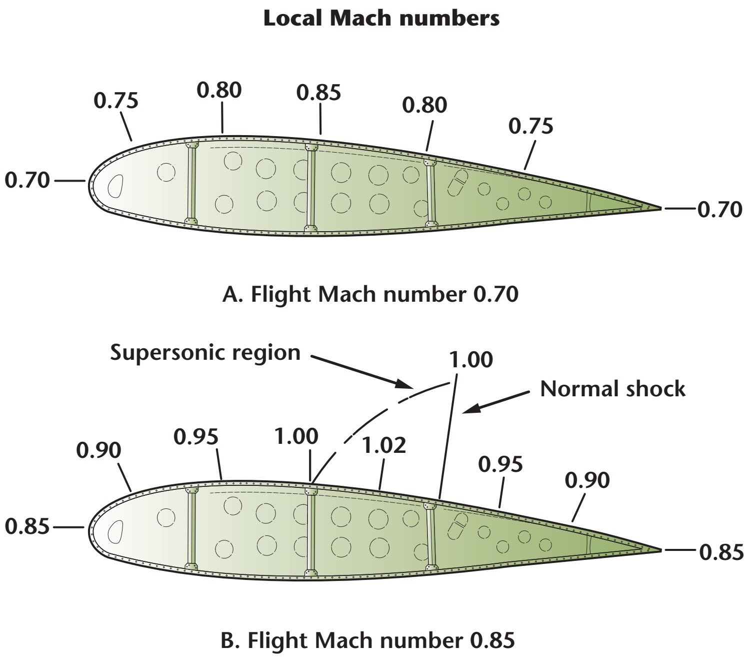


Figure 4-8-5. Normal shock-wave formation on an airfoil in a subsonic airstream.

A normal shock wave forms immediately in front of any relatively blunt object in a supersonic airstream, slowing the airstream to subsonic so that the airstream may feel the presence of the blunt object and thus flow around it. Once past the blunt nose, the airstream may remain subsonic, or it may accelerate back to supersonic, depending on the shape of the nose and the Mach number of the free stream.

A normal wave may also be formed when there is no object in the supersonic airstream. Whenever a supersonic airstream is slowed to subsonic without a change in direction, a normal shock wave forms as the boundary between the supersonic and subsonic regions. This is why airplanes encounter *compressibility effects* before the flight speed is sonic. Figure 4-8-5 illustrates how an airfoil at a high subsonic speed has local flow velocities, which are supersonic. As the local supersonic flow moves aft, a normal shock wave forms so that the flow may return to subsonic and rejoin the subsonic free stream at the trailing edge without discontinuity. The transition is made gradually with a smooth surface. The transition of flow from supersonic to subsonic without direction change always forms a normal shock wave.

A supersonic airstream passing through a normal shock wave experiences these changes:

- The airstream is slowed to subsonic. The local Mach number behind the wave is approximately equal to the reciprocal of the Mach number ahead of the wave. For example, if the Mach number ahead of the wave is 1.25, the Mach number of the flow behind the wave is 0.81264.
- The airflow direction immediately behind the wave is unchanged.
- The static pressure behind the wave is greatly increased.
- The static temperature behind the wave is greatly increased, hence the local speed of sound is increased.
- The density of the airstream behind the wave is greatly increased.
- The available energy of the airstream (indicated by the sum of dynamic and static pressure) is greatly reduced. The normal shock wave wastes energy.

The expansion wave. If a supersonic airstream is turned away from the preceding flow, an expansion wave is formed. The flow around a corner, shown in Figure 4-8-6, does not cause sudden changes in the airflow except at the corner itself and thus is not actually a shock wave.

A supersonic airstream passing through an expansion wave experiences these changes:

- The supersonic airstream is accelerated. The velocity and Mach number behind the wave are greater.
- The flow direction is changed so that the airstream runs parallel to the new surface, provided separation does not occur.
- The static pressure behind the wave is decreased.
- The static temperature behind the wave is decreased, hence the local speed of sound is decreased.
- The density of the airstream behind the wave is decreased.
- Since the flow changes in a rather gradual manner, there is no shock and no loss of energy in the airstream. The expansion wave does not dissipate airstream energy.

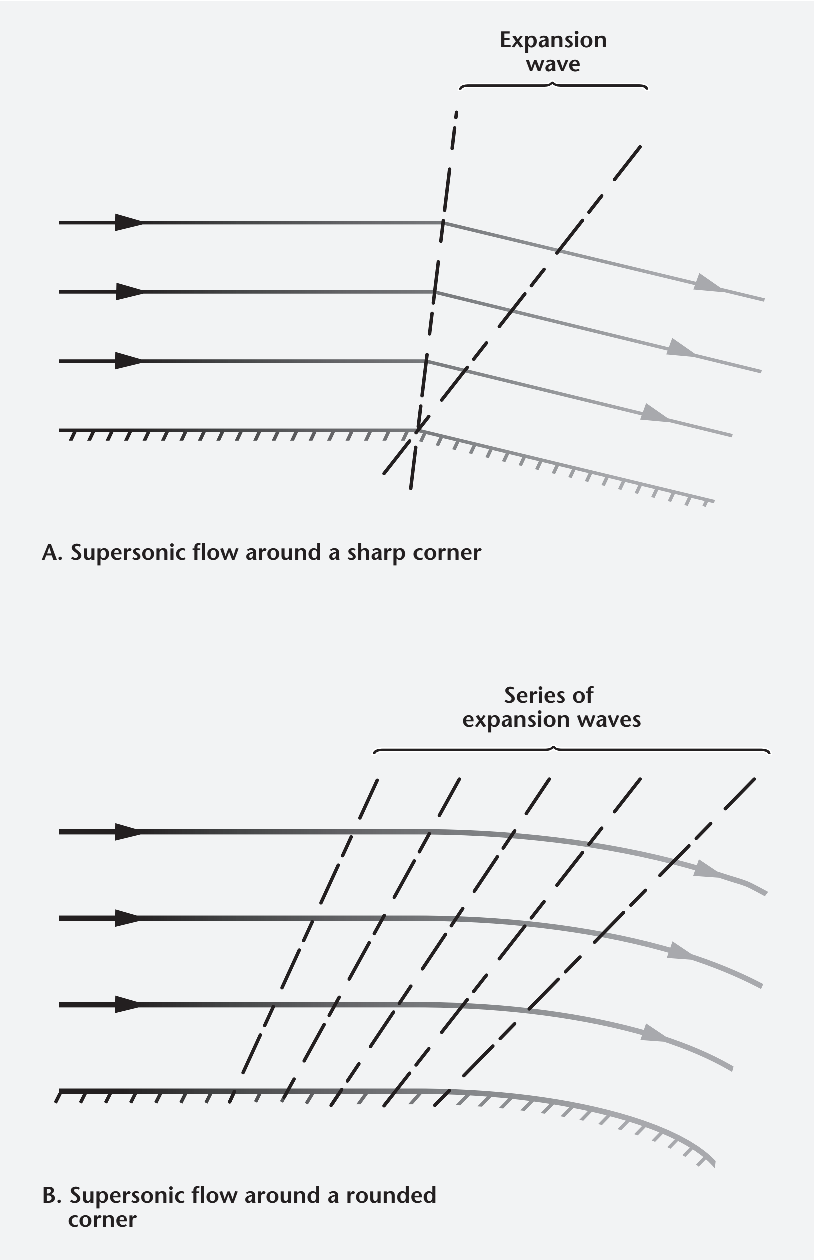


Figure 4-8-6. Expansion waves.

A summary of the characteristics of the three principal waveforms encountered with supersonic flow is shown in Table 4-8-2.

Figure 4-8-7 shows the wave pattern for a conventional blunt-nosed subsonic airfoil in a supersonic stream. When the nose is blunt, the wave must detach and become a normal shock wave immediately ahead of the leading edge. Since the flow just behind a normal shock wave is always subsonic, the airfoil's leading edge is in a subsonic region of very high static pressure, static temperature and density.

In supersonic flight, the zero lift of an airfoil of some finite thickness includes a *wave drag*, a separate and distinct from drag due to lift. Airfoil thickness has an extremely powerful effect on

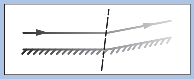
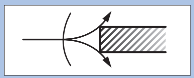
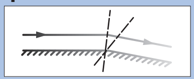
	Flow direction change	Effect on velocity and Mach number	Effect on static pressure, static temperature and density	Effect on available energy
Oblique shock wave 	Flow into a corner	Decreased but still supersonic	Increase	Decrease
Normal shock wave 	No change	Decreased to subsonic	Great increase	Great decrease
Expansion wave 	Flow around a corner	Increased to higher subsonic	Decrease	No change (no shock)

Table 4-8-2. Supersonic wave characteristics.

the wave drag. The wave drag varies with the square of the thickness ratio (maximum thickness divided by the chord). If the thickness is cut by half, the wave drag is cut by three-fourths. The leading edges of supersonic shapes must be sharp. If they are not, the wave formed near the leading edge is a strong detached normal shock wave (Figure 4-8-8).

Once the flow over the airfoil is supersonic, the aerodynamic center of the surface is located approximately at the 50-percent chord position. This contrasts with the subsonic location of the aerodynamic center, which is near the 25-percent chord position.

During supersonic flow, all changes in velocity, Mach number, static pressure, static temperature, density, and flow direction take place quite suddenly through the various waveforms. The shape of the object, the Mach number, and the required flow direction change dictate the type and strength of the wave formed.

Any object in subsonic flight that has some finite thickness or is producing lift must have local velocities on the surface that are greater than the free stream velocity. Hence, compressibility effects can be expected to occur at flight speeds that are less than the speed of sound. The transonic regime of flight provides the opportunity for mixed subsonic and supersonic local velocities and accounts for the first significant effects of compressibility.

As the flight speed approaches the speed of sound, the areas of supersonic flow enlarge and the shock waves move nearer the trailing edge. The boundary layer may remain separated or may re-attach, depending much upon the airfoil shape and angle of attack. When the flight speed exceeds the speed of sound, a bow-wave suddenly appears in front of the leading edge with a subsonic region behind the wave. The normal shock waves move to the trailing edge. If the flight speed is increased to some higher supersonic value, the bow-wave moves closer to the leading edge and inclines more downstream, and the trailing edge normal shock waves become oblique shock waves.

Of course, all components of the aircraft are affected by compressibility in a manner somewhat similar to that of the basic airfoil (the empennage, fuselage, nacelles, etc.).

Since most of the difficulties of transonic flight are associated with shock wave-induced flow separation, any means of delaying or lessening the shock wave-induced flow separation improves the aerodynamic characteristics. An aircraft configuration can make use of thin surfaces of low aspect-ratio with sweepback to delay and reduce the magnitude of transonic force divergence. In addition, various methods of boundary layer control, high-lift devices, *vortex generators*, and so forth, may be applied to improve transonic characteristics. For example, the mounting of vortex generators on a surface can produce higher local surface velocities and

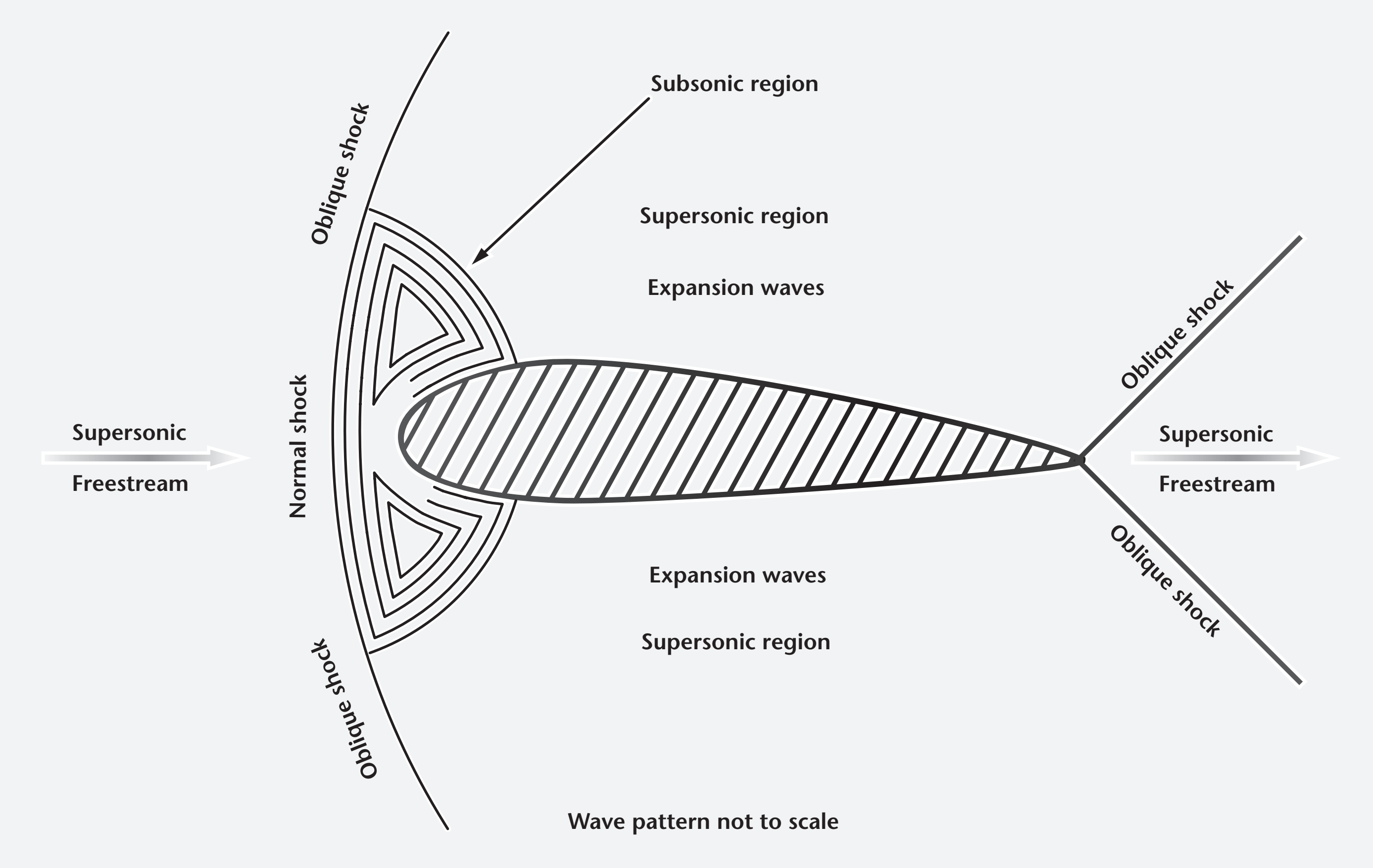


Figure 4-8-7. The conventional subsonic airfoil in supersonic flow.

increase the kinetic energy of the boundary layer. Thus, a more severe pressure gradient, or stronger shock wave, would be necessary to produce the unwanted airflow separation.

Vortex generators. A vortex generator is a complementary pair of small, low aspect-ratio (short span in relation to chord) airfoils mounted at opposite angles of attack to each other and perpendicular to the aerodynamic surface they serve. Figure 4-8-9 shows the airfoils and the airflow characteristics of a vortex generator. Like any airfoil, those of the generator develop lift. In addition, like any airfoil of especially low aspect-ratio, the airfoils of the generator also develop very strong tip vortices. These tip vortices cause air to flow outward and inward in circular paths around

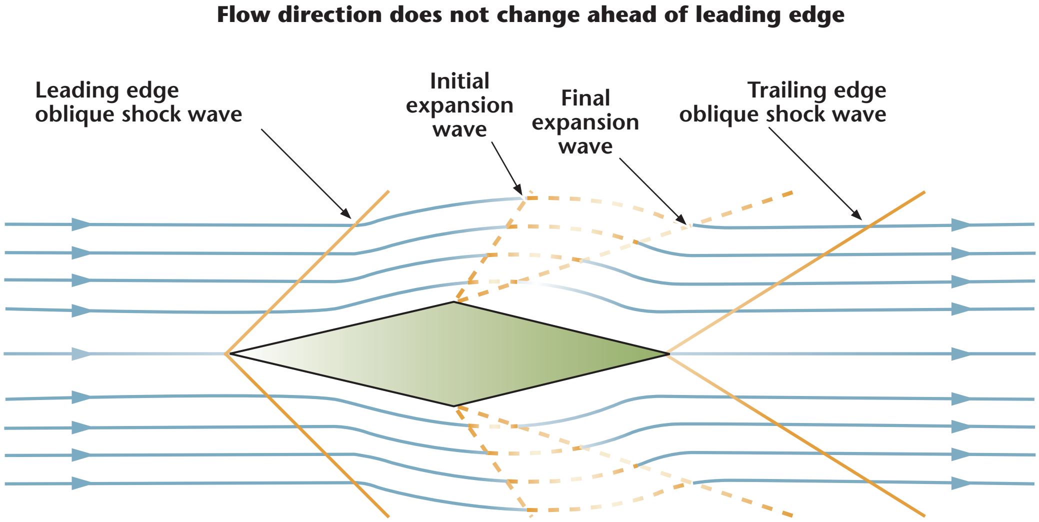


Figure 4-8-8. Typical supersonic flow pattern on a supersonic wing.

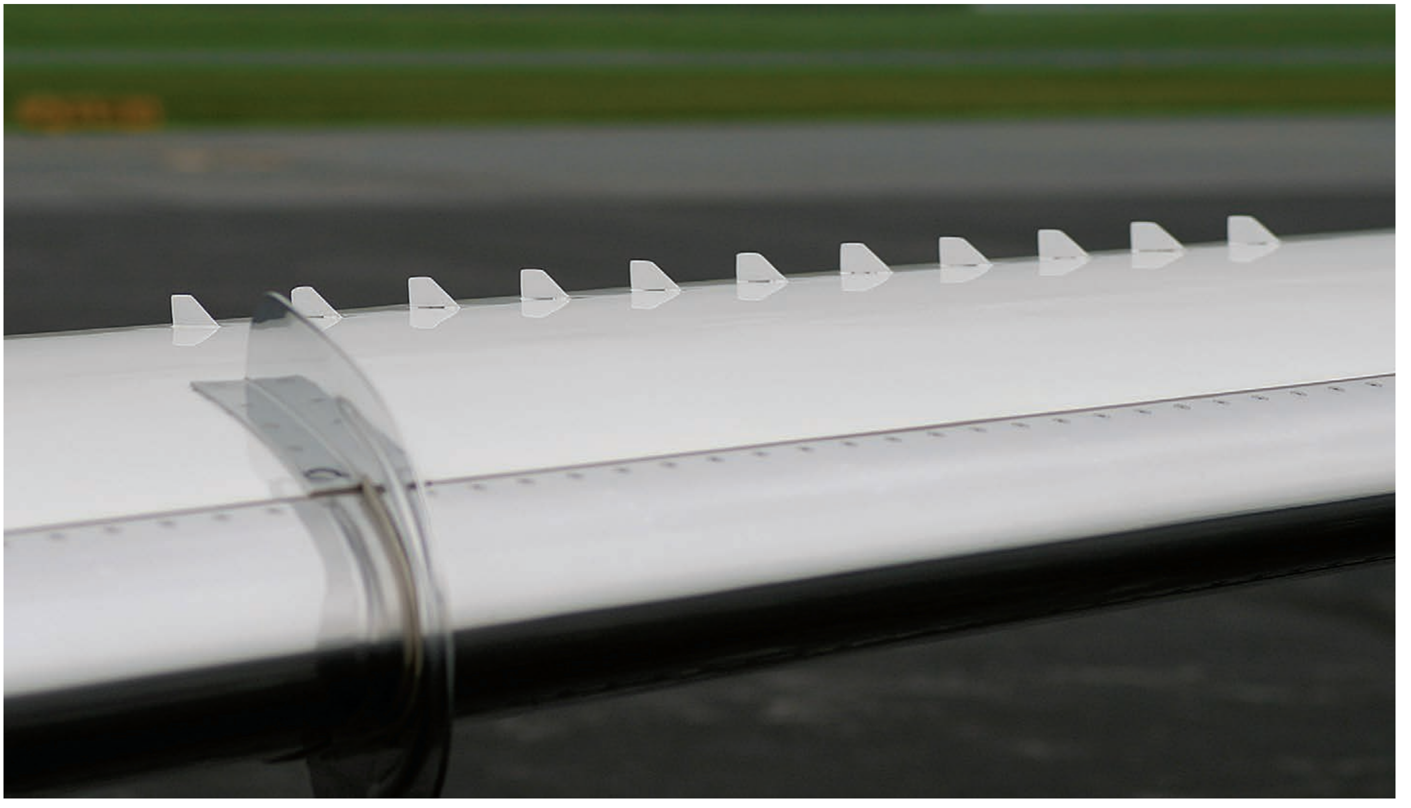


Figure 4-8-9. Vortex generators are an effective method of local speed reduction in primary wing airflow. They can prevent localized areas from exceeding the speed of sound, thereby establishing an unwanted expansion wave. On low-speed applications, they delay boundary separation by moving high-energy air into areas that will lose the boundary layer air first.

Figure 4-8-10. This nacelle shows off the airplane's inlet and diffuser, which slows airflow into the turbine engine. An aircraft's inlet design is based on the Bernoulli principle: As the air moves into the nacelle, the diffuser widens, which slows the speed of the air entering the compressor by raising the air pressure and lowering its velocity.

the boundary layer into the slower-moving air close to the skin. The strength of the vortices is proportional to the lift developed by the airfoils of the generator.

Vortex generators serve two distinctly different purposes: They delay the onset of drag divergence at high speeds, and/or they aid in maintaining aileron effectiveness at high speeds. In contrast, rows of vortex generators mounted on both sides of the vertical fin just upstream of the rudder prevent flow separation over the rudder during extreme angles of yaw. In addition, rows of vortex generators placed on the underside (and occasionally on the upper surface) of the horizontal stabilizer just upstream of the elevators prevent flow separation over the elevators at very low speeds.

In summary, vortex generators can improve high-speed characteristics, while at the same time helping to maintain proper boundary layer control by moving high-energy air into places that need help delaying separation; in essence, improving low-speed characteristics.

Supersonic engine inlets. The air entering the jet engine is normally in the subsonic range. To accomplish this, modifications to the engine inlets will be required when the aircraft exceeds the speed of sound. If the speed is only slightly above subsonic, the modifica-

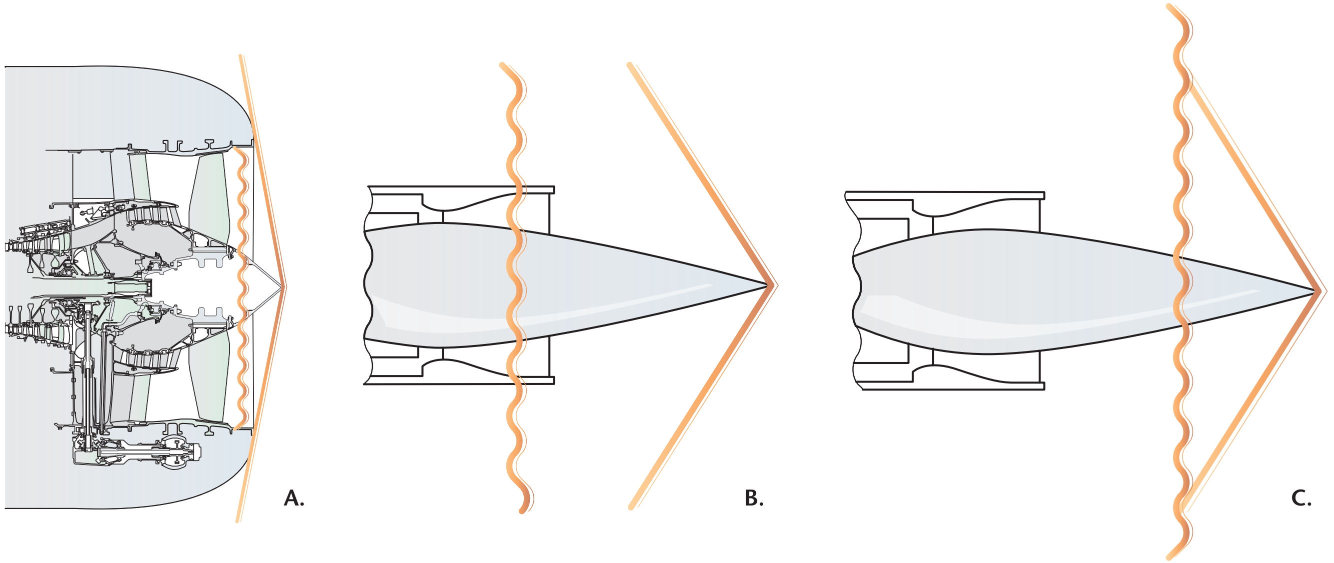


Figure 4-8-11. Because of the pressure changes in an expansion wave, jet engines cannot simply swallow air moving at more than Mach 1. The creation point of the expansion wave must be controlled so that high-pressure air behind the expansion wave is available to the compressor. In very high-speed airplanes, the creation point is a moveable spike. This allows the expansion wave to be repositioned according to the aircraft Mach number.

tions will be only slight. However, as these speeds increase, the problem becomes greater, and the inlets must be designed to slow the air to obtain the weakest series or combination of shock waves. This will minimize energy loss and heat rise, both of which will be harmful to engine performance. Figure 4-8-10 shows one example of the inlets and diffusers used to minimize these effects.

One of the least complicated of the inlets is the normal shock-type diffuser. This type of inlet has a normal shock wave at the inlet with subsonic compression in the inlet, as shown in Figure 4-8-11A. This type of inlet is practical where low supersonic speeds are attained. If the speed is increased, the wave becomes much stronger. When this occurs, this will make it more difficult to recover pressure in the inlet and the air temperature in the inlet will increase.

The next type of supersonic inlet shown is the *convergent-divergent* type shown in Figure 4-8-11B. This type of inlet will swallow the shock wave and the gradual contraction will reduce the speed of the airflow.

Another form of diffuser employs an external oblique shock wave. This slows the supersonic airstream before the normal shock occurs (Figure 4-8-11C).

Aerodynamic heating. When air flows over any aerodynamic surface, certain reductions in velocity take place, which produce corresponding increases in temperature. The greatest reduction in velocity and increase in temperature occur at the various stagnation points on the aircraft. Of course, smaller changes occur at other points on the aircraft, but these lower temperatures can be related to the ram temperature rise at the stagnation point. While subsonic flight does not produce temperatures of any real concern, supersonic flight can create temperatures high enough to be of major importance to the airframe, fuel system, and powerplant.

Higher temperatures produce definite reductions in the strength of aluminum alloys and require the use of titanium alloys and stainless steels. Continued exposure at elevated temperatures further reduces strength and magnifies the problems of creep failure and structural stiffness.

The effect of aerodynamic heating on the fuel system must be considered in the design of a supersonic airplane. If the fuel temperature is raised to the spontaneous ignition temperature, the fuel vapors will burn in the presence of air without the need of an initial spark or flame.

Turbojet engine performance is adversely affected by high compressor inlet air temperature. The thrust output of the turbojet, obviously, is some function of the fuel flow, however, the maximum allowable fuel flow depends on the maximum permissible turbine-operating temperature. If the air entering the engine is already hot, less fuel can be added in order to avoid exceeding turbine temperature limits.

5

Aircraft Weight and Balance

Section 1

The Importance of Weight and Balance

The subject of weight and balance has been a concern of aircraft designers and manufacturers since the earliest aircraft were flown. If the aircraft is too heavy or the weight is not properly distributed, the aircraft may not fly, or if the aircraft does fly, its flight characteristics may be adversely affected.

In theory, all of the weight of the aircraft is concentrated at one point, which is referred to as the center of gravity (CG). In order for the aircraft to perform properly, a relationship between the weight forces and the aerodynamic forces must be established to ensure safe operation.

Problems

Problems concerning the weight and balance of an aircraft fall into three categories: over maximum weight, too much weight forward, too much weight aft. Any of these conditions will have an adverse effect on the aircraft's flight characteristics.

If the aircraft is overloaded, the following conditions will occur:

- More runway is needed.
- A lower climb angle and high speed is required.
- Structural safety factors are reduced.
- Stalling speeds are increased.
- More engine power is required.

Learning Objectives

REVIEW
- The importance of weight and balance
- Weight and balance terms and definitions

DESCRIBE
- Procedures of weighing an aircraft:
  - Document review
  - Aircraft preparation
  - Equipment
  - Data

EXPLAIN
- Weight and balance theory

APPLY
- Calculate the CG and empty weight of a:
  - Light aircraft
  - Small transport aircraft
  - Helicopter

Left. The equipment necessary for weighing the aircraft will vary with the type of aircraft being weighed.

If the aircraft has too much weight forward, the following conditions will occur:

- The aircraft will have a tendency to dive.
- Stability is decreased.
- Adverse spin characteristics.
- More engine power is required.

If the aircraft has too much weight aft, the following conditions will occur:

- Flying speed is decreased.
- Stall characteristics occur more readily.
- Stability is decreased.
- Adverse spin characteristics.
- More engine power is required.

Any of these conditions can result in the loss of the aircraft and loss of life. For these reasons, it is very important that the aircraft technician and the pilot have a thorough understanding of weight and balance.

Empty Weight Determination

The empty weight and the corresponding CG of all civil aircraft must be determined at the time of certification. The manufacturer can weigh the aircraft or compute the weight and balance report. A manufacturer is permitted to weigh one aircraft out of each ten produced. The remaining nine aircraft are issued a computed weight and balance report based on the averaged figures of aircraft that are actually weighed. The condition of the aircraft at the time of determining empty weight must be one that is well defined so that loading requirements can be easily computed.

Need for Reweighing

Aircraft have a tendency to gain weight because of the accumulation of dirt, greases, etc., in areas not readily accessible for washing and cleaning. The weight gained in any given period of time will depend on the function of the aircraft, its hours in flight, atmospheric conditions, and the type landing field from which it is operating. For this reason, periodic aircraft weighings are desirable and, in the case of air carrier and air taxi aircraft, are required by Federal Aviation Regulations (FARs). An aircraft may also need to be reweighed if the aircraft's weight and balance records are lost, destroyed, or if there is reason to believe they are inaccurate.

Privately owned and operated aircraft are not required by regulation to be weighed periodically. They are usually weighed when originally certificated, or after making major repairs or alterations that can affect the weight and balance. Even though the aircraft need not be weighed, it must be mathematically loaded so that the maximum weight and CG limits are not exceeded during operation.

Air carrier and air taxi aircraft (scheduled and nonscheduled) carrying passengers or cargo are subject to certain rules that require owners to show that the aircraft is properly loaded and will not exceed the authorized weight and balance limitations during operation.

Section 2

Principles of Weight and Balance

Weight and Balance Theory

The theory of weight and balance is extremely simple. It is that of the familiar lever that is in equilibrium, or balance, when it rests on the fulcrum in a level position. The influence of weight is directly dependent upon its distance from the fulcrum. To balance the lever, the weight must be distributed so that the turning effect is the same on one side of the fulcrum as on the other. In general, a lighter weight far out on the lever has the same effect as a heavy weight near the fulcrum.

The distance of any object from the fulcrum is called the lever arm. The lever arm multiplied by the weight of the object is its turning effect about the fulcrum. This turning effect is known as the moment (Figure 5-2-1). In this figure, note that although the two weights are different, they balance because of the difference in the distance of the arms of the fulcrum.

An aircraft is balanced if it would remain level when suspended from an imaginary point. This point is the location of its ideal CG. To obtain this balance is simply a matter of placing loads so that the average arm of the loaded aircraft falls within the CG range. The exact location of the range is specified for each type of airplane.

Because fuel and other items are consumed, passengers and crew may move about, and for various other reasons, an aircraft cannot remain in perfect balance during flight. For this reason, a safe range of CG travel is established by the manufacturer.

Mathematical proof. Weight and balance control consists of mathematical proof of the correct

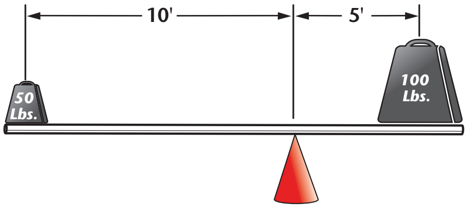


Figure 5-2-1. Balance may change by changing weights or the fulcrum points.

weight, balance, and loading within specified limits. These limits are set forth in the specifications for a particular aircraft. The removal or addition of equipment changes the aircraft empty weight and the CG. The useful load is affected accordingly. The effects that these changes produce on the balance of an aircraft must be investigated to determine the effect on the flight characteristics of the aircraft.

Weight and balance data. Weight and balance data can be obtained from the following sources:

- The Aircraft Specifications or Type Certificate Data Sheet.
- The aircraft operating limitations.
- The aircraft flight manual.
- The aircraft weight and balance report.

When weight and balance records have been lost and cannot be duplicated from any source, the aircraft must be reweighed. A new set of weight and balance records must be computed and compiled.

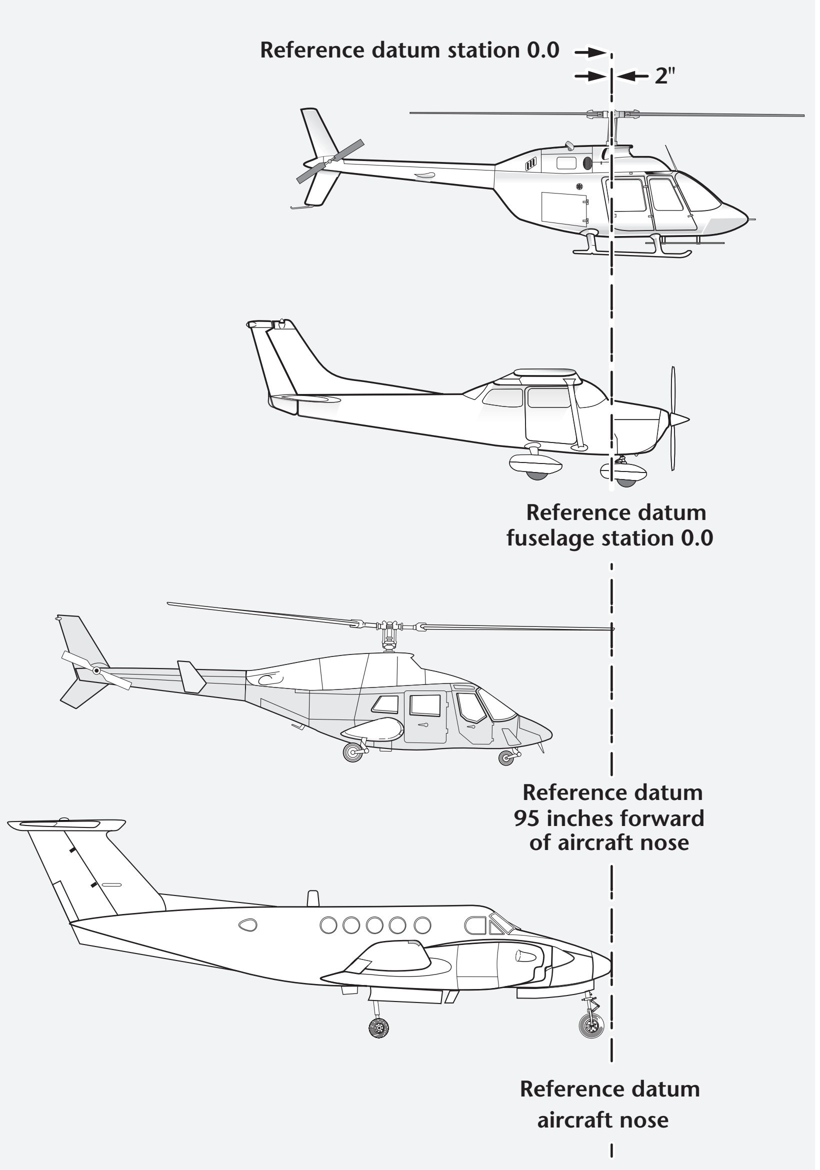


Figure 5-2-2. Reference datums chosen by different manufacturers.

Terms Used in Weight and Balance

Before any study of weight and balance can begin, the following terms must be fully understood:

Datum. The datum is an imaginary vertical plane from which all horizontal measurements for balance purposes are taken, with the aircraft in level flight attitude. It is a plane at right angles to the longitudinal axis of the aircraft. For each aircraft make and model, all locations of equipment, tanks, baggage compartments, seats, engines, propellers, etc., are listed in the Aircraft Specification or Type Certificate Data Sheets (TCDS) as being so many inches from the datum.

There is no fixed rule for the location of the datum. In some cases, it is located on the nose of the aircraft or some point on the aircraft structure itself. In most cases, it is located a certain distance forward of the nose section of the aircraft. The manufacturer has the choice of locating the datum where it is most convenient for measurement, locating equipment, and weight-and-balance computation.

The datum location is indicated on most aircraft specifications. On some of the older aircraft, where the datum is not indicated, any convenient datum may be selected. However, once the datum is selected, it must be properly identified so that anyone who reads the figures will have no doubt about the exact datum location. Figure 5-2-2 shows some datum locations used by manufacturers.

Arm. The arm is the horizontal distance that an item of equipment is located from the datum. The arm's distance is always given or measured in inches, and, except for a location which might be exactly on the datum (0), it is preceded by the algebraic sign for plus (+) or

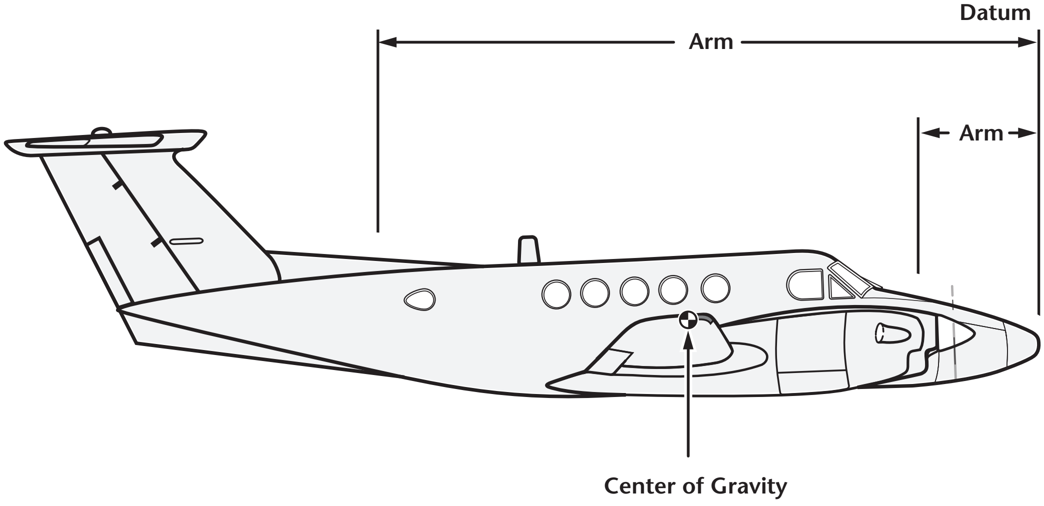


Figure 5-2-3. Reference datum line.

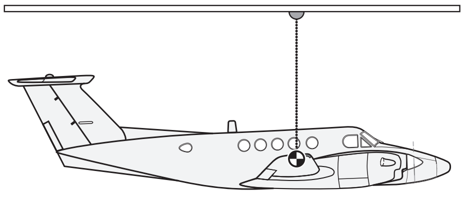


Figure 5-2-4. An airplane suspended from its center of gravity.

minus (–). The plus (+) sign indicates a distance aft of the datum, and the minus (–) sign indicates a distance forward of the datum.

If the manufacturer chooses a datum that is at the most forward location on an aircraft (or some distance forward of the aircraft), all the arms will be plus (+), or aft of the datum, and few, if any, arms will be minus (–), or forward of the datum. (Figure 5-2-3.)

The arm of each item is usually included in parentheses immediately after the item's name or weight in the specifications for the aircraft, (e.g., seat [+23]). When such information is not given, it must be obtained by actual measurement.

The following terminology is used in the practical application of weight and balance control, and should be thoroughly studied.

Aircraft leveling. Reference points are provided for leveling the aircraft on the ground. They are designated by the manufacturer and are indicated in the pertinent Aircraft Specifications or TCDS. The most common leveling procedure is to place a spirit level at designated points on the aircraft structure. Some aircraft have special leveling scales built into the airframe structure. The scale is used with a plumb bob to level the aircraft longitudinally and laterally.

Balance point. The balance point is the point at which the nose-heavy moments and the tail-heavy moments are of equal magnitude. This point may also be known as the Center of Gravity (CG). (Figure 5-2-4.)

Ballast. Ballast is any weight added to the aircraft used to bring the CG within a desirable range. This weight may be permanent or it may be temporary. Ballast is often in the form of lead and should be marked as such. Permanent ballast is often used on helicopters and is placed in the nose or the tail to minimize the weight. Temporary ballast is usually used for a specific loading problem to obtain the desired CG.

Center of gravity. The CG of an aircraft is a point about which the nose-heavy and tail-heavy moments are exactly equal in magnitude. An aircraft suspended from this point would have no tendency to rotate in either a nose-up or nose-down attitude. It is the point about which the weight of an airplane or any object is concentrated. The CG location is measured from the datum.

Empty weight. The empty weight of an aircraft includes all operating equipment that has a fixed location and is actually installed in the aircraft. It includes the weight of the airframe, powerplant, required equipment, optional or special equipment, fixed ballast, hydraulic fluid, and residual fuel and oil.

Residual fuel and oil are the fluids that will not normally drain out because they are trapped in the fuel lines, oil lines, and tanks.

Aircraft type certified under FAR Part 23 after March 1, 1978, require that all operating fluids be included in the empty weight including full oil. Information regarding fluids that will be included in the empty weight or are residual will be given in the Aircraft Specifications or TCDS for the specific aircraft.

Basic weight. Basic weight is a weight determined by the manufacturer. It typically consists of weighing every tenth aircraft prior to adding any optional equipment. The optional equipment is then added mathematically. Do not confuse the basic weight with the empty weight.

Empty-weight center of gravity (EWCG). The EWCG is the CG of an aircraft in its empty weight condition. It is an essential part of the weight and balance record of the aircraft. It has no usefulness in itself but serves as a basis for other computations and not as an indication of what the loaded CG will be. The EWCG is computed at the time of weighing, using formulas established for tailwheel- and nosewheel-type aircraft.

Empty-weight center of gravity (EWCG) range. The EWCG range is an allowable variation of travel within the CG limits. When the EWCG of the aircraft falls within this range, it is impossible to exceed the EWCG limits using standard specification loading arrangements. Not all aircraft have this range indicated on the Aircraft Specifications or TCDS. Where it is indicated, the range is valid only as long as the aircraft is loaded according to the standard specification. The installation of items not listed in the specification will not permit use of this range.

Full oil. Full oil is the quantity of oil shown as oil capacity in the Aircraft Specifications or TCDS. When weighing an aircraft, the oil tank can either contain the number of gallons of oil specified or be drained. When an aircraft with full oil tanks is weighed, the weight of the oil must be subtracted from the recorded readings to arrive at the actual empty weight. The weight and balance report must show whether weights include full oil or if the oil tanks were drained.

Lateral center-of-gravity formula. This formula is used most often on helicopter applications where the lateral CG is computed as well as the longitudinal CG.

$$CG = \frac{(AL \times C) + (BR \times D)}{W}$$

Where:
W = Weight of aircraft
AL= Butt Measurement Left
BR= Butt Measurement Right
C = Weight of Main Scale Left
D = Weight of Main Scale Right

Left Butt Line is Negative
Right Butt Line is Positive

Longitudinal center-of-gravity formulas. Two different types of formulas are used in the computation of the longitudinal CG.

The first of these is the simplest. However, it may be subject to errors due to the fact that the plus (+) or minus (-) sign may be confused.

This formula is used almost exclusively when new equipment is added to the aircraft.

$$CG = \frac{\text{Total moment}}{\text{Total weight}}$$

Other formulas used for longitudinal center of gravity are often used for the original weighing of the aircraft and are contained in AC 43.13-1B.

$$CG = D - \left(\frac{F \times L}{W}\right) = \text{Nosewheel with datum forward of the main wheels}$$

$$CG = -\left(D + \frac{F \times L}{W}\right) = \text{Nosewheel with datum aft of the main wheels}$$

$$CG = D + \left(\frac{R \times L}{W}\right) = \text{Tailwheel with datum forward of the main wheels}$$

$$CG = -D + \left(\frac{R \times L}{W}\right) = \text{Tailwheel with datum aft of the main wheels}$$

Where:
W = Weight of aircraft
D = Distance from datum to the main wheel weighing point
L = Distance from the main wheel weighing point to the nosewheel or tailwheel weighing point
F = Weight at the nosewheel weighing point
R = Weight at the tailwheel weighing point

Straight line variation between points. Straight line variation between points is a term often used to describe a weight and balance shift within the envelope. It means that a shift forward of the actual CG has the same effect as an equal shift aft of the actual CG (i.e., the variation is in equal percentages and varies in a straight line).

Maximum weight. The maximum weight is the maximum authorized weight of the aircraft and its contents and is indicated in the specifications. For many aircraft, there are variations to the maximum allowable weight, depending on the purpose and conditions under which the aircraft is to be flown.

For example, a certain aircraft is allowed a maximum gross weight of 2,750 pounds when flown in the normal category, but when flown in the utility category the same maximum allowable gross weight is 2,175 pounds.

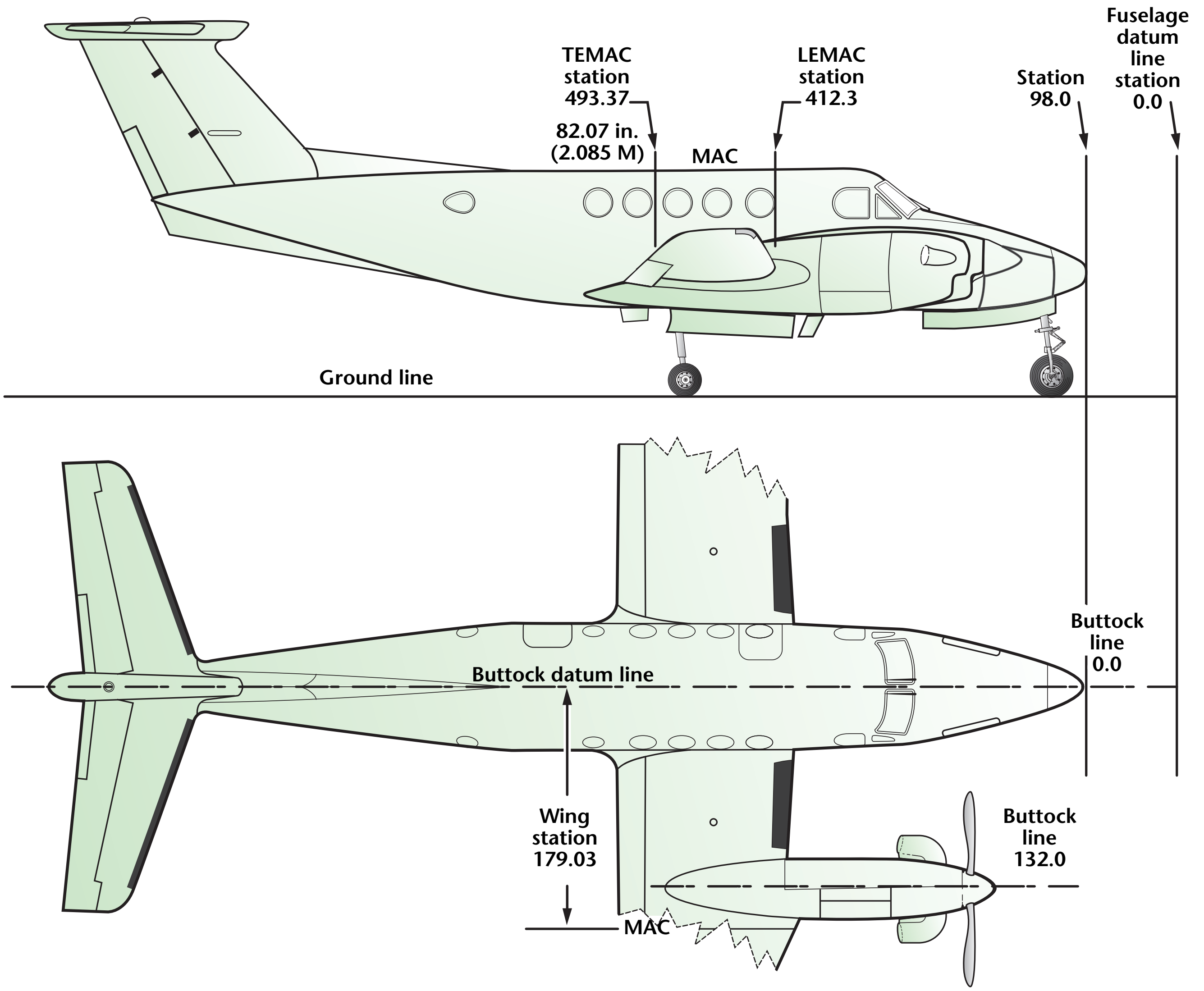


Figure 5-2-5. The MAC for a taper-winged aircraft.

Many transport category aircraft have other maximum weights, which include maximum landing weight, maximum ramp weight, and maximum takeoff weight. Their definitions are:

- Maximum landing weight is the maximum weight that the aircraft can land. This is usually less than the maximum takeoff weight due to the structural loads placed on the aircraft during landing.
- Maximum ramp weight is usually greater than the maximum takeoff weight. The weight difference between ramp weight and takeoff weight is fuel burned during taxi to the runway.
- Maximum takeoff weight is the maximum weight at which the aircraft can start its takeoff on the runway.

Mean Aerodynamic Chord (MAC). The MAC is the mean average chord of the wing. An airfoil section is a cross section of a wing from leading edge to trailing edge. A chord is usually defined as an imaginary straight line drawn parallel to the airfoil through the leading and trailing edges of the section. The MAC of a constant-chord wing would be the same as the actual chord of the wing. Any departure from a rectangular wing planform will affect the length of the MAC and the resulting distance from the MAC leading edge to the aircraft's wing leading edge. Figure 5-2-5 shows the MAC for a taper-winged aircraft.

The aircraft CG is usually placed at the maximum forward position of the center of pressure on the MAC to obtain the desired stability. Because of the relationship between the CG location and the moments produced by aerodynamic forces, the greatest of which is lift, the CG location is generally expressed with respect to the wing. This is done by specifying CG in percent of the wing's MAC.

The leading or trailing edge of the wing is used along with the reference datum line to determine MAC. The leading edge of the MAC is usually referred to as the LEMAC, and the trailing edge is referred to as the TEMAC.

The location of the MAC, in relation to the datum, is given in the Aircraft Specifications or Type Certificate Data Sheets, the weight and balance report, or the aircraft flight manual.

Minimum fuel. The term minimum fuel should not be interpreted to mean the minimum amount of fuel required to fly an aircraft. Minimum fuel, as it applies to weight and balance, is the amount of fuel that must be shown on the weight and balance report when the airplane is loaded for an extreme-condition check.

The minimum fuel load for a small aircraft with a reciprocating engine for balance purposes is based on engine horsepower. It is calculated in the maximum except takeoff (METO) horsepower and is the figure used when the fuel load must be reduced to obtain the most critical loading on the CG limit being investigated. Either of two formulas may be used:

Minimum fuel = 1/12 gallons per horsepower
hp × 1/12 × 6 lb.
1,200 × 1/12 × 6 = 1,200 × 1/2 = 600 lb. fuel

Minimum fuel = 1/2 lb. per engine horsepower
hp = 1/2 = minimum fuel
1,200 × 1/2 = 600 lb. fuel

This will be the minimum pounds of fuel required for the forward or rearward weight check.

For turbine-engine-powered aircraft, the minimum fuel load is specified by the aircraft manufacturer.

The fuel tank location in relation to the CG limit affected by the computation determines the use of minimum fuel. For example, when a forward weight check is performed, if the fuel tanks are located forward of the forward CG limit, they are assumed to be full. If the minimum fuel required for a particular aircraft exceeds the capacity of the tanks located forward of the forward CG limit, the excess fuel must be loaded in the tanks that are aft of the forward CG limit. When a rearward weight check is conducted, the fuel loading conditions are opposite to those used for the forward check.

Moment. A moment is the product of a weight multiplied by its arm.

The moment of an item about the datum is obtained by multiplying the weight of the item by its horizontal distance from the datum. Likewise, the moment of an item about the CG can be computed by multiplying its weight by the horizontal distance from the CG.

A 20-pound weight located 30 inches from the datum would have a moment of 20 × 30, or 600 lb-in. Whether the value of 600 lb.-in. is preceded by a plus (+) or minus (–) sign depends on the relationship of the arm to the datum.

Moment index. The moment index is the moment reduced by 10,000, 1,000, or 100 for ease in balance calculations, and is often shown as MOM/1000 or MOM × 100.

Operating CG range. The operating CG range is the distance between the forward and rearward CG limits indicated in the pertinent Aircraft Specification or TCDS.

Determined at the time of design and manufacture, these limits are the extreme loaded CG positions allowable within the applicable regulations controlling the design of the aircraft. They are shown in either percent of MAC or inches from the datum of the aircraft.

The loaded aircraft CG location must remain within these limits at all times. Accordingly, detailed instructions for determining load distribution are provided on placards, loading charts, and load adjusters.

Standard weights. Standard weights used in weight and balance computations are as follows:

Aviation gasoline ....6.0 pounds per gallon
Turbine fuel .... 6.7 pounds per gallon
Oil .... 7.5 pounds per gallon
Water .... 8.35 pounds per gallon
Crew and passengers ...... 170 pounds per person

Additional FAR Part 135 Standard Weights are:

Adults .... 160 (summer) per person
Adults .... 165 (winter) per person
Children .... 80 pounds per person
Crew other than
flight attendants .... 170 pounds per person
Female flight attendants . 130 pounds per person
Male flight attendants .....150 pounds per person
Check-in baggage ....23.5 pounds per item
Carry-on baggage ....10 pounds per item

Station. A station is any longitudinal location on the aircraft measured from the datum or a lateral wing point measured from buttline 0. Stations are normally measured in inches, with the least measurement usually 0.50 inches. It is not, however, unusual to find measurements as low as 0.05 inches.

Tare weight. Tare includes the weight of all extra items on the weighing scale platform that are not a part of the item being weighed, such as jacks, blocks, and chocks. The weight of these items, when included in the scale reading, is deducted to obtain the actual weight of the aircraft.

Unusable fuel. The unusable fuel is the fuel left in the fuel system, which cannot be consumed by the engine. This amount is usually given in the Aircraft Specifications or Type Certificate Data Sheets.

Undrainable oil. Undrainable oil is the oil that remains trapped in the oil system when the oil is drained.

Useful load. The useful load of an aircraft is determined by subtracting the empty weight from the maximum allowable gross weight. For aircraft certificated in both the normal and utility categories, there may be two useful loads listed in the aircraft weight and balance records.

An aircraft with an empty weight of 900 pounds will have a useful load of 850 pounds, if the normal category maximum weight is listed as 1,750 pounds. When the aircraft is operated in the utility category, the maximum gross weight may be reduced to 1,500 pounds, with a corresponding decrease in the useful load to 600 pounds. Some aircraft have the same useful load regardless of the category in which they are certificated.

The useful load consists of full oil, fuel, passengers, baggage, pilot, copilot, and crewmembers. A reduction in the weight of an item, where possible, may be necessary to remain within the maximum weight allowed for the category in which an aircraft is operating. Determining the distribution of these weights is called a weight check.

For aircraft type certified under FAR Part 23 after March 1, 1978, oil is not included in the useful load. Full oil is considered part of the empty weight of the aircraft.

Weighing points. In weighing an aircraft, the point on the scale at which the weight is concentrated is called the weighing point.

When weighing light- to medium-weight aircraft, the wheels are usually placed on the scales. This means that the weighing point is, in effect, the same location obtained by extending a vertical line through the centerline of the axle and onto the scale.

Other structural locations capable of supporting the aircraft, such as jack pads on the main spar, may also be used if the aircraft weight is resting on the jack pads. The weighing points should be clearly indicated in the weight and balance report.

Zero fuel weight. The zero fuel weight is the maximum allowable weight of a loaded aircraft without fuel. Included in the zero fuel weight is the weight of cargo, passengers, and crew. All weights in excess of the zero fuel weight must consist of usable fuel.

Section 3

Aircraft Weighing Procedures

Preparation for Weighing

Before any weighing can begin, it is necessary to become familiar with the pertinent data available concerning the weight and balance of the particular aircraft. This information will be found in the FAA documentation and the manufacturer's manuals and would include:

- Aircraft Specifications
- Type Certificate Data Sheet
- Manufacturer's maintenance manual (MM)

The Type Certificate Data Sheet and the Aircraft Specifications contain basically the same information. However, the Aircraft Specifications have more detail concerning optional approved equipment and their arms and weight. This information is now furnished by the manufacturer on aircraft that have a Type Certificate Data Sheet. In both documents, the following pertinent information can be found:

- CG range
- Empty weight CG range
- Leveling means
- Maximum weight
- Seats and location
- Baggage capacity
- Fuel capacity
- Datum location

Figure 5-3-1 is an excerpt of a typical type certificate data sheet. Much of the information necessary to perform the weighing and computations are self-explanatory. However, a few do need some explanations.

Looking at the top block of the Type Certificate Data Sheet, several aircraft are included in the same data sheet. Even though there is a large number of aircraft, it is not unusual that multiple variations of the same aircraft

DEPARTMENT OF TRANSPORTATION
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	3A19
	Revision 35
	CESSNA
150	150J
150A	150K
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150D	A150L
150E	150M
150F	A150M
150G	152
150H	A152
	August 15, 1980

TYPE CERTIFICATE DATA SHEET NO. 3A19

This data sheet which is part of Type Certificate No. 3A19 prescribes conditions and limitations under which the product for which the type of certificate was issued meets the airworthiness requirements of the Federal Aviation Regulations.

Type Certificate Holder — Cessna Aircraft Company
Pawnee Division
Wichita, Kansas 67201

IX - Model 152,2 PCLM (Utility Category) Approved March 16, 1977

Engine	Lycoming 0-235-L2C
Fuel	100LL/100 min. grade aviation gasoline
Engine Limits	For all operations 2550 rpm. (110 hp.)
C.G. Range	(+32.65) to (+36.5) 1670 lb. (+31.0) to (+36.5) at 1350 lb. or less Straight line variation between points given.
Empty Wt. C.G. Range	None
Leveling Means	Jig located nut plates and screws at Stations (+94.63) and (+132.94) on left side of tailcone
*Maximum Weight	1670 lb. 1675 lb. ramp weight (S/N 15282032 and on)
No. of Seats	2 at (+39); (for child's optional jump seat, refer to Equipment List)
Maximum Baggage	120 lb. (Reference Weight and balance data)
Fuel Capacity	26 gal. (24.5 gal usable two 13 gal. tanks in wings at +42.0) See NOTE 1 for data on usable fuel.
Oil Capacity	6qt. (-14.7; unusable 2 qt.) See NOTE 1 for data on undrainable oil

Data Pertinent to All Models

Datum	Fuselage station 0.0 front face of firewall

Note 1. Current weight and balance report together with list of equipment included in certificated empty weight and loading instructions when neccessary must be provide for each aircraft at time of original certification.

Serial Nos. 15077006 through 15079405 and A1500610 through A1500734.
The certificated empty weight and corresponding center of gravity location must include unusable fuel of 21 lb. at (+40) and full oil of 11.3 lb. at (-13.5) for landplane.

Serial Nos. 15279406 through 1520735 and A1520735 and on.
The certificated empty weight and corresponding center of gravity location must include unusable fuel of 9 lb. at (+40) and full oil of 11.3 lb. at (-14.7) for landplane.

Figure 5-3-1. Typical type certificate data sheet.

are manufactured under the same Aircraft Specification or data sheet.

When several models are covered on one data sheet, the pertinent information for a particular model is listed in one area, as shown in Figure 5-3-1. The information includes the facts such as the CG range and empty CG range. On some aircraft, no empty CG range is given. This is due to the use of a loading graph by the pilot to determine if the aircraft is loaded properly. In this case, the only CG range given is the loaded CG range. However, not all aircraft make use of a loading graph like the one described.

Additional information needed for weighing the aircraft includes the leveling means. During the actual weighing process, the aircraft must be level. The maximum weight may include a ramp weight, which is heavier than the maximum weight. This additional weight would be lost prior to takeoff due to fuel consumed during engine runup and taxiing.

Both the fuel and oil capacity refer to Note 1. These give different specifications for different serial numbered aircraft. It might be noted that the later serial numbered aircraft include full oil in the empty weight.

Some data is pertinent to all models covered by the data sheet. One of these items is the datum, which is located at the firewall of the aircraft. Other information, such as the location of seats, may have value in a loading investigation. Information such as loading charts and equipment will be found in the operator's manual for the aircraft.

Weighing an aircraft is a very important and exacting phase of aircraft maintenance and must be carried out with accuracy. Thoughtful preparation saves time and prevents mistakes.

Preparation of the aircraft. The first step in preparing the aircraft for weighing is to thoroughly clean the aircraft. The dirt, which is spread over a large area, can add to the total weight of the aircraft.

Drain the fuel system until the quantity indication reads zero or empty with the aircraft in a level attitude. If any fuel is left in the tanks, the aircraft will weigh more, and all later calculations for useful load and balance will be affected. Only trapped or unusable fuel (residual fuel) is considered part of the aircraft's empty weight. Fuel tank caps should be on the tanks or placed as close as possible to their correct locations, so that the weight distribution will be correct.

In special cases, the aircraft may be weighed with the fuel tanks full, provided a means of determining the exact weight of the fuel is available. Consult the aircraft manufacturer's instructions to determine whether a particular model aircraft would be weighed with full fuel or with the fuel drained.

Before draining oil from the aircraft, the Aircraft Specifications should be checked to determine if the tanks should be full or empty. If the engine oil is not included, drain all engine oil from the oil tanks. The system should be drained with all drain valves open. Under these conditions, the amount of oil remaining in the oil tank, lines, and engine is termed residual oil and is included in the empty weight. If impractical to drain, the oil tanks should be completely filled and the weight of the oil computed.

The position of items such as spoilers, slats, flaps, and helicopter rotor systems is an important factor when weighing an aircraft. Always refer to the manufacturer's instructions for the proper position of these items.

Unless otherwise noted in the Aircraft Specifications or manufacturer's instructions, hydraulic reservoirs and systems should be filled, drinking and washing water reservoirs and lavatory tanks should be drained, and constant-speed-drive oil tanks should be filled.

Inspect the aircraft to see that all items included in the certificated empty weight are installed in the proper location. Remove items that are not regularly carried in flight. Also look in the baggage compartments to make sure they are empty.

Replace all inspection plates, all stressed panels, oil and fuel tank caps, junction box covers, cowling, doors, emergency exits, and other parts that have been removed. All doors, windows, and sliding canopies should be in their normal flight position.

The aircraft should be in the hangar with the doors closed to minimize the air gusts that might destabilize the scales.

After the scales have been properly calibrated to zero, the aircraft must then be placed on them. If the aircraft is weighed on the wheels, ramps are usually used to roll the aircraft on to the scales. For heavier aircraft, it may be necessary to jack the aircraft and slide the scale under the wheel. On most large aircraft, the jack points are used with electronic scales. In these cases, the load cell is placed between the jack and the jackpoint, as shown in Figure 5-3-2.

All aircraft have leveling points or lugs, and care must be taken to level the aircraft, especially along the longitudinal axis. With light, fixed-wing airplanes, the lateral level is not as critical as it is with heavier airplanes. However,

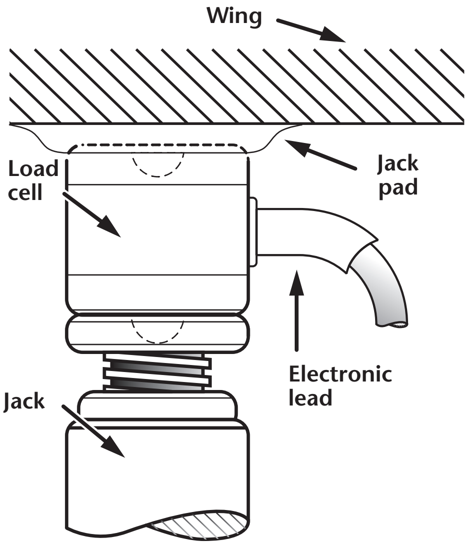


Figure 5-3-2. Load cell placement.

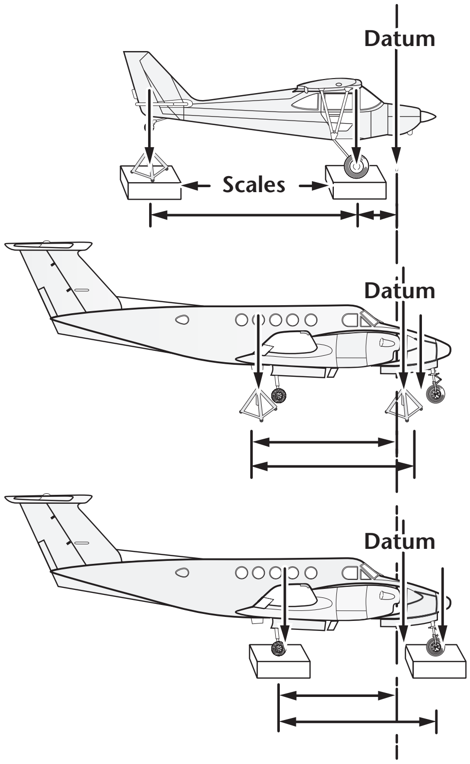


Figure 5-3-3. Jacking configurations.

a reasonable effort should be made to level the light airplanes around the lateral axis. Accuracy in leveling all aircraft longitudinally cannot be overemphasized.

Equipment. The equipment necessary for weighing the aircraft will vary with the type of aircraft to be weighed. Some aircraft are weighed at the wheels while others are weighed from jackpoints. Tailwheel aircraft will require additional equipment to raise the tail to the level position. (Figure 5-3-3.)

The preparation for weighing the aircraft should begin with a review of the manufacturer's MM and the Aircraft Specifications for the particular aircraft and gathering the necessary equipment as required.

Scales may be either mechanical or electronic. In either case they should be in good mechanical order and recalibrated as required. Electronic scales are available today that simplify the weighing procedure for light aircraft. (Figure 5-3-4.)

If the aircraft is to be weighed using the wheels as weighing points, chocks will be necessary. The chocks are used to hold the aircraft on the scales and are considered as part of the tare weight. The parking brakes should never be used for this purpose because they may place a side load on the scales.

When jackpoints are used for weighing, appropriate jacks will be necessary for all jackpoints because the aircraft must be leveled and weighed from these points.

To level the aircraft, either a spirit level or a plumb bob will be necessary depending upon the leveling means provided by the manufacturer.

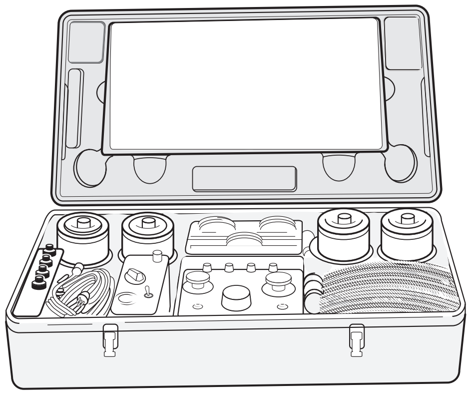


Figure 5-3-4. Aircraft electronic weighing kit.

Additional equipment includes a straight edge, measuring tape, chalk line, and plumb bob to obtain actual wheel or jackpoint measurements as required.

Appropriate data must always be available. This will include specifications and manufacturer maintenance information concerning weight and balance.

Recording the data. The distance from the datum to the main weighing point centerline and the distance from the main weighing point centerline to the tail (or nose) weighing point centerline must be known to determine the CG relative to the main weighing point and the datum.

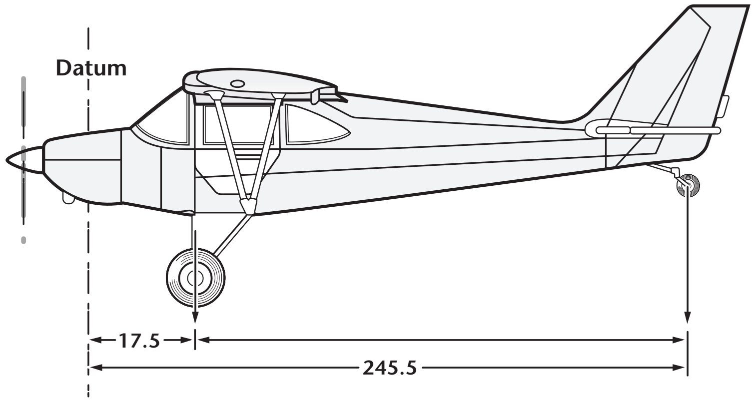


Figure 5-3-5. A typical tail wheel conventional aircraft.

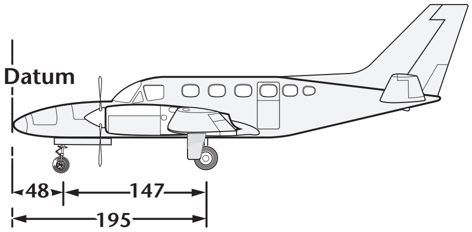


Figure 5-3-6. Typical nose wheel (tricycle) aircraft.

An example of main weighing point to datum and main weighing point to tail weighing point is shown in Figure 5-3-5. Refer to Figure 5-3-6 for an example of main weighing point to datum and main weighing point to nosewheel measurements.

These distances may be calculated using information from the Aircraft Specifications or Type Certificate Data Sheets. However, it will often be necessary to determine them by actual measurement.

After the aircraft has been placed on the scales (Figure 5-3-6) and leveled, hang plumb bobs from the datum, the main weighing point, and the tail or nose weighing point so that the points of the plumb bobs touch the floor. Make a chalk mark on the floor at the points of contact. If desired, a chalk line may be drawn connecting the chalk marks. This will make a clear pattern of the weighing point distances and their relation to the datum.

Weighing points should be clearly indicated on the aircraft weighting form. Record the weights indicated on each of the scales and make the necessary measurements while the aircraft is still level. After all weights and measurements are obtained and recorded, the aircraft may be removed from the scales. Weigh the tare and deduct its weight from the scale reading at each respective weighing point where tare is involved.

Locating the Balance Point

Balance computations. Once the scale weights and measurements are obtained from the actual weighing process, two items can be computed—one is the empty weight of the aircraft and the other is the empty weight CG. Without these two figures, the proper loading of the aircraft cannot be determined.

Since the weighing procedure varies to some degree, the weights of three different aircraft will be calculated, including one light aircraft, one small transport aircraft, and, later in the chapter, one helicopter. The first of these aircraft discussed is a light training aircraft.

Problem 1. This aircraft is a simple, single engine, nosewheel aircraft that can easily be weighed using a scale as shown in Figure 5-3-7.

The information obtained from the Type Certificate Data Sheet includes:

Datum	Front face of firewall
Maximum weight	1,670 lbs.
CG Range	(+32.65) to (+36.50) at 1,670 lbs. (+31.00) to (+36.50) at 1,350 lbs. or less
Leveling means	Stations (+94.63) and (+132.94) of the left side of the tail cone
Oil capacity	Use full oil for the empty CG calculation
Maximum baggage	120 lb.
Seats	2 at (+39)
Fuel capacity	26 gal (24.50 gal usable); Two 13 gal tanks at (+42.00)

1. Clean the aircraft and remove all loose articles. Drain the fuel and check the oil level for full. The serial number is 15285979, therefore, according to the Type Certification Data Sheet, full oil is included in the empty weight. It might also be noted that 1.5 gallons of fuel is considered unusable and will be included in the empty weight by computation.
2. Place the aircraft in a closed hangar and retract the flaps.
3. Check the scale adjustments for zero and place the aircraft on the scales. Use chocks under the wheels. Use no brakes.
4. Place a spirit level on the tailcone leveling points and deflate the nose strut to obtain level.
5. Record the scale readings and subtract the tare (Table 5-3-1).

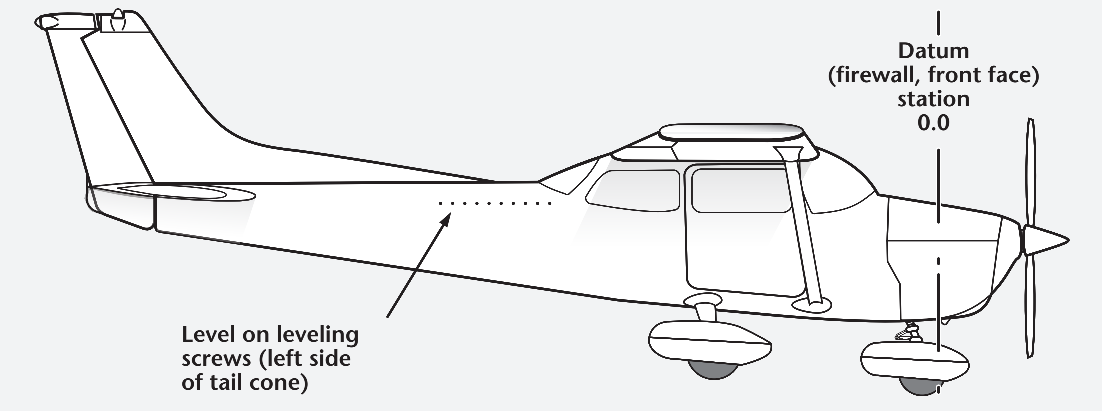


Figure 5-3-7. Typical lightweight training aircraft.

6. Using a plumb bob and a steel tape, measure the horizontal distances from the nosewheel to the main wheels and the datum to the nosewheel. The distances are (+46.75) and (–10.9), respectively.
7. Using the formula from page 5-5 for nosewheel aircraft, compute the empty CG:

$$CG = D - \left(\frac{F \times L}{W}\right)$$

D = 46.75
F = 355
L = 57.65
W = 1,143

$$46.75 - \frac{355 \times 57.65}{1{,}143} = 28.85$$

8. Using the formula for moment, compute the moment.

CG × Weight = Moment
29.85 × 1,143 = 32,975.55

9. In order to obtain the basic empty weight, unusable fuel, which is 9 lb. at (+40), must be added (Table 5-3-2).

Problem 2. A commuter aircraft is flown by several regional carriers and carries 30 passengers. Although it is much larger than the trainer, the weighing and computations are much the same (Figure 5-3-8).

Datum .... 98 inches forward of the nose
Leveling means .... Bubble level on seat track
Mean Aerodynamic Chord.. 82.07 inches, LEMAC 412.3
Empty weight .... Must include total engine and gear box oil; 75 lb. at (+363); hydraulic oil 25 lb. at (+218); unusable fuel 110 lb. at (+440)

Maximum weights:
Ramp 27,300
Takeoff .... 27,000 (27,275 with 1083 mod)
Landing.............................. 26,500
Max zero fuel weight 25,000
Minimum crew 2

1. Clean the aircraft and remove all loose articles. Drain the fuel, galley water, and baggage compartments.
2. Service the engine oil, gear box oil, hydraulic system, and other standard systems.
3. Place the aircraft in a closed hangar.
4. Check the scales for zero and place the load cells between the jacks and the jack-points and raise the aircraft (Figure 5-3-9).
5. Level the aircraft both laterally and longitudinally.
6. Record the reading.

NOTE: No use of tare is required because of use of electronic scales).

	Gross	Tare	Net
Left main	406	2	404
Right main	406	2	404
Nosewheel	355	0	355

Table 5-3-1. Typical weight record.

	Weight	Arm	Moment
As weighed	1,143	29.85	34,118.5
Fuel	+9	40.0	360
Basic empty weight	1,152		
Total moment		29.92	34,478.5

Table 5-3-2. Typical weight and balance sheet.

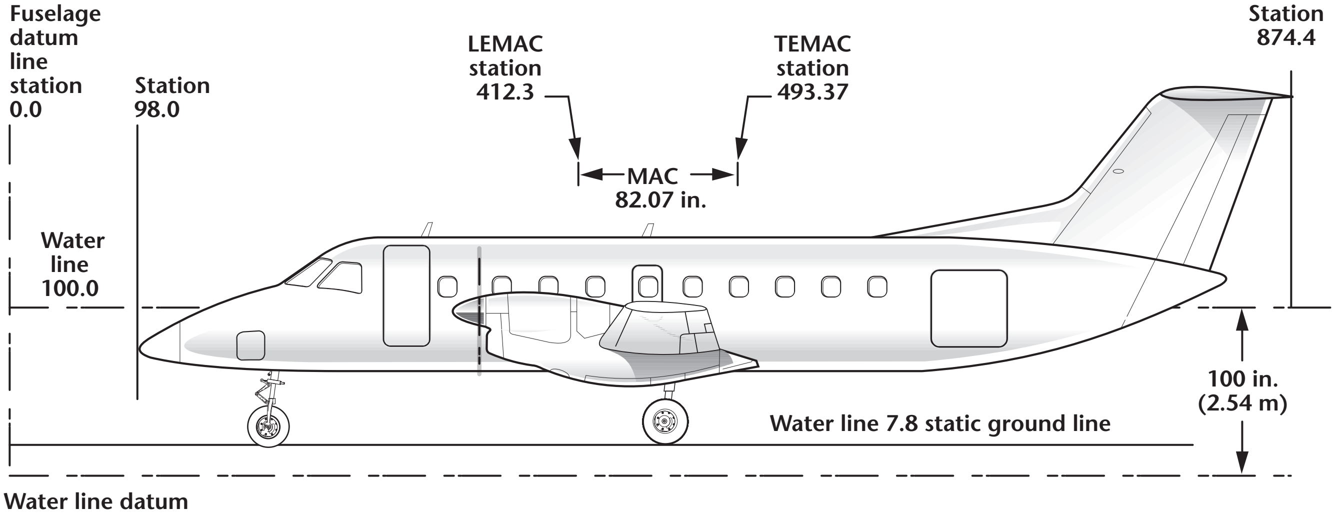


Figure 5-3-8. Typical commuter aircraft.

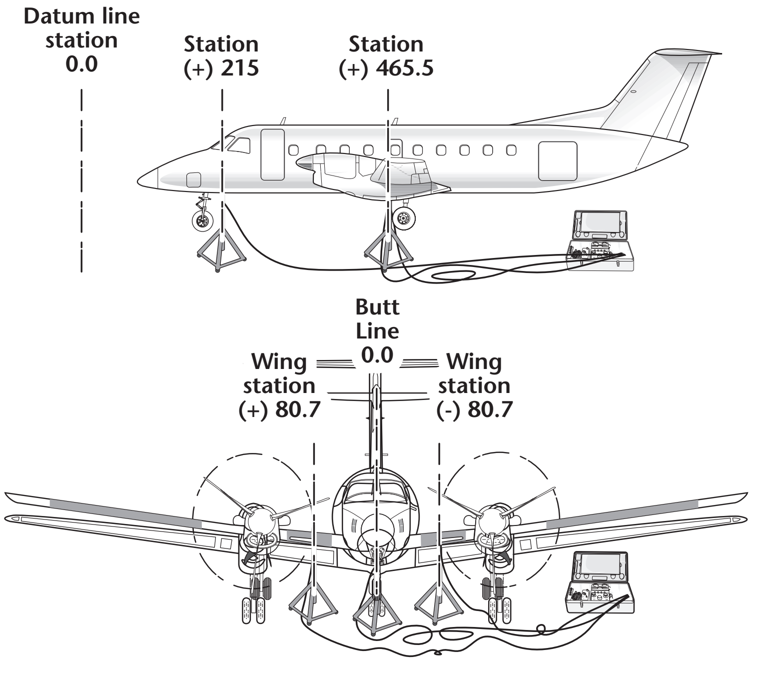


Figure 5-3-9. Weighing a commuter aircraft using an electronic weighing kit.

Left main jackpoint..............7,614

Right main jackpoint............7,564

Nose jackpoint.....................2,724

17,902

7. The jackpoint measurements are:

Nose jackpoint............... 215 inches

Wing jackpoint............... 465.5 inches

8. Using the formula for nosewheel aircraft with the datum forward of the main wheels, compute the CG.

$$CG = D - \left(\frac{F \times L}{W}\right)$$

$$= 465.50 - \frac{2{,}724 \times 250.50}{17{,}902}$$

$$= 465.50 - \frac{682{,}362}{17{,}902}$$

$$= 465.50 - 38.11$$

$$= 427.40$$

9. Since 110 lb. of unusable fuel at station 440 must be included in the empty weight and CG, this should be added at this time using the total moment/total weight formula.

NOTE: The moments can be divided by 100 to reduce the size of the number for the loading chart (Table 5-3-3).

17,902	427.40	7,651,314		76,513
110	440.00	48,400	or	484
18,012		7,699,714		76,997

NOTE: The moments can be divided by 100 to reduce the size of the number for loading chart, i.e.,

7,699,714 ÷ 100	=	76,997
76,997 ÷ 18,012	=	4.274,
then 4274 × 100	=	427.50
CG	=	427.50

The new empty weight figures are:
18,012 = Empty Weight CG = 427.50

10. Because this aircraft has tapered wings the graphs used for weight and balance express the CG in percent of MAC (Figure 5-3-8). For this reason, it will be necessary to convert the CG from inches to percent of MAC. To do so, we must know the

station of CG (427.5), the MAC (82.07) and LEMAC (412.3) and use the formula:

$$\%\,\text{MAC} = \frac{\text{STA} - \text{LEMAC}}{\text{MAC}} \times 100$$
$$= \frac{427.5 - 412.3}{82.07} \times 100$$
$$\text{CG} = 18.5\%\ \text{of MAC}$$

11. For some of the loading charts used with larger aircraft, weights and moments are used only to determine if the aircraft is within limits.

Center-of-Gravity (CG) Range

Empty CG range. Once the empty CG has been established, as has been done in the previous problems, this information is used by the flight crew in loading the aircraft within the CG range. It should be noted that some aircraft have an empty CG range and some aircraft have a loaded CG range.

The empty CG range is normally associated with older light aircraft. When the choice to use empty CG range has been made by the manufacturer, as long as the aircraft is flown within its limitations, and all standard loading is within the CG range, no further computations are required. Unfortunately, very few aircraft have an empty weight CG.

To utilize the empty weight and the empty CG, two typical systems are used. The flight crew is furnished with either a graph or a chart to determine the loaded CG. The use of these methods will be covered in the loading section of this chapter. When no chart or graph is furnished by the manufacturer, it will be necessary to investigate the extreme CG conditions in order to include the most forward and most aft conditions. These checks could require ballast for either convenience or necessity. The helicopter, which is described in the section on helicopter weight and balance, is such an aircraft.

Loaded CG range. The loaded CG range, (often referred to as the operating CG range), is the established forward and aft CG limits for a particular model of aircraft operated in a certain manner within its established weights. For example, an aircraft that can be operated in two different categories has different limitations in the normal and utility categories. Since the flight maneuvers for the two categories are different, the maximum weight and the CG range are less in the utility category than in the normal category.

It is also quite typical for aircraft to have loaded CG ranges that vary with the weight of the aircraft. Typically, the aircraft used in the empty CG problems had the CG range change as the aircraft approached the maximum weight.

Shifting the Center of Gravity (CG)

Ballast. The use of ballast on aircraft is quite limited because no one likes to carry additional weight in the aircraft when it is not necessary. The two types of ballast that may be used are temporary and permanent ballast.

Temporary ballast is normally used when an unusual flight condition occurs, or if some item is removed from the aircraft that could change the CG to an adverse condition. Normally such problems can be handled by loading the aircraft in a different configuration, such as restricting the use of certain passenger seats, placing all cargo in one compartment, or limiting the fuel load. If temporary ballast is used, it must be marked as such so that it is not removed by mistake.

Permanent ballast is used when the CG location will cause problems for normal loading of the aircraft. Under these circumstances, the ballast is marked permanent ballast and secured to the structure of the aircraft. When permanent ballast is required, the least amount of weight should be used. For this reason, the nose and the tail are typical locations for ballast as long as the structure can hold the weight required. Some manufacturers have specific locations for ballast as shown in Figure 5-3-10.

Calculations. Regardless of whether the ballast is temporary or permanent, it must be determined by the use of the formula:

$$\text{Ballast} = \frac{\text{Derived Weight} \times (\text{Required CG} - \text{Derived CG})}{\text{Ballast Arm} - \text{Required CG}}$$

Shifting weight. The CG is the distance of the exact point of balance of an aircraft from the established reference datum line. In other words, the CG is the arm of the aircraft. One way of shifting the CG without adding additional weight in the form of ballast is to move or shift weight, such as passengers, cargo, or equipment within the aircraft. By shifting weight within the aircraft, the CG is changed based on the amount of weight moved and the distance that it is moved.

Calculation. To determine how much weight is to be shifted or how far to shift a known weight, the following formula may be used:

$$\frac{\text{WS}}{\text{TW}} = \frac{\text{CG}}{\text{D}}$$

Where:
WS = Weight to be shifted
TW = Total weight
CG = Required change in CG
D = Distance weight is to be shifted

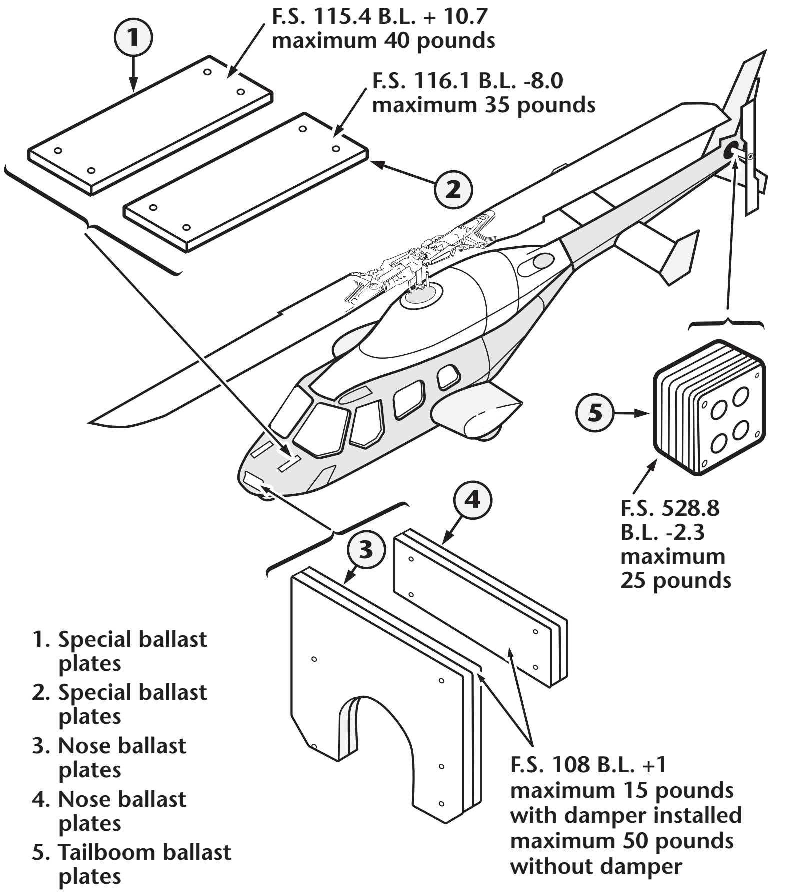


Figure 5-3-10. Typical example of ballast installation.

	Longitudinal			Lateral	
	Weight	Arm	Moment	Arm	Moment
Empty weight	5,065.00	256.30	1,298,159	0.50	2,532.50
Pilot/copilot	340.00	168.20	+57,188	+1.00	+340.00
Passengers facing aft	340.00	211.20	+71,808	0.00	0.00
Oil and engine	28.60	270.00	+7,722	0.00	0.00
	5,773.60	248.50	1,434,877	0.40	2,192.50
	Total weight	CG	Total moment	Lateral CG	Lateral moment

Table 5-3-3. Most forward CG chart.

	Longitudinal			Lateral	
	Weight	Arm	Moment	Arm	Moment
Empty weight	5,065.00	256.30	1,298,159	0.50	2,532.50
Pilot	170.00	168.20	+28,594	+16.00	+2,720.00
Passengers 3 aft seat	510.00	257.00	+131,070	0.00	0.00
Fuel	1,264.80	264.30	+334,287	0.00	0.00
Oil and engine	28.60	270.00	+7,722	0.00	0.00
	7,038.40	255.70	1,799,832	0.02	187.50

Table 5-3-4. Most rear CG chart.

Determine the weight to be shifted using the following formula:

$$WS = \frac{TW \times CG}{D}$$

Determine the distance that a given weight is to be shifted using the following formula:

$$D = \frac{TW \times CG}{WS}$$

Adverse Center of Gravity (CG)

The empty weight of an aircraft includes the aircraft and its required equipment, unusable fuel, and, when applicable, transmission and gear box oil and fixed ballast. It is this weight, arm, and moment that is used for loading the aircraft. If no loading charts have been established for an aircraft, it is necessary to investigate the most adverse forward and aft loading, as well as the maximum weight loading. The investigation of these extreme conditions is based on the empty CG of the aircraft.

The forward condition is investigated by simply loading the aircraft in such a manner that all useful load forward of the loaded CG range is at maximum weight, and all minimum weights necessary for flight are used aft of the forward limit.

The rearward condition is investigated in a similar manner. All useful load aft of the rearward loaded CG range is at maximum weight, and all minimum weights necessary for flight are used forward of the aft limit.

Fuel computations for adverse loading checks. For computation purposes, the standard weights defined in Section 2 of this chapter are used.

Minimum fuel will be used when the fuel tank lies behind the forward limit when calculating the most forward center of gravity, and ahead of the aft limit when figuring the most rearward CG.

For fuel computations during this investigation, the following rules apply:

- If the tank is ahead of the forward limit, full fuel is calculated at the standard weight.
- If the fuel tank is behind the most rearward CG, then the fuel tank should be full when the most rearward CG is calculated.
- For reciprocating-engine aircraft, minimum fuel is figured at the rate of one-twelfth of a gallon for each horsepower at maximum except takeoff (METO). To figure pounds of fuel, the formula, METO divided by 2, is used.

- On turbine-powered aircraft, minimum fuel is established by the manufacturer because specific fuel consumption varies so greatly.

Most forward CG investigation. To investigate the most forward CG limit of a given aircraft, the weight and arms after the installation were: See Table 5-3-3.

When plotted on the graphs in Figures 5-3-11 and 5-3-12, it can be seen that the aircraft is within CG limits at 248.5.

Most aft CG investigation. Rearward adverse loading requires a different set of circumstances than forward adverse loading. Note the absence of a copilot, additional fuel, and the number and location of the passengers as compared to the example of forward adverse loading: See Table 5-3-4.

As can be seen by the graphs in Figures 5-3-11 and 5-3-12, the aircraft is within limits at 255.7 with a weight of 7,038.4 lb.

Maximum weight investigation. Checking the maximum weight of an aircraft is a simple matter of adding the empty weight of the aircraft to the weight of the crew, passengers, baggage, cargo, fuel, additional equipment not included in the empty weight, and, when required, ballast and engine oil.

Empty weight	5,065.00
Pilot/copilot	340.00
Passengers (2)	340.00
Passengers (3)	510.00
Oil engine	28.60
Fuel	1,264.80
Baggage	500.00
Total Weight	8,048.40

The computed maximum weight, when compared to the graph in Figure 5-3-11 is well within the allowable maximum weight of this aircraft. Note that the maximum allowable weight, as shown by the graph, is 8,250 pounds.

Weight and Balance Changes After Alteration

When equipment to be added is on the approved equipment list, it typically will have a weight and arm given in the list and all computations will be completed on paper. If the item is not approved on the list, actual weights and arms will have to be physically measured and weighed. If the alterations are extensive, it is best to reweigh the aircraft and construct a new equipment list.

For demonstration purposes some additional equipment will be added to the light training aircraft used previously. The equipment added will be a child's seat installation in the baggage compartment. It is approved equipment and is taken from the equipment list contained in the aircraft information/owner's manual. (Table 5-3-5.)

Addition of equipment. The present empty weight is 1,152.20 and the CG is 29.90. The moment is 34,450.78.

The child seat weighs 10.50 pounds with an arm of 66.50 inches. To calculate the change in the aircraft the Total Moment over Total Weight formula will be used: (Table 5-3-6.)

The new weight is 1,162.70, the new CG is 30.20, and the new moment is 35,149.03.

Removal of equipment. Sometimes it may be necessary to delete equipment rather than add equipment. Basically the same method is used, but special attention must be given to the signs of the numbers. The weight will become a negative number changing the moment as well. If

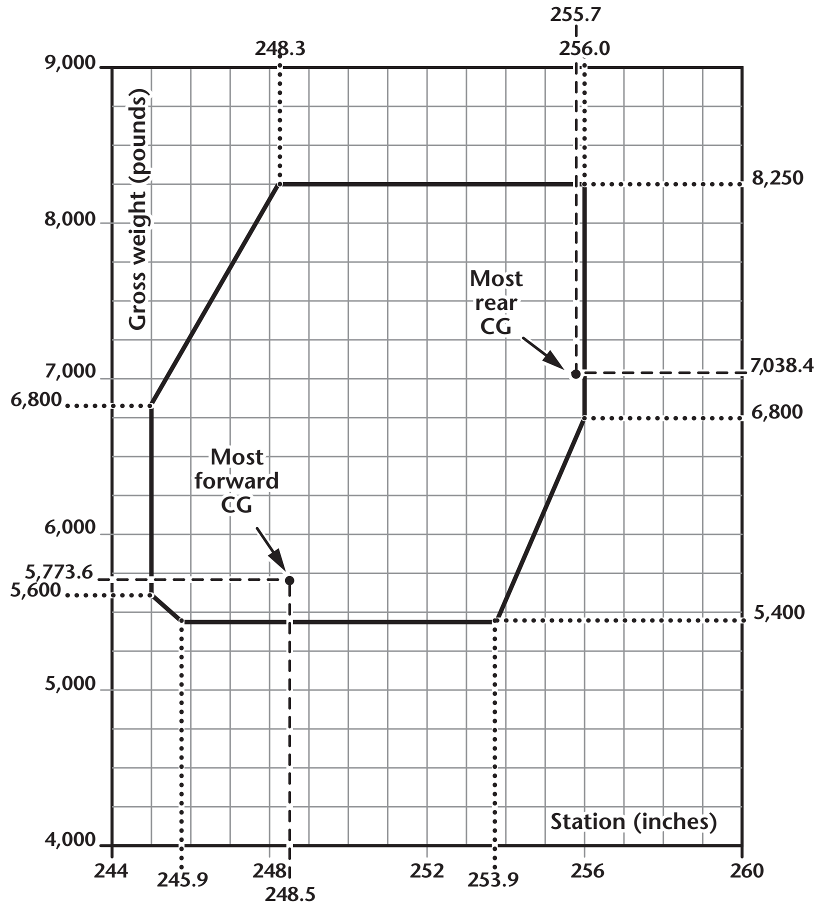


Figure 5-3-11. Longitudinal CG range graph.

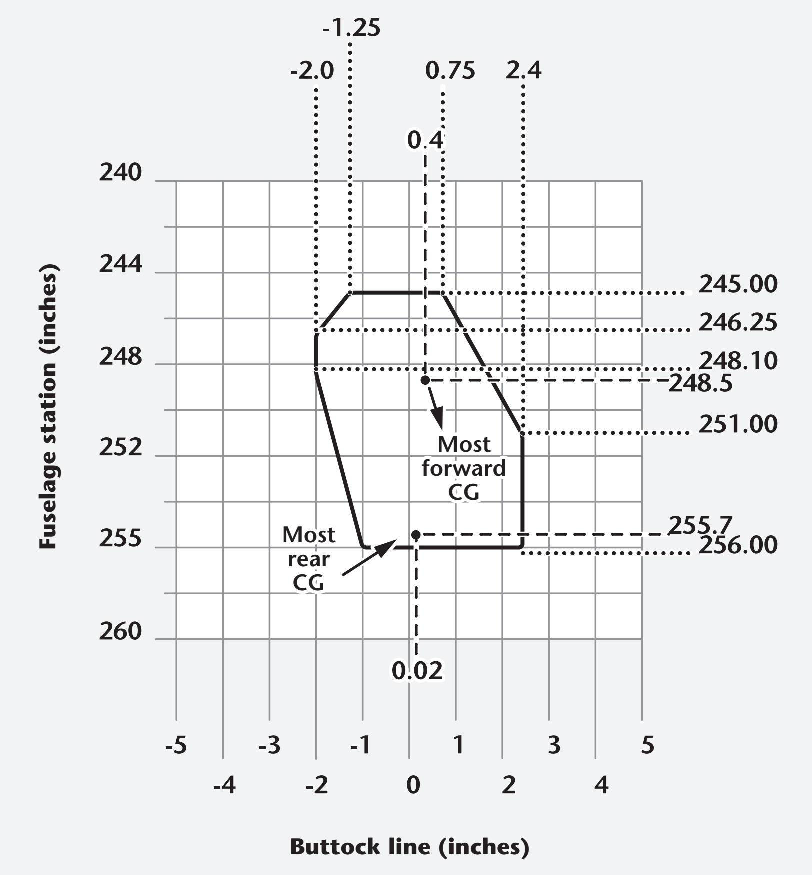


Figure 5-3-12. Lateral CG range graph.

Item no.	Equipment list description	Wt. lbs.	Arm. Ins
D-4	Recorder, engine hour meter	0.6	5.2
D-5	Outside air temperature indicator	0.1	22.0
D-6	Tachometer installation, engine – recording tach indicator	1.0	12.5
D-7	Indicator, turn coordinator (24 volt only)	0.8	17.0
D-8	Indicator, turn coordinator (10-30 volt)	1.8	17.2
D-9	Indicator, vertical speed	1.0	17.2
	E. Cabin accommodations	1.0	18.0
E-1	Seat, pilot individual sliding	11.1	45.2
E-2	Seat, vertically adjustable, pilot	17.0	45.2
E-3	Seat, copilot individual sliding	11.1	45.2
E-4	Seat vertically adjustable, copilot	17.0	45.2
E-5	Child seat installation, auxiliary	10.5	66.5

Table 5-3-5. Typical installed equipment list.

	Weight	Arm	Moment
Aircraft	1,152.20	29.90	34,450.78
Seat	10.50	66.50	698.25
New total	1,162.70	30.20	35,149.03

Table 5-3-6. Adding weight.

	Weight	Arm	Moment
Aircraft	1,162.70	30.20	35,149.03
Removed	-10.50	66.50	-698.25
New total	1,152.20	29.90	34,450.78

Table 5-3-7. Removing weight.

the seat were now to be removed, the following computations would be used: (Table 5-3-7.)

The new weight is 1,152.5, the CG is 29.9, and the moment is 34,450.78.

Once the new weight and balance has been established, the old one should be marked superseded and dated. This will prevent the old papers from being used by mistake.

Section 4

Helicopter Weight and Balance

The weight and balance principles and procedures that have been described, generally apply to helicopters. Each model helicopter is certificated for a specific maximum gross weight. However, it cannot be operated at this maximum weight under all conditions. Combinations of high altitude, high temperature, and high humidity determine the density altitude at a particular location.

This, in turn, critically affects the hovering, takeoff, climb autorotation, and landing performance of a helicopter. A heavily loaded helicopter has less ability to withstand shocks and additional loads caused by turbulent air. The heavier the load, the less the margin of safety for the supporting structures, such as the main rotor, fuselage, landing gear, etc.

Most helicopters have a much more restricted CG range than do airplanes. In some cases this range is less than 3 inches. The exact location and length of the CG range is specified for each helicopter and usually extends a short distance fore and aft of the main rotor mast or the center of a dual rotor system. Ideally, the helicopter should have such perfect balance that the fuselage remains horizontal while in a hover, and the only cyclic adjustment required should be that made necessary by the wind.

The fuselage acts as a pendulum suspended from the rotor. Any change in the CG changes the angle at which it hangs from this point of support. More recently designed helicopters have loading compartments and fuel tanks located at or near the balance point. If the helicopter is not loaded properly and the CG is not near the balance point, the fuselage does not hang horizontally in a hover. If the CG is too far aft, the nose tilts up and excessive forward cyclic control is required to maintain a stationary hover.

Conversely, if the CG is too far forward, the nose tilts down and excessive aft cyclic control is required. In extreme out-of-balance conditions, full fore or aft cyclic control may be insufficient to maintain control. Similar lateral balance problems may be encountered if external loads are carried. For this reason, it is also necessary to compute a lateral CG.

Sample Problem. For this problem, a typical corporate helicopter will be used to find the CG and empty weight. (Figure 5-4-1)

In preparing to find the empty weight and CG, the following information is taken from the Type Certification Data Sheet of the helicopter.

Datum	Location is 95 inches forward of the nose or 90.7 inches forward of the radome nose. (This helicopter has a radome).
Leveling means	Plumb line from right inside top of baggage compartment
Maximum weight	8,250 lb.
Minimum crew	1 pilot (+165)
Maximum baggage	500 lb. (+268) to (+324)
Fuel capacity	247.1 gal (+263.3) usable minus 15 lb. (+253.8) unusable (unusable fuel is included in empty weight).
Oil capacity	3.7 gal (+263.3) usable minus 15 lb. (+253.8) unusable undrainable oil 5 lb. (+264) (undrainable included in the empty weight).
Jackpoints	Fwd (+151.0) BL (– 5.15), Aft (+290.15) BL (+23.0) and (–23.0).

Like any other aircraft, the helicopter is prepared for weighing in the following steps:

1. Clean the helicopter and remove all loose articles.
2. Drain the fuel and oil from the engines. Check the hydraulic fluid and transmission oil (both must be full).
3. Place the helicopter in a closed hangar and remove the rotor tiedowns.
4. Check the scale for zero and place one load cell between each jack pad and jack.
5. Hang plumb bob from the slotted plate in the baggage compartment, as seen in Figure 5-4-2. Level the helicopter longitudinally and laterally.

Once the entire weight of the helicopter is on the jacks and load cells, and the aircraft is leveled, record the scale reading.

- No tare calculations are necessary because electronic scales are used.
- For calculation purposes for this problem, the following weights are used:

Front jackpoint ......1,150 lb.

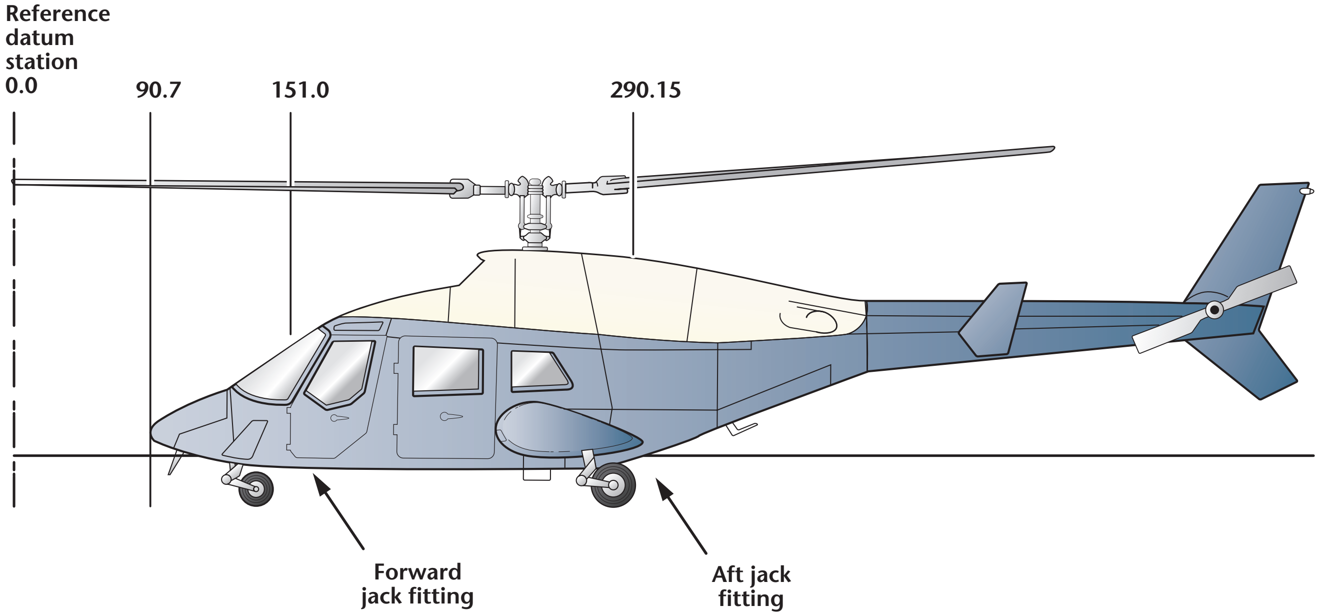


Figure 5-4-1. Typical corporate helicopter.

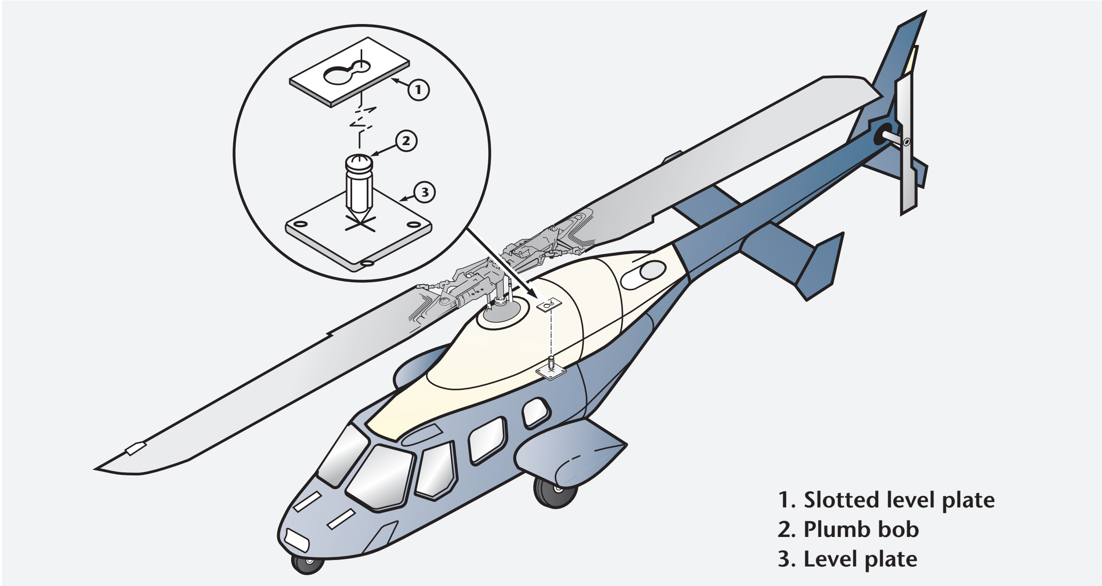


Figure 5-4-2. Plumb bob location.

Left aft jackpoint ... 1,815 lb.
Right aft jackpoint . 1,955 lb.
Total weight .... 4,920 lb.

Since all arms are positive due to the datum location, the total moment/total weight formula may be used to determine the CG and plotted as shown on the graph in Figure 5-3-11.

$$CG = \frac{(\text{Fwd Scale})\ 151 + (\text{Aft Scales})\ 290.15}{4{,}920}$$

$$= \frac{1{,}150 \times 151 + 3{,}770 \times 290.15}{4{,}920}$$

$$= \frac{173{,}650 + 1{,}093{,}865}{4{,}920}$$

$$= \frac{1{,}267{,}515}{4{,}920}$$

CG as weighed 257.60

The calculation of the lateral CG is similar to the longitudinal CG except that butt line *0* is used as the datum. Butt lines to the right are designated (+) while butt lines to the left are designated (–).

$$\text{The lateral CG} = \frac{A = (AL \times C) + (BR \times D)}{W}$$

BL= Butt measurement left
C= Weight of main scale left
BR= Butt measurement right
D= Weight of main scale right
W= Weight of aircraft

NOTE: Looking at the graph in Figure 5-3-12, the lateral limits are good.

$$CG = \frac{-5.15(1{,}150) - 23(1{,}985) + 23(1{,}955)}{4{,}920}$$

$$CG = \frac{-5{,}920 - 41{,}745 + 44{,}965}{4{,}920}$$

$$= -0.548 \text{ or } -0.55$$

The empty weight, for the purpose of these calculations, will include item in Table 5-4-1.

NOTE: This places the helicopter out of the longitudinal limits as indicated on the graph in Figure 5-3-11.

	Longitudinal			Lateral	
	Weight	Arm	Moment	Arm	0
As Weighed	4,920.00	257.60	1,267,392	–0.55	2,706.00
Passenger seats *(2)	+104.40	211.00	+22,028	0.00	0.00
Unusable fuel	+30.00	256.70	+7,701	0.00	0.00
Plumb bob	–0.20	290.70	–58	24.60	–5.00
	5,054.20	256.60	1,297,063	–0.50	–2,701.50
		CG	Moment	CG	Moment
Empty CG 256.6		**Empty weight 5,054.2**			
* Two passenger seats were removed at the time of weighing					

Table 5-4-1. Helicopter weight and balance chart.

Section 5

Loading and Weight Distribution

The loading of the aircraft varies with the manufacturer as to what type of system is used. Regardless of the system, it is important that

	Weight	Moment
Basic empty weight	1,152	34.40
Fuel 24.5 gal.	147	6.20
Pilot	170	7.00
Takeoff weight and moment	1,469	47.60
Note: The fuel weight = gallons × 6		

Table 5-5-1. Typical loading chart.

the weight and balance be figured correctly to prevent adverse flight characteristics.

Since each of the three aircraft weighed in this text utilizes a different method, these aircraft will be used in determining the loading.

Light Training Aircraft

On this particular aircraft, loading graphs are used. With the use of two different loading graphs, the safe operation of the aircraft may be determined.

The graph shown in Figure 5-5-1 is used for the weight and moment of the pilot, passengers, fuel, and baggage loading. Using information in Table 5-5-1 the total weight of the aircraft and moment may be determined.

With the weight and moment found, the graph in Figure 5-5-2, is used to determine if the aircraft is within the CG range. In this case, it is within limits. It should be noted that loaded in other configurations, it would not be within limits.

Since this is quite time consuming, some typical loading schedules could be prepared for the aircraft and used as a quick reference.

Commuter Aircraft

A different type of loading system is utilized by the commuter type aircraft. Since it is a rather large aircraft, a number of variables exist in the loading configuration with passengers, baggage, fuel, and galley. Because of this, they are required to have a loading manifest for each flight. A sample of this manifest is shown in Figure 5-5-3.

All weights used by FAR Part 135 and FAR Part 121 operators are standard weights. Although not shown, charts are used to determine the weights and moments for each seat and luggage locations, etc. Otherwise, the manifest would be a time consuming job.

Since all have maximum weights, zero fuel weight, taxi weight, and takeoff and landing weights are all considered. It is possible to have

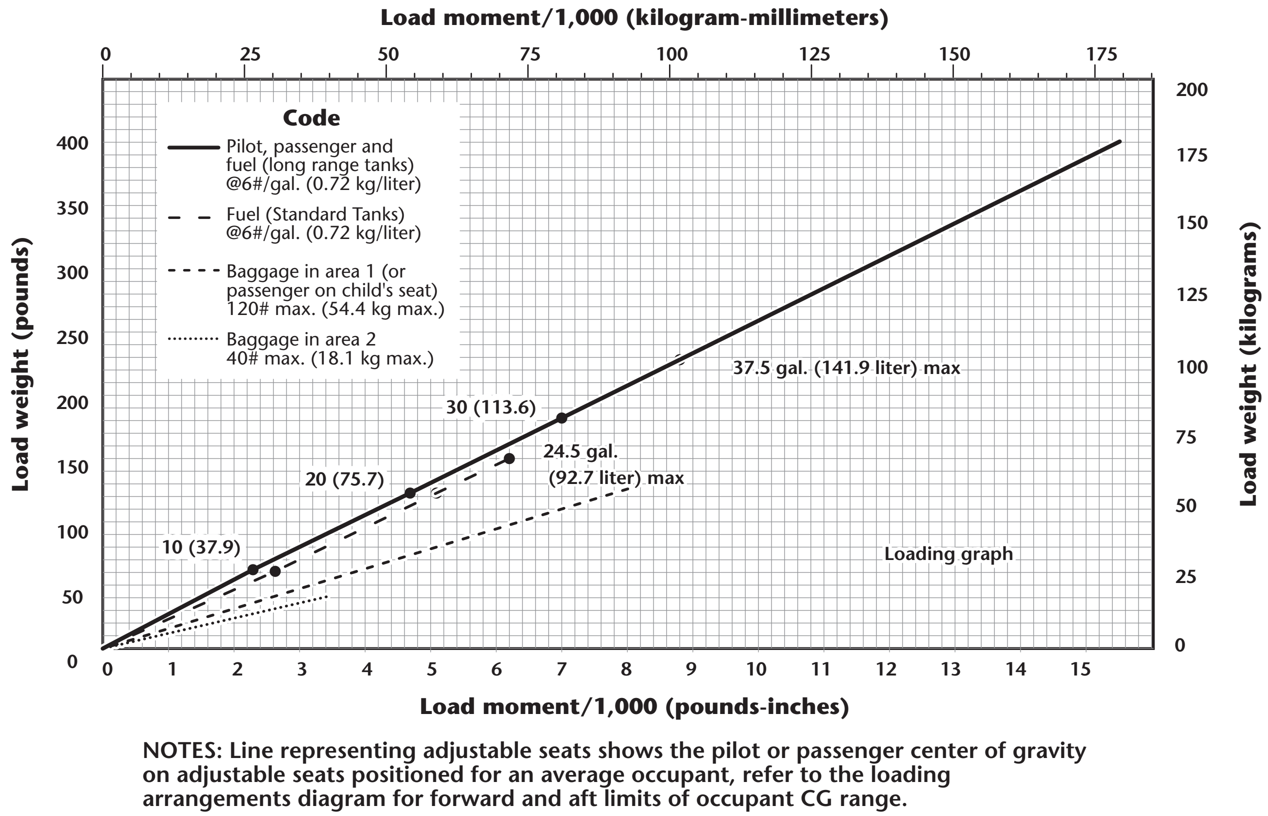


Figure 5-5-1. Loading graph.

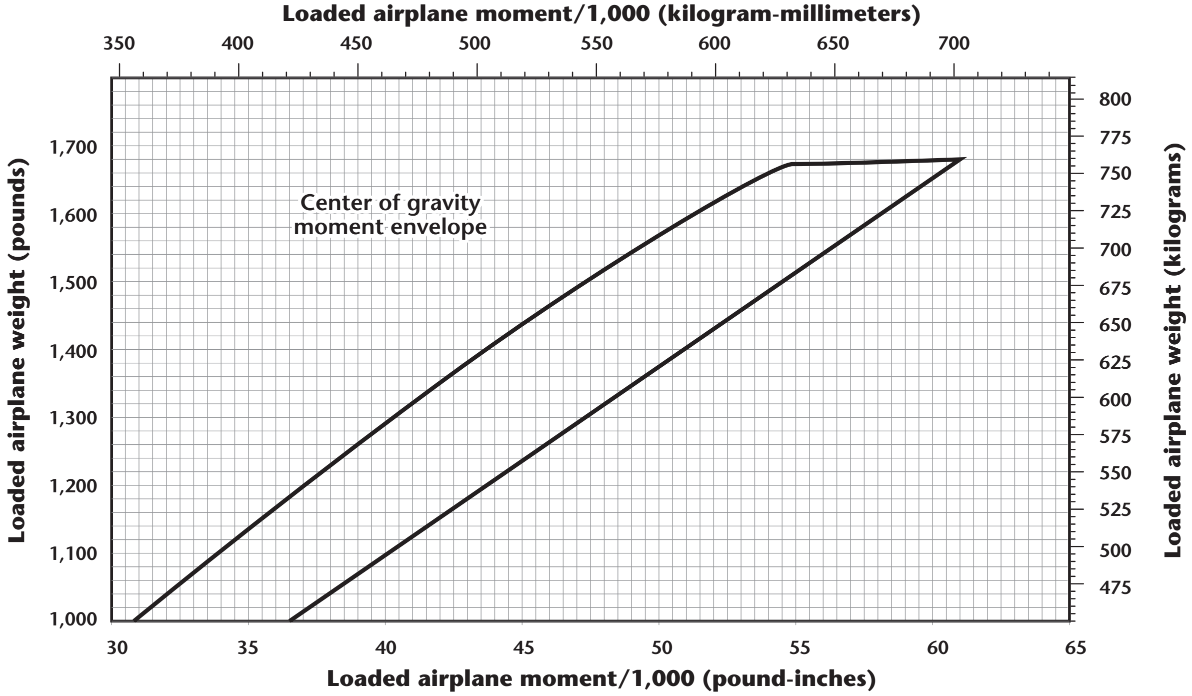


Figure 5-5-2. Center of gravity moment envelope.

the aircraft within balance at takeoff and not at landing. It should also be noted that as the manifest builds, the CG is given for zero fuel, takeoff, and landing. These can be checked with a moment/weight table for landing and takeoff (Table 5-5-2) and may also be checked on a graph as shown in Figure 5-5-4.

Helicopters

The helicopter uses a system of charts to establish the loading and to compute the aircraft load. Because of the CG limitations and the time required, several combination loads are calculated so the particular load may be compared to the already calculated CG established load. To best understand the system, the following sample loading problem is provided.

A helicopter is chartered to transport 6 passengers and 150 lb. of cargo for a trip that will require approximately 150 gallons of fuel. The 190-pound pilot will return alone. Because of the large variation in weight, the return flight must be calculated as well. To obtain this information, See Table 5-5-3.

- Empty weight of the aircraft came from the original weight and balance papers.
- The oil weight and arm was taken from the operator's manual. Since full oil is always calculated, it is probably added to the loading form.
- The pilot moment and arm was derived from the chart in Table 5-5-4
- The passenger in the copilot seat came from the same chart.
- The two forward passengers' weight and moment were derived from the same chart. Since the seating arrangement varies, this aircraft has seven-place seating.
- The aft passengers' weight and moment came from Table 5-5-4. All aft passenger seats are the same regardless of the seating.
- The fuel load came from Table 5-5-5. It might be noted some manufacturers use different charts for Jet A and Jet B fuels because of the weight difference between them.
- The cargo weights came from the chart in Table 5-5-6. It should be noted that the cargo is given by station locations.
- The weight and moments are totaled and the CG is computed for takeoff configuration.
- Since the fuel burn is large, the landing weight must also be computed. The fuel weight and moment are simply computed and subtracted from the takeoff weight. The new CG is established from these figures (Table 5-5-7).

The return flight is calculated in much the same manner as the outbound flight (Table 5-5-7).

Takeoff and landing gear down					
	Moment/100 lbs. in.			Moment/100 lbs. in.	
A/C weight (lbs.)	Fwg CG limit	Aft CG limit	A/C weight (lbs.)	Fwd CG limit	Aft CG limit
17,000	71,485	74,188	20,000	84,480	87,845
17,100	71,908	74,643	20,100	84,920	88,291
17,200	72,326	75,101	20,200	85,361	88,735
17,300	72,747	75,559	20,800	85,804	89,176
17,400	73,167	76,010	20,400	86,245	89,617
17,500	73,588	76,468	20,500	86,680	90,058
17,600	74,008	76,927	20,600	87,130	90,499
17,700	74,429	77,386	20,700	87,573	90,942
17,800	74,849	77,838	20,800	88,015	91,385
17,900	75,270	78,297	20,900	88,459	91,828
18,000	75,690	78,757	21,000	89,346	92,270
18,100	76,127	79,216	21,100	89,786	92,712
18,200	76,566	79,669	21,200	90,233	93,154
18,300	77,003	80,129	21,300	90,676	93,597
18,400	77,442	80,590	–	–	94,040
23,500	100,042	103,450	26,000	111,306	114,417
23,600	100,437	103,778	26,100	111,755	114,861
23,700	100,938	104,221	26,200	112,216	115,308
23,800	101,388	104,665	26,300	112,665	115,750
23,900	101,836	105,109	26,400	113,115	116,192
24,000	102,286	105,550	26,500	113,566	116,634
24,100	102,733	105,992	26,600	114,016	117,079
24,200	103,184	106,436	26,700	114,476	117,523
24,300	103,632	106,878	26,800	114,939	117,968
24,400	104,083	107,324	26,900	115,390	118,413
24,500	104,532	107,765	27,000	115,841	118,855
24,600	104,979	108,207	27,275	117,092	120,065
24,700	105,436	108,649	27,400	117,664	120,619
24,800	105,883	109,095	27,500	118,119	121,063
24,900	106,341	109,539	27,600	118,575	121,507
25,000	106,789	109,985	27,700	119,061	121,951
25,100	107,236	110,427	27,800	119,487	122,396
25,200	107,684	110,689	27,900	119,943	122,840
25,300	108,132	111,311	28,000	120,400	123,284
25,400	108,591	111,755	–	–	–

Table 5-5-2.Takeoff/landing moment/weight.

Outbound flight			
	Weight	Arm	Moment
Empty weight	5,065	256.30	1,298,229
Oil	29	270.00	7,830
Pilot	190	168.20	31,958
Passenger/copilot	170	168.20	28,594
Passenger frwrd (2)	(2)340	211.20	71,808
Passengers aft (3)	510	257.00	131,070
Fuel jet A	1,275	264.20	336,855
Cargo	150	288.00	43,200
Takeoff	7,729	252.00	1,949,544
Fuel burned	-1,105		292,502
Landing	6,624	250.00	1,657,042

Table 5-5-3. Inital helicopter lead chart.

WEIGHT AND BALANCE LOADING MANIFEST

REGISTRATION NO.	HOME STATION	LOADING COMPUTED BY:	
FLIGHT NO:	FROM: TO:	PILOT SIGNATURE:	DATE:

LUGGAGE			PASSENGERS			
AREA	WEIGHT lb	MOMENT/100	ROW	NO	WEIGHT lb	MOMENT/100
			1			
			2			
			3			
			4			
TOTAL			5			
CARGO			6			
			7			
			8			
AREA	WEIGHT lb	MOMENT/100	9			
			10			
			11			
			12			
			14			
TOTAL			TOTAL			

ITEM	WEIGHT lb	MOMENT/100
BASIC EMPTY WEIGHT		
FLIGHT CREW (2)		
FL. CR. BRIEF CASES		
ATTENDANT		
GALLEY CONTENTS		
TOIL. SUPPLIES WATER		
OPERATL. EMPTY WEIGHT		
PASSENGERS - TOTAL		
LUGGAGE - TOTAL		
CARGO - TOTAL		
OBSERVER		
ZERO FUEL WEIGHT		
(MAX:)		
FUEL		
TAXI WEIGHT		
(MAX:)		
FUEL CONSUMED: TAXI		
TAKE OFF WEIGHT		
(MAX:)		
FUEL CONSUMED - FLIGHT		
EST LANDING WEIGHT		
(MAX:)		

FOR REFERENCE: CG POS. IN INCHES= $\frac{\text{MOMENT}}{100} \times 100$ / WEIGHT

CG POS. IN %MAC= $\frac{(\text{STA}^* - 412.3) \times 100}{82.07}$

*STA = CG POS. IN INCHES

	CG POS. INCHES	CG POS. %MAC
ZERO FUEL WT.		
TAKE OFF WT.		
EST LAND WT.		

REMARKS:

Figure 5-5-3. Typical loading manifest.

Crew and passenger loading table (English)					
Moment chart (in-lbs.)					
Weight (lbs.)	Pilot and copilot F.S. 168.2	Frwrd pssngr 10-place stnd F.S. 200.7	Forward passenger 10-place F.S. 200.7	Mid passenger 10-place F.S. 229.2	Aft pssngr any cnfgrtn F.S. 257.0
100	16,820	20,070	21,670	22,920	25,700
110	18,502	22,077	23,837	25,212	28,270
120	20,184	24,084	26,004	27,504	30,840
130	21,866	26,091	28,171	29,796	33,410
140	23,548	28,098	30,338	32,088	35,980
150	25,230	30,105	32,505	34,380	38,550
160	26,912	32,112	34,672	36,672	41,120
170	28,594	34,119	36,839	38,964	43,690
180	30,276	36,126	39,006	412,561	46,260
190	31,958	38,133	41,173	43,548	48,830
200	33,640	40,140	43,340	45,840	51,400
210	35,322	42,147	45,507	48,132	53,970
220	37,004	44,154	47,674	50,424	56,540
230	38,686	46,161	49,841	52,716	59,110
240	40,368	48,168	52,008	55,008	61,680
250	42,050	50,175	54,175	57,300	64,250

Table 5-5-4. Typical loading tables.

Fuel loading table jet A 6.8 lbs./U.S. gallons			
Gal.	Wt. (lbs.) 6.8 lbs./gal.	CG (in.)	Moment (in. lbs.)
5	34.0	257.0	8,738
10	68.0	258.7	17,592
15	102.0	259.7	26,489
20	136.0	260.5	35,428
25	170.0	260.9	44,353
30	204.0	261.2	53,285
35	238.0	261.4	62,213
40	272.0	261.6	71,155
45	306.0	261.6	80,050
50	340.0	261.7	88,978
55	374.0	261.9	97,951
60	408.0	262.1	106,937
65	442.0	262.3	115,937
70	476.0	262.6	124,998
75	510.0	262.9	134,079
80	544.0	263.0	143,072
85	578.0	263.2	152,130
90	612.0	263.4	161,201
95	646.0	263.5	170,221
100	680.0	263.6	179,248
105	714.0	263.7	188,282
110	748.0	263.7	197,248
115	782.0	263.8	206,292
120	816.0	263.9	215,342
125	850.0	263.9	224,315
130	884.0	264.0	233,376
135	918.0	264.0	242,352
140	952.0	264.1	251,423
145	986.0	264.1	260,403
150	1,020.0	264.1	269,382
155	1,054.0	264.1	278,361
160	1,088.0	264.2	28,7450
165	1,122.0	264.2	29,6432
170	1,156.0	264.2	29,6432
175	1,190.0	264.2	30,5415
180	1,224.0	264.2	31,4398
185	1,258.0	264.2	32,3381
187.5	1,275.0	264.2	33,2364

Table 5-5-5. Typical fuel loading chart.

Baggage compartment loading table					
Moment chart (in. lbs.)					
	100lbs./sq.ft. maximum allowable		500 lbs. maximum allowable		
Weight (lbs.)	F.S. 288	F.S. 300	F.S. 312	F.S. 330	F.S. 366
25	7,200	7,500	7,800	8,250	8,400
50	14,400	15,000	15,600	16,500	16,800
75	21,600	22,500	23,400	24,750	25,200
100	28,800	30,000	31,200	33,000	33,600
125	36,000	37,500	39,000	41,250	42,000
150	43,200	45,000	46,800	49,500	50,400

Warning: The aft center of gravity limit may readily be exceeded by use of the baggage compartment together with insufficient cabin loading. Proper distribution of cargo/baggage and passengers must be determined prior to flight.

Table 5-5-6. Baggage/cargo loading chart.

Return flight			
	Weight	Arm	Moment
Empty weight	5,065	256.30	1,298,229
Oil	29	270.00	7,830
Pilot	190	168.20	31,958
Fuel	1,275	264.20	336,855
Takeoff	6,559	255.00	1,674,872
	-1,071		-283,571
Landing weight	5,488	253.00 CG	1,391,301

Table 5-5-7. Return flight weight and balance.

Center of gravity limits. Applicable before modification numbers 12345 and 56789 are installed									
A/C weight		Forward limit				Aft limit			
		In flight		T.O. landing		T.O. landing		In flight	
LB	KG	%MAC	STA	%MAC	STA	%MAC	STA	%MAC	STA
27,275	12,370	18.7	427.6	20.7*	429.3*	34*	440.2*	38	443.5
23,100	10,480							38	443.5
13,400	8,800					32.7	436.1	32.7	439.1
18,000	8,160	8	418.9	10	420.5				
16,000	7,260	8	418.9	10	420.5	28	435.3	28	435.3

NOTE: For values of CG Limits not shown in above table the CG graph below should be used. *= T.O. only.
NOTE: Maximum Taxi Weight (MTW) = 27,300 lb (12,380 kg).

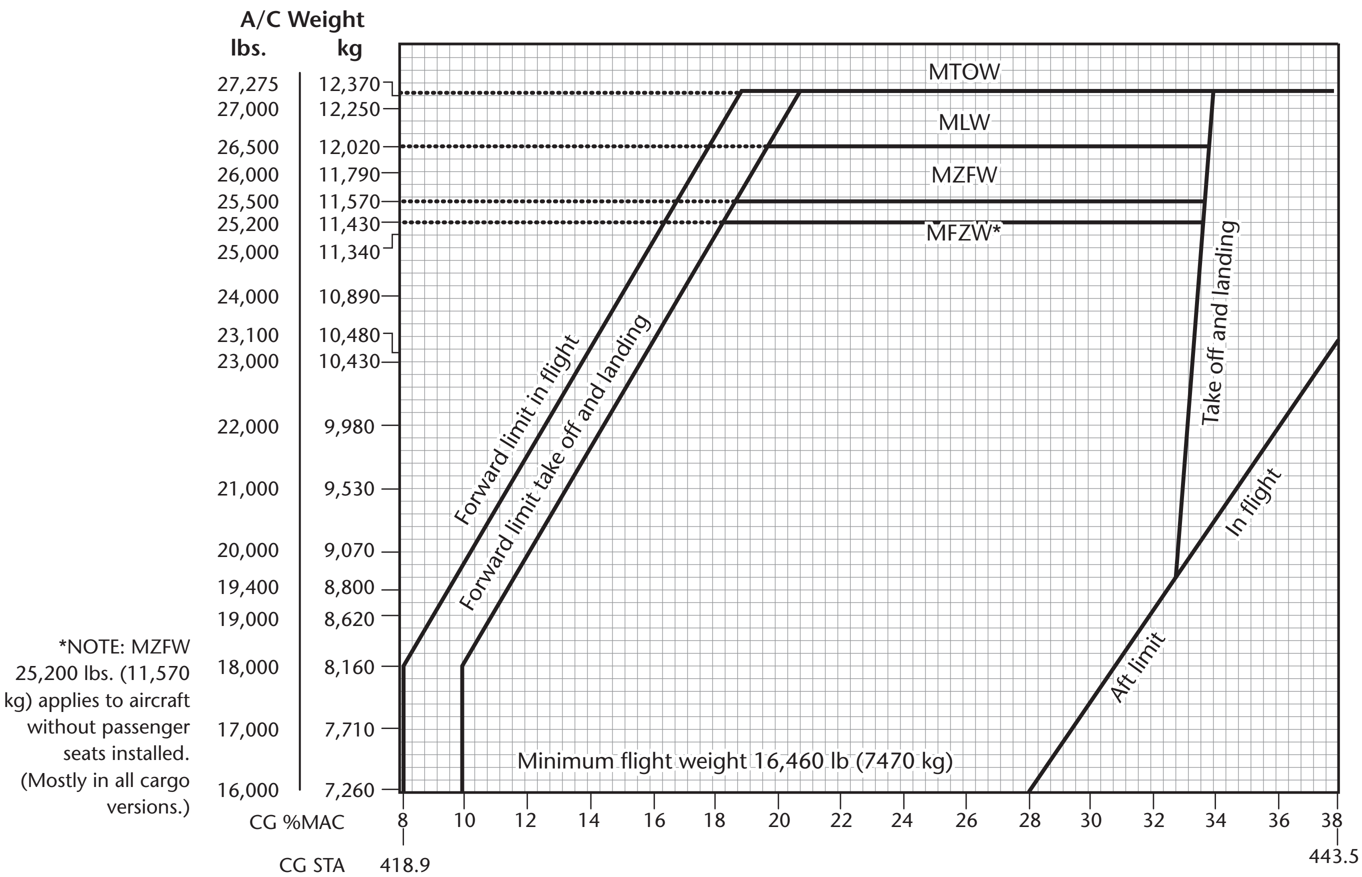
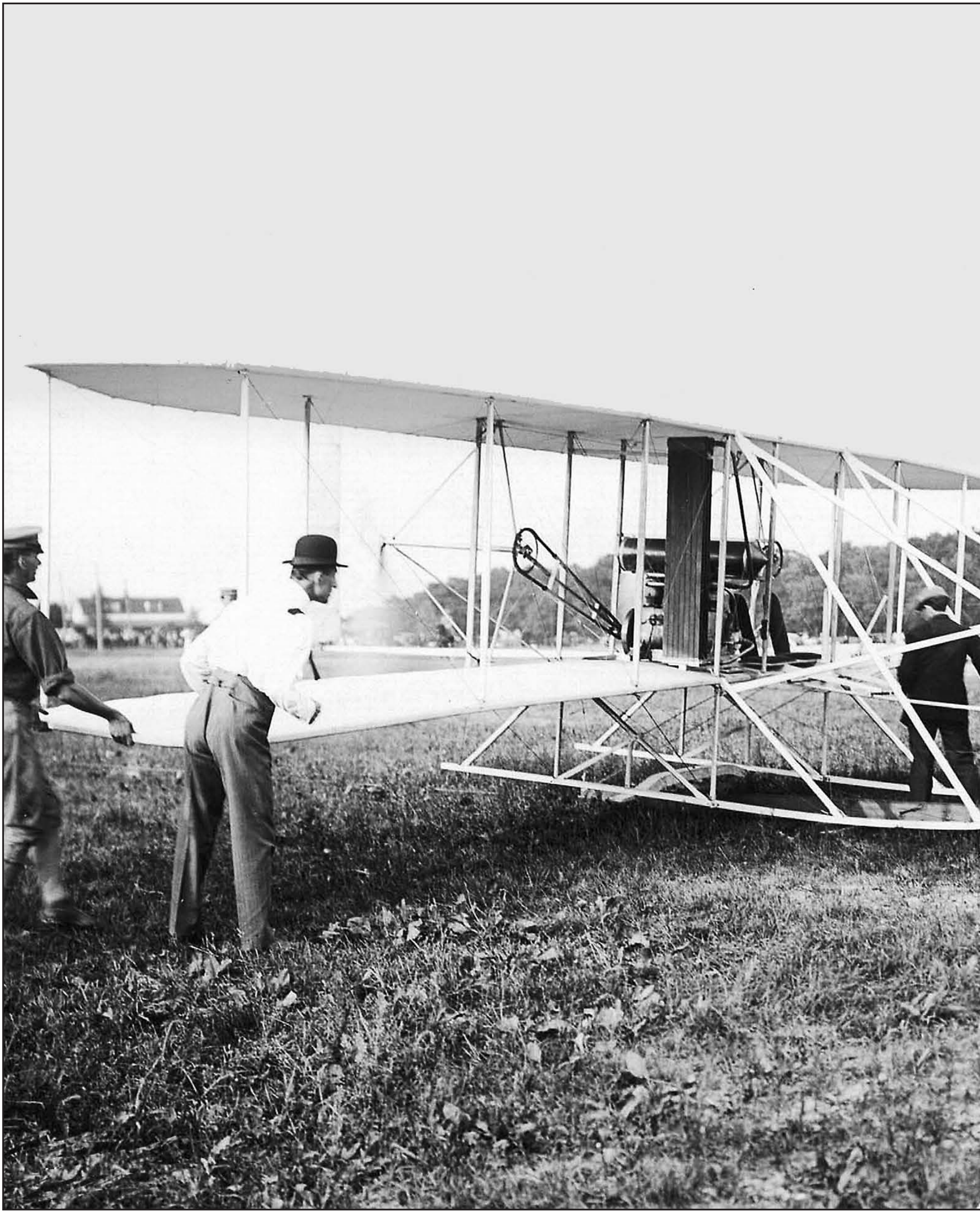
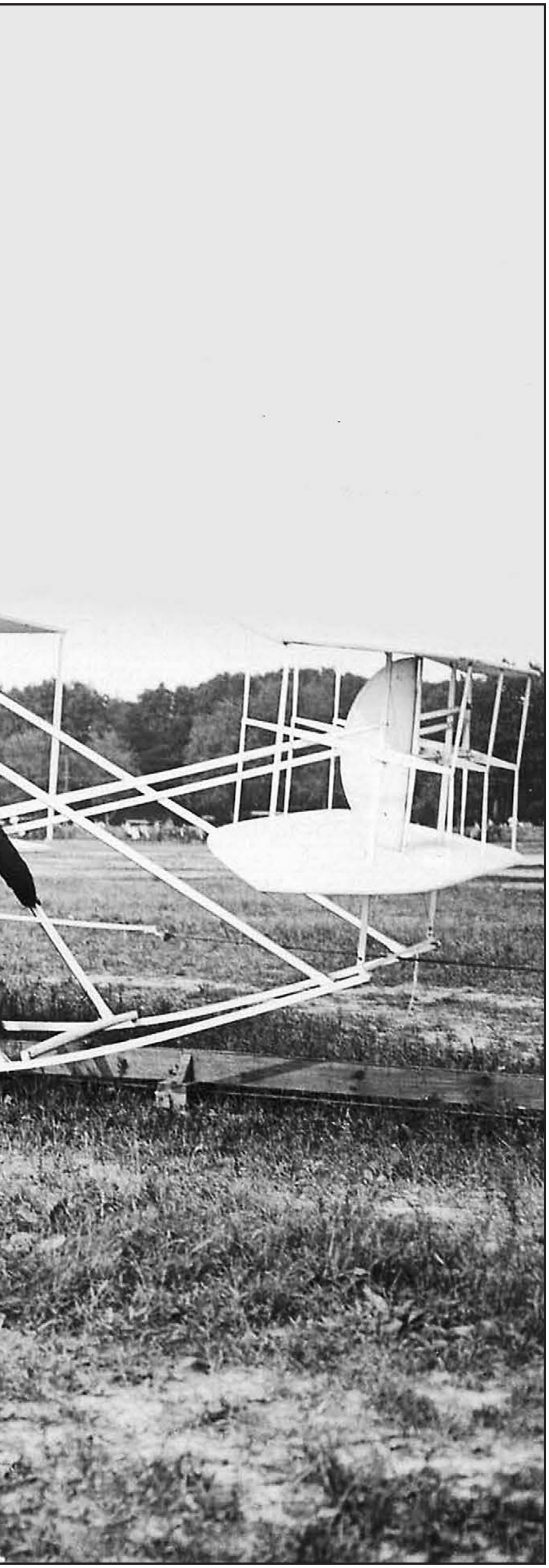


Figure 5-5-4. Top: Loading graph; Bottom: Center-of-gravity moment envelope.





6

Hardware and Materials

Because of the small size of most hardware items, their importance is often overlooked. Fasteners are, however, the most significant items in an airplane's construction. The Boeing Commercial Airplane Company claims there are over six million individual items used in the manufacture of a B-747; over half of them are fasteners and hardware.

The safe and efficient operation of any aircraft is greatly dependent upon correct selection and use of aircraft structural hardware and seals. This chapter discusses these various items. It also provides information that can aid you in the selection and correct use of aircraft structural hardware and seals. However, only the normal day-to-day type of hardware can be discussed in any detail. To cover all available aviation hardware would take a textbook of considerable size all by itself.

Aircraft hardware is usually identified by its specification number or trade name. Threaded fasteners and rivets are usually identified by AN (Air Force-Navy), NAS (National Aircraft Standard), or MS (Military Standard) numbers. Quick-release fasteners are usually identified by factory trade names and size designations.

Learning Objectives

REVIEW

- Types and uses of aircraft structural hardware and threaded fasteners

DESCRIBE

- Aircraft control cable and fittings
- Types and uses of electrical system hardware
- Aerospace materials production and terms

EXPLAIN

- Safetying materials and techniques
- The purpose, id and installation processes for hydraulic hardware and seals

Left. Aircraft materials and hardware have advanced from the cloth, wire, wood and bamboo of the Wright Flyer to a multi-billion dollar industry. Some of the most sophisticated production standards in the world (AN, MS, NAS and SAE) are used for aircraft materials and hardware.

Section 1

Aircraft Structural Hardware

The term aircraft structural hardware refers to many items used in aircraft construction. You should be concerned with such hardware as rivets, fasteners, bolts, nuts, screws, washers, cables, and guides, and you should be familiar with common electrical system hardware.

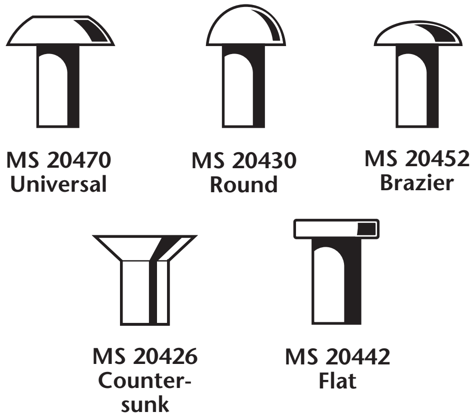


Figure 6-1-1. Rivet head shapes and code numbers.

Rivets

A glance at any metal aircraft will show the thousands of rivets in the outer skin alone. Besides the riveted skin, rivets are also used for joining spar sections, for holding rib sections in place, for securing fittings to various parts of the aircraft and for fastening bracing members and other parts together. Rivets that are satisfactory for one part of the aircraft are often unsatisfactory for another part. Therefore, it is important that you know the strength and driving properties of the various types of rivets and how to identify them, as well as how to drive or install them.

Solid rivets. Solid rivets are classified by their head shape, by the material from which they are manufactured and by their size. Rivet head shapes and their identifying code numbers are shown in Figure 6-1-1. The prefix MS identifies hardware that conforms to written military standards. The prefix AN identifies specifications that are developed and issued under the joint authority of the Air Force and the Navy.

Rivet identification code. The rivet codes shown in Figure 6-1-1 are sufficient to identify rivets only by head shape. To be meaningful and precisely identify a rivet, certain other information is encoded and added to the basic code.

A letter or letters following the head-shaped code identify the material or alloy from which the rivet was made. Table 6-1-1 includes a listing of the most common of these codes. The alloy code is followed by two numbers separated by a dash. The first number is the numerator of a fraction, which specifies the shank diameter in thirty-seconds of an inch. The second number is the numerator of a fraction in sixteenths of an inch and identifies the length of the rivet. The rivet code is shown in Figure 6-1-2.

Rivet Composition

Most of the rivets used in aircraft construction are made of aluminum alloy. A few special-

Material or alloy	Code letters	Head marking on rivet
1100	A	Plain
2117-T4	AD	Indented dimple
2017-T4	D	Raised teat
2024-T4	DD	Raised double dash
5056-H32	B	Raised cross

Table 6-1-1. Rivet material identification.

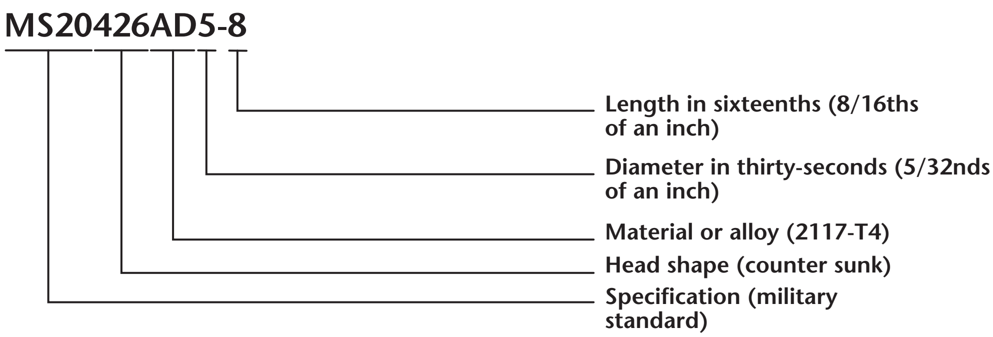


Figure 6-1-2. Rivet coding example.

purpose rivets are made of mild steel, monel, titanium, and copper. Those aluminum alloy rivets made of 1100, 2117, 2017, 2024, and 5056 are considered standard.

Alloy 1100 rivets. Alloy 1100 rivets are supplied as fabricated (F) temper and are driven in this condition. No further treatment of the rivet is required before use, and the rivet's properties do not change with prolonged periods of storage. They are relatively soft and easy to drive. The cold work resulting from driving increases their strength slightly. The 1100-F rivets are used only for riveting nonstructural parts. These rivets are identified by their plain head, as shown in Table 6-1-1.

Alloy 2117 rivets. Like the 1100-F rivets, these rivets need no further treatment before use and can be stored indefinitely. They are furnished in the solution-heat-treated (T4) temper, but change to the solution-heat-treated and cold-worked (T3) temper after driving. The 2117-T4 rivet is in general use throughout aircraft structures and is by far the most widely used rivet, especially in repair work. In most cases, the 2117-T4 rivet may be substituted for 2017-T4 and 2024-T4 rivets for repair work by using a rivet with the next larger diameter. This is desirable since both the 2017-T4 and 2024-T4 rivets must be heat treated before they are used or kept in cold storage. The 2117-T4 rivets are identified by a dimple in the head.

Alloy 2017 and 2024 rivets. As mentioned in the preceding paragraph, both these rivets are supplied in the T4 temper and must be heat treated. These rivets must be driven within 20 minutes after quenching or refrigerated at or below 32°F (0°C) to delay the aging time 24 hours. If either time is exceeded, reheat treatment is required. These rivets may be reheated as many times as desired, provided the proper solution heat-treatment temperature is not exceeded. The 2024-T4 rivets are stronger than the 2017-T4 and are, therefore, harder to drive. The 2017-T4 rivet is identified by the raised teat on the head, while the 2024-T4 has two raised dashes on the head.

Alloy 5056 rivets. These rivets are used primarily for joining magnesium alloy structures because of their corrosion-resistant qualities. They are supplied in the H32 temper (strain-hardened and then stabilized). These rivets are identified by a raised cross on the head. The 5056-H32 rivet may be stored indefinitely with no change in its driving characteristics.

Blind Rivets

In places accessible from only one side or where space on one side is too restricted to properly use a bucking bar, blind rivets are usually used. Blind rivets may also be used to secure nonstructural parts to the airframe. Some blind rivets are also referred to as "pop rivets".

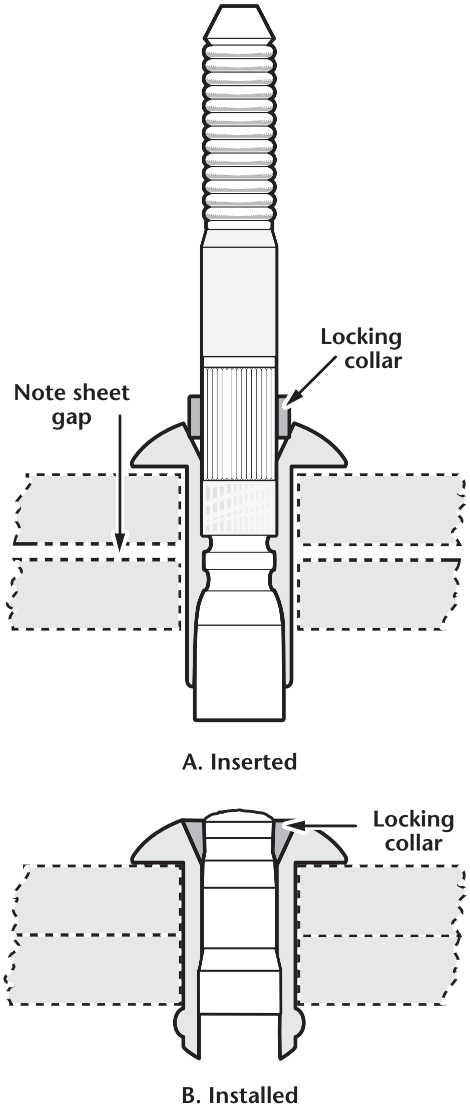


Figure 6-1-3. Self-plugging rivet (mechanical lock).

Figure 6-1-3 shows a blind rivet that uses a mechanical lock between the head of the rivet and the pull stem. Note in illustration B that the collar that is attached to the head has been driven into the head and has assumed a wedge or cone shape around the groove in the pin. This holds the shank firmly in place from the head side.

The self-plugging rivet is made of 5056-H14 aluminum alloy and includes the conical recess and locking collar in the rivet head. The stem is made of 2024-T36 aluminum alloy. Pull grooves that fit into the jaws of the rivet gun are provided on the stem end that protrudes above the rivet head. The blind end portion of the stem incorporates a head and a land (the raised portion of the grooved surface) with an extruding angle that expands the rivet shank.

Applied loads for self-plugging rivets are comparable to those for solid shank rivets of the same shear strength, regardless of sheet thickness. The composite shear strength of the 5056-H14 shank and the 2024-T36 pin exceeds 38,000 p.s.i. Their tensile strength is in excess of 28,000 p.s.i. Pin retention characteristics are excellent in these rivets. The possibility of the pin working out is minimized by the lock formed in the rivet head.

Hi-shear rivets. Hi-shear (pin) rivets are essentially threadless bolts. The pin is headed at one end and is grooved about the circumference at the other. A metal collar is swaged onto the grooved end. They are available in two head styles: the flat protruding head and the flush 100-degree countersunk head. Hi-shear rivets are made in a variety of materials and are used only in shear applications. Because the shear strength of the rivet is greater than either the shear or bearing strength of sheet aluminum alloys, they are used primarily to rivet thick gauge sheets together. They are never used where the grip length is less than the shank diameter. Hi-shear rivets are shown in Figure 6-1-4.

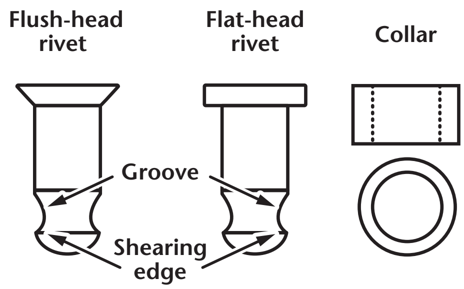


Figure 6-1-4. Hi-shear rivet.

Hi-shear rivets are identified by code numbers similar to the solid rivets. The size of the rivet is measured in increments of thirty-seconds of an inch for the diameter and sixteenths of an inch for the grip length. For example, an NAS 1055-5-7 rivet would be a hi-shear rivet with a countersunk head. Its diameter would be 5/32 of an inch and its maximum grip length would be 7/16 of an inch.

The collars are identified by a basic code number and a dash number that correspond to the diameter of the rivet. An A before the dash number indicates an aluminum alloy collar. The NAS 528-A5 collar would be used on a 5/32-inch-diameter rivet pin. Repair procedures involving the installation or replacement of hi-shear rivets generally specify the collar to be used.

Rivnuts. The rivnut is a hollow rivet made of 6063 aluminum alloy, counterbored and

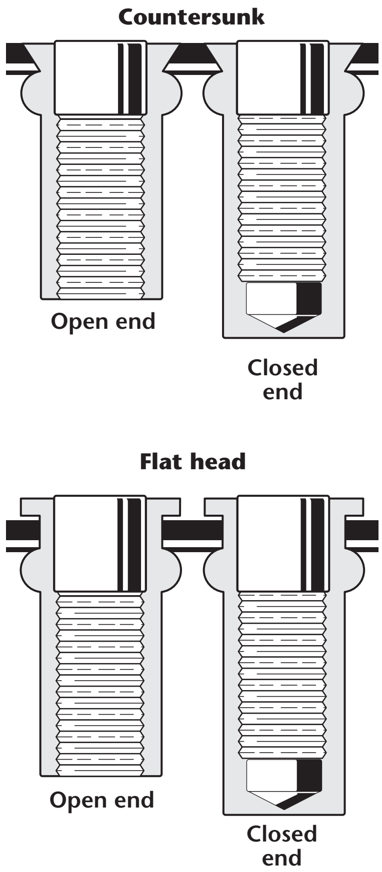


Figure 6-1-5. Sectional illustration of rivnut showing head and end designs.

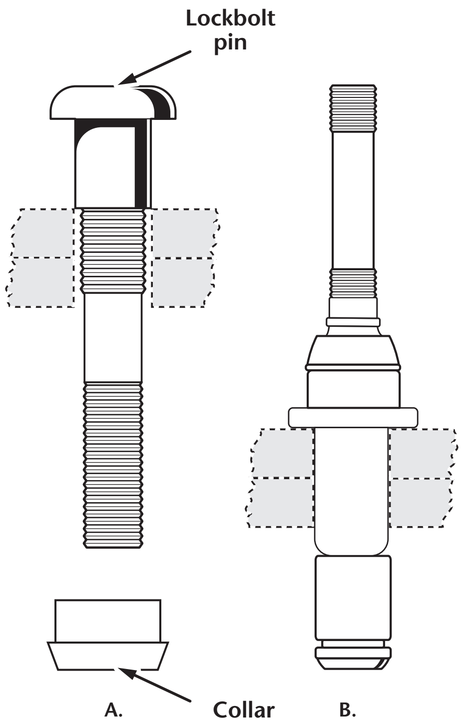


Figure 6-1-6. Lock bolts.

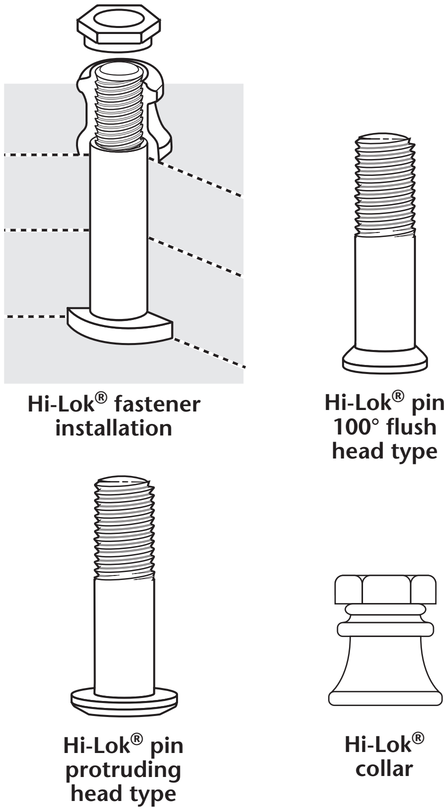


Figure 6-1-7. Hi-Lok fastener.

threaded on the inside. They are manufactured in two head styles, flat and countersunk, and in two shank designs, open and closed ends (Figure 6-1-5). Each of these rivets is available in three sizes: 6-32, 8-32, and 10-32. These numbers indicate the nominal diameter and the actual number of threads per inch of the machine screw that fits into the rivnut.

Open-end rivnuts are the most widely used and are recommended in preference to the closed-end type. However, in sealed, flotation or pressurized compartments, the closed-end rivnut must be used.

Fasteners (Special)

Fasteners on aircraft are designed for many different functions. Some are made for high-strength requirements, while others are designed for easy installation and removal.

Lock-bolt fasteners. Lock-bolt fasteners are designed to meet high-strength requirements. Used in many structural applications, their shear and tensile strengths equal or exceed the requirements of AN and NAS bolts.

The lock-bolt pin, shown in illustration A of Figure 6-1-6, consists of a pin and collar. It is available in two head styles: protruding and countersunk. Pin retention is accomplished by swaging the collar into the locking grooves on the pin.

The blind lock bolt, shown in illustration B of Figure 6-1-6, is similar to the self-plugging rivet shown in Figure 6-1-3. It features a positive mechanical lock for pin retention.

Hi-Lok® fasteners. The Hi-Lok fastener, shown in Figure 6-1-7, combines the features of a rivet and a bolt and is used for high-strength, interference-free fit of primary structures. The Hi-Lok fastener consists of a threaded pin and threaded locking collar. The pins are made of cadmium-plated alloy steel with protruding or 100-degree flush heads. Collars for the pins are made of anodized 2024-T6 aluminum or stainless steel.

The threaded end of the pin is recessed with a hexagon socket to allow installation from one side. The major diameter of the threaded part of the pin has been truncated (cut undersize) to accommodate a 0.004-inch maximum interference-free fit. One end of the collar is internally recessed with a 1/16-inch, built-in variation that automatically provides for variable material thickness without the use of washers and without fastener preload changes. The other end of the collar has a torque-off wrenching device that controls a predetermined residual tension of preload (10%) in the fastener.

Jo-bolt fasteners. The Jo-bolt, shown in Figure 6-1-8, is a high strength blind structural fastener that is used on difficult riveting jobs when access to one side of the work is impossible. The Jo-bolt consists of three factory-assembled parts: an aluminum alloy or alloy steel nut, a threaded alloy steel bolt and a corrosion-resistant steel sleeve. The head styles available for Jo-bolts are the 100-degree flush head, the hexagon protruding head, and the 100-degree flush millable head.

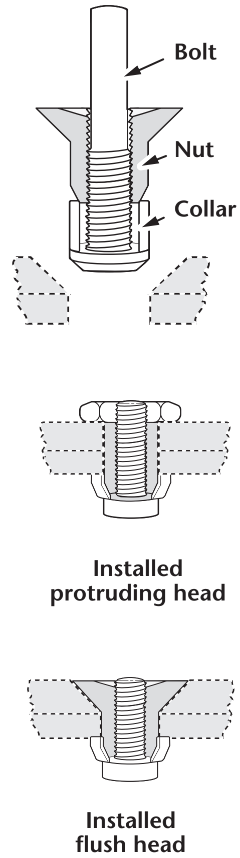


Figure 6-1-8. Jo-bolt.

Turnlock Fasteners

Turnlock fasteners are used to secure panels that require frequent removal. These fasteners are available in several different styles and are usually referred to by the manufacturer's trade name.

Camloc® fasteners. The 4002 series Camloc fastener consists of four principal parts: the receptacle, the grommet, the retaining ring, and the stud assembly (Figure 6-1-9). The receptacle is an aluminum alloy forging mounted in a stamped sheet metal base. The receptacle assembly is riveted to the access door frame, which is attached to the structure of the aircraft.

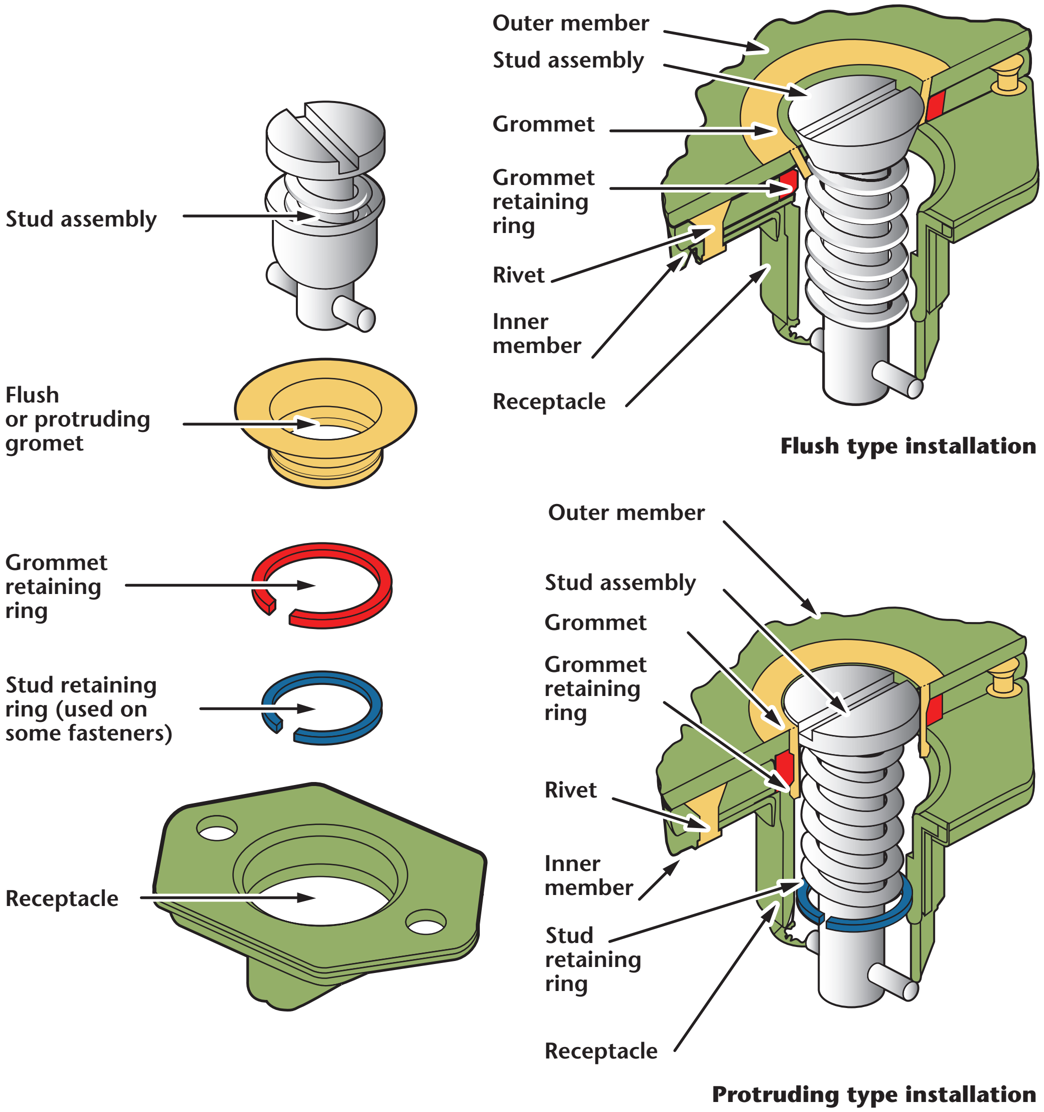


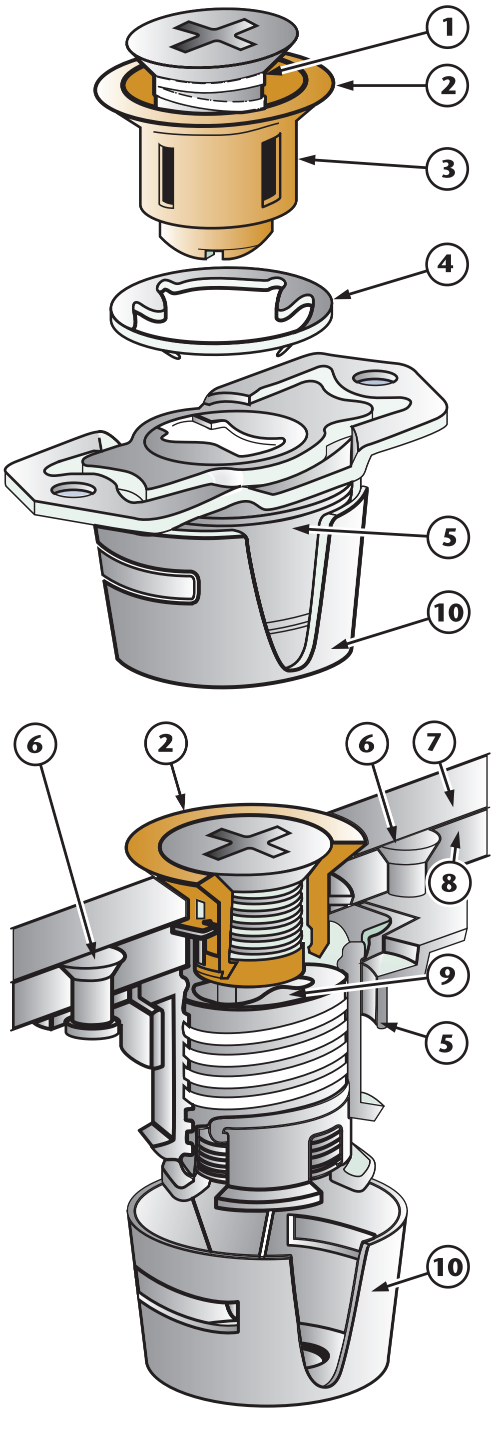
Figure 6-1-9. Camloc 4002 series fastener.

The grommet is a sheet metal ring held in the access panel with the retaining ring. Grommets are furnished in two types: the flush type and the protruding type. Besides serving as a grommet for the hole in the access panel, it also holds the stud assembly. The stud assembly consists of a stud, a cross pin, a spring, and a spring cup. The assembly is designed so it can be quickly inserted into the grommet by compressing the spring. Once installed in the grommet, the stud assembly cannot be removed unless the spring is again compressed.

The Camloc high-stress panel fastener, shown in Figure 6-1-10, is a high-strength, quick-release rotary fastener and may be used on flat or curved inside or outside panels. The fastener may have either a flush or protruding stud. The studs are held in the panel with flat or cone-shaped washers—the latter being used with flush fasteners in dimpled holes. This fastener may be distinguished from screws by the deep No. 2 Phillips recess in the stud head and by the bushing in which the stud is installed.

A threaded insert in the receptacle provides an adjustable locking device. As the stud is inserted and turned counterclockwise one-half turn or more, it screws out the insert to permit the stud key to engage the insert cam when turned clockwise. Rotating the stud clockwise one-fourth turn engages the insert. Continued rotation screws the insert in and tightens the fastener. Turning the stud one-fourth turn counterclockwise releases the stud but does not screw the insert out far enough to permit re-engagement. The stud should be turned at least one-half turn counterclockwise to reset the insert.

Airloc® fasteners. Figure 6-1-11 shows the parts that make up an Airloc fastener. The Airloc fastener also consists of a receptacle, a stud, and a cross pin. The stud is attached to the access



1. Tension spring
2. Stud assembly
3. Bushing
4. Retaining ring
5. Receptacle assembly
6. Receptacle attaching rivets
7. Outer skin
8. Inner skin
9. Insert
10. Cover

Figure 6-1-10. Camloc high-stress panel fastener.

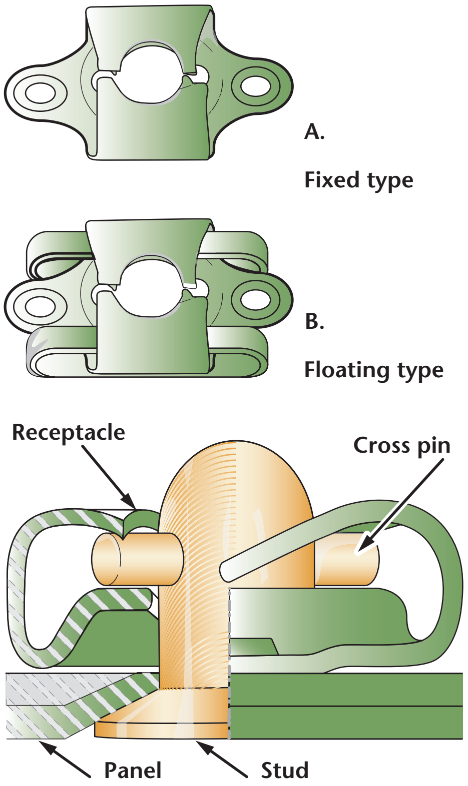


Figure 6-1-11. Airloc fastener.

panel and is held in place by the cross pin. The receptacle is riveted to the access panel frame.

Two types of Airloc receptacles are available: the fixed (illustration A) and the floating (illustration B). The floating receptacle makes for easier alignment of the stud in the receptacle. Several types of studs are also available, but in each instance the stud and cross pin come as separate units so the stud may be easily installed in the access panel.

The Airloc receptacle is fastened to the inner surface of the access panel frame by two rivets. The rivet heads must be flush with the outer surface of the panel frame. When you are replacing receptacles, drill out the two old rivets and attach the new receptacle by flush riveting. Be careful not to mar the sheet. When you are inserting the stud and cross pin, insert the stud through the access panel and, by using a special hand tool, insert the cross pin in the stud. Cross pins can be removed by means of special ejector pliers.

Dzus® fasteners. Dzus fasteners are available in two types. A light-duty type is used on box covers, access hole covers, and lightweight fairings. The heavy-duty type is used on cowling and heavy fairings. The main difference between the two Dzus fasteners is a grommet, which is only used on the heavy-duty

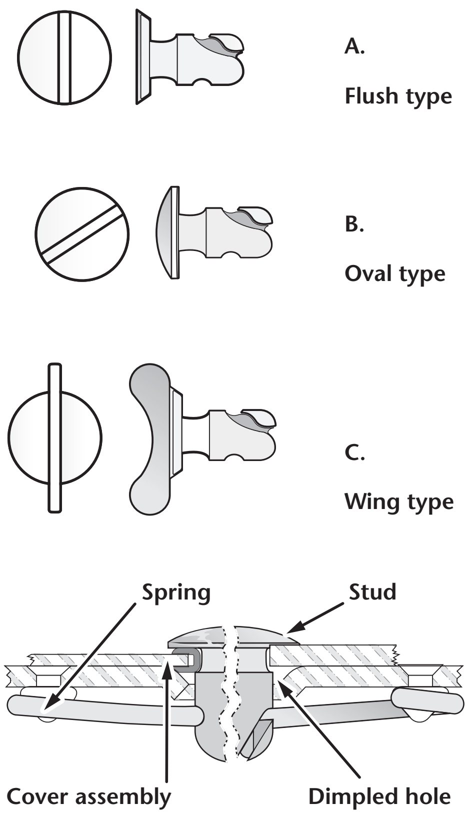


Figure 6-1-12. Dzus fastener.

fasteners. Otherwise, their construction features are about the same.

Figure 6-1-12 shows the parts of a light-duty Dzus fastener. Notice that they include a spring and a stud. The spring is made of cadmium-plated steel music wire and is usually riveted to an aircraft structural member. The stud comes in a number of designs (as shown in illustrations A, B, and C) and mounts in a dimpled hole in the cover assembly.

When the panel is being positioned on an aircraft, the spring riveted to the structural member enters the hollow center of the stud. Then, when the stud is turned about one-fourth turn, the curved jaws of the stud slip over the spring and compress it. The resulting tension locks the stud in place and secures the panel.

Miscellaneous Fasteners

Some fasteners cannot be classified as rivets, turnlocks, or threaded fasteners. Included in this category are connectors, couplings, clamps, taper and flat-head pins, snap rings, studs, and helicoil inserts.

Connectors and Couplings. A variety of clamping devices are used in connecting ducting sections to each other or to various

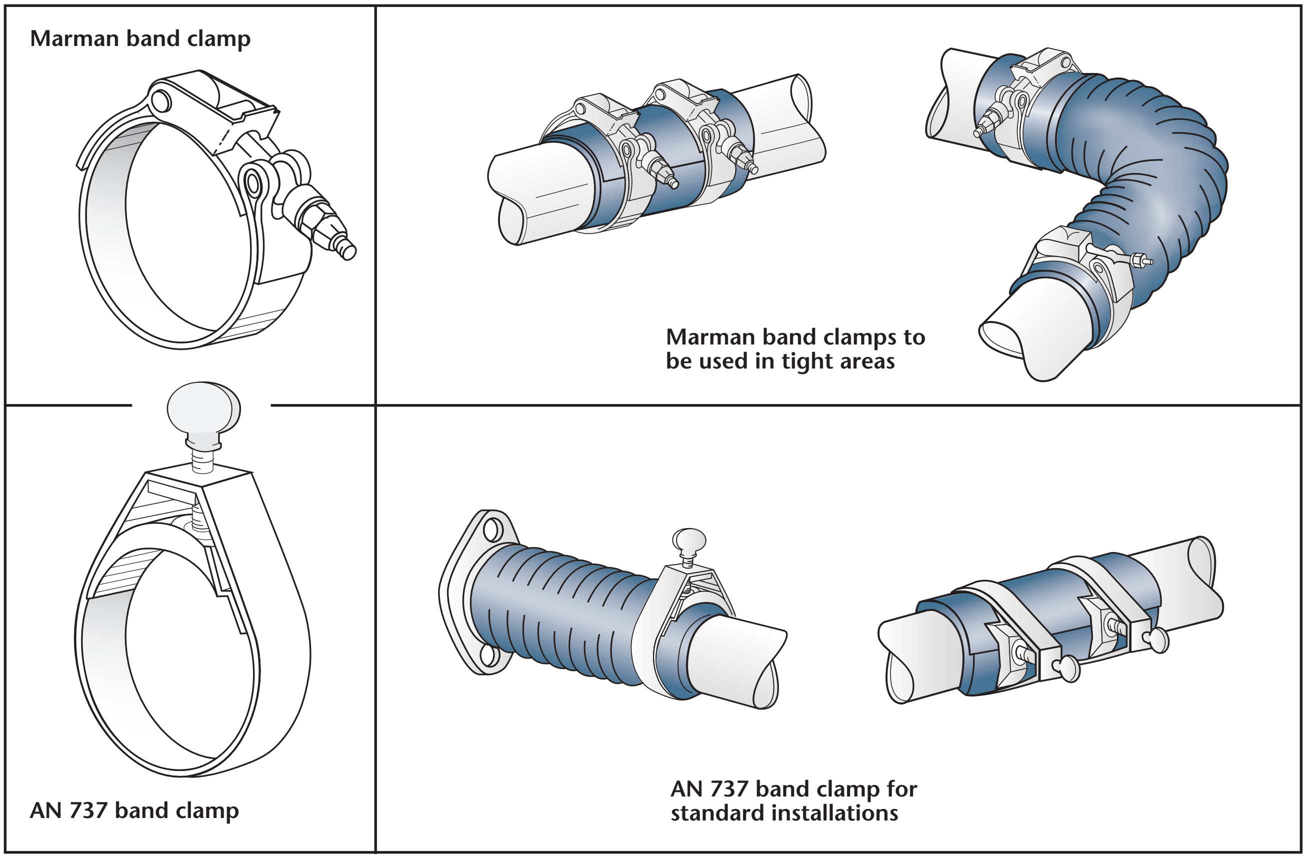


Figure 6-1-13. Flexible line connectors.

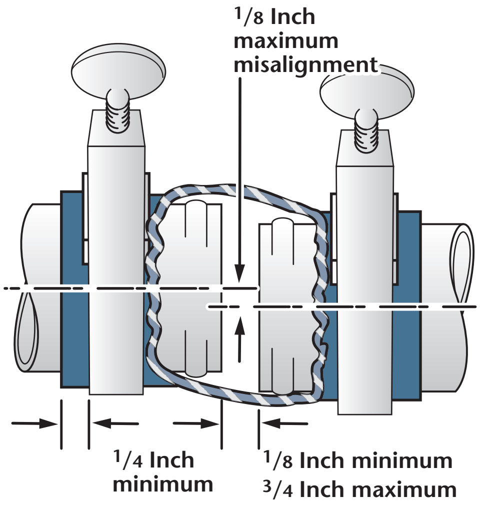


Figure 6-1-14. Flexible line coupling.

components. Whenever lines, components, or ducting are disconnected or removed for any reason, you should install suitable plugs, caps, or coverings on the openings to prevent the entry of foreign materials. You should also tag the various parts to ensure correct reinstallation. You should exercise care during handling and installation to ensure that flanges are not scratched, distorted, or deformed. Flange surfaces should be free of dirt, grease, and corrosion. The protective flange caps should be left on the ends of the ducting until the installation progresses to the point where removal is necessary.

In most cases it is mandatory to discard and replace seals and gaskets. You should ensure that seals and gaskets are properly seated and that mating and alignment of flanges are fitted. This will prevent excessive torque required to close the joint, which imposes structural loads on the clamping devices. Adjacent support clamps and brackets should remain loose until installation of the coupling has been completed.

Some of the most commonly used plain-band couplings are shown in Figure 6-1-13. When you install a hose between two duct sections, the gap between the duct ends should be a minimum of 1/8 of an inch and a maximum of 3/4 of an inch. When you install the clamps on the connection, the clamp should be 1/4 of an inch from the end of the connector. Misalignment between the ducting ends should not exceed 1/8 of an inch.

Marmon clamps. Marmon clamps are commonly used in ducting systems and should be tightened to the torque value indicated on the coupling. Tighten all couplings in the manner and to the torque value specified on the clamp or in the applicable maintenance instruction manual (Figure 6-1-13).

Flexible Coupling Installation

When you install flexible couplings, such as the one shown in Figure 6-1-14, the following steps are recommended to assure proper security:

1. Fold back half of the sleeve seal and slip it onto the sleeve.
2. Slide the sleeve (with the sleeve seal partially installed) onto the line.
3. Position the split sleeves over the line beads.
4. Slide the sleeve over the split sleeves, and fold over the sleeve seal so it covers the entire sleeve.
5. Install the coupling over the sleeve seal and torque to correct value.

Rigid couplings. The rigid line coupling shown in Figure 6-1-15 is referred to as a V-band coupling. When you install this coupling in restricted areas, some of the stiffness of the coupling can be overcome by tightening the coupling over a spare set of flanges and a gasket to the recommended torque value of the joint. Tap the coupling a few times with a plastic mallet before removing it.

When you install rigid couplings, follow the steps listed below:

1. Slip the V-band coupling over the flanged tube.
2. Place a gasket into one flange. One quick rotary motion assures positive seating of the gasket.
3. Hold the gasket in place with one hand while the mating flanged tube is assembled into the gasket with a series of vertical and horizontal motions to assure the seating of the mating flange to the gasket.

NOTE: View B of Figure 6-1-15 shows the proper fitting and connecting of a rigid coupling using a metal gasket between the ducting flanges.

4. While holding the joint firmly with one hand, install the V-band coupling over the two flanges.
5. Press the coupling tightly around the flanges with one hand while engaging the latch.
6. Tighten the coupling firmly with a ratchet wrench. Tap the outer periphery of the coupling with a plastic mallet to assure proper alignment of the flanges in the coupling. This will seat the sealing edges of the flanges in the gasket. Tighten again, making sure the recommended torque is not exceeded.

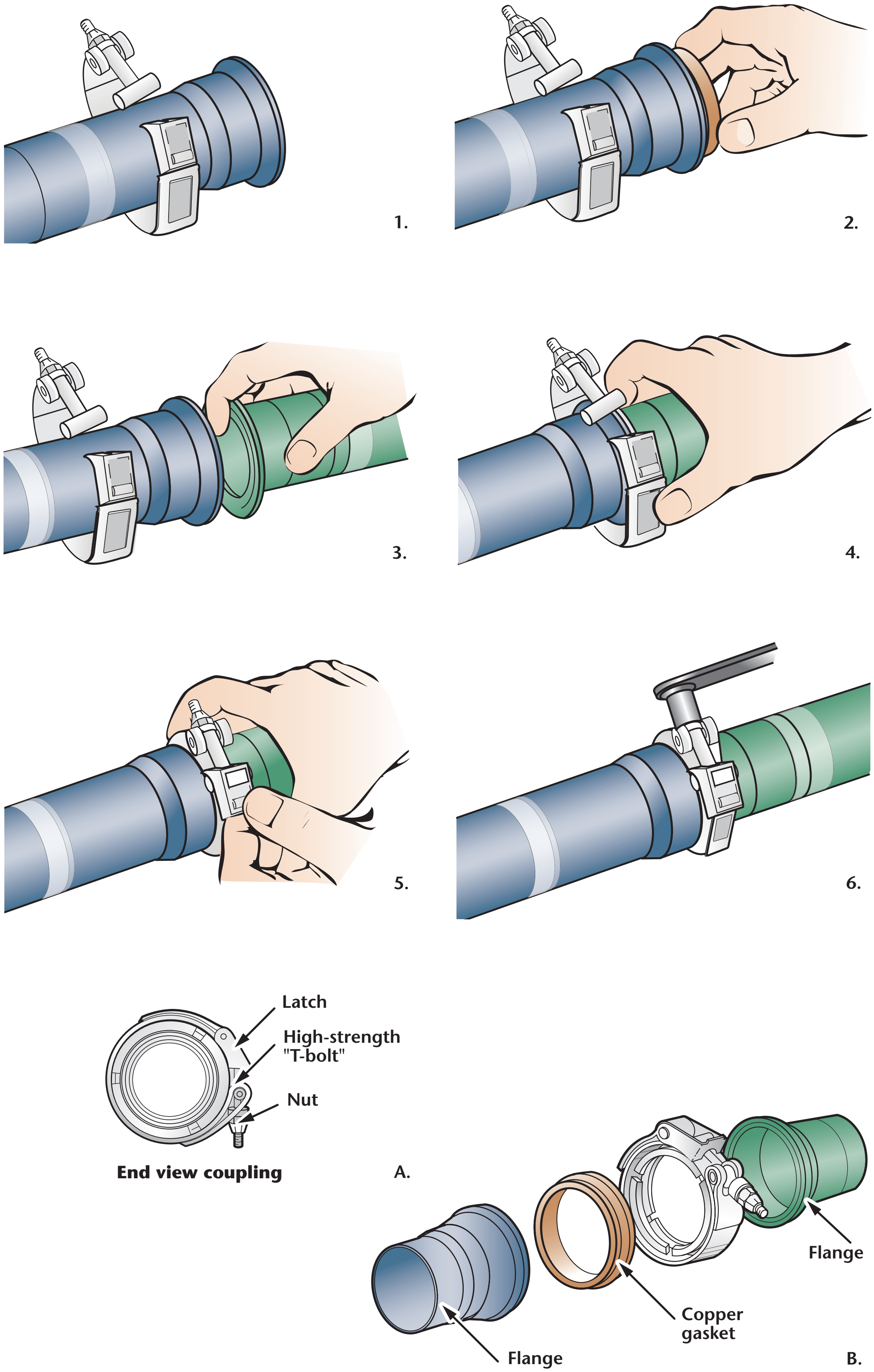


Figure 6-1-15. Installation of rigid line couplings.

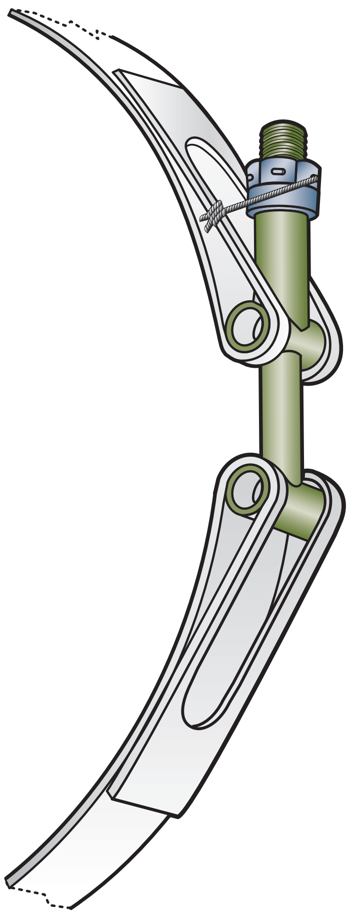


Figure 6-1-16. Safetying a V-band coupling.

7. Check the torque of the coupling with a torque wrench and tighten until the specified torque is obtained.
8. Safety wire the V-band coupling, as shown in Figure 6-1-16, as an extra measure of security in the event of T-bolt failure. The safety wire will be installed through the band loops that retain the T-bolt and the trunnion or quick coupler. A minimum of two turns of the wire is required. Most V-band connectors will use a T-bolt with some type of self-locking nut.

Miscellaneous Hardware

Taper pins. Taper pins are used in joints that carry shear loads and where the absence of clearance is essential (Figure 6-1-17). The threaded taper pin is used with a taper pin washer and a shear nut if the taper pin is drilled, or with a self-locking nut if undrilled. When a shear nut is used with the threaded taper pin and washer, the nut is secured with a cotter pin.

Flat-head pins. The flat-head pin is used with tie rod terminals or secondary controls, which do not operate continuously. The flat-head pin should be secured with a cotter pin. The pin is normally installed with the head up (Figure 6-1-17.) This precaution is taken to maintain the flat-head pin in the installed position in case of cotter pin failure.

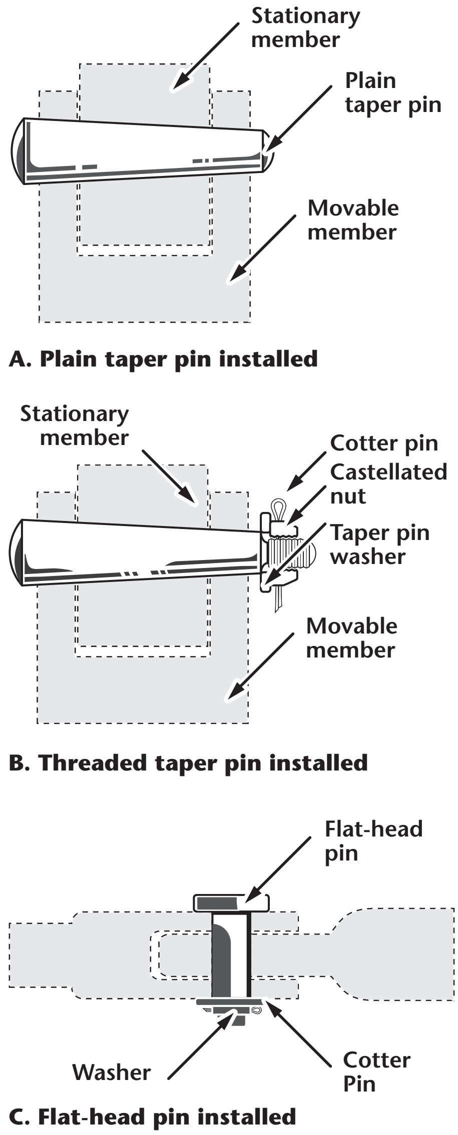


Figure 6-1-17. Types of aircraft pins.

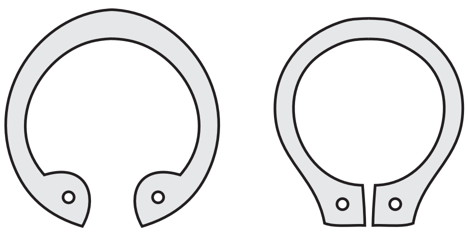


Figure 6-1-18. Internal and external snap rings.

Snap rings. A snap ring is a ring of metal, either round or flat in cross section that is tempered to have spring-like action (Figure 6-1-18). This spring-like action holds the snap ring

Figure 6-1-19. Threaded stud.

firmly seated in a groove. The external types are designed to fit in a groove around the outside of a shaft or cylinder. The internal types fit in a groove inside a cylinder. Special pliers are designed to install each type of snap ring.

Snap rings can be reused as long as they retain their shape and springlike action. External snap rings may be safety wired, but internal types are never safetied.

Studs. There are four types of studs used in aircraft structural applications. They are the coarse thread, fine thread, stepped, and lockring studs. Studs may be drilled or undrilled on the nut end. Coarse (NAS183) and fine (NAS184) thread studs are manufactured from alloy steel and are heat treated. They have identical threads on both ends. The stepped stud has a different thread on each end of the stud. The lockring stud may be substituted for undersize or oversize studs. The lockring on this stud prevents it from backing out due to vibration, stress, or temperature variations (Figure 6-1-19).

Heli-coil inserts. Heli-coil thread inserts are primarily designed to be used in materials that are not suitable for threading because of their softness. The inserts are made of a diamond cross-sectioned stainless steel wire that is helically coiled and, in its finished form, is similar to a small, fully compressed spring. There are two types of heli-coil inserts (Figure 6-1-20). One is the plain insert, made with a tang that forms a portion of the bottom coil offset and is used to drive the insert. This tang is left on the insert after installation, except when its removal is necessary to provide clearance for the end of the bolt. The tang is notched to break off from the body of the insert, thereby providing full penetration for the fastener.

The second type of insert used is the self-locking, mid-grip insert, which has a specially formed grip coil midway on the insert. This produces a gripping effect on the engaging screw. For quick identification, the self-locking, mid-grip inserts are dyed red.

Section 2

Fasteners (Threaded)

Although thousands of rivets are used in aircraft construction, many parts require frequent dismantling or replacement. For these parts it is more practical to use some form of threaded fastener. Furthermore, some joints require greater strength and rigidity than can be provided by riveting. Manufacturers solve this problem by using various types of screws, bolts, and nuts.

Bolts and screws are similar in that both have a head at one end and a screw thread at the other, but there are several differences between them. The threaded end of a bolt is always relatively blunt, while that of a screw may be either blunt or pointed. The threaded end of a bolt must be screwed into a nut, but the threaded end of the screw may fit into a nut or other female arrangement, or directly into the material being secured.

A bolt has a fairly short threaded section and a comparatively long grip length (the unthreaded part); a screw may have a longer threaded section and no clearly defined grip length. A bolt assembly is generally tightened by turning

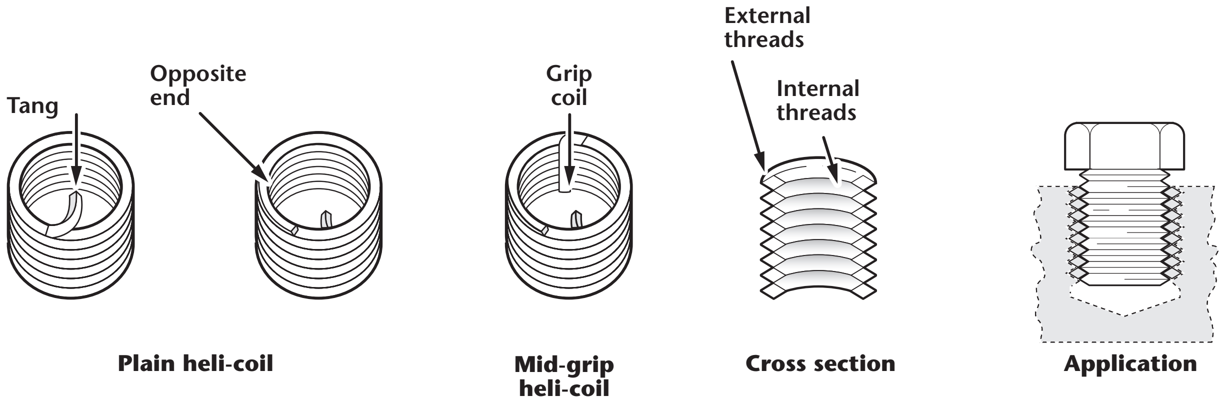


Figure 6-1-20. Heli-coil insert.

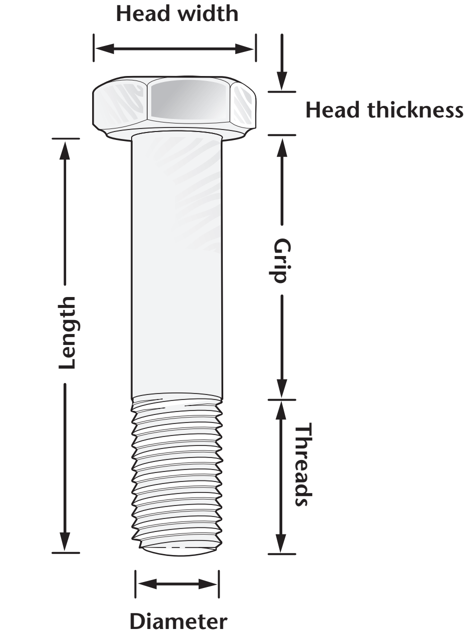


Figure 6-2-1. Bolt terms and dimensions. Bolts are installed inboard, down and aft.

the nut. Its head may or may not be designed to be turned. A screw is always designed to be turned by its head. Another minor but frequent difference between a screw and a bolt is that a screw is usually made of lower strength materials.

Threads on aircraft bolts and screws are of the American National Standard type. This standard contains two series of threads: national coarse (NC) and national fine (NF) series. Most aircraft threads are of the NF series.

Threads are also produced in right-hand and left-hand types. A right-hand thread advances into engagement when turned clockwise. A left-hand thread advances into engagement when turned counterclockwise.

Threads are sized by both the diameter and the number of threads per inch. The diameter is designated by screw gauge number for sizes up to 1/4 inch and by nominal size for those 1/4 inch and larger. Screw gauge numbers range from 0 to 12, except that numbers 7, 9, and 11 are omitted. Threads are designated by the diameter, number of threads per inch, thread series, and class in parts catalogs, on blueprints, and on repair diagrams.

For example, No. 8-32 NF-3 indicates a No. 8 size thread, 32 threads per inch, national fine series, and a class 3 thread. Also, 1/4-20 NC-3 indicates a 1/4-inch thread, 20 threads per inch, national coarse series, and a class 3 thread. A left-hand thread is indicated by the letters LH following the class of thread.

Bolts

Many types of bolts are used on aircraft. However, before discussing some of these types, it might be helpful to list and explain some commonly used bolt terms. You should know the names of bolt parts and be aware of the bolt dimensions that must be considered in selecting a bolt. Figure 6-2-1 shows both types of information.

The three principal parts of a bolt are the head, thread, and grip. The head is the larger diameter of the bolt, and may be one of many shapes or designs. The head keeps the bolt in place in one direction, and the nut used on the threads keeps it in place in the other direction.

To choose the correct replacement, several bolt dimensions must be considered. One is the length of the bolt. Note in Figure 6-2-1 that the bolt length is the distance from the tip of the threaded end to the head of the bolt. Correct length selection is indicated when the chosen bolt extends through the nut at least two full threads.

In the case of flat-end bolts or chamfered-(rounded-) end bolts, at least the full chamfer plus one full thread should extend through the nut. If the bolt is too short, it may not extend out of the bolt hole far enough for the nut to be securely fastened. If it is too long, it may extend so far that it interferes with the movement of nearby parts. Unnecessarily long bolts can affect weight and balance and reduce the aircraft payload capacity.

In addition, if a bolt is too long or too short, its grip is usually the wrong length. As shown in Figure 6-2-2, grip length should be approximately the same as the thickness of the material to be fastened. If the grip is too short, the threads of the bolt will extend into the bolt hole and may act like a reamer when the material is vibrating. To prevent this, make certain that no more than two threads extend into the bolt hole.

Also make certain that any threads that enter the bolt hole extend only into the thicker member that is being fastened. If the grip is too long, the nut will run out of threads before it can be tightened. In this event, a bolt with a shorter grip should be used, or if the bolt grip extends only a short distance through the hole, a washer may be used.

A second bolt dimension that must be considered is diameter. Figure 6-2-1 shows that the diameter of the bolt is the thickness of its shaft. If this thickness is 1/4 of an inch or more, the bolt diameter is usually given in fractions of an inch; for example, 1/4, 5/16, 7/16, and 1/2. However, if the bolt is less than 1/4 of an inch thick, the diameter is usually expressed as a whole number. For instance, a bolt that is 0.190

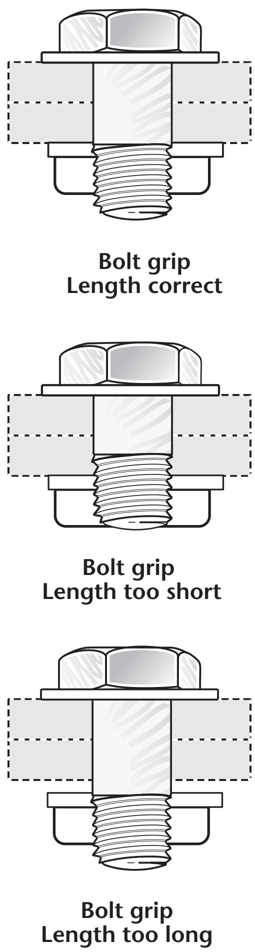


Figure 6-2-2. Correct and incorrect grip lengths.

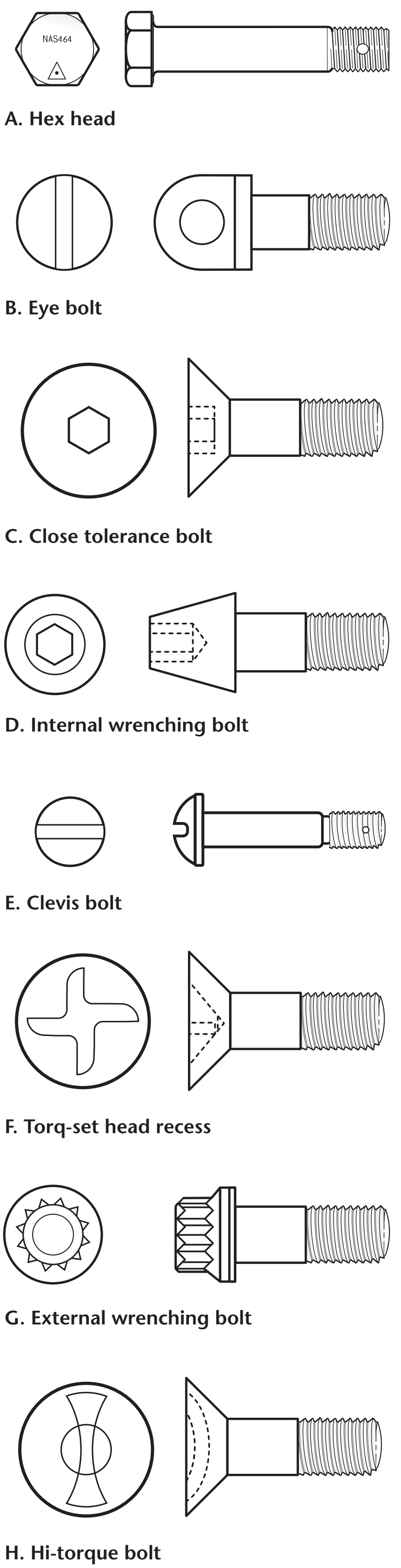


Figure 6-2-3. Bolt heads.

inch in diameter is called a No. 10 bolt, while a bolt that is 0.164 inch in diameter is called a No. 8.

The results of using a bolt of the wrong diameter should be obvious. If the bolt is too big, it cannot enter the bolt hole. If the diameter is too small, the bolt has too much play in the bolt hole, and it likely is not as strong as the correct bolt.

The third and fourth bolt dimensions that should be considered when choosing a bolt replacement are head thickness and width. If the head is too thin or too narrow, it may not be strong enough to bear the load imposed on it. If the head is too thick or too wide, it may extend so far that it interferes with the movement of adjacent parts.

Bolt heads. The most common type of head is the hex head (Figure 6-2-3A). This type of head may be thick for greater strength or relatively thin in order to fit in places having limited clearances. In addition, the head may be common or drilled to lockwire the bolt. A hex-head bolt may have a single hole drilled through it between two of the sides of the hexagon and still be classed as common. The drilled head-hex bolt has three holes drilled in the head, connecting opposite sides of the hex.

Seven additional types of bolt heads are shown in Figure 6-2-3. Notice that illustration B shows an eyebolt, often used in flight control systems. View C shows a countersunk-head, close-tolerance bolt. View D shows an internal-wrenching bolt. Both the countersunk-head bolt and the internal-wrenching bolt have hexagonal recesses (six-sided holes) in their heads. They are tightened and loosened by use of appropriate sized Allen wrenches.

View E shows a clevis bolt with its characteristic round head. This head may be slotted, as shown, to receive a common screwdriver or recessed to receive a Reed-and-Prince or a Phillips screwdriver. It is for shear applications.

View F shows a torque-set wrenching recess that has four driving wings, each one offset from the one opposite it. There is no taper in the walls of the recess. This permits higher torque to be applied with less tendency for the driver to slip or cam out of the slots.

View G shows an external-wrenching head that has a washer face under the head to provide an increased bearing surface. The 12-point head gives a greater wrench gripping surface.

View H shows a hi-torque style driving slot. This single slot is narrower at the center than at the outer portions. This and the center dimple provide the slot with a bowtie appearance. The recess is also undercut in a taper from the center

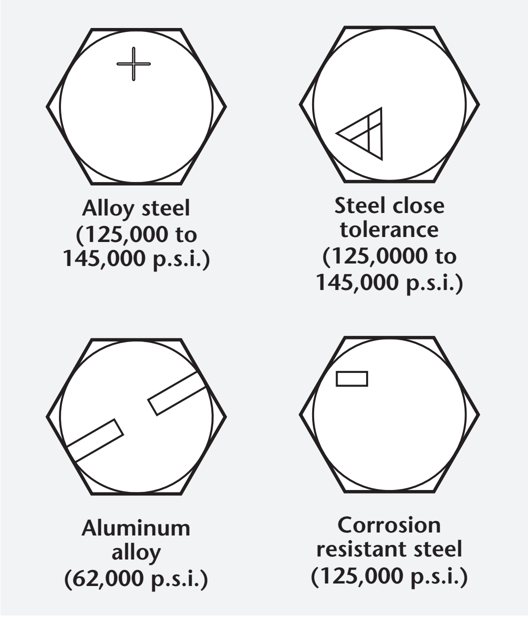


Figure 6-2-4. Bolt head markings.

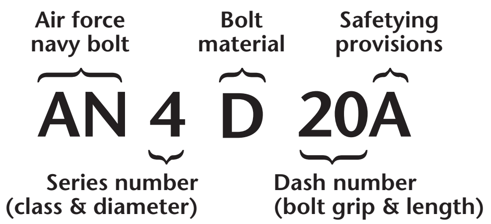


Figure 6-2-5. AN bolt part number breakdown.

to the outer ends, producing an inverted keystone shape. These bolts must be installed with a special hi-torque driver adapter. They must also be driven with some type of torque-limiting or torque-measuring device. Each diameter of bolt requires the proper size of driver for that particular bolt. The bolts are available in standard and reduced 100-degree flush heads. The reduced head requires a driver one size smaller than the standard head.

Bolt threads. Another structural feature in which bolts may differ is threads. These usually come in one of two types: coarse and fine. The two are not interchangeable. For any given size of bolt there is a different number of coarse and fine threads per inch.

For instance, consider the 1/4-inch bolts. Some are called 1/4-28 bolts because they have 28 fine threads per inch. Others have only 20 coarse threads per inch and are called 1/4-20 bolts. Forcing one size of thread into another size, even though both are 1/4 of an inch, can strip the finer threads on softer metal. The same thing is true concerning the other sizes of bolts; therefore, make certain that bolts you select have the correct type of threads.

Class of fit. Threads are also designated by the Class of fit. The Class indicates the tolorance in the screw-cutting process during manufacture. There are 4 classes of fit. Aircraft bolts are almost always class 3.

- Class 1 is loose fit, meaning that the nut can be turned on by hand.
- Class 2 is free fit. Most aircraft screws are class 2.
- Class 3 fit is medium fit. Some effort will be needed to turn the nut by hand.
- Class 4 fit is close fit. A wrench will be needed to turn the nut onto the bolt.

Bolt material. The type of metal used in an aircraft bolt helps to determine its strength and resistance to corrosion. Make certain that the material is considered when selecting replacement bolts. Like solid shank rivets, bolts have distinctive head markings that help to identify the material from which they are manufactured. Figure 6-2-4 shows the tops of several hex-head bolts, each marked to indicate the type of bolt material.

Bolt identification. Normally every unserviceable bolt should be replaced with a bolt of the same type. Of course, substitute and interchangeable items are sometimes available, but the ideal fix is a bolt-for-bolt replacement. The part number of a needed bolt may be obtained by referring to the illustrated parts breakdown (IPB) for the aircraft concerned. Exactly what this part number means depends upon whether the bolt is AN (Air Force-Navy), NAS (National Aircraft Standard), or MS (Military Standard).

AN part number. There are several classes of AN bolts and, in some instances, their part numbers reveal slightly different types of information. However, most AN numbers contain the same type of information.

Figure 6-2-5 shows a breakdown of a typical AN bolt part number. Like the AN rivets discussed earlier, it starts with the letters AN. A number follows the letters. This number usually consists of two digits. The first digit (or absence of it) shows the class of the bolt. For instance, in Figure 6-2-5 the series number has only one digit, and the absence of one digit shows that this part number represents a general-purpose hex-head bolt. However, the part numbers for some bolts of this class have two digits. In fact, general-purpose hex-head bolts include all part numbers beginning with AN3, AN4, and so on through AN20. Other series numbers and the classes of bolts that they represent are as follows:

- AN21 through AN36 — clevis bolts
- AN42 through AN49 — eyebolts

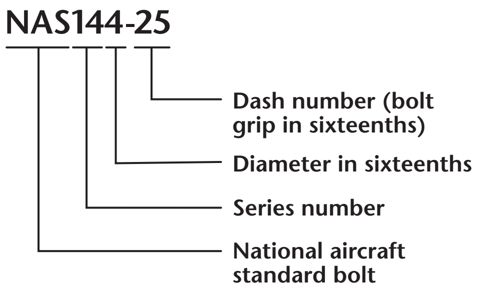


Figure 6-2-6. NAS bolt part number breakdown.

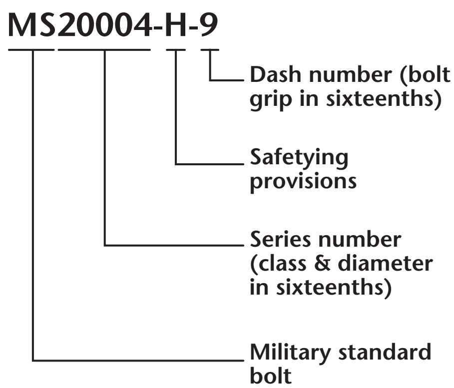


Figure 6-2-7. MS bolt part number breakdown.

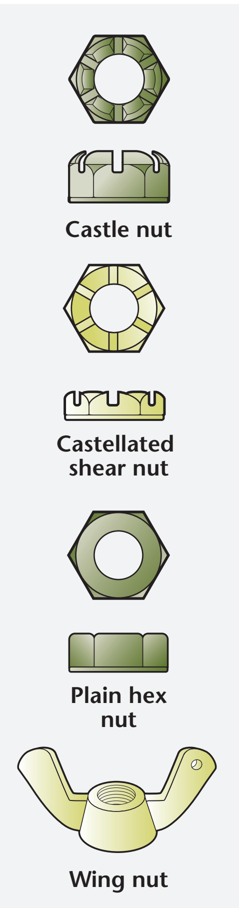


Figure 6-2-8. Nuts.

The series number shows another type of information other than bolt class. With a few exceptions, it indicates bolt diameter in sixteenths of an inch. For instance, in Figure 6-2-5 the last digit of the series number is 4; therefore, this bolt is 4/16 of an inch (1/4 of an inch) in diameter. In the case of a series number ending in 0, for instance AN10, the 0 stands for 10 and the bolt has a diameter of 10/16, or 5/8, of an inch.

Refer again to Figure 6-2-5 and observe that a dash follows the series number. When used in the part numbers for general-purpose AN bolts, clevis bolts, and eyebolts, this dash indicates that the bolt is made of carbon steel. With these types of bolts, the letter C, used in place of the dash, means corrosion-resistant steel. The letter D means 2017 aluminum alloy. The letters DD stand for 2024 aluminum alloy. For some bolts of this type, a letter H is used with these letters or with the dash. If it is so used, the letter H shows that the bolt has been drilled for safetying.

Next, observe the number 20 that follows the dash. This is called the dash number. It represents the bolt's grip (as taken from special tables). In this instance the number 20 stands for a bolt that is 2-1/32 inches long.

The last character in the AN number shown in Figure 6-2-5 is the letter A. This signifies that the bolt is not drilled for cotter pin safetying. If no letter were used after the dash number, the bolt shank would be drilled for safetying.

NAS part number. Another series of bolts used in aircraft construction is the NAS (Figure 6-2-6.) In considering the NAS 144-25 bolt (special internal-wrenching type), observe that the bolt identification code starts with the letters NAS. Next, the series has a three-digit number, 144. The first two digits (14) show the class of the bolt. The next number (4) indicates the bolt diameter in sixteenths of an inch. The dash number (25) indicates bolt grip in sixteenths of an inch.

MS part number. MS is another series of bolts used in aircraft construction. In the part number shown in Figure 6-2-7, the MS indicates that the bolt is a Military Standard bolt. The series number (20004) indicates the bolt class and diameter in sixteenths of an inch (internal-wrenching, 1/4-inch diameter). The letter H before the dash number indicates that the bolt has a drilled head for safetying. The dash number (9) indicates the bolt grip in sixteenths of an inch.

Nuts

Aircraft nuts differ in design and material, just as bolts do, because they are designed to do a specific job with the bolt. For instance, some of the nuts are made of cadmium-plated carbon steel, stainless steel, brass, or aluminum alloy. The type of metal used is not identified by markings on the nuts themselves. Instead, the material must be recognized from the luster of the metal.

Nuts also differ greatly in size and shape. In spite of these many and varied differences, they all fall under one of two general groups: self-locking and non-self-locking. Nuts are further divided into types such as plain nuts, castle nuts, check nuts, plate nuts, channel nuts, barrel nuts, internal-wrenching nuts, external-wrenching nuts, shear nuts, sheet spring nuts, wing nuts, and Klincher locknuts.

Non-self-locking nuts. Non-self-locking nuts require the use of a separate locking device for security of installation. There are several types of these locking devices mentioned in the following paragraphs in connection with the nuts on which they are used. Since no single locking device can be used with all types of non-self-locking nuts, you must select one suitable for the type of nut being used.

Self-locking nuts. Self-locking nuts provide tight connections that will not loosen under vibrations. Self-locking nuts approved for use on aircraft meet critical strength, corrosion-resistance, and temperature specifications. The two major types of self-locking nuts are prevailing torque and free spinning. The two general types of prevailing torque nuts are the all-metal nuts and the nonmetallic insert nuts.

New self-locking nuts must be used each time components are installed in critical areas throughout the entire aircraft, including all flight, engine, and fuel control linkage and attachments. The flexloc nut is an example of the all-metal type. The elastic stop nut is an example of the nonmetallic insert type.

All-metal, self-locking nuts are constructed with the threads in the load-carrying portion of the nut out of phase with the threads in the locking portion, or with a saw cut top portion with a pinched-in thread. The locking action of these types depends upon the resiliency of the metal when the locking section and load-carrying section are forced into alignment when engaged by the bolt or screw threads.

Fiber-type lock nut. A fiber lock nut uses an unthreaded fiber insert that is locked into the recess end of the nut. When the nut is screwed onto the bolt, it is forced through the fiber lock portion. The fiber grips the bolt threads, applying downward pressure between the threads in the nut and the threads on the bolt. The force created by the "fiber lock" prevents the nut from coming loose under most conditions. Fiber lock nuts are not suitable for all applications

Plain hex nuts. These nuts are available in self-locking or non-self-locking styles. When the non-self-locking nuts are used, they should be locked with an auxiliary locking device such as a check nut or lock washer (Figure 6-2-8).

Castle nuts. These nuts are used with drilled shank bolts, hex-head bolts, clevis bolts, eyebolts, and drilled-head studs. These nuts are designed to be secured with cotter pins or safety wire.

Castellated shear nuts. Like the castle nuts, these nuts are castellated for safetying. They are used in shear applications.

Check nuts. These nuts are used in locking devices for non-self-locking plain hex nuts, setscrews, and threaded rod ends.

Plate nuts. These nuts are used for blind mounting in inaccessible locations and for easier maintenance. They are available in a wide range of sizes and shapes. One-lug, two-lug, and right-angle shapes are available to accommodate the specific physical requirements of nut locations. Floating nuts provide a controlled amount of nut movement to compensate for subassembly misalignment. They can be either self-locking or non-self-locking (Figure 6-2-9).

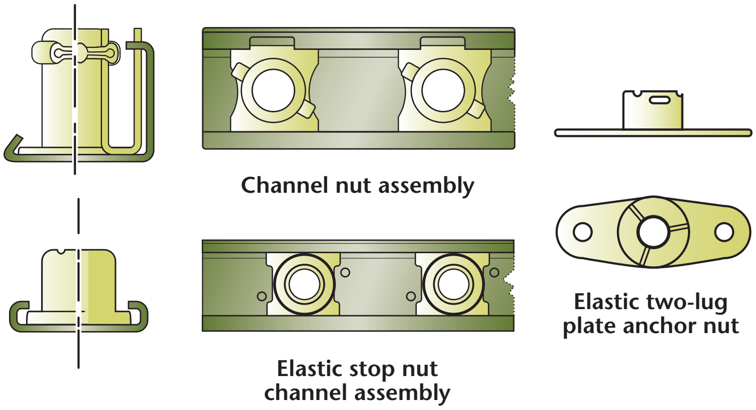


Figure 6-2-9. Self-locking nuts.

Channel nuts. These nuts are used in applications requiring anchored nuts equally spaced around openings such as access and inspection doors and removable leading edges. Straight or curved channel nut strips offer a wide range of nut spacings and provide a multi-nut unit that has all the advantages of floating nuts. They are usually self-locking.

Barrel nuts. These nuts are installed in drilled holes. The round portion of the nut fits in the drilled hole and provides a self-wrenching effect. They are usually self-locking (Figure 6-2-10A).

Internal-wrenching nuts. These nuts are generally used where a nut with a high tensile strength is required or where space is limited and the use of external-wrenching nuts would not permit the use of conventional wrenches for installation and removal. This is usually where the bearing surface is counterbored. These nuts have a nonmetallic insert that provides the locking action.

Point-wrenching nuts. These nuts are generally used where a nut with a high tensile length is required. These nuts are installed with a small socket wrench. They are usually self-locking (Figure 6-2-10B).

Shear nuts. These nuts are designed for use with devices such as drilled clevis bolts and threaded taper pins that are normally subjected to shearing stress only. They are usually self-locking (Figure 6-2-10C).

Sheet spring nuts. These nuts are used with standard and sheet metal self-tapping screws to support line clamps, conduit clamps, electrical equipment, and access doors. The most common types are the float, the two-lug anchor, and the one-lug anchor. The nuts have an arched spring lock that prevents the screw from working loose. They should be used only

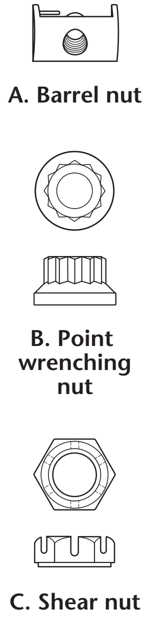


Figure 6-2-10. Nuts.

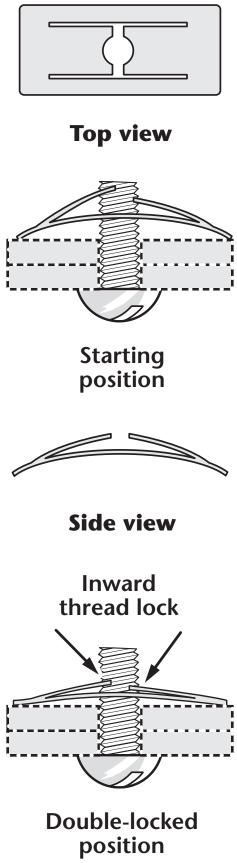


Figure 6-2-11. Sheet spring nut.

where originally used in the fabrication of the aircraft (Figure 6-2-11).

Wing nuts. These nuts are used where the desired tightness is obtained by the use of your fingers and where the assembly is frequently removed.

Klincher locknuts. Klincher locknuts are used to ensure a permanent and vibration proof, bolted connection that holds solidly and resists thread wear. They can withstand extremely high or low temperatures and exposure to lubricants, weather, and compounds without impairing the effectiveness of their locking elements. The nut is installed with the end that looks like a double washer toward the metal being fastened. Notice in Figure 6-2-12 that the end that looks like a double hexagon is away from the metal being fastened.

Screws

The most common threaded fastener used in aircraft construction is the screw. The three most used types are the structural screw, machine screw, and the self-tapping screw.

Structural screws. Structural screws are used for assembling structural parts. They are made of alloy steel and are heat treated. Structural screws have a definite grip length and the same shear and tensile strengths as the equivalent size bolt. They differ from structural bolts only in the type of head. These screws are available in round-head, countersunk-head, and brazier-head types, either slotted or recessed, for the various types of screwdrivers (Figure 6-2-13).

Machine screws. The commonly used machine screws are the flush-head, round-head, fillister-head, socket-head, pan-head, and truss-head types (Figure 6-2-14).

Flush-head. Flush-head machine screws are used in countersunk holes where a flush finish is desired. These screws are available in 82 and 100 degrees of head angle and have various types of recesses and slots for driving.

Round-head. Round-head machine screws are frequently used in assembling highly stressed aircraft components.

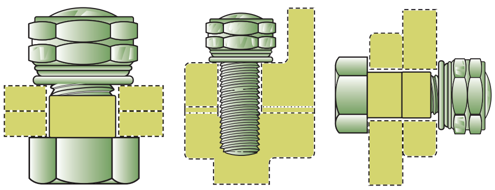


Figure 6-2-12. Typical installations of the Klincher locknut.

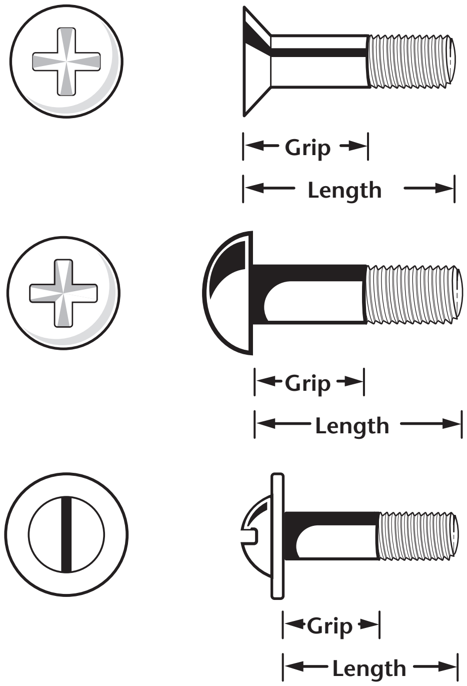


Figure 6-2-13. Structural screws.

Phillister-head. Phillister-head machine screws are used as general-purpose screws. They may also be used as cap screws in light applications such as the attachment of cast aluminum gearbox cover plates.

Socket-head. Socket-head machine screws are designed to be screwed into tapped holes by internal wrenching. They are used in applications that require high-strength precision products, compactness of the assembled parts, or sinking of the head into holes.

Pan- and truss-head. Pan-head and truss-head screws are general-purpose screws used where head height is unimportant. These screws are available with cross-recessed heads only.

Self-tapping screws. A self-tapping screw is one that cuts its own internal threads as it is turned into the hole. Self-tapping screws can be used only in comparatively soft metals and materials. Self-tapping screws may be further divided into two classes or groups: machine self-tapping screws and sheet metal self-tapping screws.

Machine self-tapping screws are usually used for attaching removable parts, such as nameplates, to castings. The threads of the screw cut mating threads in the casting after the hole has been predrilled. Sheet metal self-tapping screws are used for such purposes as temporarily attaching sheet metal in place for riveting. They may also be used for permanent assembly of nonstructural parts, where it is necessary to insert screws in blind applications.

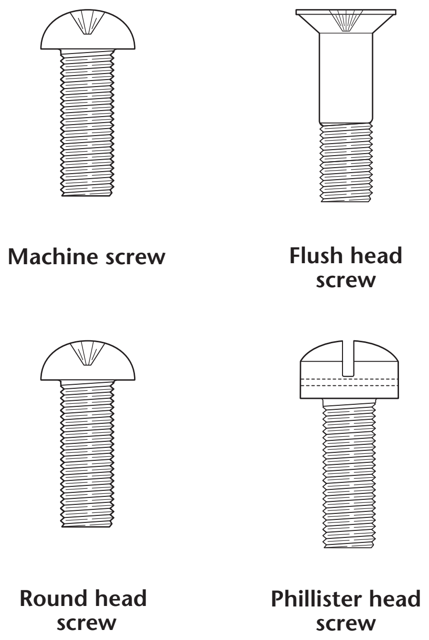


Figure 6-2-14. Machine screws.

CAUTION: Self-tapping screws should never be used to replace standard screws, nuts, or rivets in the original structure. Over a period of time, vibration and stress will loosen this type of fastener, causing it to lose its holding ability.

Washers

Washers used in aircraft structures may be grouped into three general classes—plain washers, lockwashers and special washers. Figure 6-2-15 shows some of the most commonly used types.

Plain washers are widely used under AN hex nuts to provide a smooth bearing surface, to act as a shim in obtaining the correct relationship between the threads of the bolt and the nut, and to adjust the position of castellated nuts with respect to drilled cotter pin holes in bolts. Plain washers are also used under lockwashers to prevent damage to surfaces of soft materials.

Lockwashers are used whenever the self-locking or castellated nut is not used. Sufficient friction is provided by the spring action of the washer to prevent loosening of the nut from vibration. Lockwashers should not be used as part of a fastener for primary or secondary aircraft structures.

Washers such as ball socket and seat washers, taper pin washers, and washers for internal wrenching nuts and bolts have been designed for special applications.

Ball socket and seat washers are used where a bolt is installed at an angle to the surface, or where perfect alignment with the surface is required at all times. These washers are used together.

Taper pin washers are used in conjunction with threaded taper pins. They are installed under the nut to effect adjustment where a plain washer would distort.

Washers for internal-wrenching nuts and bolts are used in conjunction with NAS internal-wrenching bolts. The washer used under the head is countersunk to seat the bolt head or shank radius. A plain washer is used under the nut.

Section 3

Aircraft Control Cable

Cables

A cable is a group of wires or a group of strands of wires twisted together into a strong wire

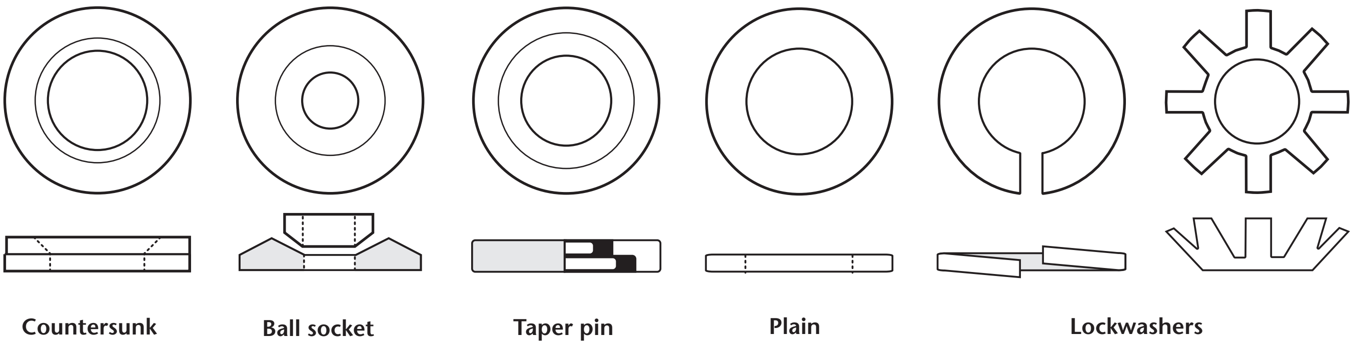


Figure 6-2-15. Various types of special washers.

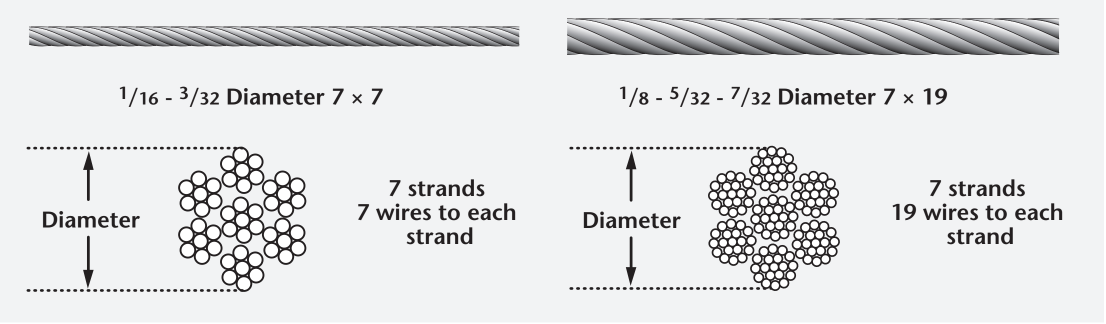


Figure 6-3-1. Cable cross section.

rope. The wires or strands may be twisted in various ways. The relationship of the direction of twist of each strand to each other and to the cable as a whole is called the lay. The lay of the cable is an important factor in its strength, for if the strands are twisted in a direction opposite to the twist of the strands around the center strand or core, the cable will not stretch (or set) as much as one in which they are all twisted in the same direction.

This direction of twist (in opposite direction) is most commonly adopted, and it is called a regular or an ordinary lay. Cables may have a right regular lay or a left regular lay. If the strands are twisted in the direction of twist around the center strand or core, the lay is called a lang lay. There is a right and left lang lay. The only other twist arrangement, twisting the strands alternately right and left, then twisting them all either to the right or to the left about the core, is called a reverse lay. Most aircraft cables have a right regular lay.

When aircraft cables are manufactured, each strand is first formed to the spiral or helical shape to fit the position it is to occupy in the finished cable. The process of such forming is called preforming, and cables made by such a process are said to be preformed.

The process of preforming is adopted to ensure flexibility in the finished cable and to relieve bending and twisting stresses in the strands as they are woven into the cable. It also keeps the strands from spreading when the cable is cut. All aircraft cables are internally lubricated during construction.

Aircraft control cables are fabricated either from flexible, preformed carbon steel wire or from flexible, preformed, corrosion-resistant steel wire. The small corrosion-resistant steel cables are made of steel containing not less than 17 percent chromium and 8 percent nickel, while the larger ones (those of the 5/16-, 3/8-, and 7/16-inch diameters) are made of steel that, in addition to the amounts of chromium and nickel just mentioned, also contains not less than 1.75 percent molybdenum.

Cables may be designated 7 × 7, 7 × 19, or 6 × 19 according to their construction. A 7 × 7 cable consists of six strands of seven wires each, laid around a center strand of seven wires. A 7 × 19 cable consists of six strands of 19 wires, laid around a 19-wire central strand, A 6 × 19 I.W.R.C. (Independent Wire Rope Core) cable consists of six strands of 19 wires each, laid around an independent wire rope center.

The size of cable is given in terms of diameter measurement. A 1/8-inch cable or a 5/16-inch cable means that the cable measures 1/8 inch

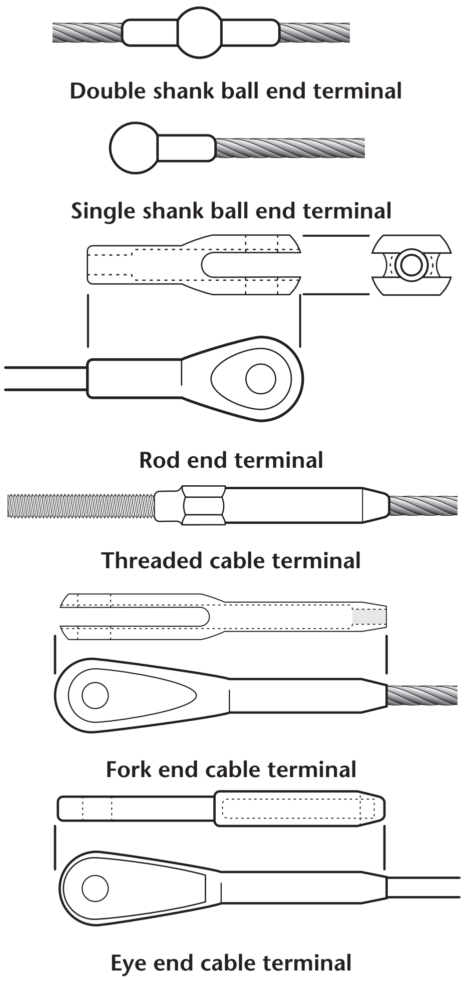


Figure 6-3-2. Types of cable terminal fittings.

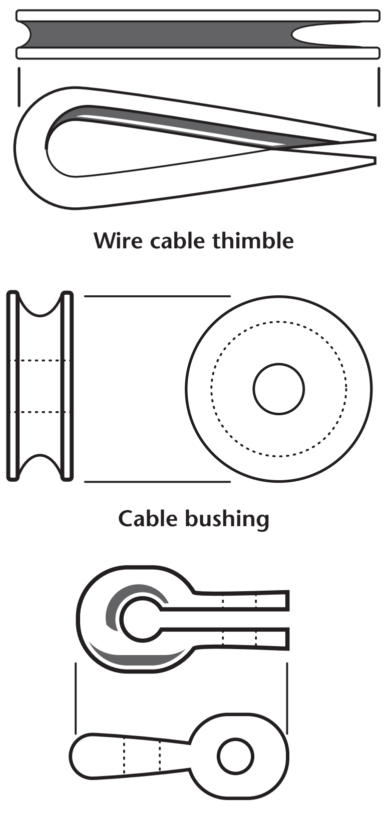


Figure 6-3-3. Thimble, bushing, and shackle fittings.

or 5/16 inch in diameter, as shown in Figure 6-3-1. Note that the cable diameter is that of the smallest circle that would enclose the entire cross section of the cable. Aircraft control cables vary in diameters, ranging from 1/16 of an inch to 3/8 of an inch.

Fittings

Cable ends may be equipped with several different types of fittings such as terminals, thimbles, bushings, and shackles. Terminal fittings are generally of the swaged type. Terminal fittings are available with threaded ends, fork ends, eye ends, and single-shank and double-shank ball ends.

Threaded-end, fork-end, and eye-end terminals are used to connect the cable to turnbuckles, bell cranks, and other linkage in the system. The ball terminals are used for attaching cable to quadrants and special connections where space is limited. The single-shank ball end is usually used on the ends of cables, and the double-shank ball end may be used at either the ends or in the center of a cable run using a clevis bolt attachment. Figure 6-3-2 shows the various types of terminal fittings.

Thimble, bushing, and shackle fittings may be used in place of some types of terminal fittings when facilities and supplies are limited and immediate replacement of the cable is necessary. Figure 6-3-3 shows these fittings.

Turnbuckles. A turnbuckle is a mechanical screw device consisting of two threaded terminals and a threaded barrel. Figure 6-3-4 shows a typical turnbuckle assembly. Turnbuckles are fitted in the cable assembly for the purpose of making minor adjustments in cable length and for adjusting cable tension. One of the terminals has right-hand threads and the other has left-hand threads. The barrel has matching right- and left-hand threads internally. The end of the barrel, with left-hand threads inside, can usually be identified by either a groove or knurl around the end of the barrel. Barrels and terminals are available in both long and short lengths.

When you install a turnbuckle in a control system, it is necessary to screw both of the terminals an equal number of turns into the turnbuckle barrel. It is also essential that all turnbuckle terminals be screwed into the barrel at least until not more than three threads are exposed. On initial installation, the turnbuckle terminals should not be screwed inside the turnbuckle barrel more than four threads. Figure 6-3-5 shows turnbuckle thread tolerances.

After a turnbuckle is properly adjusted, it must be safetied. There are several methods of safetying turnbuckles. However, only two methods have been adopted as standard procedures by the aircraft industry. These methods are discussed later in this chapter.

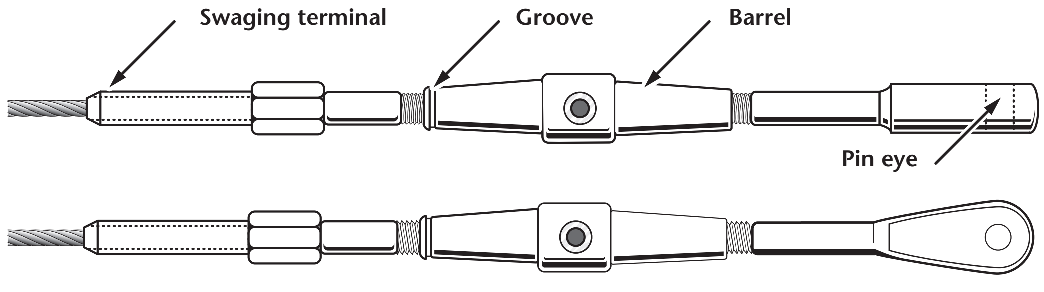


Figure 6-3-4. Typical turnbuckle assembly.

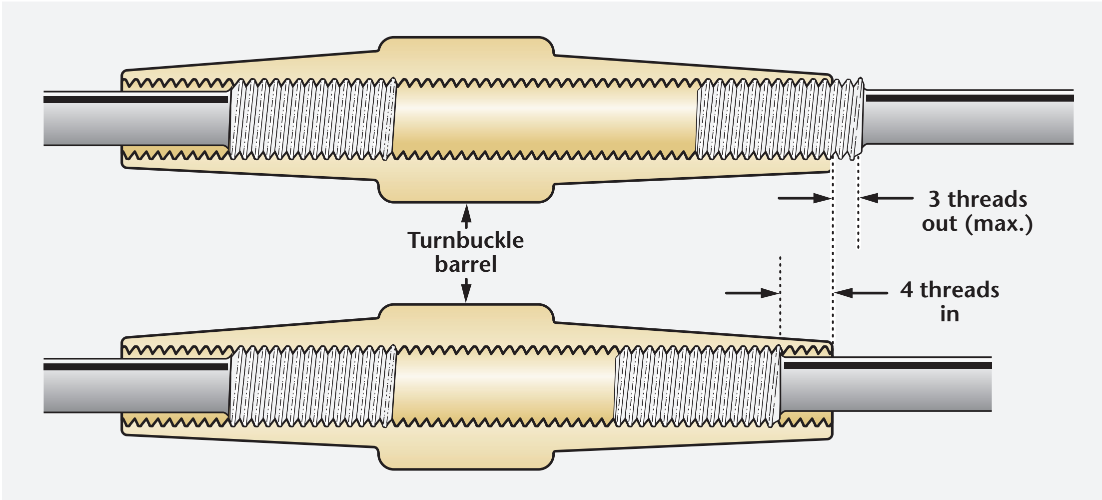


Figure 6-3-5. Turnbuckle tolerances.

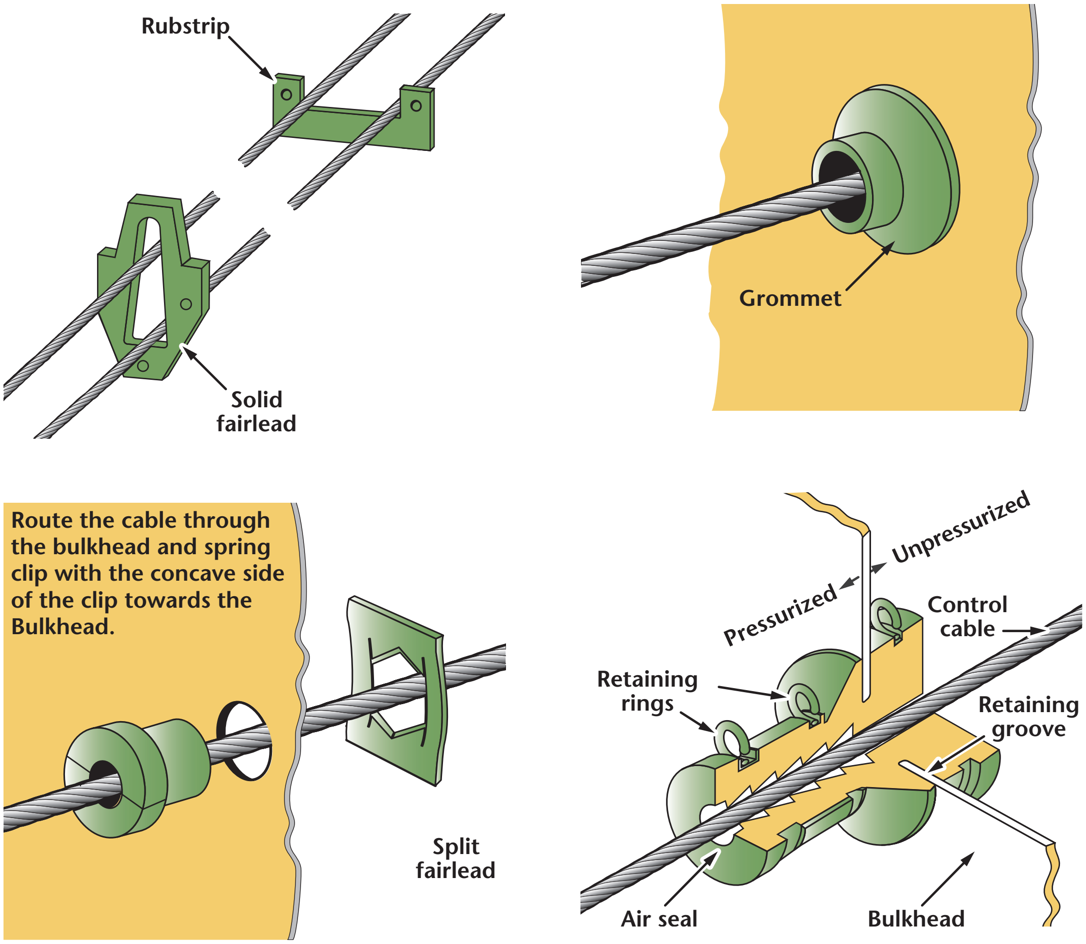


Figure 6-3-6. Typical cable guides.

Adjustable connector links. An adjustable connector link consists of two or three metal strips with holes so arranged that they may be matched and secured with a clevis bolt to adjust the length of the connector. They are installed in cable assemblies for the purpose of making major adjustments in cable length and to compensate for cable stretch. Adjustable connector links are usually used in very long cable assemblies.

Guides. Fairleads (rubstrips), grommets, pressure seals, and pulleys are all types of cable guides. They are used to protect control cables by preventing the cables from rubbing against nearby metal parts. They are also used as supports to reduce cable vibration in long stretches (runs) of cable. Figure 6-3-6 shows some typical cable guides.

Fairleads. Fairleads may be made of a solid piece of material to completely encircle cables when they pass through holes in bulkheads or other metal parts. Fairleads may be used to reduce cable whipping and vibration in long runs of cable. Split fairleads are made for easy installation around single cables to protect them from rubbing on the edges of holes. No more than 3° of cable deflection is allowed through a fairlead or cable guide.

Grommets. Grommets are made of rubber, and they are used on small openings where single cables pass through the walls of unpressurized compartments.

Pressure seals. Pressure seals are used on cables or rods that must move through pressurized bulkheads. They fit tightly enough to prevent air pressure loss, but not so tightly as to hinder movement of the unit.

Pulleys. Pulleys (or sheaves) are grooved wheels used to change cable direction and to allow the cable to move with a minimum of friction. Most pulleys used on aircraft are made from layers of cloth impregnated with phenolic resin and fused together under high temperatures and pressures. Aircraft pulleys are extremely strong and durable and cause minimum wear on the cable passing over them. Pulleys are provided with grease-sealed bearings and usually do not require further lubrication. However, pulley bearings may be pressed out, cleaned, and relubricated with special equipment. Pulley brackets made of sheet or cast aluminum are required with each pulley installed in the aircraft (Figure 6-3-7). Besides holding the pulley in the correct position and at the correct angle, the brackets prevent the cable from slipping out of the groove on the pulley wheel.

Sectors and Quadrants

These units are generally constructed in the form of an arc or in a complete circular form. They are grooved around the outer circumference to receive the cable, as shown in Figure 6-3-7. The names sector and quadrant are used interchangeably. Sectors and quadrants are similar to bell cranks and walking beams, which are used for the same purpose in rigid control systems.

Section 4

Aircraft Hydraulic Hardware and Seals

Hardware, such as the quick-disconnect coupling, seals, and packings are used throughout the aircraft. They are essential for safe and proper operation of aircraft systems.

Quick-Disconnect Couplings

Quick-disconnect couplings provide a means of quickly disconnecting a line without the loss of hydraulic fluid or entrance of air into the system. Each coupling assembly consists of two halves, held together by a union nut. Each half contains a valve, which is held open when the coupling is connected.

This action allows fluid to flow in either direction through the coupling. When the coupling

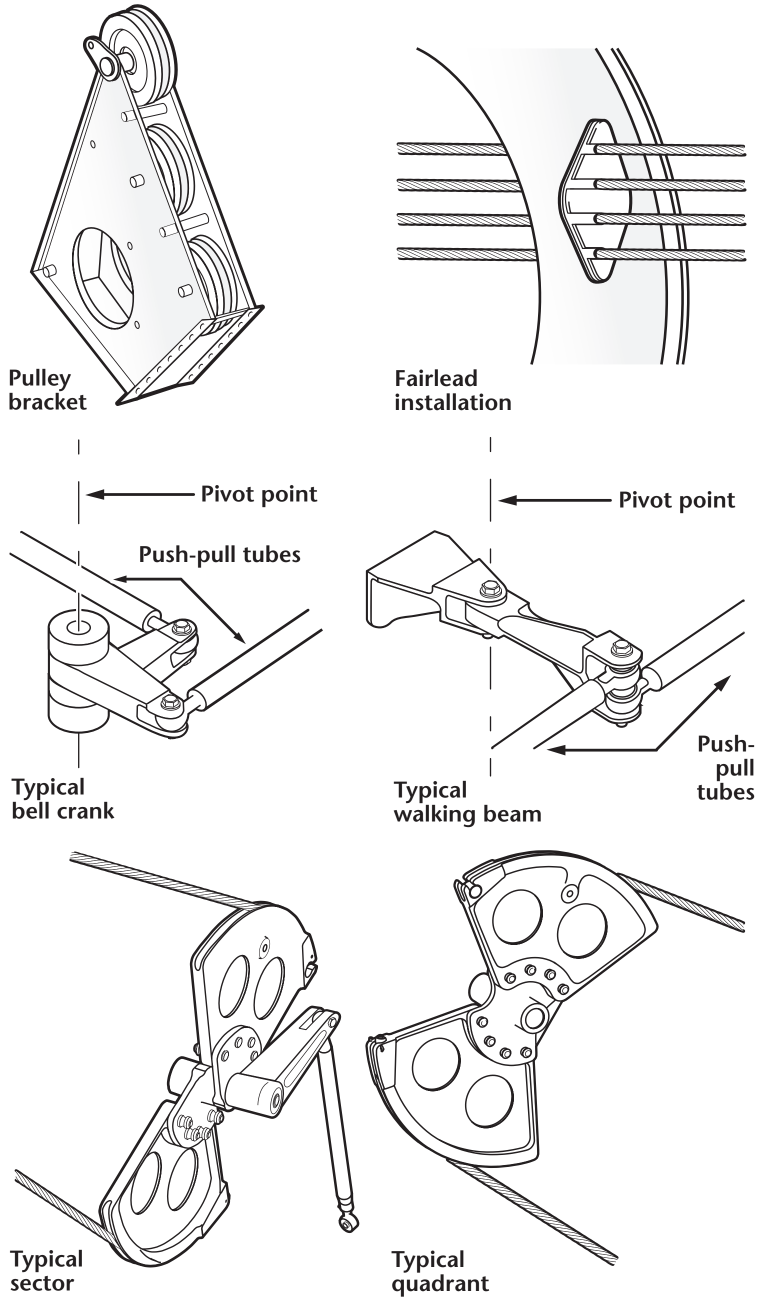


Figure 6-3-7. Control system components.

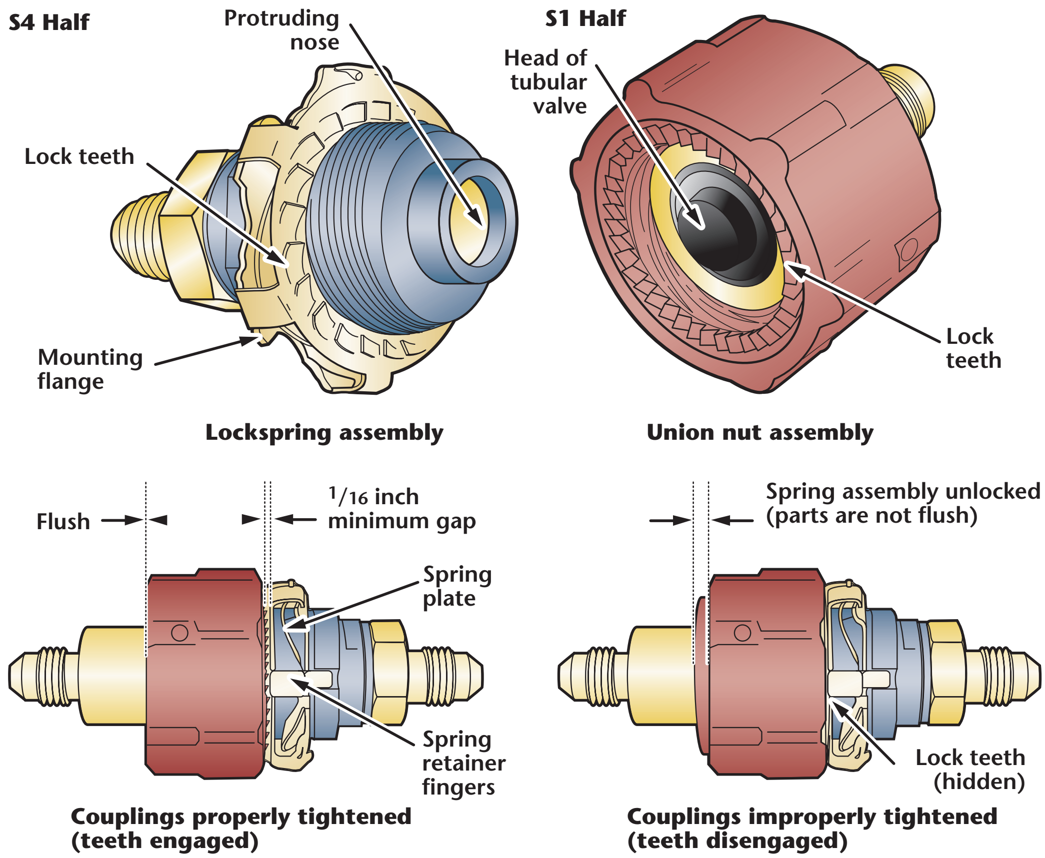


Figure 6-4-1. Series 145 and 155 quick-disconnect couplings.

is disconnected, a spring in each half closes the valve, preventing the loss of fluid and entrance of air.

The union nut has a quick-lead thread that permits connecting or disconnecting the coupling by turning the nut. The amount the nut must be turned varies with different styles of couplings. For one style, a quarter turn of the union nut locks or unlocks the coupling. For another style, a full turn is required.

Some couplings require wrench tightening; others are connected and disconnected by hand. Some installations require that the coupling be safetied with safety wire; others do not require any form of safetying. Because of these individual differences, all quick disconnects should be installed in accordance with the instructions in the applicable maintenance manual (MM).

The series 145 and 155 (Aeroquip) couplings make up one type of quick-disconnect coupling found on aircraft. These couplings may be identified by the part number (145 or 155) stamped on the face of the union nut.

Each quick-disconnect coupling consists of two halves, referred to as S1 half and S4 half (Figure 6-4-1).

When disconnected, the union nut remains with the S1 half. The S4 half has a mounting flange for attaching to a bulkhead or other structural member of the aircraft.

All parts referred to in the following paragraphs are identified in Figure 6-4-1. The two halves of the coupling may be connected by placing the tubular valve within the protruding nose of the mating half and rotating the union nut in a clockwise direction. The union nut must be rotated until its teeth fully engage the lock spring.

A properly tightened coupling will have compressed the lock spring until a 1/16-inch minimum gap exists between the inside lip of the spring retainer fingers and the spring plate. Figure 6-4-1 shows the coupling both properly connected and improperly connected.

The locking action may be followed by referring to Figure 6-4-1. Positive locking is assured by the locking spring with teeth, which engage ratchet teeth on the union nut when the coupling is fully connected. The lock spring automatically disengages when the union nut is unscrewed. An O-ring packing seals against leakage as the coupling halves are joined. Positive opening of the valves occurs as the halves are connected.

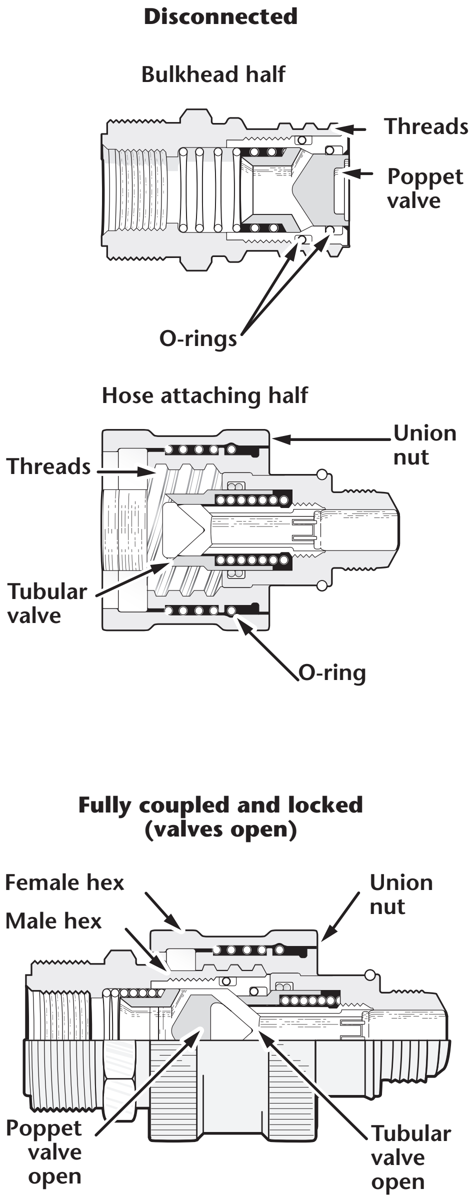


Figure 6-4-2. Quick disconnects properly and improperly connected.

When the coupling halves are joined, the protruding nose of the S4 half contacts the sleeve of the S1 half. Simultaneously, the head of the tubular valve contacts the face of the poppet valve, thus preventing air from entering the system. Tightening the union nut pulls the coupling halves together. This causes the nose of the S4 half to push the sleeve into the S1 half, uncovering the ports to the tubular valve. At the same time, the head of the tubular valve depresses the poppet valve.

When the coupling halves are fully connected, the sleeve and poppet valve have reached the positions shown in the bottom illustration of Figure 6-4-2. The nose of the S4 half has engaged the O-ring packing of the S1 half, providing a positive seal.

Figure 6-4-3. Series 3200 (Aeroquip) quick disconnect.

> **NOTE:** Do not use a wrench to couple or uncouple series 145 or 155 quick-disconnects unless a modified union nut is incorporated. Modified union nuts may be identified by the letter C preceding the part number on the nut. On these modified union nuts, a wrench may be used to assist in tightening the coupling. Torque values for the various size couplings may be found in the aircraft MM and should be strictly complied with in all instances.

A newer type of quick-disconnect coupling is the series 3200 (Aeroquip). This is an improved version and is simple to operate. This series is designed for use in hydraulic systems up to 3,000 p.s.i. operating pressure. Figure 6-4-3 shows the quick disconnect in both the disconnected and connected positions. To connect, align the tabular valve of the hose-attaching half with the recess in the bulkhead-coupling half. The nut is then brought forward to engage the threads and rotated in a clockwise direction until the hex nut engages the hex on the coupling body. This may be done in one continuous turn of the union nut, about one-quarter of a revolution. The quick-lead Acme thread allows the coupling to be connected by hand against pressures up to 300 p.s.i.

The connection may be inspected by three different methods as follows: If the nut can be turned by hand in a clockwise direction, the coupling is not locked. A slight tug on the hose will separate the halves if the couplings are not locked. Inspect the locking male hex on the bulkhead coupling half; if the coupling is not connected, the red male hex of the bulkhead half will be visible.

Hydraulic Seals

Hydraulic seals are used throughout aircraft hydraulic systems to minimize internal and external leakage of hydraulic fluid. They prevent the loss of system pressure. A seal may consist of more than one component, such as an O-ring and a backup ring, or possibly an O-ring and two backup rings. Hydraulic seals used internally on a sliding or moving assembly are normally called packings. Hydraulic seals used between non-moving fittings and bosses are normally called

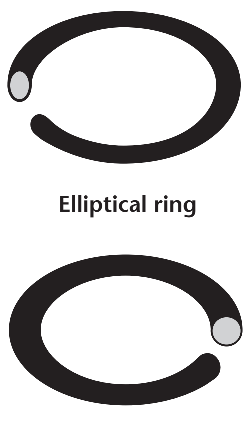


Figure 6-4-4. Hydraulic seals.

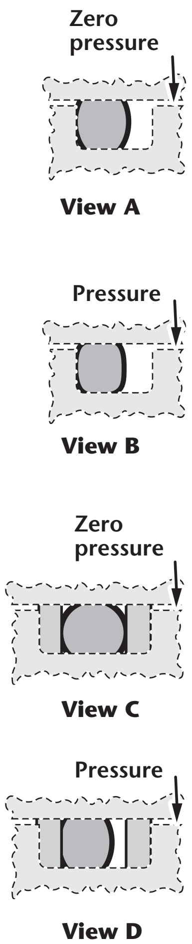


Figure 6-4-5. Action of O-rings.

gaskets. Most packings and gaskets are manufactured in the form of O-rings.

An O-ring is circular in shape, and its cross section is small in relation to its diameter. The cross section is truly round and has been molded and trimmed to extremely close tolerances. In some landing gear struts, an elliptical seal is used. The elliptical seal is similar to the O-ring seal except for its cross-sectional shape. As its name implies, its cross section is elliptical in shape. Both the O-ring and elliptical seals are shown in Figure 6-4-4.

Advances in aircraft design have made new O-ring composition necessary to meet changing conditions. Hydraulic O-rings were originally established under AN (Air Force-Navy) specification numbers (6227, 6230, and 6290) for use in fluid at operating temperatures ranging from -65°F (-53°C) to +160°F (71°C). When new designs raised operating temperatures to a possible +275°F (135°C), more compounds were developed and perfected.

Recently, newer compounds were developed under MS (Military Standard) specifications that offered improved low-temperature performance without sacrificing high-temperature performance. These superior materials were adopted in the MS28775 O-ring, which replace AN6227 and AN6230 O-rings, and the MS28778 O-ring, which replace the AN6290 O-ring. These O-rings are now standard for systems where the operating temperatures may vary from -65°F (-53°C) to +275°F (135°C).

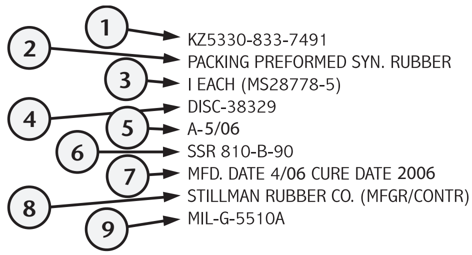
Packings used in aircraft hydraulic installations are normally manufactured from synthetic rubber. They are used in units that contain moving parts, such as actuating cylinders, selector valves, etc. Although packings are made in many forms, the O-ring type is most widely used. The U-rings, V-rings and other various types are obsolete in most cases and are not discussed in this book.

The O-ring packing seals effectively in both directions. This sealing is done by distortion of its elastic compound. Views A and C of Figure 6-4-5 show O-rings of the proper size and installed in grooved seats. Notice that the clearance for the O-rings is less than their free outer diameter. The cross sections of the O-rings are squeezed out of round prior to the application of pressure. In this manner, contact is ensured with the inner and outer walls of the passage under static (no pressure) conditions. Illustrations B and D of Figure 6-4-5 show the action of the O-rings when pressure is applied. You should also observe in illustrations C and D of Figure 6-4-5 that backup rings are installed. In hydraulic systems of 1,500 p.s.i. pressure or less, AN6227B, AN6230B, and MS28775 packings are used. In such installations, backup rings are not required, although they are desirable. In most modern aircraft with hydraulic system pressures up to 3,000 p.s.i., backup rings are used in conjunction with the MS28775 packings.

Gaskets are used in the sealing of boss fittings, as end caps of actuators, piston accumulators, and other installations where moving parts do not come in contact with the seal. Normally, the type of gasket used is an O-ring. In some cases it might be the same seal that is used as a packing in other installations, or it may be one that is manufactured only for use as a gasket.

In hydraulic systems where the operating temperature ranges from -65°F (-53°C) to +160°F (+71°C), the AN6290, MS28778, AN6230B-1 through -25, MS28775-013 through -028, -117 through -149, and -223 through -247 O-rings are intended for use as gaskets. In systems where temperature limits range from -65°F (-53°C) to +275°F (+135°C), MS28778 and designated sizes of MS28775 O-rings are used as gaskets. Normally, O-rings designated as MS28778 should be used only in connections with straight thread tube fittings, such as boss fittings and end caps of check valves, etc.

Identification. O-rings are manufactured according to military specifications and are identified from the technical information printed on the package (Figure 6-4-6.) The size of O-rings cannot be positively identified by visual examination without the use of special equipment. For this reason, O-rings are made available in individual, hermetically sealed envelopes labeled with all the necessary pertinent data.



1. Stock number
2. Nomenclature
3. Part number
4. Contract number
5. Preservation
6. Rubber composition number
7. Date of manufacturer
9. Military specification number

Figure 6-4-6. O-ring package identification.

> **NOTE:** Colored dots, dashes, and stripes, or combinations of dots and dashes, on the surface of the O-ring are no longer used for identification. O-rings still found with these color identification markings are NOT to be used and should be depleted from stock.

Figure 6-4-6 shows the information printed on O-ring packages that is essential to determine the intended use, qualifications, and age limitations. The manufacturer's cure date is one of the more important items listed on the package. This cure date is denoted in quarters. For example, the cure date 2Q02 indicates that the O-ring was manufactured during the second quarter of 2002. Synthetic rubber parts manufactured during any given quarter are not considered one quarter old until the end of the succeeding quarter. Most O-ring age limitation is determined by this cure date, anticipated service life, and replacement schedule.

Age limitation of synthetic rubber O-rings is based on the fact that the material deteriorates with age. O-ring age is computed from the cure date. The term cure date is used in conjunction with replacement kits, which contain O-rings, parts, and hardware for shop repair of various components. O-ring cure dates also provide the basis for O-ring replacement schedules, which are determined by O-ring service life.

The service life (estimated time of trouble-free service) of O-rings also depends upon such conditions as use, exposure to certain elements—both natural and imposed—and subjection to physical stress. Operational conditions imposed on O-rings in one component may necessitate O-ring replacement more frequently than replacement of identical O-rings in other components. O-ring replacement, when scheduled, will be spelled out in the manufacturer's MM.

Storage. Proper storage practices must be observed to prevent deformation and deterioration of rubber O-rings. Most synthetic rubbers are not damaged by several years of storage under ideal conditions. However, most synthetic rubbers deteriorate when exposed to heat, light, oil, grease, fuels, solvents, thinners, moisture, strong drafts, or ozone (form of oxygen formed from an electrical discharge). Damage by exposure is magnified when rubber is under tension, compression, or stress.

There are several conditions to be avoided, which include the following:

- Deformation as a result of improper stacking of parts and storage containers
- Creasing caused by a force applied to corners and edges and by squeezing between boxes and storage containers
- Compression and flattening, as a result of storage under heavy parts
- Punctures caused by staples used to attach identification
- Deformation and contamination due to hanging the O-rings from nails or pegs

Figure 6-4-7. Typical O-ring installation and removal tools.

O-rings should be kept in their original envelopes, which provide preservation, protection, identification, and cure date. Contamination is caused by piercing the sealed envelopes to store O-rings on rods, nails, or wire hanging devices. Contamination may be caused by fluids leaking from parts stored above and adjacent to O-ring surfaces. Contamination can also be caused by adhesive tapes applied directly to O-ring surfaces. A torn O-ring package should be secured with a pressure-sensitive, moisture-proof tape, but the tape must not contact the O-ring surfaces. O-rings should be arranged so the older seals are used first.

Removal and Installation

The successful operation of a hydraulic system and the units within depends greatly upon the methods and procedures used in handling and installing hydraulic seals. These seals are comparatively soft and should not be subjected to any nicks, scratches, or dents. They should be kept free of dirt and foreign matter and should not be exposed to extreme weather conditions. When hydraulic seals are chosen for installation, they should not be picked up with sharp instruments, and the preservative should not be removed until they are ready for installation.

During the installation or removal of hydraulic seals, as well as other tasks, your best friend is the correct tool. A variety of these tools may be used on any given job. Suggestions for fabricating typical tools for use in replacing and installing O-rings and backup rings are shown in Figure 6-4-7. These tools should be fabricated from soft metal such as brass and aluminum; however, tools made from phenolic rod, plastics, and wood may also be used.

When removing or installing O-rings, avoid using pointed or sharp-edged tools that might cause scratching or marring of hydraulic component surfaces or cause damage to the O-rings. While using the seal removal and the installation tools, contact with cylinder walls, piston heads, and related precision components is not desirable. With practice, you should become proficient in using these tools.

Notice in Figure 6-4-8A how the hook-type removal tool is positioned under the O-ring, and then lifted to allow the extractor tool, as well as the removal tool, to pull the O-ring from its cavity. Figure 6-4-8B shows the use of another type of extractor tool in the removal of internally installed O-rings.

In Figure 6-4-8C, notice the extractor tool positioned under both O-rings at the same time. This method of manipulating the tool positions both O-rings, which allows the hook-type removal tool to extract both O-rings with minimum effort. Figure 6-4-8D shows practically the same removal as illustration C, except for the use of a different type of extractor tool.

The removal of external O-rings is less difficult than the removal of internally installed O-rings. Figures 6-4-8E and 6-4-8F show two accepted removal methods. View E shows the use of a spoon-type extractor, which is positioned under the seal. After the O-ring is dislodged from its cavity, the spoon is held stationary while simultaneously rotating and withdrawing the piston.

Figure 6-4-8F is similar to illustration E except only one O-ring is installed, and a different type of extractor tool is used. The wedge-type extractor tool is inserted beneath the O-ring; the hook-type removal tool hooks the O-ring. A slight pull on the latter tool removes the O-ring from its cavity.

After the removal of all O-rings, it is mandatory that you clean the affected parts that will receive new O-rings. Ensure that the area used for such installations is clean and free from all contamination.

Each replacement O-ring should be removed from its sealed package and inspected for

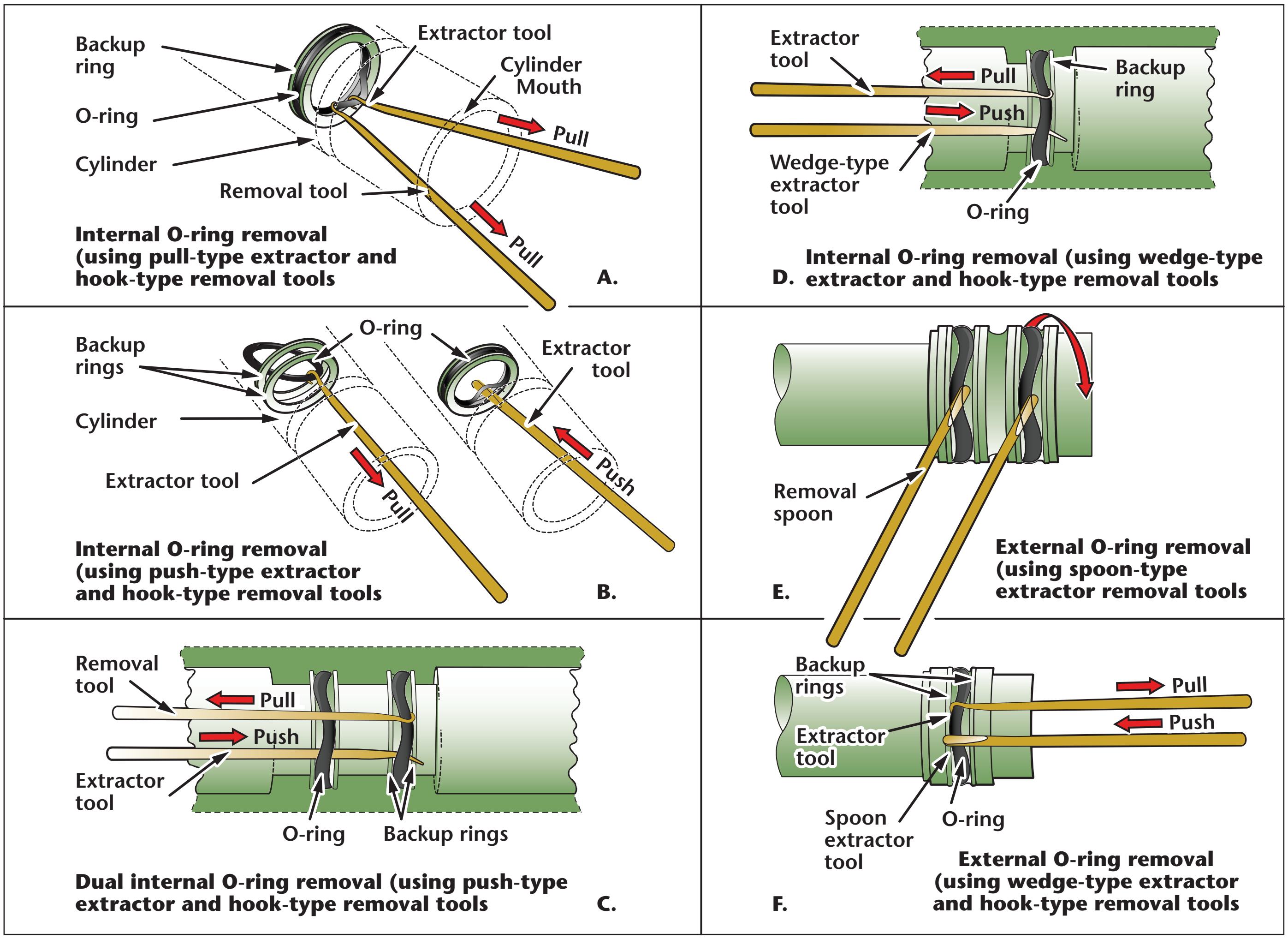


Figure 6-4-8. O-ring removal.

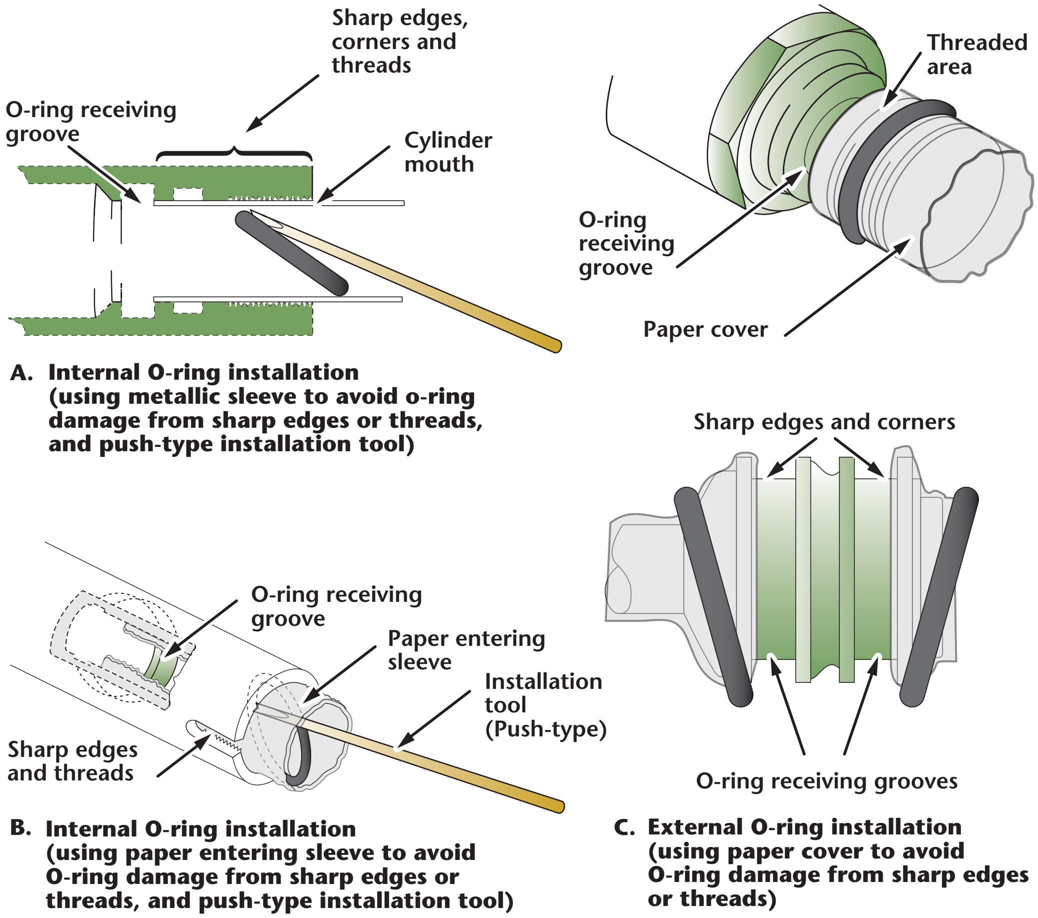


Figure 6-4-9. O-ring installation.

defects such as blemishes, abrasions, cuts, or punctures. Although an O-ring may appear perfect at first glance, slight surface flaws may exist. These are often capable of preventing satisfactory O-ring performance under the variable operating pressures of aircraft systems. O-rings should be rejected for flaws that will affect their performance.

Such defects are difficult to detect. One aircraft manufacturer recommends using a four-power magnifying glass with adequate lighting to inspect each ring before it is installed.

By rolling the ring on an inspection cone or dowel, the inner diameter surface can also be checked for small cracks, particles of foreign material, and other irregularities that will cause leakage or shorten the life of an O-ring. The slight stretching of the ring when it is rolled inside out will help to reveal some defects not otherwise visible.

A further check of each O-ring should be made by stretching it between the fingers, but you must take care not to exceed the elastic limits of the rubber. Following these inspection practices will prove to be a maintenance economy. It is far more desirable to take care identifying and inspecting O-rings than to repeatedly overhaul components with faulty seals.

After inspection, prior to installation, immerse the O-ring in clean hydraulic fluid. During the installation, avoid rolling and twisting the O-ring to maneuver it into place. If possible, keep the position of the O-ring's mold line constant. When the O-ring installation requires spanning or inserting through sharp threaded areas, ridges, slots, and edges, use protective measures, such as entering sleeves, as shown in Figure 6-4-9A.

If the recommended O-ring entering sleeve (soft, thin-wall metallic sleeve) is not available, paper sleeves and covers may be fabricated by using the seal package (gloss side out) or lint-free bond paper (Figure 6-4-9B and Figure 6-4-9C).

Adhesive tapes should not be used to cover danger areas on components. Gummy substances left by the adhesives are extremely detrimental to hydraulic systems.

After the O-ring is placed in the cavity provided, gently roll the O-ring with the fingers to remove any twist that might have occurred during installation.

Backup Rings

Backup rings are used to support O-rings and to prevent O-ring deformation and resultant leakage. Two types of backup rings are normally used in aircraft: Teflon single and double spiral.

Teflon rings are made from a fluorocarbon-resin material, which is tough, friction-resistant, and more durable than leather. Precautions similar to those applicable to O-rings must be taken to avert contamination of backup rings and damage to hydraulic components. Teflon backup rings may be stocked in individual sealed packages similar to those in which O-rings are packed, or several may be installed on a cardboard mandrel.

If unpackaged rings are stored for a long period of time without the use of mandrels, a condition of overlap may develop. To eliminate this condition, stack Teflon rings in a mandrel of a diameter comparable to the desired diameter of the spiral ring, Stack and clamp the rings with their coils flat and parallel. Then place the rings in an oven at a maximum temperature of 350°F (177°C) for a period of approximately 10 minutes. The rings are then removed and water quenched.

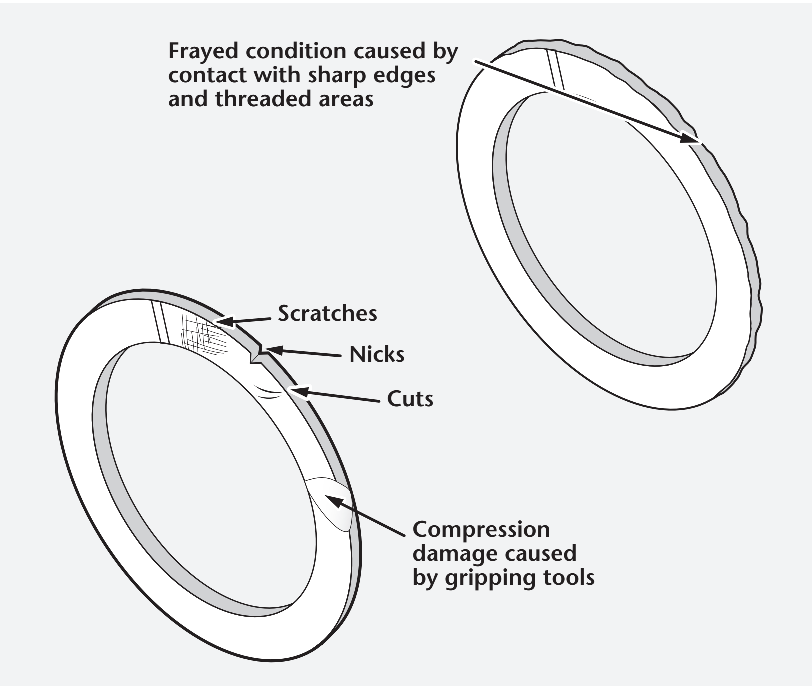


Figure 6-4-10. Teflon backup ring damages caused by improper handling.

NOTE: After this treatment, rings should be stored at room temperature for a period of 48 hours prior to use.

Identification. Backup rings are not color coded or otherwise marked and must be identified from package labels. Backup rings made from Teflon do not deteriorate with age and are unaffected by system fluid or vapor. They tolerate temperatures in excess of those encountered in high-pressure hydraulic systems.

The specification number of a backup ring can be found on the package label. This specification number is followed by a dash (-) and a number. The number following the dash indicates the size. In some cases, this number is directly related to the dash number of the O-ring for which the backup ring is intended to be used. For example, the single spiral Teflon ring, MS28774-6, is used with MS28775-006 O-ring; and the double spiral Teflon ring, MS28782-1, is used with the AN6227B-1 O-ring.

Installation. Care must be taken during the handling and installation of backup rings. If possible, backup rings should be inserted by hand and without the use of sharp tools. The Teflon® backup rings must be inspected prior to reuse for evidence of compression damage, scratches, cuts, nicks, and fraying conditions, as shown in Figure 6-4-10.

To install the Teflon backup ring, the following steps should be used (Figure 6-4-11):

1. Examine the fitting groove for roughness that might damage the seal.
2. Position the jam nut well above the fitting groove and coat the male threads of the fitting sparingly with hydraulic fluid.
3. Install the backup ring in the fitting groove and work the backup ring into the counterbore of the jam nut.
4. Install the gasket in the fitting groove against the backup ring.
5. Turn down the jam nut until the packing is pushed firmly against the threaded portion of the fitting.
6. Install the fitting into the boss and turn until the packing has contacted the boss. The jam nut must turn with the fitting.
7. Hold the jam nut and turn the fitting an additional one-half turn.
8. Position the fitting by turning it not more than one turn.
9. Hold the fitting in the desired position, turn the nut down tight against the boss.

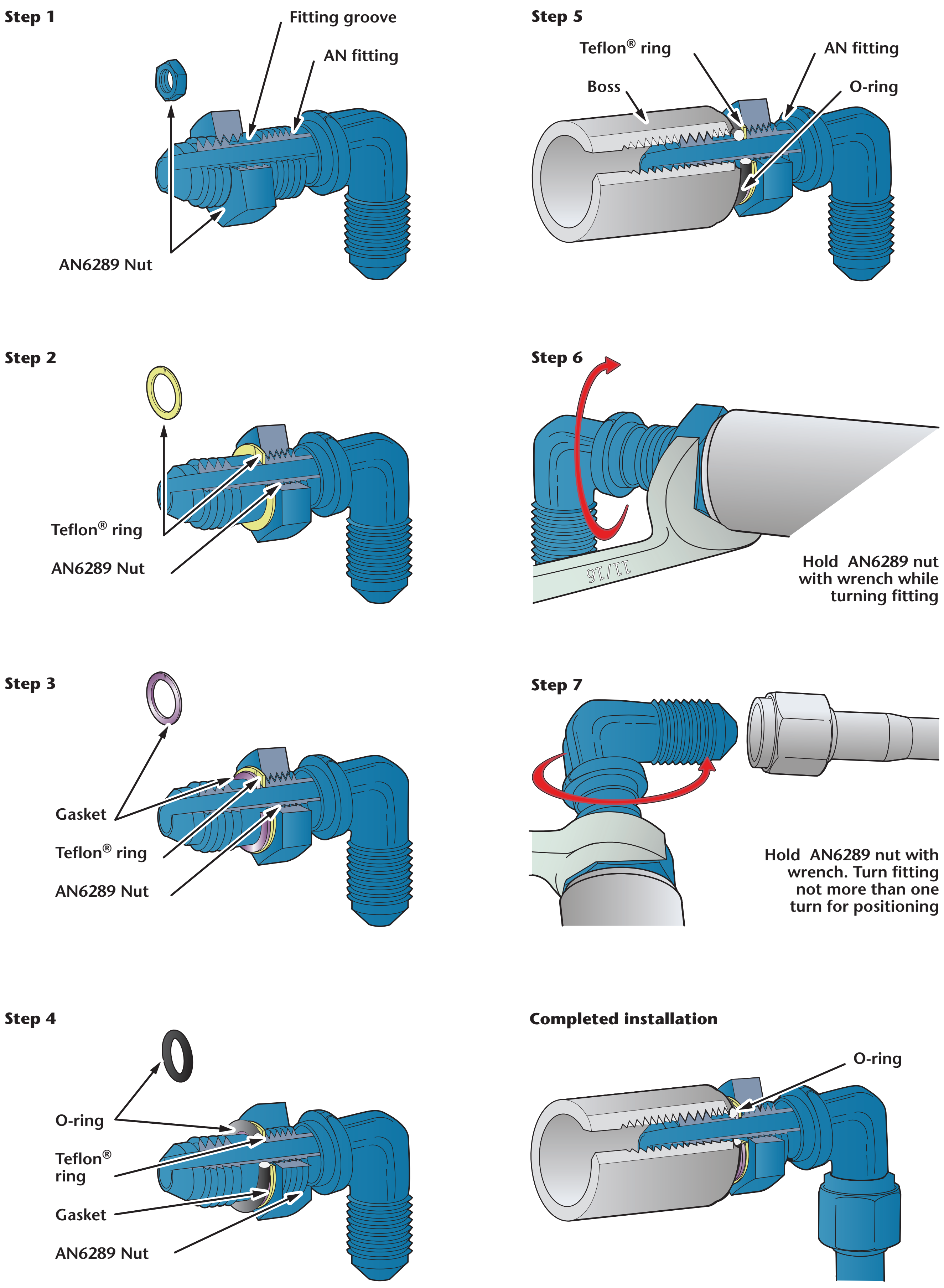


Figure 6-4-11. Properly installed gasket and backup ring.

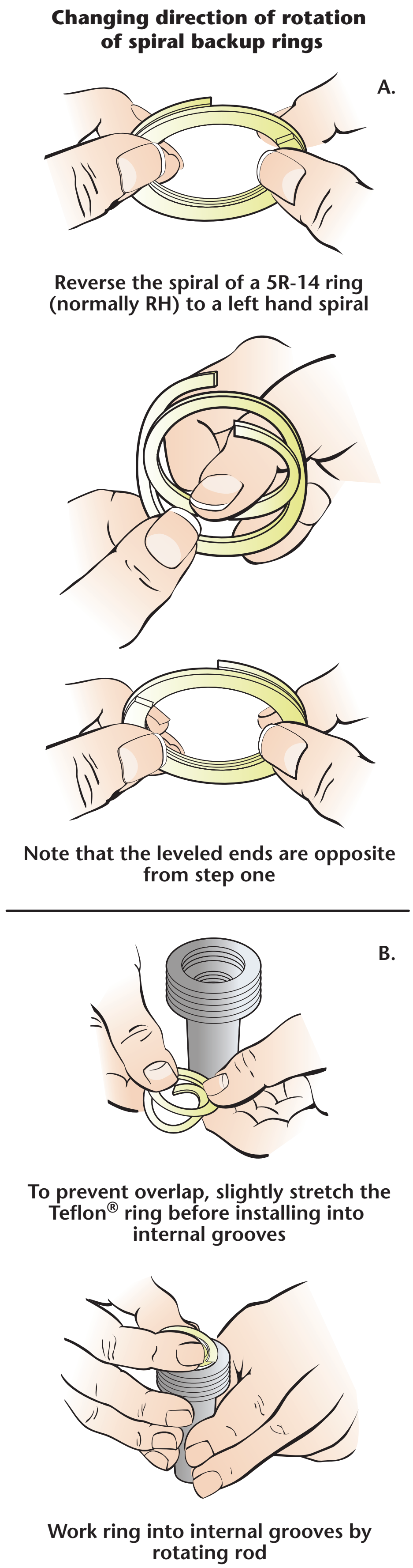


Figure 6-4-12. Installation of Teflon backup rings (internal).

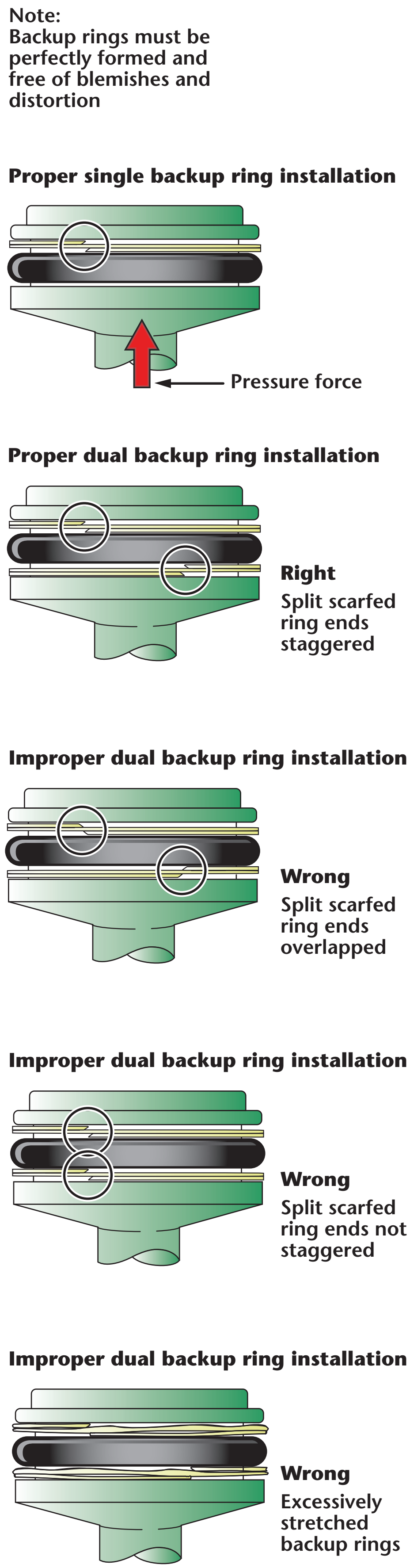


Figure 6-4-13. Teflon backup ring installation (external).

Type	Application	Applicable specification
Cap	Flared fitting	MIL-C-5501 *(Preferred)* *or* NAS-817
Cap	Beaded hose connection	MIL-C-5501
Cap	Pipe thread	MIL-C-5501
Cap	Assembly, pressure seal flared tube fitting	AN929
Cap	Pressure seal, flareless tube fitting	MS21914
Plug	Flared tube end and straight threaded box	MIL-C-5501 (Preferred) *or* NAS-818 *or* AN806
Plug	Flareless tube end	MIL-C-5501 (Preferred) *or* MS21913
Plug	Flared tube precision type	MS24404
Plug	Pipe thread	MIL-C-5501
Plug	Bleeded, screw thread	AN814
Plug	Machine thread O-ring seal	MS9015
Plug	Machine thread AMS 5646 preformed backing	MS9404
Plug	Bleeder, screw thread precision type	MS24391
NOTE: When ordering, be sure to specify metal caps or plugs.		

Table 6-4-1. Protective caps and plugs.

When Teflon spiral rings are being installed in internal grooves, the ring must have a right-hand spiral. Figure 6-4-12A shows the method used to change directions of the spiral. The Teflon ring is then stretched slightly prior to installation into its groove. While the Teflon ring is being inserted in the groove, rotate the component in a clockwise direction. This action will tend to expand the ring diameter and reduce the possibility of damage to the ring.

When Teflon spiral rings are being installed in external grooves, the ring should have a left-hand spiral. As the ring is inserted into the groove, rotate the component in a clockwise direction. This action will contract the ring diameter and reduce the possibility of damage to the ring.

Backup rings may be installed singly, if pressure acts only upon one side of the seal. In this case, the backup ring is installed next to the O-ring, opposite the pressure force (Figure 6-4-13). When dual backup rings are installed, the split ends must be staggered, as shown. The bottom three illustrations in the figure show an improper dual ring installation.

Wipers. Wipers (scrapers) are used to clean and lubricate the exposed portion of piston shafts. This prevents foreign matter from entering the system and scoring internal surfaces. Wipers may be of the metallic (usually copper-based alloys) or felt types. They are used in practically all landing gear shock struts and most actuating cylinders. At times, they are used together, the felt wiper being installed behind the metallic wiper. Normally, the felt wiper is lubricated with system hydraulic fluid from a drilled bleed passage or from an external fitting.

Wipers are manufactured for a specific hydraulic component and must be ordered for that application. Wipers are normally inspected and changed, if necessary, while component repair is in process. Metallic wipers are formed in split rings for ease in installation, and they are manufactured slightly undersized to ensure a tight fit. One side of the metallic wiper has a lip, which should face outward upon installation. Metallic wipers must be inspected for foreign matter and condition, then installed by sliding them over the piston shaft in the proper order.

The felt wiper may be a continuous felt ring or a length of felt with sufficient material to overlap its ends. The felt wiper should be soft, clean, and well saturated in hydraulic fluid during installation.

Protective closures. Contamination is hazardous and expensive. To protect hydraulic systems from contaminants, use protective closures. Two types of protective metal closures are approved for sealing hydraulic equipment. They are caps and plugs conforming to appropriate military specifications. Guidelines for selection and use of protective closures for hydraulic equipment are as follows:

- Use caps and plugs of the proper size and material.
- Never blank-off openings with wooden plugs, paper, rags, taps, or other unauthorized devices.

Use closures of metal construction conforming to specifications listed in Table 6-4-1 for sealing hydraulic system equipment, lines, tubes, accessories, and components.

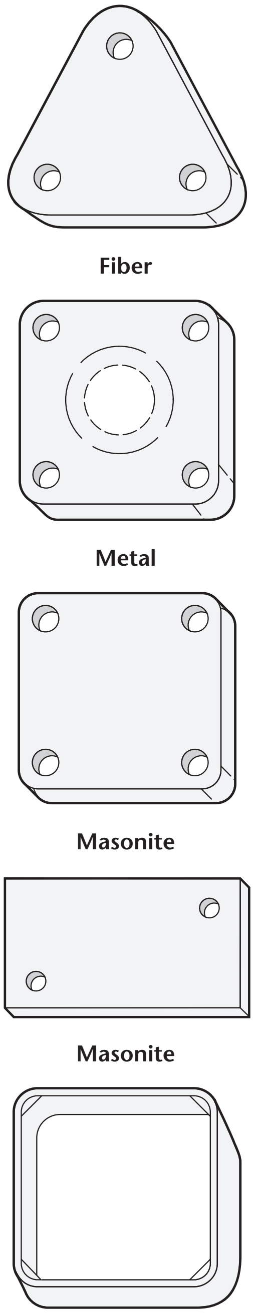


Figure 6-4-14. Typical blank-off plates.

Figure 6-4-14 shows typical blank-off plates. In all cases where there is a choice between an internal or external installation, use the external type of closure. Use metal protective closures to seal open ports of all hydraulic lines and accessories, and to seal new and reusable hydraulic tubing and hose assemblies. Plastic closures may be used to seal electrical fittings and receptacles or other nonfluid openings where contamination is not considered a problem. Keep all protective closures clean, sorted by size, properly identified, and stored in readily accessible bins. Check protective closures visually for cleanliness, thread damage, or sealing deformation before using.

Rubber, plastic, or unthreaded protective closures designed to fit over open ends of bulk hose and tubing should be used in accordance with design function only. Do not use this type of protective closure as a plug for insertion into open lines, hoses, or ports of hydraulic equipment. Remove protective closures before installing equipment. If an opening normally requiring protection is found uncovered, the part or assembly should be cleaned and checked before installation or assembly.

Section 5

Aircraft Electrical System Hardware

An important part of aircraft electrical maintenance is determining the correct type of electrical hardware for a given job. You must become familiar with wire and cable, connectors, terminals, and bonding devices.

Wire and Cable

For electrical installations, a wire is described as a stranded conductor covered with an insulating material. The term cable, as used in aircraft electrical installations, includes the following:

- Two or more insulated conductors contained in the same jacket (multiconductor cable)
- Two or more insulated conductors twisted together (twisted pair)
- One or more insulated conductors covered with a metallic braided shield (shielded cable)
- A single insulated conductor with a metallic braided outer conductor (RF cable)

For wire replacement work, the aircraft maintenance instruction manual should be consulted first. The manual normally lists the wire used in a given aircraft.

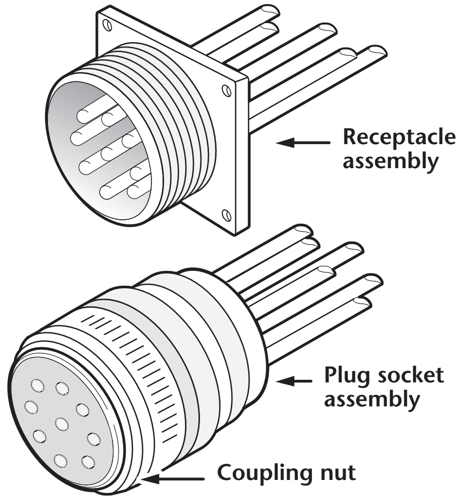


Figure 6-5-1. Connector assembly.

Connectors

Connectors are devices attached to the ends of cables and sets of wires to make them easier to connect and disconnect. Each connector consists of a plug assembly and a receptacle assembly. The two assemblies are coupled by means of a coupling nut. Each consists of an aluminum shell containing an insulating insert that holds the current-carrying contacts.

The plug is usually attached to the cable end, and is the part of the connector on which the coupling nut is mounted. The receptacle is the half of the connector to which the plug is connected. It is usually mounted on a part of the equipment. One type of connector commonly used in aircraft electrical systems is shown in Figure 6-5-1.

Terminals

Since most aircraft wires are stranded, it is necessary to use terminal lugs to hold the strands together. This allows a means of fastening the wires to terminal studs. The terminals used in electrical wiring are either of the soldered or crimped type. Terminals used in repair work must be of the size and type specified in the applicable maintenance instruction manual. The crimped-type terminals are generally recommended for use on aircraft. Soldered-type terminals are usually used in emergencies only.

The basic types of solderless terminals are shown in Figure 6-5-2. They are the straight, right angle, flag, and splice types. There are variations of these types.

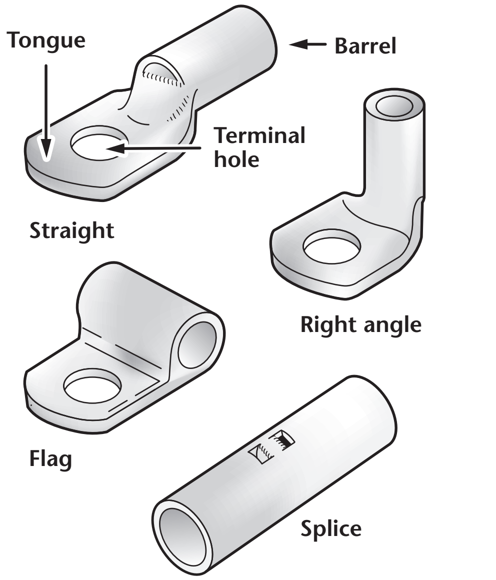


Figure 6-5-2. Basic types of solderless terminals.

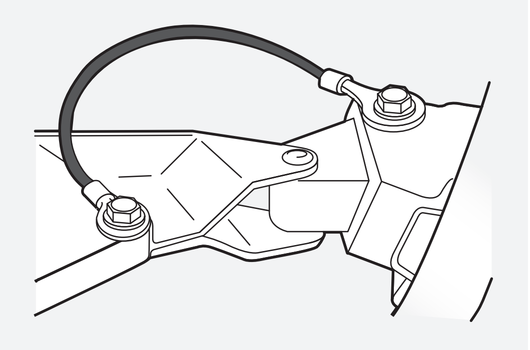


Figure 6-5-3. Typical bonding link installation.

Bonding

An aircraft can become highly charged with static electricity while in flight. If the aircraft is improperly bonded, all metal parts do not have the same amount of static charge. A difference of potential exists between the various metal surfaces. If the resistance between insulated metal surfaces is great enough, charges can accumulate. The potential difference could become high enough to cause a spark. This constitutes a fire hazard and also causes radio interference. If lightning strikes an aircraft, a good conducting path for heavy current is necessary to minimize severe arcing and sparks.

When you connect all the metal parts of an aircraft to complete an electrical unit, it is called bonding. Bonding connections are made of screws, nuts, washers, clamps, and bonding jumpers. Figure 6-5-3 shows a typical bonding link installation.

Bonding also provides the necessary low-resistance return path for single-wire electrical systems. This low-resistance path provides a means of bringing the entire aircraft to the earth's potential when it is grounded.

Whenever you perform an inspection, both bonding connections and safetying devices must be inspected with great care.

Static Dischargers

Static dischargers are commonly known as *static wicks* or *static discharge wicks*. They are used on aircraft to allow the continuous satisfactory operation of onboard navigation and radio communication systems. During adverse charging conditions, they limit the potential static buildup on the aircraft and control interference generated by static charge.

Static dischargers are not lightning arrestors and do not reduce or increase the likelihood of an aircraft being struck by lightning. Static dischargers are subject to damage or significant changes in resistance characteristics as a result of lightning strike to the aircraft and should be inspected after a lightning strike to ensure proper static discharge operation.

Static dischargers are fabricated with a wick of wire or a conductive element on one end, which provides a high resistance discharge path between the aircraft and the air (Figure 6-5-4). They are attached on some aircraft to

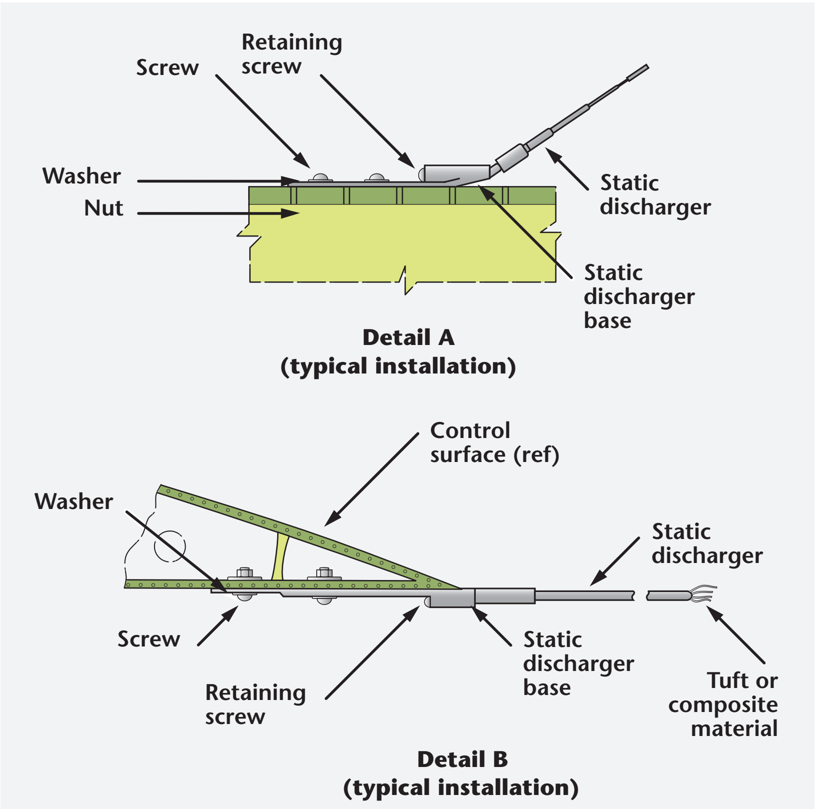


Figure 6-5-4. Typical static dischargers.

the ailerons, elevators, rudder, wing, horizontal and vertical stabilizer tips, etc. Refer to your aircraft's MM for proper maintenance procedures.

Section 6

Aircraft Safetying Methods

You will come in contact with many different types of safetying materials. These materials are used to stop rotation and other movement of fasteners.

Cotter pins. Cotter pins are used to secure bolts, screws, nuts, and pins. Some cotter pins are made of low-carbon steel; those made of stainless steel are more resistant to corrosion. Also, stainless steel cotter pins may be used in locations where nonmagnetic material is required. Regardless of shape or material, all cotter pins are used for the same general purpose: safetying. Figure 6-6-1 shows three types of cotter pins and how their size is determined.

> **NOTE:** A castle nut may not be overtightened to align the slot with the bolt hole. Use a combination of thin and standard washers to adjust the bolt grip, or use different hardware.

Safety wire. Safety wire comes in many types and sizes. You must first select the correct type and size of wire for the job. Annealed corrosion-resistant wire is used in high-temperature, electrical equipment, and aircraft instrument applications. All nuts except the self-locking types must be safetied; the method used depends upon the particular installation.

Figure 6-6-2 shows various methods commonly used in safety-wiring nuts, bolts, and screws.

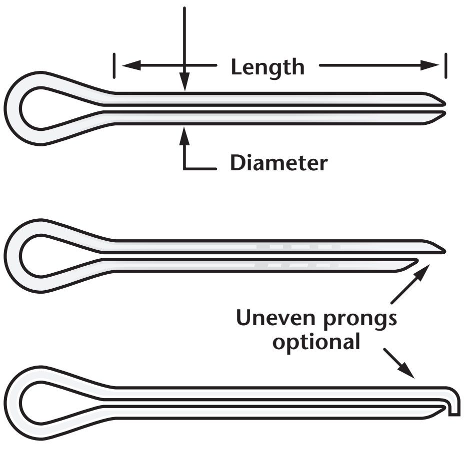


Figure 6-6-1. Types of cotter pins.

Examples 1, 2, and 5 of Figure 6-6-2 show the proper method of safety-wiring bolts, screws, square head plugs, and similar parts when wired in pairs. Examples 6 and 7 show a single-threaded component wired to a housing or lug. Example 3 shows several components wired in series. Example 4 shows the proper method of wiring castellated nuts. Note that there is no loop around the nut. The large, curved pattern on the left shows several components in a pattern, using the single-wire method. The following general rules apply to safety wiring:

1. All safety wires must be tight after installation, but not under so much tension that normal handling or vibration will break the wires.
2. The wire must be applied so that all pull exerted by the wire tightens the nut.
3. Twists should be tight and even and the wire between nuts as taut as possible without over-twisting. Wire should be twisted by hand. Pliers will damage the wire. Pliers may be used only for final end twist before cutting excess wire.

Annealed copper safety wire is used for sealing first aid kits, portable fire extinguishers, oxygen regulator emergency valves and other valves and levers used for emergency operation of aircraft equipment. This wire can be broken by hand in case of an emergency.

Turnbuckle Safetying

When all adjusting and rigging on the cables is completed, safety the turnbuckles as necessary. Only two methods of safetying turnbuckles have been adopted as standard procedures by the aircraft industry: the clip-locking (preferred) method and the wire-wrapping method.

Lock clips must be examined after assembly for proper engagement of the hook lip in the turnbuckle barrel hole by the application of slight pressure in the disengaging direction. Lock clips must not be reused, as removal of the clips from the installed position will severely damage them.

Wire-wrapping turnbuckles. First, two safety wires are passed through the hole in the center of the turnbuckle barrel. The ends of the wires are bent 90 degrees toward the ends of the turnbuckle, as shown in Figure 6-6-3B.

Next, the ends of the wires are passed through the holes in the turnbuckle eye or between the jaws of the turnbuckle fork, as applicable. The wires are then bent toward the center of the turnbuckle, each one wrapped four times around the shank. This secures the wires.

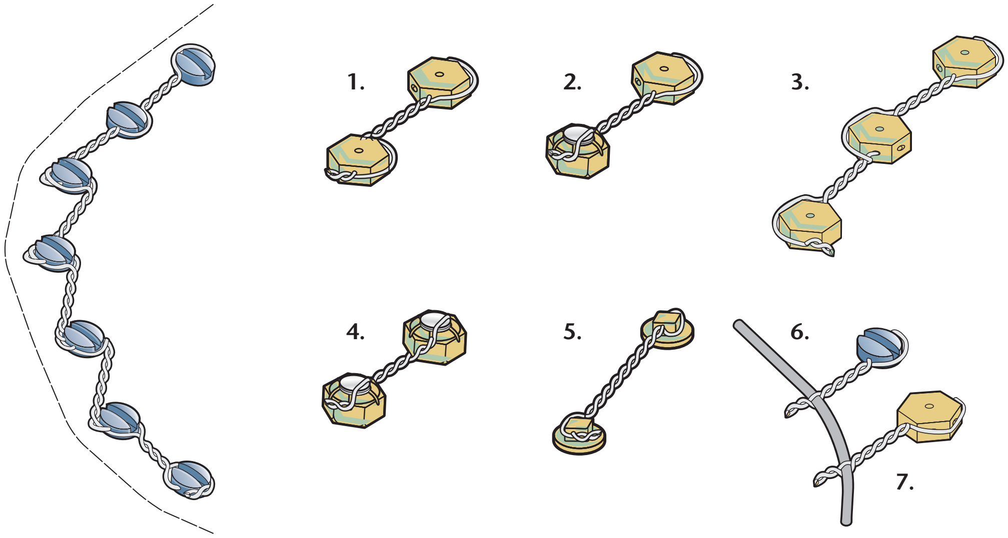


Figure 6-6-2. Safety wiring methods.

When a swaged turnbuckle terminal is being safetied, one wire must be passed through the provided hole in the terminal. It is then looped over the free end of the other wire and both ends wrapped around the shank.

Clip-locking turnbuckles. The clip-locking method of safetying uses an NAS lock clip. To safety the turnbuckle (Figure 6-6-3A), align the slot in the barrel with the slot in the cable terminal. Hold the lock clip between the thumb and forefinger at the end loop. Insert the straight end of the clip into the aperture formed by the aligned slots. Bring the hook end of the lock clip over the hole in the center of the turnbuckle barrel and seat the hook loop into the hole.

Application of pressure to the hook shoulder at the hole will engage the hook lip in the turnbuckle barrel and complete the safety locking of one end. The above steps are then repeated on the opposite end of the turnbuckle barrel. Both locking clips may be inserted into the same turnbuckle barrel hole or into opposite holes.

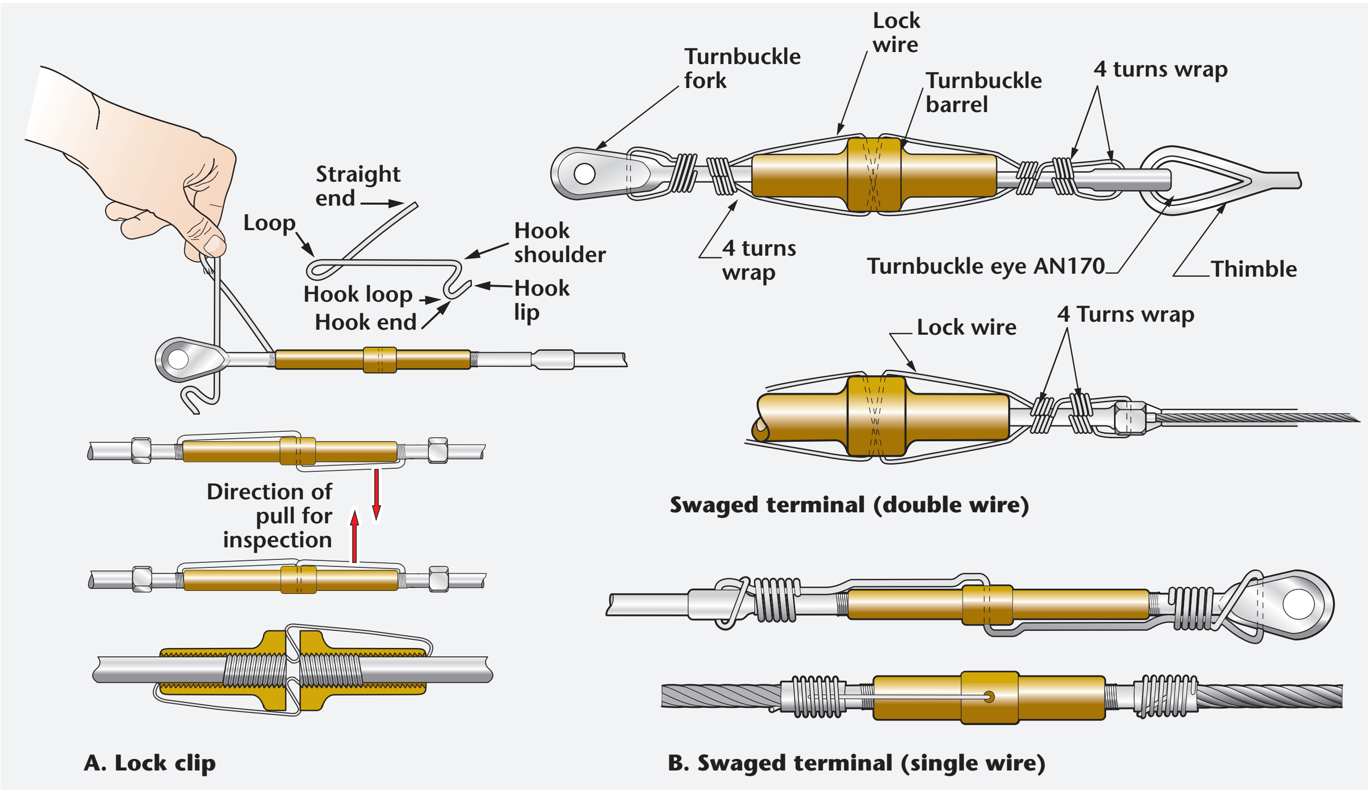


Figure 6-6-3. Safetying turnbuckles: (A) clip-locking (preferred) method; (B) wire-wrapped method.

Section 7

Aerospace Materials

Knowledge and understanding of the uses, strengths, limitations, and other characteristics of structural metals are vital to properly construct and maintain any equipment, especially airframes. In aircraft maintenance and repair, even a slight deviation from design specification or the substitution of inferior materials may result in the loss of both lives and equipment. The use of unsuitable materials can readily erase the finest craftsmanship. The selection of the correct material for a specific repair job demands familiarity with the most common physical properties of various metals.

Properties of metals are of primary concern in aircraft maintenance. Of specific importance are such general properties of metals and their alloys as strength, hardness, malleability, ductility, brittleness, conductivity, thermal expansion, elasticity, toughness, fusibility, and density. These terms are explained within this section to establish a basis for further discussion of structural metals.

Terms

Strength. The ability of a material to withstand forces which tend to deform it in any direction and the ability of that material to resist stress without breaking is known as *strength*. There are four primary types of strength, which are of importance when working with metals: tensile, yield, shear, and bearing strengths.

Tensile strength of a material is its resistance to a force which tries to pull it apart. Tensile strength is measured in pounds per square inch (p.s.i), and is calculated by dividing the load, in pounds, required to pull the material apart by its cross-sectional area.

Yield strength is that point at which a load would cause an initial indication of a permanent distortion. It is measured in p.s.i.

Shear strength is that point at which a material would fail under a shear force. The shear strength, measured in p.s.i., is found by dividing the shear force or load by the shear area.

Bearing strength is the ability of a material to resist the forces that tend to damage it at the point of an applied load.

The relationship between the strength of a material and its weight per cubic inch, expressed as a ratio, is known as the *strength-to-weight ratio*. This ratio forms the basis for comparing the desirability of various materials for use in airframe construction and repair. Neither strength nor weight alone can be used as a means of true comparison.

Hardness. The ability of a metal to resist abrasion, penetration, cutting action, or permanent distortion is referred to as *hardness*. Hardness may be increased by cold-working the metal, and, in the case of steel and certain aluminum alloys, by heat-treatment.

Structural parts are often formed from metals in their soft state, and are then heat-treated to harden them so that the finished shape will be retained. Hardness and strength are closely associated properties of metals.

Malleability. A metal that can be hammered, rolled, or pressed into various shapes without cracking, breaking, or having some other detrimental effect, is said to be *malleable*. This property is necessary in sheet metal that is worked into curved shapes such as cowlings, fairings, or wingtips. Copper is an example of a malleable metal.

Ductility. Similar to malleability, *ductility* is the property of a metal that permits it to be permanently drawn, bent, or twisted into various shapes without breaking. This property is essential for metals used in making wire and tubing. Ductile metals are greatly preferred for aircraft use because of their forming ease and resistance to failure under shock loads. For this reason, aluminum alloys are used for cowl rings, fuselage, and wing skin, and for formed or extruded parts, such as ribs, spars, or bulkheads. Chromium molybdenum steel is also easily formed into desired shapes.

Brittleness. The property of a metal that allows little bending or deformation without shattering is *brittleness*. A brittle metal is apt to break or crack without change of shape. Because structural metals are often subjected to shock loads, brittleness is not a very desirable property. Cast iron, cast aluminum, and very hard steel are examples of brittle metals.

Conductivity. The ability of a metal to transmit heat or electricity is known as *conductivity*.

Thermal conductivity is the ability of a metal to transmit heat. The thermal conductivity of a metal must be carefully considered if the metal is to be used in applications where the metal will be welded or where expansion and contraction are critical.

Electrical conductivity is the ability of a metal to freely accept and release electrons when an electrical current is applied. To eliminate radio interference in aircraft, electrical conductivity and bonding of metals parts must be considered.

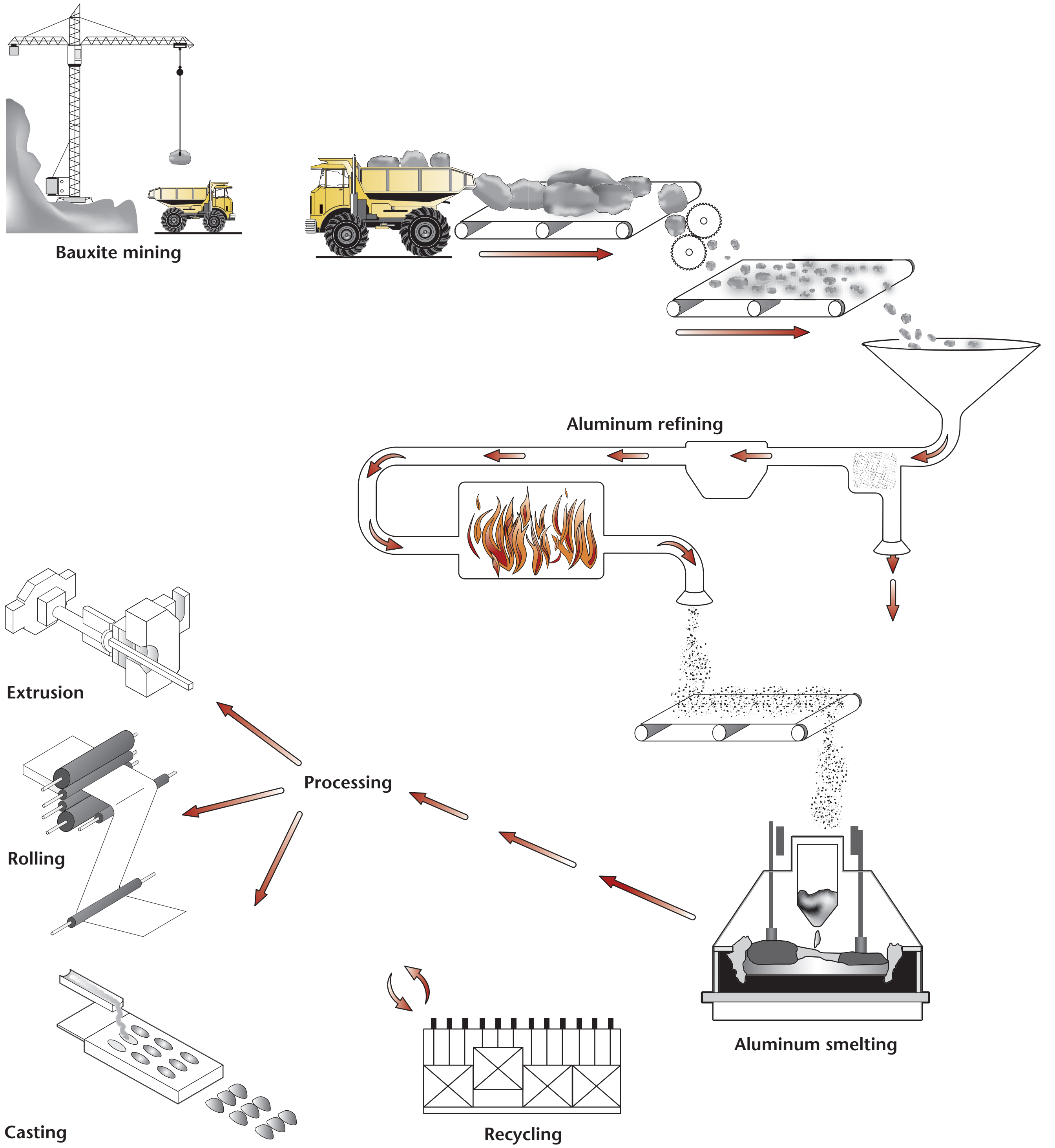


Figure 6-7-1. The process of refining aluminum, from mining to the finished process.

Elasticity. The property which enables a metal to return to its original shape when the force which causes the change of shape is removed is *elasticity*. This property is extremely valuable, because it would be highly undesirable to have a part permanently distorted after an applied load was removed. Each metal has a point, known as the elastic limit, beyond which it cannot be loaded without causing permanent distortion. In aircraft construction, parts and components are designed so that the maximum loads to which they are subjected will not stress them beyond their elastic limits. This desirable property is present in spring steel.

Toughness. A material which possesses *toughness* will withstand tearing or shearing and may be stretched or otherwise deformed without breaking. This is desirable in aircraft metals.

Density. The mass of a unit volume of a material is its *density*. In aircraft work, the specified mass of a material per cubic inch is preferred. This figure can be used in determining the weight of a part before it is actually manufactured. Density is critical when choosing a material to be used in the design of a part, so that the proper weight and balance of the aircraft can be maintained.

Aluminum Production

Aluminum ore, most commonly bauxite, is plentiful and occurs mainly in tropical and sub-tropical areas: Africa, the West Indies, South America, and Australia. There are also some deposits in Europe. Bauxite is refined into aluminum oxide trihydrate (alumina) and then electrolytically reduced into metallic aluminum. Primary aluminum production facilities are located all over the world, often in areas where there are abundant supplies of inexpensive energy, such as hydroelectric power.

Two to three tons of bauxite are required to produce one ton of alumina, and two tons of alumina are required to produce one ton of aluminum metal. Figure 6-7-1 illustrates the complete process.

Bauxite Mining. Bauxite is normally extracted by open cast-mining from strata, typically some four to six meters thick under a shallow covering of topsoil and vegetation. In most cases, the topsoil is removed and stored.

Alumina Refining

The Bayer process. The aluminum industry relies on the Bayer process to produce alumina from bauxite. It remains the most economic means of obtaining alumina, which in turn is vital for the production of aluminum metal.

The aluminum industry is dependent on a regular supply of alumina for four functions:

- Basic raw material for aluminum production
- Thermal insulator for tops of electrolytic cells
- Coating for pre-baked anodes
- Absorbent filter for cell emissions

Bauxite is washed, ground, and dissolved in caustic soda (sodium hydroxide) at high pressure and temperature. The resulting liquor contains a solution of sodium aluminate and undissolved bauxite residues containing iron, silicon, and titanium. These residues sink gradually to the bottom of the tank and are removed. They are known colloquially as "red mud." The clear sodium aluminate solution is pumped into a huge tank called a precipitator. Fine particles of alumina are added to seed the precipitation of pure alumina particles as the liquor cools. The particles sink to the bottom of the tank, are removed, and are then passed through a rotary or fluidised calciner at 1,100°C, to drive off the chemically combined water. The result is a white powder, pure alumina. The caustic soda is returned to the start of the process and used again. Figure 6-7-2 illustrates the aluminum refining process.

Alumina smelting. The basis for all modern primary aluminum-smelting plants is the *Hall-Héroult Process*, invented in 1886. Alumina is dissolved in an electrolytic bath of molten cryolite (sodium aluminum fluoride) within a large carbon- or graphite-lined steel container known as a "pot." An electric current is passed through the electrolyte at low voltage but very high current, typically 150,000 amperes. The electric current flows between a carbon anode (positive) — made of petroleum coke and pitch — and a cathode (negative), formed by the thick carbon or graphite lining of the pot. Molten aluminum is deposited at the bottom of the pot and is siphoned off periodically, taken to a holding furnace, often, but not always, blended to an alloy specification, cleaned, and then generally cast.

A typical aluminum smelter consists of around 300 pots. These will produce some 125,000 tons of aluminum annually. However, some of the latest generation of smelters are in the 350,000-400,000 ton range.

Aluminum is formed at about 1,652°F (900°C), but once formed, it has a melting point of only 1,220°F (660°C). In some smelters, this spare heat is used to melt recycled metal. Producing recycled aluminum requires only 5 percent of the energy required to make new aluminum. Blending recycled metal with new metal allows considerable energy savings, as well as the efficient use of process heat. There is no difference between primary and recycled aluminum in terms of quality or properties.

Aluminum smelting is energy intensive, which is why the world's smelters are located in areas which have access to abundant power resources (hydro-electric, natural gas, coal, or nuclear). Many locations are remote, and the electricity is generated specifically for the aluminum plant.

The smelting process is continuous. A smelter cannot easily be stopped and restarted. If production is interrupted by a power supply failure of more than four hours, the metal in the pots will solidify, often requiring an expensive rebuilding process.

From time to time, individual pot linings reach the end of their useful life, and the pots are then taken out of service and relined.

Most smelters produce aluminum of 99.7 percent purity, which is acceptable for most applications.

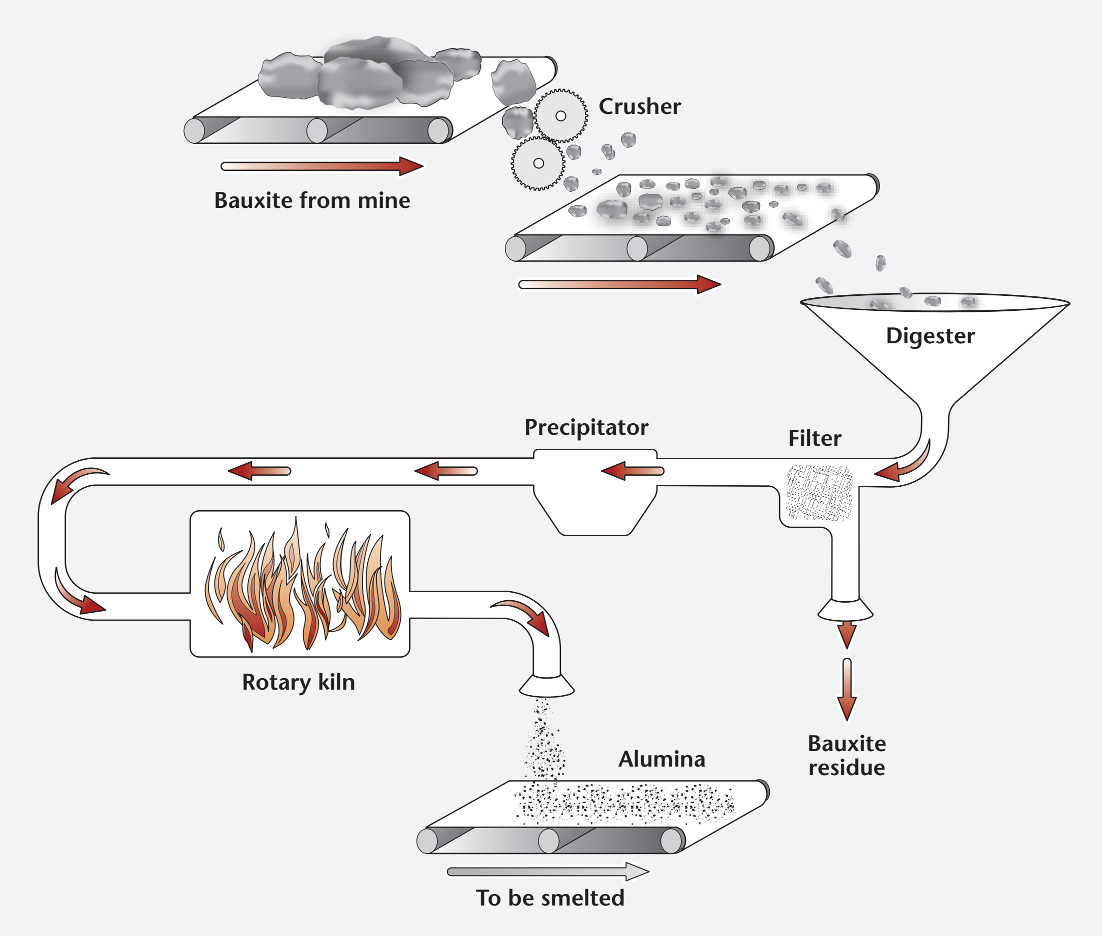


Figure 6-7-2. Alumina refining, from the raw ore to the finished alumina.

However, super-purity aluminum (99.99 percent) is used for some special applications, typically those where high ductility or conductivity is required. The marginal difference in the purities of smelter-grade aluminum and super-purity aluminum results in significant changes in the properties of the metal.

Value of Scrap: Recycling

Anything made of aluminum can be recycled repeatedly: not only cans, but aluminum foil, plates and pie molds, window frames, garden furniture, and automotive components are melted down and used to make similar products again. The recycling of aluminum requires only 5 percent of the energy to produce secondary metal, as compared to primary metal, and generates only 5 percent of the greenhouse gas emissions. Scrap aluminum has significant value and commands good market prices. Aluminum companies have invested in dedicated state of the art secondary metal processing plants to recycle aluminum. In the case of beverage cans, the process uses gas collected from burning off the coating to preheat the material prior to processing. The recycling of aluminum beverage cans eliminates waste. It saves energy, conserves natural resources, reduces the use of city landfills, and provides added revenue for recyclers, charities, and local town government. The aluminum can is therefore good news for the environment and good for the economy.

Used beverage cans are normally back on supermarket shelves as new beverage cans in six to eight weeks in those countries which have dedicated can collecting and recycling schemes. The recycling rate for aluminum cans is already above 70 percent in some countries. Cans made from aluminum are worth 6 to 20 times more than any other used packaging material.

In Europe, the aluminum beverage can meets the minimum targets set in the European Directive on Packaging and Waste. Sweden (92 percent) and Switzerland (88 percent) are the European can-recycling champions. The European average is 40 percent, a 10-percent increase since 1994.

Recycle Rates

Recycling rates for building and transport applications range from 60 to 90 percent in various countries. Just over 11.6 million tons of old and new scrap were recycled in 1998

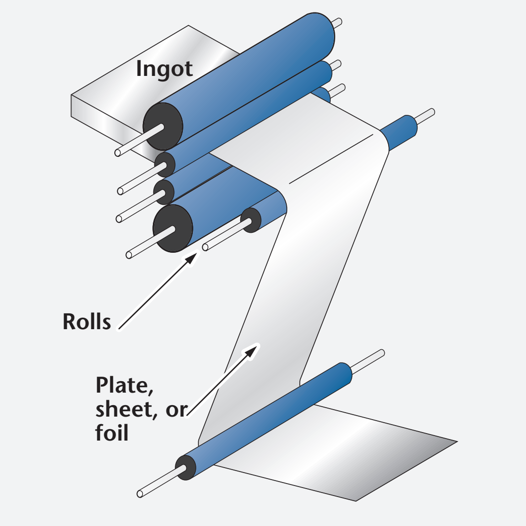


Figure 6-7-3. An illustration of the cold-rolling process required to finish aluminum sheet.

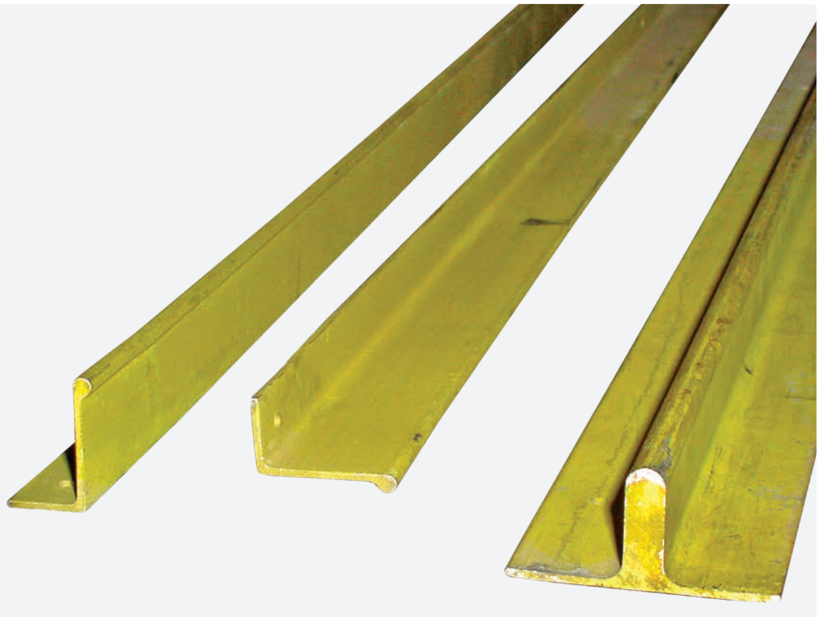


Figure 6-7-4. Extruded aluminum is a familiar product. Extruding can form lengths of very complicated designs.

worldwide, which fulfilled close to 40 percent of the global demand for aluminum. Of this total, 17 percent came from packaging, 38 percent from transport, 32 percent from building, and 13 percent from other products. The aluminum industry is working with automobile manufacturers to enable easier dismantling of aluminum components from cars in order to improve the sorting and recovery of aluminum. In 1997, more than 4.4 million tons of scrap were used in the transport sector, and the use of aluminum in automobiles is increasing year upon year. Worldwide, the future of scrap recycling certainly looks promising, especially with growth of packaging expected in South America, Europe, and Asia.

Production of Sheets and Plates

Cold-rolling mills. Aluminum is first passed through a hot-rolling mill and then transferred to a cold-rolling mill.

Hot-rolling mills. Prior to rolling, the aluminum is in the form of an ingot, which can be up to 23.62 inches thick. This ingot is then heated to around 932°F (500°C) and passed several times through the hot-rolling mill. This gradually reduces the thickness of the metal to around 0.24 inch.

This thinner aluminum is then coiled and transported to the cold-rolling mill for further processing.

There are various types of cold-rolling mills, and they produce various types of rolled product, with thicknesses as low as .0020 inches (Figure 6-7-3). In general, the type of product depends on the alloy used, the rolling deformation and thermal treatment used in the process, as well as careful adjustments to the mechanics and chemistry of the process. Rolling mills are controlled by very precise mechanisms and measuring systems.

Products

Rolled products can be divided into foil, sheet, and plate.

Foil is less than 0.0079 inch thick and is used mainly in the packaging industry for foil containers and wrapping. Foil is also used for electrical applications, building insulation, and in the printing industry.

Sheet is between .0079 inch and 0.24 inch in thickness and has a wide variety of uses in the construction industry, including aluminum siding and roofing. Sheet is also used extensively in transport applications such as automobile body panels, airframes, and the hulls of boats.

Plate is any rolled product over 0.24 inch in thickness. It also is found in a number of applications including airframes, military vehicles, and structural components in bridges and buildings.

Aluminum extrusions are made from solid aluminum cylinders called *billets*, which are continuously cast from molten aluminum. Billets are available in a wide variety of alloys, pretreatments, and dimensions, depending on the requirements of the manufacturer.

Extrusions

The extrusion process involves aluminum metal being forced through a die with a shaped opening. This is made possible by preheating the billet to 842°F to 932°F (450°C to 500°C) and then applying a pressure of 72,500-101,500 p.s.i.—equivalent to the pressure found at the bottom of a water tank 37 miles tall. The heated and softened metal is forced against the container walls and the die by a hydraulic ram. The only exit is the geometric cross-section of the die opening, and the metal is squeezed out.

The extrusion leaves the die at a temperature of around 932°F (500°C), and the exit temperature is carefully controlled in order to achieve specified mechanical properties, a high-quality surface finish, and good productivity. Examples of extruded forms are shown in Figure 6-7-4.

The press. The press supplies the force necessary to squeeze the billet through the extrusion die. It consists of:

- The container where the billet is put under pressure
- The ram for pushing the billet into the container and through the die
- The counter support to the die package
- The main columns fixing the ram and the cylinder
- A series of backers and bolsters, which support the die, for transferring the main press load to the front plate

The principle of an extrusion press can be seen in the schematic diagram (Figure 6-7-5).

Applications. Aluminum extrusions are used throughout the construction industry, particularly in window and doorframe systems, prefabricated houses/building structures, roofing and exterior cladding, and curtain walling. Extrusions are also used in road and rail vehicles, airframes, and marine applications.

Aluminum Casting

Applications. Cast parts are used in a variety of applications, including:

- Lightweight components for vehicles, aircraft, ships, and spacecraft
- General engineering components where light weight and corrosion resistance are required
- Architectural fittings where light weight and good appearance are important
- High-tech products for office and home
- Tools and motor housings

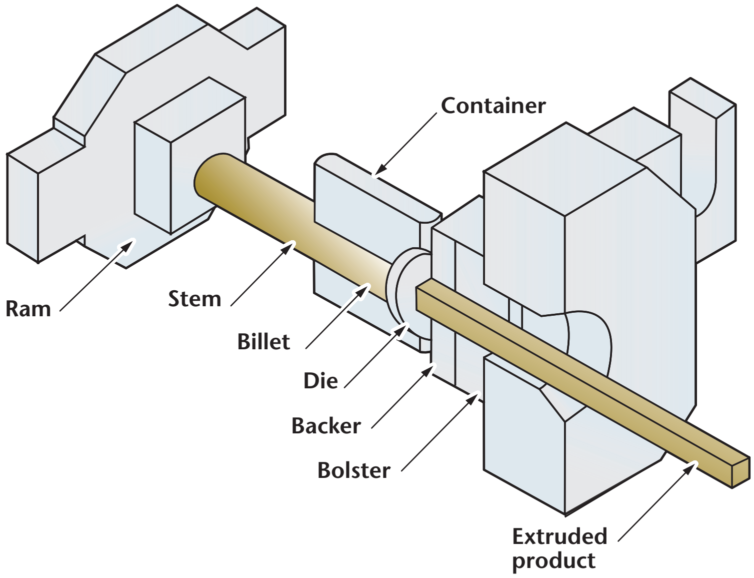


Figure 6-7-5. This illustration shows the basic extrusion process. Very complex parts can be extruded.

Casting falls into three main categories: *sand casting, permanent mold casting*, and *die casting.* Of all aluminum castings made, 95 percent are one of these three types.

Sand casting. *Sand casting*, as a process, is a centuries old technique. It was used in both the New and the Old World, making it universal. Sand molds must be bonded together using either synthetic compounds or clay and water. Molds must be rebuilt after each casting.

Pattern making for sand casting, or all casting for that matter, is an exacting process. Not only must the mold contain the shape of the part being cast, it must also contain the sprues and risers to accommodate flow of the molten metal. Sand castings have the greatest potential for *inclusions* (impurities encased in the metal) than other types of casting. Sand castings are also susceptible to *gas holes* and *excess porosity*, both of which are defects.

The design of molds is a very complicated process; but they are filled simply by gravity without the need for any pressure differentials or mechanical action.

Patterns, and the molds made from them, allow for shrinkage of the molten metal as it cools. The way to accomodate this size change is to do all measuring with the *shrink rules* that have a built in allowance. As an example, if the metal will shrink 5/32 inch per foot when it cools, the ruler used to fabricate a foot-long pattern is 12-5/32 inches long. Therefore, when the metal shrinks, it is the correct size.

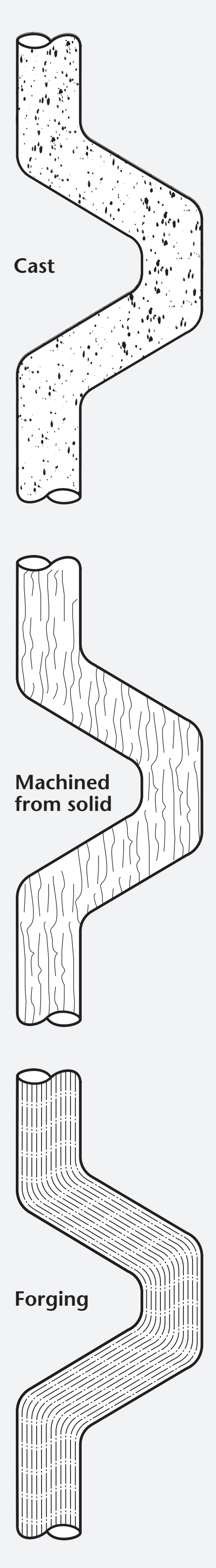


Figure 6-7-6. Comparison of grain structures in different metal processes.

Permanent mold casting. *Permanent molds* are made from cast iron or steel and may be used any number of times. A higher quality product can be produced because permanent molds have the following benefits:

- Finer grain structure
- Better strength than sand castings
- Cast surfaces are smoother and can hold closer dimensional tolerances
- Virtually no inclusions or gas bubbles
- Less shrinkage and lower porosity

An excellent example of the benefits of permanent mold casting over sand casting is aircraft engine crankcases. As reciprocating engines became more sophisticated and produced more horsepower, their sand cast crankcases started to crack in service. The need was for stronger crankcases, and the answer was permanent mold casting. In your career you will come across several of the Per-Mold® crankcases manufactured by Continental Engines.

Die casting. *Die casting* molds are similar to permanent molds and made of either cast iron or steel. There are three main modes of die-casting: high pressure, low pressure, and gravity die-casting.

Die-casting can produce very fine-grained structures with amazing accuracy. Of all the cast products you will encounter in the course of a day, most will be die cast. The process is used for most automotive parts, from engine blocks the clock housings. Most consumer cast parts are also die-castings.

High-pressure die-casting. High-pressure die-casting is the most commonly used process, in which molten aluminum is injected at high pressure into a metal mold by a hydraulically powered piston. The machinery needed for the process can be very costly, thus high-pressure die-casting is only used for high volume production.

Low-pressure die-casting. Low-pressure die-casting uses a die, which is filled from a pressurized crucible underneath. The process is particularly suited to the production of rotationally symmetrical products such as automobile wheels. High strength wheels are forged instead of cast.

Gravity die-casting. This process is suitable for mass production and for fully mechanized casting.

Advantages of die-casting. The process has these advantages:

- Almost finished as cast
- Very long die life
- Less shrinkage and porosity
- Virtually no inclusions
- More dimensionally stable
- Higher strength

Heat-treatment. All castings are heat treatable by all the normal processes. They do take more time and care, as the cross sections are naturally thicker than sheet products. Castings take longer to heat up and to cool down. If heated too fast, they can warp; if too hot, porosity can develop; if cooled too quickly, they can crack or warp.

Inspecting Castings

Because of the possibility of inclusions and gas holes, the best method to inspect castings is by X-ray. This is usually done during the manufacturing quality control process. Though infrequent, a casting may have to be X-rayed as the result of an airworthiness directive or special inspection. In service normally they are inspected through the dye penetrant process.

A casting found defective in service can almost never be repaired in the field. However, there are exceptions. Many certified repair stations do weld repairs on aluminum castings, particularly crankcases and cylinder heads. A technician may not weld them.

Forging

Forging is a manufacturing process where metal is pressed, pounded or squeezed under great pressure into high-strength parts known as forgings. The process is normally (but not always) performed hot by preheating the metal to a desired temperature before it is worked. It is important to note that the forging process is entirely different from the casting (or foundry) process. The metal used to make forged parts is never melted and poured, as in the casting process.

The forging process can create parts that are stronger than those manufactured by any other metalworking process. This is why forgings are almost always used where reliability and safety are critical.

Compared to castings, the advantages of forgings are:

- **Strength.** Casting cannot obtain the strengthening effects of hot and cold working. Forging surpasses casting in predictable strength properties.

- **Defect-refining.** A casting has neither grain flow nor directional strength. The process cannot prevent formation of certain metallurgical defects. Preworking forge stock produces a grain flow oriented in directions requiring maximum strength (Figure 6-7-6).
- **Reliable, less costly.** Because hot working refines grain pattern and imparts high strength, ductility, and resistance properties, forged products are more reliable.
- **Better response to heat-treatment.** Castings require close control of melting and cooling processes because alloy segregation may occur. This results in non-uniform heat-treatment response that can affect straightness of finished parts. Forgings respond more predictably to heat-treatment and offer better dimensional stability.

Hand tools and hardware. Forging has traditionally been the mark of quality in hand tools and hardware. Pliers, hammers, sledges, wrenches, and garden tools, as well as wire-rope clips, sockets, hooks, turnbuckles, and eye bolts, are common examples. Surgical and dental instruments are also often forged.

Aviation and aerospace. High strength-to-weight ratio and structural reliability can favorably influence performance, range, and payload capabilities of aircraft. Made of various ferrous, non-ferrous, and special alloy materials, forgings are widely used in commercial jets, helicopters, piston-engine planes, military aircraft, and spacecraft. Some examples of where a forging's versatility of size, shape, and properties make it an ideal component include bulkheads, wing roots and spars, hinges, engine mounts, brackets, beams, shafts, landing gear cylinders and struts, wheels, brake carriers and discs. In jet turbine engines, iron-base, nickel-base, and cobalt-base superalloys are forged into components such as discs, blades, buckets, couplings, manifolds, rings, chambers, and shafts.

Forged parts vary in size, shape, and sophistication—from the hammer and wrench in your toolbox to close tolerance precision components in airplanes and NASA's space shuttle. In fact, over 18,000 forgings are contained in a Boeing 747. Some of the largest customer markets include: aerospace, national defense, automotive, and agriculture, construction, mining, material handling, and general industrial equipment. Even the dies themselves that make forgings (and other metal and plastic parts) are forged. Figures 6-7-7A and 6-7-7B show the visual difference between a forged and a welded nose gear assembly.

Figure 6-7-7A. This welded nose gear assembly, used on many Beechcraft King Air executive turboprops, is prone to cracking and is subject to a repetitive AD inspection.

Figure 6-7-7B. The welded assembly has been replaced by this forged nose gear leg. The greater strength and predictable load bearing characteristics eliminate the need for a repetitive inspection.

Forging Processes

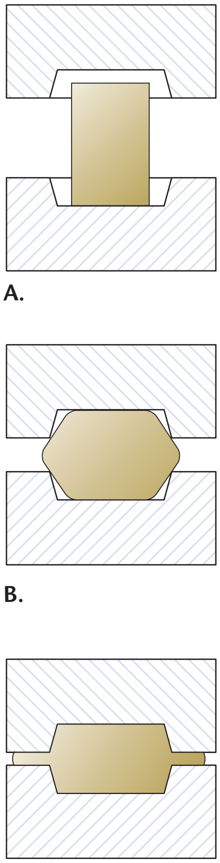


Figure 6-7-8. (A) shows a forging die starting to close. (B) shows the part in process, while (C) shows the completed operation.

There are basically four methods (or processes) to make a forged part.

- Impression die forging
- Cold forging
- Open die forging
- Seamless rolled ring forging

Impression die forging. *Impression die forging* pounds or presses metal between two dies (called tooling) that contains a precut profile of the desired part. Parts from a few ounces to 60,000 lbs. can be made using this process. Some of the smaller parts are actually forged cold.

Commonly referred to as closed-die forging, impression-die forging of steel, aluminum, titanium, and other alloys can produce an almost limitless variety of 3-D shapes that range in weight from mere ounces up to more than 25 tons. Impression-die forgings are routinely produced on hydraulic presses, mechanical presses and hammers, with capacities up to 50,000 tons, 20,000 tons, and 50,000 lbs., respectively. Figure 6-7-8 shows a forging sequence. In practice, the complete operation happens extremely fast: one quick blow.

As the name implies, two or more dies containing impressions of the part shape are brought together as forging stock undergoes plastic deformation. Because metal flow is restricted by the die contours, this process can yield more complex shapes and closer tolerances than open-die forging processes. Additional flexibility in forming both symmetrical and non-symmetrical shapes comes from various preforming operations (sometimes bending) prior to forging in finisher dies.

Cold forging. Most forging is done as hot work, at temperatures up to 2,300°F (1,260°C), however, a variation of impression die forging is *cold forging*. Cold forging encompasses many processes: bending, cold drawing, cold heading, coining, extrusions, and more, to yield a diverse range of part shapes. The temperature of metals being cold forged may range from room temperature to several hundred degrees (Figure 6-7-9).

Open die forging. *Open die forging* is performed between flat dies with no precut profiles in the dies. Movement of the work piece is the key to this method. Larger parts over 200,000 lbs. and 80 feet long can be hammered or pressed into shape this way.

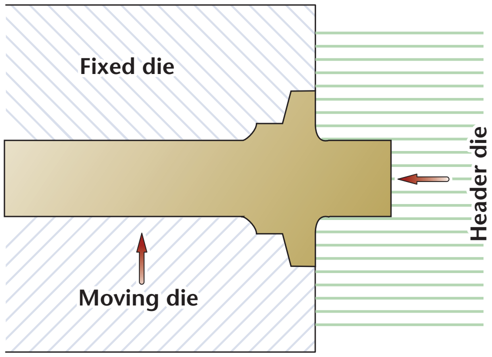


Figure 6-7-9. Cold forging can be both a swaging and a heading operation at the same time.

Open-die forging can produce forgings from a few pounds up to more than 150 tons. Called open-die because impression dies do not confine the metal laterally during forging, this process progressively works the starting stock into the desired shape, most commonly between flat-faced dies.

Practically all forgeable ferrous and non-ferrous alloys can be open-die forged, including some exotic materials like age-hardening superalloys and corrosion-resistant refractory alloys.

Seamless rolled ring forging. *Seamless rolled ring* forging is typically performed by punching a hole in a thick, round piece of metal (creating a donut shape), and then rolling and squeezing (or in some cases, pounding) the donut into a thin ring. Ring diameters can be anywhere from a few inches to 30 ft.

High tangential strength and ductility make forged rings well-suited for torque- and pressure-resistant components, such as gears, engine bearings for aircraft, wheel bearings, couplings, rotor spacers, sealed discs and cases, flanges, pressure vessels, and valve bodies. Materials include not only carbon and alloy steels, but also non-ferrous alloys of aluminum, copper, and titanium, and nickel-base alloys.

Forging Equipment

Although the styles and drive systems vary widely, a forging can be produced on any of the following pieces of equipment:

- *Hammers* with a driving force of up to 50,000 pounds, pound the metal into shape with controlled high pressure impact blows.
- *Presses* with a driving force of up to 50,000 tons, squeeze the metal into shape vertically with controlled high pressure.

- *Upsetters* are basically forging presses used horizontally for a forging process known as upsetting.
- *Ring rollers* turn a hollow round piece of metal under extreme pressure against a rotating roll, thereby squeezing out a one-piece ring (with no welding required).

Aluminum: Practical Applications in Aviation

The modern commercial aviation industry would never have succeeded without aluminum. The Wright brothers' first airplane, which flew in 1903, had a four-cylinder, 12-horsepower auto engine modified with a 30-lb. aluminum block to reduce weight. Aluminum gradually replaced the wood, steel, and other airplane parts in the early 1900s, and the first all-aluminum plane was built in the early 1920s. Since then, airplanes of all kinds and sizes have been made largely of aluminum.

Its combination of lightness, strength, and workability makes it the ideal material for mass-produced commercial aircraft. Strong aluminum alloys take the extraordinary pressures and stresses involved in high-altitude flying; wafer thin aluminum panels keep the cold out and the warm air in.

Many internal fittings, like the seating on planes, are made from aluminum or aluminum composite in order to save weight and fuel, reduce emissions, and increase the aircraft's payload.

Today, there are around 5,300 commercial passenger aircraft flying in the world, and many thousands of light aircraft and helicopters. The industry continues to grow. Demand for commercial aircraft is forecast to rise by around 60 percent over the next decade.

Aluminum is the primary aircraft material, comprising about 80 percent of an aircraft's unladen weight. The standard Boeing 747 jumbo jet contains approximately 165,000 lbs. (75,000 kg) of aluminum. Because the metal resists corrosion, some airlines don't paint their planes, saving several hundred kilograms of weight.

The process of producing pure alumina from bauxite has changed very little since the first plant was opened in 1893. The Bayer process can be considered in three chemical stages: *extraction*, *decomposition*, and *calcination*.

Extraction. The hydrated alumina is selectively removed from the other (insoluble) oxides by transferring it into a solution of sodium hydroxide (caustic soda):

$$Al_2O_3 \bullet XH_2O + 2NaOH \Longrightarrow 2NaAlO_2 + (X+1)H_2O$$

The process is far more efficient when the ore is reduced to a very fine particle size prior to reaction. This reduction is achieved by crushing and milling the pre-washed ore. This is then sent to a heated pressure digester.

Conditions within the digester (concentration, temperature, and pressure) vary according to the properties of the bauxite ore being used. Although higher temperatures are theoretically favored, these produce several disadvantages, including corrosion problems and the possibility of other oxides (other than alumina) dissolving into the caustic liquor.

Modern plants typically operate at 392°F to 464°F (200°C to 240°C) and can involve pressures of around 30 atmospheres.

After the extraction stage, the liquor (containing the dissolved Al_2O_3) must be separated from the insoluble bauxite residue, purified as much as possible, and filtered before it is delivered to the decomposer. The mud is thickened and washed so that the caustic soda can be removed and recycled.

Decomposition. Crystalline alumina trihydrate is extracted from the digestion liquor by hydrolysis:

$$2NaAlO_2 + 4H_2O \Longrightarrow Al_2O_3 \text{ X } 3H_2O + 2NaOH$$

This is the reverse of the extraction process, except that the product's nature can be carefully controlled by plant conditions (including seeding or selective nucleation, precipitation temperature, and cooling rate). The alumina trihydrate crystals are then sorted into size fractions and fed into a rotary bed calcination kiln.

Calcination. Alumina trihydrate crystals are calcined to remove their water of crystallization and prepare the alumina for the aluminum smelting process. The mechanism for this step is complex, but the process, when carefully controlled, dictates the properties of the final product.

Properties of Aluminum

Pure aluminum is a silvery-white metal with many desirable characteristics. It is light, nontoxic (in metal form), non-magnetic, and nonsparking. Although not found free in nature, aluminum is an abundant element in the Earth's crust.

It is decorative, easily formed, machined, and cast. Alloys with small amounts of copper, magnesium, silicon, manganese and other elements have very useful properties.

Physical properties	
Density/specific gravity (68°F) (20°C)	168.5
Melting point (°F)	1,220.0°F (649°C)
Specific heat at 212°F (100°C), cal/g (J/kg)	32.403 (938)
Latent heat of fusion cal/g (kJ/kg)	400.0 (1.67)
Electrical conductivity at 68°F (20°C) (percent of international annealed copper standard)	64.94
Thermal conductivity (cal/sec/cm2/cm/°C)	0.5
Thermal emmisivity at 100°F (38°C) (%)	3.0
Reflectivity for light, tungsten filament (%)	90.0

Table 6-7-1. Physical properties of aluminum.

Strength depends on purity. Aluminum of 99.996 percent purity has a tensile strength of about 7,000 p.s.i., rising to 100,000 p.s.i. following alloying and suitable heat-treatment. A key property is low density. Aluminum is only one-third the weight of steel.

Aluminum and most of its alloys are highly resistant to most forms of corrosion. Its natural coating of aluminum oxide provides a very effective barrier to the ravages of air, temperature, moisture, and chemical attack.

Aluminum is a superb conductor of electricity. This property, allied with other intrinsic qualities, has ensured the replacement of copper by aluminum in many situations. Being non-magnetic and non-combustible are properties invaluable in advanced industries such as electronics or in offshore structures.

Aluminum's non-toxic and impervious qualities have established its use in the food and packaging industries.

Other valuable properties include high reflectivity, good heat-barrier properties, and excellent heat conduction. The metal is malleable and easily worked by the common manufacturing and shaping processes.

Altering Physical Properties

The properties outlined in Table 6-7-1 can be very significantly altered with the addition of small amounts of alloying materials. Aluminum reacts with oxygen to form a microscopic protective film of oxide, which prevents corrosion.

Aluminum in massive form is non-flammable, though finely divided particles will burn. Carbon monoxide or dioxide, aluminum oxide, and water will be emitted. This is a useful property for making rocket fuel.

Non-Ferrous Metals

The term non-ferrous refers to all metals that have elements other than iron as their base or principal constituent. This group includes such metals as aluminum, titanium, copper, and magnesium, as well as alloyed metals like Monel.

Aluminum Alloys

Commercially pure aluminum is very light, but has no great amount of strength. It is, however, very valuable in the construction of many nonstructural units. In order to increase the strength of aluminum, it is alloyed with various other metals to form the so-called "strong-alloys" for structural use. These alloys are available in both wrought and cast forms.

Alloy Designation System

Wrought Alloys (Sheet and Plate)

- First digit: Principal alloying constituent(s)
- Second digit: Variations of initial alloy (modifications)
- Third and fourth digits: Individual alloy variations (number has no significance but is unique)

First digit alloy identification:

1xxx	Aluminum (99 percent or greater) non-heat-treatable
2xxx	Copper heat-treatable
3xxx	Manganese non-heat-treatable
4xxx	Silicon non-heat-treatable
5xxx	Magnesium non-heat-treatable
6xxx	Magnesium & silicon heat-treatable
7xxx	Zinc heat-treatable

Heat-Treatment

Heat-treatment of aluminum is generally used to increase the strength of precipitation-hardenable wrought and cast alloys. These are usually referred to as the *heat-treatable alloys*, to distinguish them from those alloys in which no significant strengthening can be achieved by heating and cooling. The heat-treatable cast alloys are the 2xx0, 3xx0, and 7xx0 series. The basic definitions of the numerous temper codes designating aluminum alloy heat-treatments are listed in Table 6-7-2.

Alloys that are not strengthened by heating and cooling are generally referred to as the *non-heat-treatable* types. When in wrought form, these alloys are hardened by cold work.

NOTE: A special forging alloy, 4032, is hardened by heat-treatment.

Heating to reduce strength and increase ductility (*annealing*) and heating to relieve internal stresses (*stress relief*) are commonly used for both heat-treatable and non-heat-treatable alloys.

We will discuss the 2xxx and the 7xxx in more detail, because they are the primary alloys used in aircraft construction.

2xxx aluminum-copper alloys. The 2xxx series are heat-treatable and possess, in individual alloys, good combinations of high strength (especially at elevated temperatures) and toughness; they are not resistant to atmospheric corrosion and are usually painted or clad in such exposures. The higher strength 2xxx alloys are primarily used for aircraft (2024) and truck body (2014) applications; these are usually used in bolted or riveted construction. Specific members of the series (e.g. 2219 and 2048) are readily welded, and so, are used for aerospace applications where that is the preferred joining method.

Alloy 2195 is a new Li-bearing alloy for space applications providing very high modules of elasticity, along with high strength and weldablility. There are also high-toughness versions of several of the alloys (2124, 2324, 2419). Developed specifically for the aircraft industry, these alloys have fewer impurities that may diminish resistance to unstable fractures. Alloys 2011, 2017, and 2117 are widely used for fasteners and screw-machine stock.

Properties of 2xxx aluminum copper alloys are:

- Heat-treatable
- High strength at room and elevated temperatures
- Aircraft, transportation applications
- Representative alloys: 2014, 2017, 2024, 2195, 2219
- Typical ultimate tensile strength range: 27,000-62,000 p.s.i.

7xxx aluminum-zinc alloys. The 7xxx alloys are heat treatable and, among the Al-Zn-Mg-Cu versions, provide the highest strengths of all aluminum alloys. There are several alloys in the series that are produced especially for their high toughness, notably 7150 and 7475, both with controlled impurity level to maximize the combination of strength and fracture-resistance.

The widest application of the 7xxx alloys has historically been in the aircraft industry, where fracture-critical design concepts have provided the impetus for the high-toughness alloy development. These alloys are not considered weldable by routine commercial processes and are regularly used in riveted construction.

The atmospheric corrosion resistance of the 7xxx alloys is not as high as that of the 5xxx and 6xxx alloys, so in such service they are usually coated or, for sheet and plate, used in an Alclad version. The use of special tempers such as the T73-type is required in place of T6-type tempers whenever stress corrosion cracking may be a problem.

Properties of 7xxx aluminum-zinc alloys are:

- Heat-treatable
- Very high strength; special high-toughness versions
- Aerospace; automotive applications
- Representative alloys: 7005, 7075, 7150, 7475
- Typical ultimate tensile strength range: 32,000-88,000 p.s.i.

Specific Heat-Treatments for Aluminum

Specific instructions for the heat-treatment of various aluminum alloys used in aircraft construction are beyond the capabilities of this textbook, but can be found in MIL Handbook 5.

Although general procedures for heat-treating aluminum remains the same, differences in composition demand that factors, such as time, temperature, and quenching media, be defined for each material.

Solution heat-treating. To take advantage of the *precipitation-hardening* reaction, it is necessary to first produce a solid solution. This

Non heat-treatable alloys		Heat-treatable alloys	
Temper designation	**Definition**	**Temper designation**	**Definition**
-O	Annealed recrystallized (wrought products only) applies to softest temper of wrought products	-O	Annealed recrystallized (wrought products only) applies to softest temper of wrought products
-H1	Strain-hardened only. Applies to products which are strain-hardened to obtain the desired strength without supplementary thermal treatment	-T1	Cooled from an elevated temperature shaping process (such as extrusion or casting) and naturally aged to a substantially stable condition
-H12	Strain-hardened one-quarter-hard temper	-T2	Annealed (castings only)
-H14	Strain-hardened half-hard temper	-T3	Solution heat-treated and cold-worked by the flattening or straightening operation
-H16	Strain-hardened three-quarters-hard temper	-T36	Solution heat-treated and cold-worked by reduction of 6 percent
-H18	Strain-hardened full-hard temper	-T4	Solution heat-treated
-H2	Strain-hardened and then partially annealed. Applies to products which are strain-hardened more than the desired final amount and then reduced in strength to the desired level by partial annealing	-T42	Solution heat-treated by the user regardless of prior temper (applicable only to 2014 and 2024 alloys)
-H22	Strain-hardened and partially annealed to one-quarter-hard temper	-T5	Artificially aged only (castings only)
-H24	Strain-hardened and partially annealed to half-hard temper	-T6	Solution heat-treated and artificially aged
-H26	Strain-hardened and partially annealed to three-quarters-hard temper	-T62	Solution heat-treated and aged by user regardless of prior temper (applicable only to 2014 and 2024 alloys)
-H28	Strain-hardened and partially annealed to full-hard temper	-T351, -T451, -T3510, -T3511, -T4510, -T4511	Solution heat-treated and stress relieved by stretching to produce a permanent set of 1 to 3 percent, depending on the product
-H30	Strain-hardened and then stabilized. Applies to products which are strain-hardened and then stabilized by a low temperature heating to slightly lower their strength and increase ductility	-T651, -T851, -T6510, -T8510, -T6511, -T8511	Solution heat-treated, stress relieved by stretching to produce a permanent set of 1 to 3 percent, and artificially aged
-H32	Strain-hardened and then stabilized; Final temper is one-quarter hard	-T652	Solution heat-treated, compressed to produce a permanent set and then artificially aged
-H34	Strain-hardened and then stabilized; Final temper is one-half hard	-T8	Solution heat-treated, cold-worked and then artificially aged
-H36	Strain-hardened and then stabilized; Final temper is three-quarters hard	-T4	Solution heat-treated, cold-worked by the flattening or straightening operation, and then artificially aged
-H38	Strain-hardened and then stabilized; Final temper is full-hard	-T86	Solution heat-treated, cold-worked by reduction of 6 percent, and then artificially aged
-H112	As fabricated; with specified mechanical property limits	-T9	Solution heat-treated, artificially aged and then cold-worked
-F	For wrought alloys; as fabricated. No mechanical properties limits; For cast alloys; as cast	-T10	Cooled from an elevated temperature shaping process artificially aged and then cold-worked
		-F	For wrought alloys as fabricated; No mechanical properties limits; For cast alloys; as cast

Table 6-7-2. Temper designations and definitions for non-heat-treatable and heat-treatable alloys.

Typical soaking times for solution heat-treatment	
Thickness (inch)	Time (minutes)
Up to 0.125	30
$^1/_8$ to $^1/_4$	40
Over $^1/_4$	60

Table 6-7-3. Reheat-treatment.

process is referred to as *solution heat-treating*. The objective is to take into solid solution the maximum practical amounts of the soluble hardening elements in the alloy. The process consists of soaking the alloy at a temperature sufficiently high and for a time long enough to achieve a nearly homogeneous solid solution.

Solutionizing temperatures vary with alloy composition, but the specific temperature must be carefully controlled within ±10°F (±12°C). If the solution temperature is lower than required, insufficient solute will be dissolved and the final aging treatment will not reach the desired hardness. If overheated, low melting-point phases called eutectics at the grain boundaries will liquefy and ruin the material.

The time at the nominal solution heating temperature is called soak time, and is a function of microstructure before heat-treatment, the thickness of the material being heated and the loading of the furnace being used. The time at temperature must be sufficient to completely dissolve the solute phases and homogenize the solid solution.

Reheat-treatment. The treatment of material that has been previously heat-treated is considered a *reheat-treatment*. The unclad heat-treatable alloys can be solution heat-treated repeatedly without harmful effects.

The number of solution heat-treatments allowed for clad sheet is limited, due to increased diffusion of core and cladding with each reheating. Existing specifications allow one to three reheat-treatments of clad sheet, depending on thickness. Cladding will be discussed later in more detail.

Soak time for Alclad sheet and for parts made from Alclad sheet must be held to a minimum, because excessive diffusion of alloying elements from the core into the cladding reduces corrosion protection. (Table 6-7-3). For the same reason, reheat-treatment of Alclad sheet less than 0.030 inches thick is generally prohibited, and the number or reheat-treatments permitted for thicker Alclad sheet is limited.

> **NOTE:** Heat-treatment of a previously heat-treated material is classified as a reheat-treatment. Therefore, the first heat-treatment of material purchased in the heat-treated condition is a reheat-treatment. As far as Table 6-7-3 is concerned, annealing and precipitation treatments are not considered heat-treatments.

Quenching. In most instances, to avoid the types of precipitation that are detrimental to strength or corrosion resistance, the solid solution formed during solutionizing must be *quenched* rapidly and without interruption to produce a supersaturated solution at room temperature. Most frequently, parts are quenched by immersion in cold water. Large aluminum production facilities use water spray quenching. For parts with complex shapes and abrupt changes in thickness, somewhat slower cooling may be required to prevent cracking. In these instances, boiling water or an aqueous solution of polyalkaline glycol is used. Some forgings and castings, which require maximum dimensional stability, are air-cooled. The hardening response of these parts is limited, but satisfactory for the applications.

Lag between soaking and quenching. The time interval between the removal of the material from the furnace to the quenching media, quench delay, is critical for some alloys and should not exceed 15 seconds. This is to prevent precooling into a critical temperature range with un-wanted results. For instance, when solution heat-treating 2017 or 2024 sheet material, the elapsed time must not exceed 10 seconds. The extent of the temperature range varies with the alloy, but the temperatures between 750°F (399°C) and 500°F (260°C) should be avoided for virtually all aluminum alloy quenches.

Allowing the metal to cool slightly before quenching promotes re-precipitation from the solid solution. The precipitation occurs along grain boundaries and in certain slip planes, causing poor formability. In the case of 2017, 2024, and 7075 alloys, their resistance to intergranular corrosion is decreased.

Straightening after solution heat-treatment. Some warping occurs during solution heat-treatment, producing kinks, buckles, waves, or twists. These imperfections are generally removed by straightening and flattening operations.

When the straightening operations produce an appreciable increase in the tensile and yield strengths and a slight decrease in the percent of elongation, the material is designated T3 temper. When the above values are not materially affected, the material is designated T4 temper.

The solution heat-treatment process that results in the metal becoming age-hardened goes through three events: heating, quenching, and aging. The heating range is usually about 940°F (504°C). The quenching medium is cold water. During this step, the operator wants to get the metal cooled down as soon as possible to prevent early corrosion from starting. The aging period varies for each thickness of metal, but it usually levels out to about 12 to 16 hours. After the metal has age-hardened, it is suitable for aircraft structural work.

Precipitation hardening. After quenching, the material is a supersaturated, solid solution of alloying elements dissolved in aluminum. This is an unstable condition. The chemical balance of the material is out of equilibrium, and the elements suspended in solid solution will have a tendency to precipitate in order to restore the equilibrium. When this precipitation occurs at room temperature, it is referred to as *natural aging*. Depending upon the alloy, this process can take from one hour to many years to reach completion. Of course, alloys which would require years to naturally age couldn't be used in this condition and would require further heat-treatment. The heat energy required to drive the chemical reactions in these more sluggish alloys is supplied by *artificial aging* heat-treatments.

In both natural and artificial aging, the precipitates harden the material by setting up submicroscopic strains throughout the aluminum matrix. The secondary phases that fall out of the solution actually crowd and stretch the surrounding material. This serves to reduce the elasticity or ductility of the metal, which, in turn, increases hardness and structural strength. There is an optimum particle size, neither too small nor too large, which imparts the best compromise between strength and corrosion properties.

Strain hardening. Mechanically working metals at temperatures below their critical range (the temperature at which crystals begin to form) results in *strain hardening* of the metal. The mechanical working may consist of *rolling*, *drawing*, *stamping*, or *pressing*. During strain hardening, the metal becomes so hard that it becomes difficult to continue the forming process without softening the metal by annealing.

Strength, hardness, and elasticity are increased by strain hardening. Ductility decreases. Since this makes the metal more brittle, it must be heated sometimes during certain operations to remove the undesirable effects of the working.

Natural aging. The more highly alloyed members of the 6xxx wrought series, the copper-containing alloys of the 7xxx group, and all of the 2xxx series are almost always solution heat-treated and quenched. For some of these alloys, particularly the 2xxx alloys, the precipitation hardening that results from natural aging alone produces useful tempers (T3 and T4 types of temper). The tensile property specifications for the T3 and T4 types of tempers of most alloys are based on a nominal natural aging time of four days. Aluminum aircraft rivets, however, age within hours.

Heat-Treatment of Rivets

Rivets requiring heat-treatment are usually heated in small screen wire baskets, which allow free and rapid circulation of water during the quenching process. The load should be held at the specified temperature for at least one hour in a still air furnace, and then quenched in the coldest water available. Rivets removed from the cold water and held at room temperature should be driven within 15 minutes after quenching, or it may be held for much longer periods without hardening if stored under refrigeration. Rivets will harden completely at room temperature in about 24 hours due to the effects of natural aging. Rivets driven in the full hardened or partially hardened condition show a much greater tendency to crack than those driven within 15 minutes after quenching. Rivets made from 2017 (D) and 2024 (DD) alloy must be heat-treated before use; 1xxx, 4xxx and 5xxx alloy rivets may be driven in the condition in which they are received.

Artificial aging. Precipitation heat-treatment is also called *artificial aging*. The process consists of heating the aluminum alloy into a narrow temperature range (±10°F, ±12°C,) and holding for several hours, sometimes days. This treatment produces the T6 and T7 types of tempers. The heat causes a fine dispersion of strengthening particles to precipitate out of solution. The times and temperatures for specific alloys were developed to produce an optimum particle size. If the alloys are heated to above the proper temperature or held for too long a period of time, the suspended particles will become too large and the metal will lose both strength and corrosion properties. This excessive heat-treatment is called *overaging.*

Annealing

Annealing treatments employed for aluminum alloys are of several types that differ in objective. Annealing times and temperatures depend on alloy type, as well as initial structure and temper. The types of annealing are full, partial, and stress-relief annealing.

Full annealing. The softest, most ductile and workable condition of both non-heat-treatable and heat treatable wrought alloys is produced by *full annealing* to the temper designated "O." For work-hardened material like 1xxx-, 3xxx-, 4xxx-, and 5xxx-series aluminums, the heating removes the hardening strains induced by deformation. A temperature in the range of 650°F (343°C) for a time just long enough to insure that the entire load comes to temperature will be sufficient to accomplish full annealing of these types. The rate of cooling in this case is not important.

The heat-treatable alloys are annealed by thoroughly precipitating the solutes into coarse, widely spaced particles. This removes the effects of heat-treatment and prevents natural age hardening. The temperatures required for the treatment are in the 750º-850ºF range for a time of not less than one hour. Slow enough cooling at about 50ºF per hour maximum is required. Although material annealed from the precipitation-hardening condition usually has sufficient ductility for most forming operations, this ductility is often slightly lower than the ductility of metal which has received a prior heat-treatment. Therefore, when maximum ductility is required, annealing of a previously heat-treated product is sometimes unsuccessful.

Partial annealing. Partial annealing is also referred to as *recovery annealing*. Partial annealing is performed on the non-heat-treatable alloys, which have been severely *work-hardened* (H18 temper). Heating to between 350ºF to 550ºF restores some of the ductility, and gives the material an intermediate hardness value (H2-type temper). Bendability and formability of an alloy annealed to an H2-type temper generally are significantly higher than those of the same alloy in which an equal strength level is developed by a final cold working operation (H1-type temper). Times and temperatures for partial annealing must be carefully controlled in order to achieve the desired strength.

Stress-relief annealing. For cold-worked wrought alloys, annealing merely to remove the effects of strain hardening is referred to as stress-relief annealing. Such treatments employ heating to 650ºF and cooling to room temperature. No appreciable holding time is required.

Annealing of castings. The suggested annealing treatment for most aluminum alloy castings is 600ºF to 650ºF for two to four hours. This provides the most complete release of residual stresses. Such annealing treatments produce maximum dimensional stability at high temperatures and are designated as the "O" temper.

Cladding

Pure aluminum has such a very high resistance to corrosion that under normal conditions it rarely ever corrodes. Due to this excellent corrosion-resistant characteristic, sheet metal manufacturers apply, or clad, pure aluminum to the surface of most aluminum alloy flat stock in a process known as cladding.

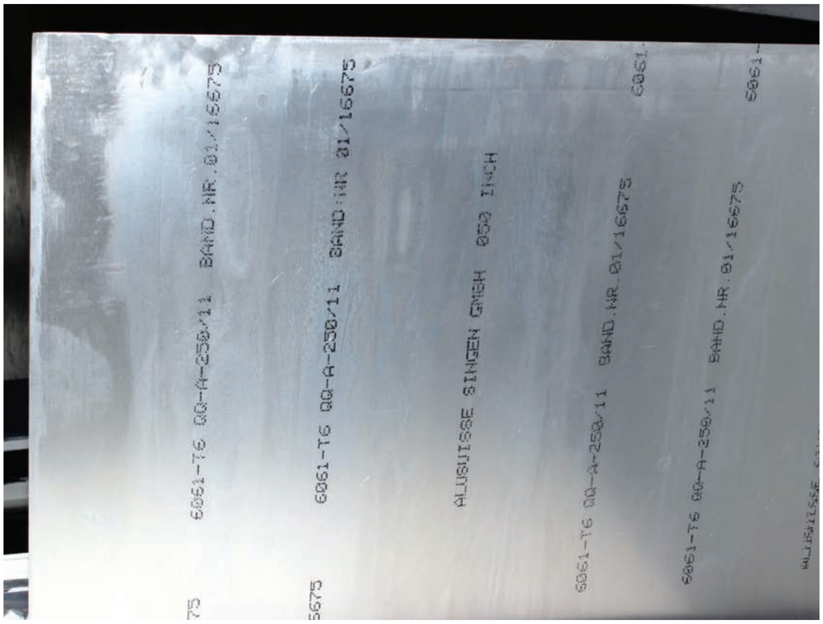


Figure 6-7-10. Manufacturer's markings on an aluminum sheet.

In the cladding process, this pure aluminum alloy sheet is clad to a thickness approximately 5 percent on each side.

Alclad versus clad. Aluminum products sometimes are coated on one or both surfaces with a metallurgically bonded, thin layer of pure aluminum or aluminum alloy. If the combination of core and cladding alloys is selected so that the cladding is anodic to the core, it is called *Alclad*. Alclad products are designed for corrosion protection.

Clad products resemble Alclad products in many respects, but they are distinguished by a cladding alloy that is not intentionally anodic to the core. Clad products are designed to provide improved surface appearance.

Aluminum Sheet Identification Marks

Aircraft aluminum alloy is marked the full length of the sheet with an ink roller after all manufacturing operations are completed. If it weren't marked, it would not be possible to know what you really had.

The markings consist of the alloy, its temper condition, clad or Alclad, and the federal specification number under which it was manufactured (QQA number). The aluminum manufacturer is also identified by name, and the batch number is included. Figure 6-7-10 shows the markings on the reverse side of the sheet.

Tests to distinguish heat-treatable and non-heat-treatable aluminum alloys. Clad aluminum alloys have surface layers of pure aluminum or corrosion-resistant aluminum alloy bonded to the core material to inhibit corrosion. Presence of such a coating may be determined under a magnifying glass by examination of the edge surface that will show three distinct layers. In aluminum alloys, the properties of any specific alloy can be altered by work-hardening (often called strain-hardening), heat-treatment, or by a combination of these processes.

If, for any reason, the identification mark of the alloy is not on the material, it is possible to distinguish between some heat-treatable alloys and some non-heat-treatable alloys by immersing a sample of the material in a 10-percent solution of caustic soda (sodium hydroxide).

Those heat-treated alloys containing several percent of copper (2014, 2017, and 2024) will turn black due to the copper content. High-copper alloys are not based primarily on the use of copper as an alloying agent. These include, among others, 6053, 6061, and 7075 alloys. The composition and heat-treating ability of alloys that do not turn black in a caustic soda solution can be established by a testing laboratory.

Specifications and Inspection

All material ordered on the basis of Alcoa specifications will comply with corresponding government specifications.

Quantitative inspection items include chemical composition, mechanical properties, dimensional requirements (which sometimes include straightness), and packing and shipping requirements. The limits to which these factors must conform are set forth in detail in government specifications.

Qualitative inspection items include general surface appearance, specific surface abrasions and blemishes, flatness, and straightness. Government specifications discuss these items under workmanship. The following, among others, are not normally considered grounds for rejection:

- Surface discoloration of heat-treated materials. Alclad sheet is less susceptible than other heat-treated sheet.
- A few small surface blisters on heat-treated Alclad sheet.
- Shallow scratches on Alclad sheet. The surface of Alclad sheet is relatively soft and is therefore somewhat susceptible to handling scratches. Extensive investigations have shown that these scratches do not detract from the resistance to corrosion and do not have a measurable effect on the tensile strength, yield strength, or elongation.
- Light die scratches and minor surface abrasion on extrusions, tubing, rods, bars, and rolled shapes.
- Small residual heat-treating buckles and lack of perfect flatness, particularly on thin-gauge (less that 0.040 inch think) heat-treated alloy sheet.
- Lack of perfect flatness on annealed sheets of any gauge.

Those not familiar with accepted standards for these qualitative items of inspection are urged to consult with the local company representative. Special inspection requirements are sometimes included in contracts for material to be used for special purposes for which commercial grades are not applicable.

Substitution of Aircraft Metals

In selecting substitute metals for the repair and maintenance of aircraft, it is very important to check the appropriate structural repair manual. Most manufacturers will have a skin plating chart or diagram listed. As a general rule, 2024-T3 can be substituted for 7075-T6 if the next heavier gauge is used. There are exceptions, so consult the manual first.

Aircraft manufacturers design structural members to meet a specific load requirement for a particular aircraft. The methods of repairing these members, apparently similar in construction, will thus vary with different aircraft.

Four requirements must be kept in mind when selecting substitute metals:

1. The most important is maintaining the original strength of the structure.
2. Maintaining contour or aerodynamic smoothness.
3. Maintaining original weight, if possible, or keeping added weight to a minimum.
4. Maintaining the original corrosion-resistant properties of the metal.

Magnesium Alloys

Magnesium, the world's lightest structural metal, is a silvery-white material weighing only two-thirds as much as aluminum. Magnesium does not possess sufficient strength in its pure state for structural uses, but when alloyed with zinc, aluminum, and manganese, it produces an alloy having the highest strength-to-weight ratio of any of the commonly used metals. Magnesium is not used as much today due to its poor corrosion characteristics.

Magnesium alloys produced in the United States consist of magnesium alloyed with varying proportions of aluminum, manganese, and zinc. These alloys are designated by a letter of the alphabet and with the number 1, indicating high purity and maximum corrosion resistance.

Magnesium alloys are subject to such treatments as annealing, quenching, solution heat-treatment, aging, and stabilizing. Sheet and plate magnesium are annealed at the rolling mill. The solution heat-treatment is used to put as much of the alloying ingredients as possible into solid solution, which results in high tensile strength and maximum ductility. Aging is applied to castings following heat-treatment where maximum hardness and yield strength are desired.

Magnesium embodies fire hazards of an unpredictable nature. When in large sections, its high thermal conductivity makes it difficult to ignite and prevents it from burning. Magnesium will not burn until the melting point is reached, which is 1,204°F (651°C). However, magnesium dust and fine chips are ignited easily. Extreme caution must be taken to prevent this from occurring. Should a fire occur, it can be extinguished with an extinguishing powder, such as powdered soapstone or graphite powder. Water or any standard liquid or foam fire extinguisher will cause magnesium to burn much more rapidly, and can even cause the magnesium to explode.

Titanium Alloys

Weighing 0.63 lbs. per cubic inch, titanium has a very high strength, particularly in an alloyed form. In addition, it has excellent corrosion-resistant characteristics. Certain forms of titanium alloys are used extensively in many aerospace applications. Sensitive to both nitrogen and oxygen, titanium has to be converted to titanium dioxide with chlorine gas and a reducing agent, usually carbon, to be used effectively as a strong metal. Not as lustrous as chromium or stainless steel, pure titanium is soft and ductile, and its weight is between that of aluminum and iron.

Titanium alloys are classified as alpha, alpha-beta, and beta alloys. These classifications are based on the specific chemical bonding within the alloy itself.

Alpha titanium alloy. *Alpha alloys* have medium strength, and good elevated-temperature strength. They can be welded, and are used mostly for forgings.

Alpha-beta titanium alloy. *Alpha-beta alloys* are the most versatile of the titanium alloys. In the annealed condition they have medium strength, but when heat-treated their strength greatly increases. This form of titanium is generally not weldable, but it has good forming characteristics.

Beta titanium alloy. *Beta alloys* have medium strength and excellent forming characteristics. Beta titanium can be heat treated to a very high strength.

Nickel Alloys

Monel®. Combining the properties of high strength and excellent corrosion resistance, Monel is the leading high-nickel alloy. This metal consists of 68 percent nickel, 29 percent copper, 0.2 percent iron, 1 percent manganese, and 1.8 percent of other elements. It cannot be hardened by heat-treatment.

Monel is adaptable to castings and either hot or cold working, and it can be successfully welded. It has working properties similar to those of steel, and when forged and annealed, has a tensile strength of 80,000 p.s.i. This can be increased by cold-working to 125,000 p.s.i, which is sufficient for it to be classified among the tough alloys.

Monel has been successfully used for gears and chains to operate retractable landing gear, and for structural parts subject to corrosion. Monel is often used for rivets to rivet stainless steel parts.

Inconel®. Closely resembling stainless steel in appearance, Inconel is a nickel-chromium-iron alloy. Its tensile strength is 100,000 p.s.i. annealed, 125,000 p.s.i. when hard-rolled. It is highly resistant to salt water and is able to withstand temperatures as high as 1,600°F (871°C). Inconel welds readily and has working qualities quite similar to those of corrosion-resistant steel.

Because Inconel and stainless steel look very much alike, a distinguishing test is often necessary. One method of identification is to use a solution of 10 grams of cupric chloride in 100 cubic centimeters of hydrochloric acid. The procedure is as follows:

1. Using a medicine dropper, place one drop of the solution on a sample of each metal to be tested and allow it to remain for 2 minutes.

2. At the end of the 2-minute period, slowly add three or four drops of water to the solution on the metal samples, one drop at a time.
3. Wash the samples in clear water and dry them.
4. If the metal is stainless steel, the copper in the cupric chloride solution will be deposited on the metal, leaving a copper-colored spot. If the sample is Inconel, a shiny spot will be seen.

Ferrous Aircraft Metals

Many different metals are required in the repair of aircraft. This is a result of the varying needs with respect to strength, weight, durability, and resistance to deterioration of specific structures and parts. In addition, the particular shape or form of the material plays an important role. In selecting materials for aircraft repair, these and many other factors are considered in relation to the mechanical and physical properties. Among the common materials used are ferrous metals. The term *ferrous* applies to the group of metals having iron as their principal constituent.

Iron. One of the basic chemical elements, iron is extracted from iron ore. When combined with limestone and melted down, iron ore can be converted into what is commercially known as *pig iron*. Depending on how the iron ore is melted and what its intended use is, the pig iron is then used for castings, wrought iron, or in the manufacture of steel.

Steel. If carbon is added to iron in percentages ranging up to approximately 1 percent, the product is vastly superior to iron alone and is classified as *carbon steel*. Just as with the previously discussed non-ferrous metals, a base metal (such as iron) to which small quantities of other metals have been added is called an alloy. The addition of other metals changes, or improves, the chemical or physical properties of the base metal for a particular use. Steel alloys are produced by combining carbon steel with elements which are known to improve the properties of steel. Carbon steel forms the base of those steel alloys.

Alloying Agents in Steel

Carbon. Steel containing carbon in percentages ranging from 0.10-0.30 percent is classified as *low-carbon steel*. The equivalent SAE numbers range from 1010 to 1030. (SAE numbers will be discussed in a later paragraph.) Steels of this grade are used for making such items as safety wire, certain nuts, cable bushings, or threaded rod ends. This steel, in sheet form, is used for secondary structural parts, clamps, and, in tubular form, for moderately stressed structural parts.

Steel containing carbon in percentages ranging from 0.30-0.50 percent is classified as *medium-carbon steel*. This steel is especially adaptable for machining or forging and where surface hardness is desirable. Certain rod ends and light forgings are made from SAE 1035 steel.

Steel containing carbon in percentages ranging from 0.50 to 1.05 percent is classified as *high-carbon steel*. The addition of other elements in varying quantities adds to the hardness of this steel. In the fully heat-treated condition, it is very hard, will withstand high shear and wear, and will have little deformation. It has limited use in aircraft. SAE 1095 in sheet form is used for making flat springs and in wire form for making coil springs.

Sulfur. During the refining process, as much sulfur as possible is removed from the steel, because it causes steel to be brittle during some forming processes. The effect of any sulfur that cannot be removed is counteracted by adding manganese. The manganese will draw the sulfur to it, creating *manganese sulfides*, which have no appreciable detrimental effects in the later forming processes.

Manganese. As carbon steel is processed, if manganese is added, the steel becomes very brittle. As the quantity of manganese is increased, the brittleness increases (up to a point). At a manganese content of about 5.5 percent, the brittleness begins to decrease, with the steel becoming more ductile and very hard. Manganese steel reaches its maximum hardness and ductility at a manganese content of about 12 percent.

Silicon. When this non-metallic chemical is added to steel (often manganese steel), it aids in the hardening and ductility qualities of the steel. Silicon is usually added to steel in amounts as small as fractions of 1 percent.

Phosphorus. Used to increase the resistance of low-carbon steel to corrosion, phosphorus is added in minute quantities of 0.05 percent or less. Quantities of phosphorus greater than 0.05 percent will cause the steel to become brittle.

Nickel. The various nickel steels are produced by combining nickel with carbon steel. Steels containing from 3 to 3.75 percent nickel are commonly used. Nickel increases the hardness, tensile strength, and elastic limit of steel without appreciably decreasing the ductility. It also intensifies the hardening effect of heat-treatment. SAE 2330 steel is used extensively for aircraft parts, such as bolts, terminals, keys, clevises, and pins.

Chromium. High in hardness, strength, and corrosion-resistant properties, chromium steel is particularly adaptable for heat-treated forgings that require greater toughness and strength than may be obtained in plain carbon steel. It can be used for such articles as the balls and rollers of anti-friction bearings. The amount of chromium used in chromium steels varies greatly, dependent upon the desired usage of the final product.

Molybdenum. In combination with chromium, small percentages of molybdenum are used to form *chromium-molybdenum steel*, which has various uses in aircraft. Molybdenum is a strong alloying element that raises the ultimate strength of steel without affecting ductility or workability. Molybdenum steels are tough and wear resistant, and they harden throughout when heat treated. Because they are especially adaptable for welding, molybdenum steels are used principally for welded structural parts and assemblies. This type steel has practically replaced carbon steel in the fabrication of fuselage tubing, engine mounts, landing gear, and other structural parts. For example, a heat-treated SAE 4130 chromium-molybdenum steel tube is approximately four times as strong as a carbon steel tube of the same weight and size. (4130 is commonly called chrome-moly steel.)

Vanadium. When used to alloy steel, vanadium will increase the strength, toughness, and resistance to wear and fatigue. Vanadium steel normally consists of 0.16-0.25 percent vanadium and is often alloyed with chromium. A special grade of this steel in sheet form can be cold-formed into intricate shapes. It can be folded and flattened without signs of breaking or failure. Vanadium steel is used for making springs, gears subjected to severe service conditions, and for all parts that must withstand constant vibrations, variance, loads, and repeated stresses.

Titanium. When alloyed with stainless steel, a small amount of titanium will keep the steel from becoming brittle under high-temperature conditions. This is used extensively in tail pipe and exhaust stack applications.

Tungsten. Able to withstand high temperatures without losing strength, tungsten is used extensively in high-speed metal-cutting tools and metals to be used for magnets. Tungsten steels normally contain 5 to 15 percent tungsten, although as much as 24 percent is not unusual.

SAE Classification of Steels

In order to facilitate the discussion of steels, some familiarity with their nomenclature is desirable. A numerical index, sponsored by the Society of Automotive Engineers (SAE) and the American Iron and Steel Institute (AISI), is used to identify the chemical compositions of the structural steels (Table 6-7-4).

Figure 6-7-11. This pallet of steel tubing is marked with its four-digit number and with the heat-treat condition.

In the SAE numerical index system, a four-numeral series is used to designate the plain carbon, and alloy steels; five numerals are used to designate certain types of alloy steels. The first two digits indicate the type of steel, the second digit also generally (but not always) gives the approximate amount of the major alloying element, and the last two (or three) digits are intended to indicate the approximate middle of the carbon range. However, a deviation from the rule of indicating the carbon range is sometimes necessary (Figure 6-7-11).

Small quantities of certain elements are present in alloy steels that are not specified as required. These elements are considered as incidental and may be present to the maximum amounts as follows: copper, 0.35 percent; nickel, 0.25 percent; chromium, 0.20 percent; molybdenum, 0.06 percent.

The list of standard steels is altered from time to time to accommodate steels of proven merit and to provide for changes in the metallurgical and engineering requirements of industry.

Carbon Steel

The element which provides the greatest influence on steel is carbon. The greater the amount of carbon in the steel, the harder the steel will be. However, the harder the steel, the more difficult it is to weld. Carbon steels vary from soft (low carbon) steels, with between 0.06 and 0.60 percent carbon content, to high-grade razor steel at about 1.25 percent carbon content.

Series designation	Types of steel
10xx	Non-sulphurized carbon steels
11xx	Re-sulphurized carbon steels (free machining)
12xx	Re-phosphorized and re-sulphurized carbon steels (free machining)
13xx	Manganese (1.75%)
*23xx	Nickel (3.50%)
*25xx	Nickel (5.00%)
31xx	Nickel (1.25%); Chromium (0.65%)
33xx	Nickel (3.50%); Chromium (1.55%)
40xx	Molybdenum (0.20 or 0.25%)
41xx	Chromium (0.50 or 0.95%); Molybdenum (0.12 or 0.20%)
43xx	Nickel (1.80%); Chromium (0.50 or 0.80%); Molybdenum (0.25%)
44xx	Molybdenum (0.40%)
45xx	Molybdenum (0.52%)
46xx	Nickel (1.80%); Molybdenum (0.25%)
47xx	Nickel (1.05%); Chromium (0.45%); Molybdenum (0.20 or 0.35%)
48xx	Nickel (3.50%); Molybdenum (0.25%)
50xx	Chromium (0.25, 0.45 or 0.50%)
50xxx	Carbon (1.00%); Chromium (0.50%)
51xx	Chromium (0.80, 0.90, 0.95 or 1.00%)
51xxx	Carbon (1.00%); Chromium (1.05%)
52xxx	Carbon (1.00%); Chromium (1.45%)
61xx	Chromium (0.60, 0.80 or 0.95%); Vanadium (0.12%, 0.10% min. or 0.15% min.)
81xx	Nickel (0.30%); Chromium (0.40%); Molybdenum (0.12%)
86xx	Nickel (0.55%); Chromium (0.50%); Molybdenum (0.20%)
87xx	Nickel (0.55%); Chromium (0.05%); Molybdenum (0.25%)
88xx	Nickel (0.55%); Chromium (0.05%); Molybdenum (0.35%)
92xx	Manganese (0.85%); Silicon (2.00%); Chromium (0 or 0.35%)
93xx	Nickel (3.25%); Chromium (1.20%); Molybdenum (0.12%)
94xx	Nickel (0.45%); Chromium (0.40%); Molybdenum (0.12%)
98xx	Nickel (1.00%); Chromium (0.80%); Molybdenum (0.25%)
*Not included in the current list of standard steels	

Table 6-7-4. SAE numerical index of steel alloy designations.

Alloy Steels

Chromium-molybdenum steel. The series of chromium molybdenum steels (chrome-moly) most widely used in aircraft construction contains 0.25-0.55 percent carbon, 0.15-0.25 percent molybdenum, and 0.50-1.10 percent chromium. These steels, when suitably heat-treated, are deep-hardening, easily machined, readily welded by either gas or electric methods, and are especially adapted to high-temperature service.

Nickel steel. Sensitive to heat-treatment, nickel steels are primarily used in aviation for hardware, such as rod ends, nuts, bolts, and screws.

Chromium-nickel steels are corrosion-resistant metals. The anti-corrosive degree of this steel is determined by the surface condition of the metal, as well as by the composition, temperature, and concentration of the corrosive agent.

Stainless steel. The principal alloy of stainless steel is chromium. The corrosion-resistant steel most often used in aircraft construction is known as 18-8 steel because of its content of 18 percent chromium and 8 percent nickel. One of the distinctive features of 18-8 steel is that its strength may be increased by cold-working.

Stainless steel may be rolled, drawn, bent, or formed to any shape. Because these steels expand about 50 percent more than carbon steel and conduct heat only about 40 percent as rapidly, they are more difficult to weld. Stainless steel can be used for almost any part of an aircraft. Some of its common applications are in the fabrication of firewalls, exhaust collectors, stacks, manifolds, structural and machined parts, springs, castings, tie rods, and control cables.

Heat-Treatment of Steel

Heat-treatment is a series of operations involving the heating and cooling of metals in the solid state. Its purpose is to change a mechanical property or combination of mechanical properties so that the metal will be more useful, serviceable, and safe for a definite purpose. By heat-treating, a metal can be made harder, stronger, and more resistant to impact. Heat-treating can also make a metal softer and more ductile. However, no single heat-treating operation can produce all of these characteristics. In fact, one property is often improved at the expense of another. For example, in the process of being hardened, a metal may be made brittle.

The various heat-treating processes are similar in that they all involve the heating and cooling of metals. They differ, however, in the temperatures to which the metal is heated, the rate at which it is cooled, and, of course, in the final result.

The most common forms of heat-treatment for ferrous metals are annealing, normalizing, hardening, tempering, and case hardening. An advantage of ferrous metals over non-ferrous metals is that most ferrous metals can be annealed, and many of them can be hardened by heat-treatment; however, there is only one non-ferrous metal, titanium, that can be case hardened, and none can be tempered or normalized.

Knowing the chemical composition is the first important consideration in the heat-treatment of a steel part. This, in turn, determines its *upper critical point*. When the upper critical point is known, the next consideration is the rate of heating and cooling to be used. Carrying out these operations involves the use of uniform heating furnaces, proper temperature controls, and suitable quenching mediums.

Annealing

Metals are annealed to relieve internal stresses, soften the metal, make it more ductile, and refine the grain structure. In the annealed state, steel has its lowest strength. In general, annealing is the opposite of hardening.

Annealing of steel is accomplished by heating the metal to just above the upper critical point, soaking at that temperature, and cooling very slowly in the furnace (Table 6-7-5) for recommended temperatures. Soaking time is approximately one hour per inch of thickness of the material.

To produce maximum softness in steel, the metal must be cooled very slowly. Slow cooling is obtained by shutting off the heat and allowing the furnace and metal to cool together to 900°F (482°C) or lower, then removing the metal from the furnace and cooling in still air. Another method is to bury the heated steel in ashes, sand, or other substance that does not conduct heat readily.

Normalizing

The process of *normalizing* steel removes the internal stresses caused by welding, machining, forming, or any type of handling. These stresses, if not reduced or eliminated, will eventually cause extreme brittleness, which in turn will lead to cracking. The application of the normalizing process does exactly what the name implies. It brings the metal back to a normal, shock-resistant state.

Steel designation number	Temperatures (Fahrenheit)			Quenching medium (N)	Tempering (drawing) temperature for tensile strength (p.s.i.)				
	Normalizing air cool °F	Annealing °F	Hardening °F		100,000 (p.s.i.)	125,000 (p.s.i.)	150,000 (p.s.i.)	180,000 (p.s.i.)	200,000 (p.s.i.)
1020	1,650-1,750	1,600-1,700	1,575-1,675	H_2O	-	-	-	-	-
1022(X1022)	1,650-1,750	1,600-1,700	1,575-1,675	H_2O	-	-	-	-	-
1025	1,600-1,700	1,575-1,650	1,575-1,675	H_2O	(a)	-	-	-	-
1035	1,575-1,650	1,575-1,625	1,525-1,625	H_2O	875	-	-	-	-
1045	1,550-1,600	1,550-1,600	1,475-1,550	Oil/ H_2O	1,150	-	-	(n)	-
1095	1,475-1,550	1,450-1,500	1,425-1,500	Oil	(b)	-	1,100	850	750
2330	1,475-1,525	1,425-1,475	1,450-1,500	Oil/ H_2O	1,100	950	800	-	-
3135	1,600-1,650	1,500-1,550	1,475-1,525	Oil	1,250	1,050	900	750	650
3140	1,600-1,650	1,500-1,550	1,475-1,525	Oil	1,325	1,075	925	775	700
4037	1,600	1,525-1,575	1,525-1,575	Oil/ H_2O	1,225	1,100	975	-	-
4130 (X4130)	1,600-1,700	1,525-1,575	1,575-1,625	Oil (c)	(d)	1,050	900	700	575
4140	1,600-1,650	1,525-1,575	1,525-1,575	Oil	1,350	1,100	1,025	825	675
4150	1,550-1,600	1,475-1,525	1,500-1,550	Oil	-	1,275	1,175	1,050	950
4340 (X4340)	1,550-1,625	1,525-1,575	1,475-1,550	Oil	-	1,200	1,050	950	850
4640	1,675-1,700	1,525-1,575	1,500-1,550	Oil	-	1,200	1,050	750	625
6135	1,600-1,700	1,550-1,600	1,575-1,625	Oil	1,300	1,075	950	800	750
6150	1,600-1,650	1,525-1,575	1,550-1,625	Oil	(d) (e)	1,200	1,000	900	800
6195	1,600-1,650	1,525-1,575	1,500-1,550	Oil	(f)	-	-	-	-
8620	-	-	1,525-1,575	Oil	-	1,000	-	-	-
8630	1,650	1,525-1,575	1,525-1,575	Oil	-	1,125	975	775	675
8735	1,650	1,525-1,575	1,525-1,575	Oil	-	1,175	1,025	875	775
8735	1,625	1,500-1,550	1,500-1,550	Oil	-	1,200	1,075	925	850
30905	-	(g) (h)	(i)	-	-	-	-	-	-
51210	1,525-1,575	1,525-1,575	1,775-1,825 (j)	Oil	1,200	1,100	(k)	750	-
51335	-	1,525-1,575	1,775-1,010	Oil	-	-	-	-	-
52100	1,625-1,700	1,400-1,450	1,525-1,550	Oil	(f)	-	-	-	-
Corrosion resisting (16-2) (l)	-	-	-	-	(m)	-	-	-	-
Silicon chromium (for Springs)	-	-	1700-1725	Oil	-	-	-	-	-

(a) Draw at 1,150°F for tensile strength of 70,000 p.s.i.
(b) For spring temper draw at 800-900°F. Rockwell hardness C-40-45
(c) Bars and forgings may be quenched in water from 1,500-1,600°F.
(d) Air-cooling from the normalizing temperature will produce a tensile strength of approx. 90,000 p.s.i.
(e) For spring temper draw at 858-950°F. Rockwell hardness C-40-45.
(f) Draw at 350-450°F to remove quenching strains. Rockwell hardness C-60-65.
(g) Anneal at 1,600-1,700°F to remove residual stresses due to welding or cold-work. May be applied to steel containing titanium or columbium.
(h) Anneal at 1,900-2,100°F to produce maximum softness and corrosion resistance. Cool in air or quench in water.
(i) Harden by cold-work only.
(j) Lower side of range for sheet 0.06 inch and under. Middle of range for sheet and wire 0.125 inch. Upper side of range for forgings.
(k) Not recommended for intermediate strengths because of low impact.
(l) An-QQ-S-770. It is recommended that, prior to tempering, corrosion-resisting (16 Cr2Ni) steel be quenched in oil from a temperature of 1,875-1,900°F, after a soaking period of 1/2 hour at this temperature. To obtain a tensile strength of 115,000 p.s.i., the tempering temperature should be approximately 525°F. A holding time at these temperatures of 2 hours is recommended. Tempering temperatures from 700-1,100°F will not be approved.
(m) Draw at approximately 800°F and cool in air for rockwell hardness of C-50.
(n) Water used for quenching shall not exceed 65°F. Oil used for quenching shall be within a range of 80-150°F.

Table 6-7-5A. Heat-treatment procedures for steels in Fahrenheit.

Steel designation number	Temperatures (celsius)			Quenching medium (N)	Tempering (drawing) temperature for tensile strength (p.s.i.)				
	Normalizing air cool °C	Annealing °C	Hardening °C		100,000 (p.s.i.)	125,000 (p.s.i.)	150,000 (p.s.i.)	180,000 (p.s.i.)	200,000 (p.s.i.)
1020	899-954	871-927	857-913	H_2O	-	-	-	-	-
1022(X1022)	899-954	871-927	857-913	H_2O	-	-	-	-	-
1025	871-927	857-899	857-913	H_2O	(a)	-	-	-	-
1035	857-899	857-885	829-885	H_2O	875	-	-	-	-
1045	843-871	843-871	801-843	Oil/ H_2O	1,150	-	-	(n)	-
1095	801-843	788-816	774-816	Oil	(b)	-	1,100	850	750
2330	801-829	774-801	788-816	Oil/ H_2O	1,100	950	800	-	-
3135	871-899	816-843	801-829	Oil	1,250	1,050	900	750	650
3140	871-899	816-843	801-829	Oil	1,325	1,075	925	775	700
4037	871	829-857	829-857	Oil/ H_2O	1,225	1,100	975	-	-
4130 (X4130)	871-927	829-857	857-885	Oil (c)	(d)	1,050	900	700	575
4140	871-899	829-857	829-857	Oil	1,350	1,100	1,025	825	675
4150	843-871	801-829	816-843	Oil	-	1,275	1,175	1,050	950
4340 (X4340)	843-885	829-857	801-843	Oil	-	1,200	1,050	950	850
4640	913-927	829-857	816-843	Oil	-	1,200	1,050	750	625
6135	871-927	843-871	857-885	Oil	1,300	1,075	950	800	750
6150	871-899	829-857	843-885	Oil	(d) (e)	1,200	1,000	900	800
6195	871-899	829-857	816-843	Oil	(f)	-	-	-	-
8620	-	-	829-857	Oil	-	1,000	-	-	-
8630	899	829-857	829-857	Oil	-	1,125	975	775	675
8735	899	829-857	829-857	Oil	-	1,175	1,025	875	775
8735	885	816-843	816-843	Oil	-	1,200	1,075	925	850
30905	-	(g) (h)	(i)	-	-	-	-	-	-
51210	829-857	829-857	968-996 (j)	Oil	1,200	1,100	(k)	750	-
51335	-	829-857	968-1,010	Oil	-	-	-	-	-
52100	885-927	760-788	829-843	Oil	(f)	-	-	-	-
Corrosion resisting (16-2) (l)	-	-	-	-	(m)	-	-	-	-
Silicon chromium (for springs)	-	-	927-941	Oil	-	-	-	-	-

(a) Draw at 621°C for tensile strength of 70,000 p.s.i.
(b) For spring temper draw at 427-482°C Rockwell hardness C-40-45
(c) Bars and forgings may be quenched in water from 816-871°C.
(d) Air-cooling from the normalizing temperature will produce a tensile strength of approx. 90,000 p.s.i.
(e) For spring temper draw at 459-910°C. Rockwell hardness C-40-45.
(f) Draw at 177-232°C to remove quenching strains. Rockwell hardness C-60-65.
(g) Anneal at 871-927°C to remove residual stresses due to welding or cold-work. May be applied to steel containing titanium or columbium.
(h) Anneal at 1,038-1,149°C to produce maximum softness and corrosion resistance. Cool in air or quench in water.
(i) Harden by cold-work only.
(j) Lower side of range for sheet 0.06 inch and under. Middle of range for sheet and wire 0.125 inch. Upper side of range for forgings.
(k) Not recommended for intermediate strengths because of low impact.
(l) An-QQ-S-770. It is recommended that, prior to tempering, corrosion-resisting (16 Cr2Ni) steel be quenched in oil from a temperature of 1,024-1,038°C, after a soaking period of 1/2 hour at this temperature. To obtain a tensile strength of 115,000 p.s.i., the tempering temperature should be approximately 274°C. A holding time at these temperatures of 2 hours is recommended. Tempering temperatures from 371-593°C will not be approved.
(m) Draw at approximately 427°C and cool in air for rockwell hardness of C-50.
(n) Water used for quenching shall not exceed 18°C. Oil used for quenching shall be within a range of 27-66°C.

Table 6-7-5B. Heat-treatment procedures for steels in Celsius.

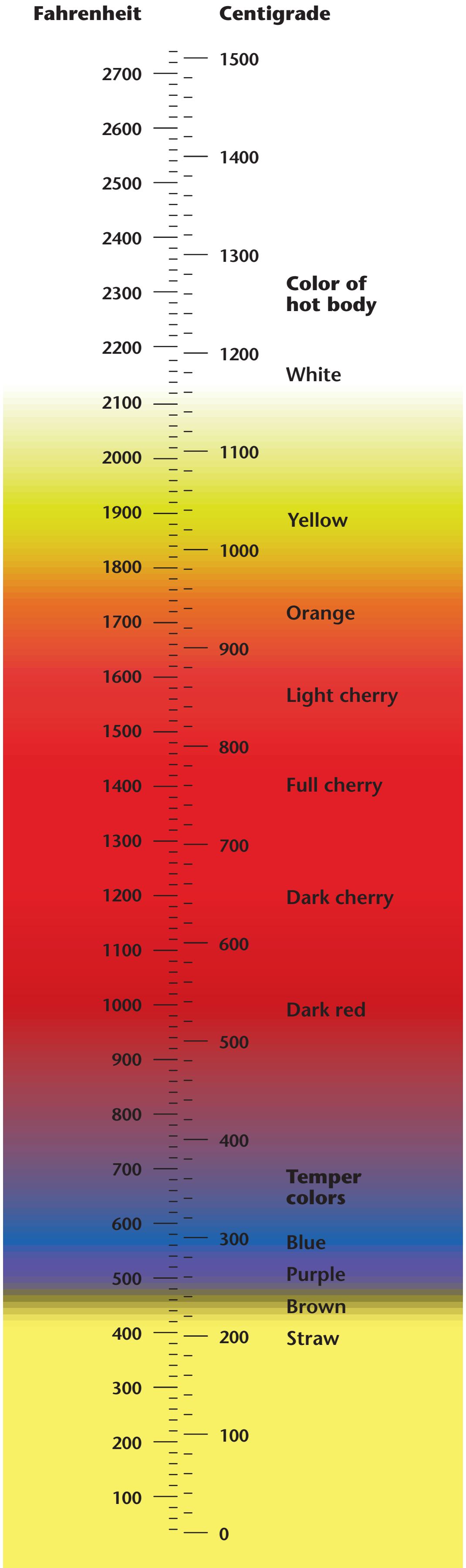


Figure 6-7-12. Approximate temperature/color relationship for steel.

Applying to ferrous metals only, normalizing is accomplished by heating the steel above the upper critical point and cooling it in still air. The more rapid quenching obtained by air-cooling, as compared to furnace-cooling, results in a harder and stronger material than that obtained by annealing. Recommended normalizing temperatures for the various types of aircraft steels are listed in Tables 6-7-5AB.

One of the most important uses of normalizing in aircraft work is in welded parts. Welding causes strains to be set up in the adjacent material. Additionally, the weld itself is a cast structure, as opposed to the wrought structure of the rest of the material. These two types of structures have different grain sizes, and to refine the grain as well as to relieve the internal stresses, all welded parts should be normalized after fabrication.

Hardening. Pure iron, wrought iron, and extremely low-carbon steels cannot be appreciably hardened by heat-treatment, since they contain little or no hardening element. Since the maximum hardness depends almost entirely on the carbon content of the steel, as the carbon content increases, the ability of the steel to be hardened increases, to a point. When the carbon content is increased beyond that point (which is about 0.85 percent) there is no appreciable increase in hardness.

For most steels, the hardening treatment consists of heating the steel to a temperature just above the upper critical point, soaking or holding at that temperature for the required length of time and then cooling it rapidly by plunging the hot steel into oil, water, or brine. Hardening increases the strength of the steel but makes it less ductile.

When hardening carbon steel, it must be cooled to below 1,000°F (538°C) in less than 1 second. Should the time required for the temperature to drop to 1,000°F (538°C) exceed 1 second, the hardness will vary and will not reach the maximum hardness possible. After the 1,000°F (538°) temperature is reached, the rapid cooling must continue if the final structure is to reach the maximum hardness.

When alloys are added to steel, the time limit for the temperature drop to 1,000°F (538°C) increases above the 1-second limit for carbon steels. Therefore, a slower quenching medium will produce hardness in alloy steels.

Because of the high internal stresses in the as-quenched condition, steel must be tempered just before it becomes cold. The part should be removed from the quenching bath at a temperature of approximately 200°F (93°C), since the range from 200°F (93°C) down to room temperature is where most cracks occur. Hardening temperatures and quenching mediums for the various types of steel are listed in Table 6-7-5AB.

Tempering

Tempering reduces the brittleness imparted by hardening and produces definite physical properties within the steel. Tempering always follows, never precedes, the hardening operation. In addition to reducing brittleness, tempering softens the steel. Another name for tempering is *drawing* (i.e. *drawing* the temper).

Tempering is always conducted at temperatures below the low critical point of the steel.

When hardened steel is re-heated, tempering begins at 212°F (100°C) and continues as the temperature increases toward the low critical point. By selecting a definite tempering temperature, the resulting hardness and strength can be predetermined. Approximate temperatures for various tensile strengths are listed in Table 6-7-5AB.

The minimum time at the tempering temperature should be 1 hour. If the part is over an inch in thickness, the time should be increased by 1 hour for each additional inch of thickness. Tempered steels used in aircraft work have 125,000-200,000 p.s.i. ultimate tensile strength.

The rate of cooling from the tempering temperature generally has no effect on the resulting structure; therefore, the steel is usually cooled in still air after being removed from the furnace.

Determining the Temperature of Steel

If temperature-measuring equipment is not available, it becomes necessary to estimate temperatures by some other means. An inexpensive, yet fairly accurate, method involves the use of commercial crayons, pellets, or paints that melt at various temperatures within the range of 125° to 1,600°F. (52° to 871°C) The least accurate method of temperature estimation is by observing the color of the hot hearth of the furnace or the color of the work. The heat colors observed are affected by many factors, such as the conditions of artificial or natural light, the character of the scale on the work, etc.

Steel begins to appear dull red at about 1,000°F (538°C), and as the temperature increases, the color changes gradually through various shades of red, to orange, to yellow, and finally, to white. A rough approximation of the correspondence between color and temperature is indicated in Figure 6-7-12.

It is also possible to find the temperature of a piece of carbon or low-alloy steel from the color of the thin oxide film that forms on the cleaned surface of the steel when heated to the low temperature range used for tempering. The approximate temperature/color relationship for a given time at temperature is indicated in Figure 6-7-12.

Judging temperature from color is a holdover from the days of blacksmithing and ironworking. It is an outdated process that simply will not go away. Modern steels and alloys require more precise process controls than temperature-by-color guessing will allow. The best method to indicate temperature in the field is to obtain a set of temperature indicating crayons. To use them, you mark the steel and then heat it. When the color changes, the steel is at the correct temperature for that particular crayon.

Case Hardening

Producing a hard wear-resistant surface, or case, over a strong, tough core, case hardening is ideal for parts that require a wear-resistant surface and, at the same time, must be tough enough internally to withstand the applied loads. The steels best suited to case hardening are the low-carbon and low-alloy steels. If high-carbon steel is case hardened, the hardness penetrates the core and causes brittleness.

Carburizing. Carburizing is a case-hardening process in which carbon is added to the surface of low-carbon steel. Thus, a carburized steel has a high-carbon surface and a low-carbon interior. When the carburized steel is hea treated, the case is hardened while the core remains soft and tough.

A common method of carburizing is called *pack carburizing*. When carburizing is performed using this method, the steel parts are packed in a container with charcoal or some other material rich in carbon. The container is then sealed with fire clay, placed in a furnace, heated to approximately 1,700°F (927°C), and soaked at that temperature for several hours. As the temperature increases, carbon monoxide gas forms inside the container and, being unable to escape, combines with the gamma iron on the surface of the steel. The depth to which the carbon penetrates depends on the length of the soaking period. For example, when carbon steel is soaked for 8 hours, the carbon penetrates to a depth of about 0.062 inch.

Another method of carburizing is called *gas carburizing*, in which a carbon-rich atmosphere

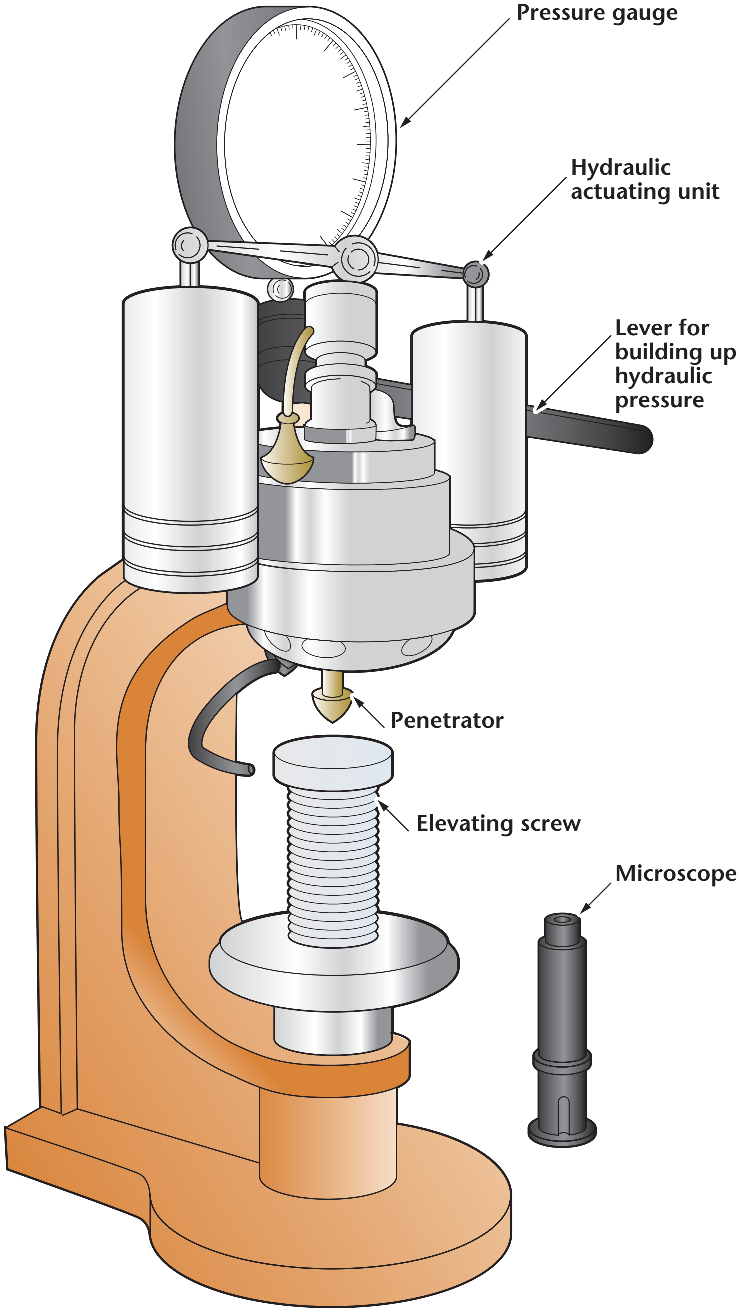


Figure 6-7-13. Brinell hardness tester.

is introduced into the furnace. The carburizing atmosphere is produced by the use of various gases, or by the burning of oil, wood, or other materials. When the steel parts are heated in this atmosphere, carbon monoxide combines with the gamma iron to produce practically the same results as those described under the pack carburizing process.

A third method of carburizing is called *liquid carburizing*. In this method, the steel is placed in a molten salt bath that contains the carbon-based chemicals required to produce a case comparable with one resulting from pack or gas carburizing.

Alloy steels with low-carbon content, as well as low-carbon steels, may be carburized by any one of these three processes. However, some alloys, such as nickel, tend to retard the absorption of carbon. As a result, the time required to produce a given thickness of case varies with the composition of the metal.

Nitriding. Nitriding is unlike other case hardening processes in that, before nitriding, the part is heat-treated to produce definite physical properties. Thus, parts are hardened and tempered before being nitrided. Most steels can be nitrided, but special alloys are required for the best results. These special alloys contain aluminum as one of the alloying elements and are called nitralloys.

In the nitriding process, the part is placed in a special nitriding furnace and heated to a temperature of approximately 1,000°F (538°C). With the part at this temperature, ammonia gas is circulated within the specially constructed furnace chamber. The high temperature cracks the ammonia gas into nitrogen and hydrogen. The nitrogen reacts with the iron to form iron nitride. The iron nitride is dispersed as minute particles at the surface and works inward. The ammonia that does not break down is caught in a water trap below the regions of the other two gases. The depth of penetration depends on the length of the treatment. In nitriding, soaking periods as long as 72 hours are frequently required to produce the desired thickness of case.

Nitriding can be accomplished with a minimum of distortion because of the low temperature at which parts are case hardened, and because no quenching is required after exposure to the ammonia gas.

Hardness Testing

The results of heat-treatment, as well as the state of a metal prior to heat treatment can be determined by hardness testing. Since hardness values can be tied in with tensile strength values and, in part, with wear resistance, hardness tests are a valuable check of heat-treat control and of material properties.

Methods of Hardness Testing

Most hardness-testing equipment uses the resistance to penetration as a measure of hardness. Included among the better-known hardness testers are the Brinell and Rockwell testers, both of which are described and illustrated in this section.

The Brinell hardness testing system. The Brinell tester (Figure 6-7-13) uses a hardened spherical ball, which is forced into the surface of the metal. This ball is 10 millimeters (0.3937 inch) in diameter. A pressure of 3,000 kilograms is used for ferrous metals and 500 kilograms for non-ferrous metals. The pressure must be maintained at least 10 seconds for ferrous metals and at least 30 seconds for non-ferrous metals.

Pressure for the test is supplied by hydraulic pressure from either a hand pump or an electric motor, depending on the model of tester, and is monitored through a pressure gauge. A release mechanism is included in the hydraulic system for relieving the pressure after the test has been made, and a calibrated microscope is provided for measuring the diameter of the impression in millimeters.

The machine uses various shaped anvils for supporting the specimen and an elevating screw for bringing the specimen in contact with the ball penetrator. The various anvils and other attachments are used for each of the variety of tests that the tester can perform.

The Brinell hardness number for a metal is determined by measuring the diameter of the impression left by the ball, using the calibrated microscope furnished with the tester. The measurement is converted into a Brinell hardness number using the conversion table furnished with the tester.

The Rockwell hardness testing system. The Rockwell hardness tester (Figure 6-7-14) measures the resistance to penetration, as does the Brinell tester. Instead of measuring the diameter of the impression, however, the Rockwell tester measures the depth. The hardness is indicated directly on a dial attached to the machine. The dial numbers in the outer circle are black and the inner numbers are red. Rockwell hardness numbers are based on the difference between the depth of penetration at major and minor loads. The greater this difference, the less the hardness number and the softer the material.

Two types of penetrators are used with the Rockwell tester, a diamond cone (used on materials known to be hard and on materials of unknown hardness) and a hardened steel ball (used to test soft materials). The load which forces the penetrator into the metal is called the *major load* and is measured in kilograms. The results of each penetrator and load combination are reported on the separate red and black scales and are designated by letters. The penetrator, the major load and the scale vary with the kind of metal being tested. The scales, penetrators, major loads and dial numbers to be read are listed in Table 6-7-6.

The metal to be tested in the Rockwell tester must be ground smooth on two opposite

Rockwell hardness scales			
Scale symbol	Penetrator	Major lead (kg)	Dial number
A	Diamond	60	Black
B	$^1/_{16}$ Inch ball	100	Red
C	Diamond	150	Black
D	Diamond	100	Black
E	$^1/_8$ Inch ball	100	Red
F	$^1/_{16}$ Inch ball	60	Red
G	$^1/_{16}$ Inch ball	150	Red
H	$^1/_8$ Inch ball	60	Red
K	$^1/_8$ Inch ball	150	Red

Table 6-7-6. Standard Rockwell hardness scales.

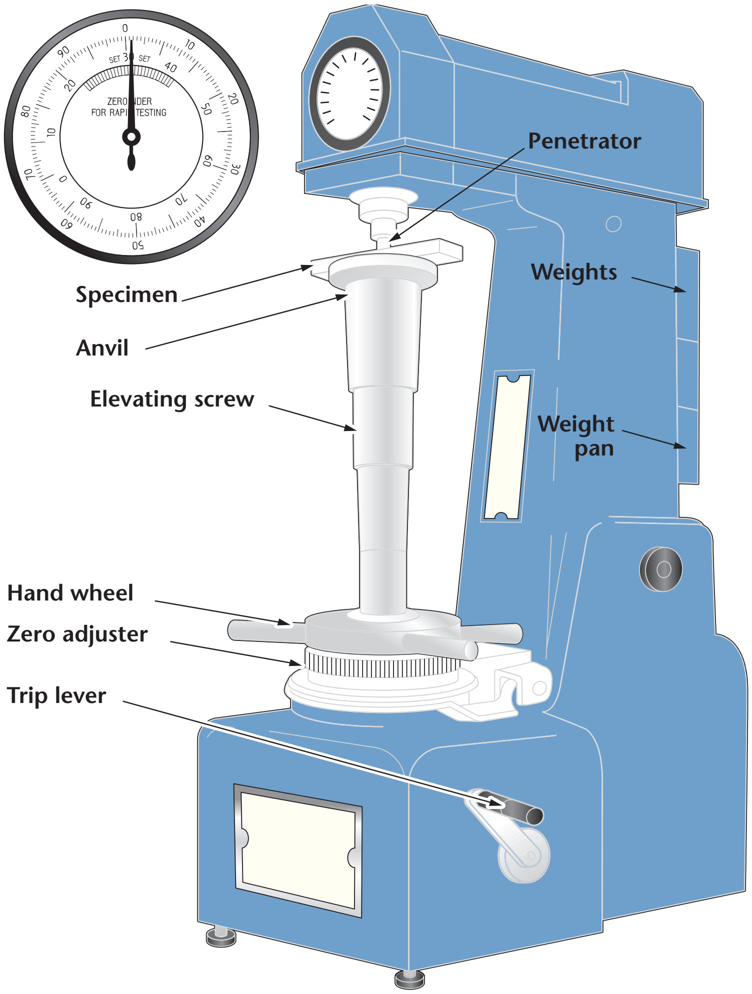


Figure 6-7-14. Rockwell hardness tester.

Hardness values for aluminum alloys		
Material (commercial designation)	**Hardness (temper)**	**Brinell number (500 kg load, 10 mm ball)**
1100	O	23
	H18	44
3003	O	28
	H16	47
2014	O	45
	T6	135
2017	O	45
	T6	105
2024	O	47
	T4	120
2025	T6	110
6151	T6	100
5052	O	47
	H36	73
6061	O	30
	T4	65
	T6	95
7075	T6	135
7079	T6	135
195	T6	75
220	T4	75
C355	T6	80
A356	T6	70

Table 6-7-7. Hardness values for aluminum alloys (ref. Mil-H-6088G).

sides and be free of scratches and foreign matter. The surface should be perpendicular to the axis of penetration, and the two opposite ground surfaces should be parallel. If the specimen is tapered, the amount of error will depend on the taper.

A curved surface will also cause a slight error in the hardness test. The amount of error depends on the curvature; i.e., the smaller the radius of curvature, the greater the error. To eliminate such error, a small flat should be ground on the curved surface, if possible.

Clad aluminum-alloy sheets cannot be tested directly with any accuracy by a Rockwell hardness tester (Table 6-7-7) for the Brinell numbers for aluminum alloys. If the hardness value of the base metal is desired, the pure aluminum coating must be removed from the area to be checked prior to testing.

Vickers hardness test. In this test, a small pyramidal diamond is pressed into the metal being tested. The *Vickers hardness number* (HV) is the ratio of the load applied to the surface area of the indention. This is done with the following formula:

HV = Constant x Test Force/Indent Diagonal^2

The indenter is made of diamond and is in the form of a square-based pyramid, having an angle of 136° between faces. The facets are highly-polished, free from surface imperfections and the point is sharp. The loads applied vary from 1 to 120 kg; the standard loads are 5, 10, 20, 30, 50, 100, and 120 kg. For most hardness testing, 50 kg is maximum.

A Vickers hardness tester should be calibrated to meet ASTM standard E1O specifications, acceptable for use over a loading range.

Webster hardness gauge. If a part is too large to use in a standard bench tester, the portable Webster style of tester can be used. In appearance, a Webster hardness gauge looks like a pair of pliers with a dial attached.

Before use, the gauge must be calibrated using a strip of the same material being tested, but with a known Rockwell hardness. The pliers are squeezed until they bottom out and the hardness is read on the gauge.

The Webster gauge is especially useful in testing heat-treated aluminum.

Microhardness testing. This is an indentation hardness test made with loads not exceeding 1 kg (1,000 grams). Such hardness tests have been made with a load as light as 1 gram, although the majority of microhardness tests are made with loads of 100-500 grams. In general, the term is related to the size of the indentation rather than to the load applied.

Fields of application. Microhardness testing is capable of providing information regarding the hardness characteristics of materials which cannot be obtained by hardness tests, such as the Brinell or Rockwell, and are as follows:

- Measuring the hardness of precision work pieces that are too small to be measured by the more common hardness-testing methods
- Measuring the hardness of product forms, such as foil or wire, that are too thin or too small in diameter to be measured by more conventional methods
- Monitoring of carburizing or nitriding operations, which is sometimes accomplished by hardness surveys taken on cross sections of test pieces that accompa-

nied the work pieces through production operations

- Measuring the hardness of individual microconstituents
- Measuring the hardness close to edges, thus detecting undesirable surface conditions such as grinding burn and decarburization
- Measuring the hardness of surface layers, such as plating or bonded layers

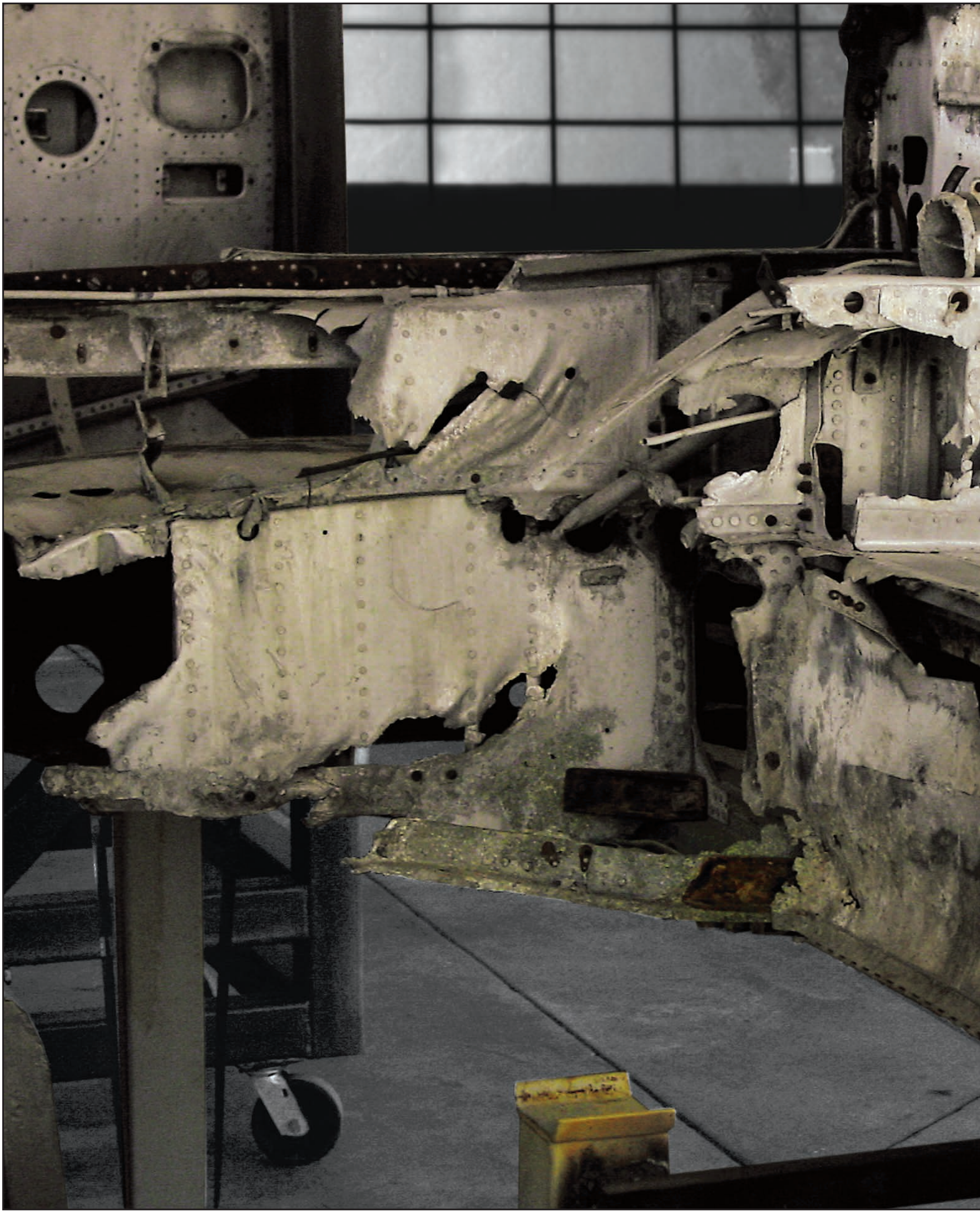
Indenters

Microhardness testing can be performed with either the Knoop or Vickers indenter. The *Knoop indenter* is used mostly in the U.S.; the Vickers indenter is the more widely used in Europe.

Knoop indentation testing is performed with a diamond, ground to pyramid form, that produces a diamond-shape indentation with an approximate ratio between long and short diagonals of 7:1. The indentation depth is about 1/30 of its length. Due to the shape of the indenter, indentations of accurately measurable length are obtained with light loads.

The Knoop hardness number (HK) is the ratio of the load applied to the indenter to the unrecovered projected area of indentation.

The Vickers indenter penetrates about twice as far into the work piece as does the Knoop indenter. The diagonal of the Vickers indentation is about one-third of the total length of the Knoop indentation. The Vickers indenter is less sensitive to minute differences in surface conditions than the Knoop. However, the Vickers indentation, because of the shorter diagonal, is more prone to errors in measuring than is the Knoop indentation.



7

Corrosion and Cleaning

Section 1

Aircraft Corrosion

Learning Objectives

DESCRIBE

- Forms of corrosion found on aircraft
- Common corrosive substances
- Cleaning equipment, materials and procedures used on corroded areas

EXPLAIN

- Why particular areas on aircraft are prone to corrosion
- Corrosion removal procedures and treatments for aircraft surfaces
- Corrosion prevention techniques and materials

Chapter 9, Aircraft Inspection, deals with corrosion and NDT as it applies to inspection. In this chapter, corrosion and cleaning are discussed in much more detail.

Electrochemical action. Corrosion and its control are of significant importance to all operators. Corrosion weakens primary structural members that, if the destruction is allowed to continue, must be replaced or reinforced in order to sustain the loads to which they may be subjected. Such replacements or reinforcements are costly and time consuming, resulting in unscheduled delays and, frequently keep the airplane out of service for a considerable amount of time. Preventive maintenance of the aircraft on a regular schedule, as with any valuable equipment, is the only sound practice. It minimizes the cost of total labor expended and productive time lost. It puts both of these costs on a predictable track and removes uncertainty and guesswork as to the actual condition of the equipment.

Corrosion is a natural phenomenon that destroys metal by chemical or electrochemical action, converting it into a metallic compound such as an oxide, hydroxide, or sulfate (Figure 7-1-1). The tendency of most metals to corrode creates one of the major problems in the maintenance of aircraft, particularly in areas where adverse atmospheric or weather conditions exist.

Metal corrosion is the deterioration of the metal by chemical or electrochemical attack, and the process can take place internally as well as on the surface. As in the rotting of wood, this deterioration may change the smooth surface,

Left. An extreme example of the effects of corrosion, this P-63 was shot down during World War II and spent several decades decaying in a jungle before being retrieved.

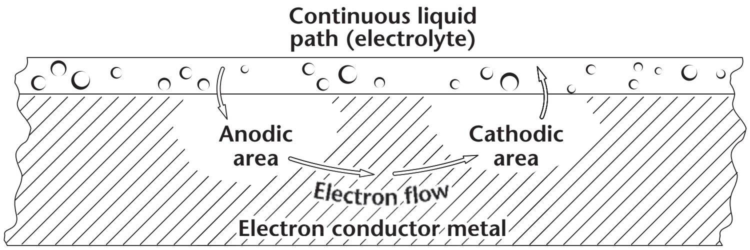


Figure 7-1-1. An electrochemical action.

weaken the interior or damage or loosen adjacent parts.

If left unchecked, corrosion can cause eventual structural failure. The appearance of the corrosion varies with the metal. On aluminum alloys and magnesium, it appears as surface pitting and etching, often combined with a gray or white powdery deposit. On copper and copper alloys, the corrosion forms a greenish film. On steel, a reddish rust. When the gray, white, green, or reddish deposits are removed, each of the surfaces may appear etched and pitted, depending upon the length of exposure and severity of attack. If these surface pits are not too deep, they may not significantly alter the strength of the metal, however, the pits may become sites for crack development. Some types of corrosion can travel beneath surface coatings and can spread until the part fails.

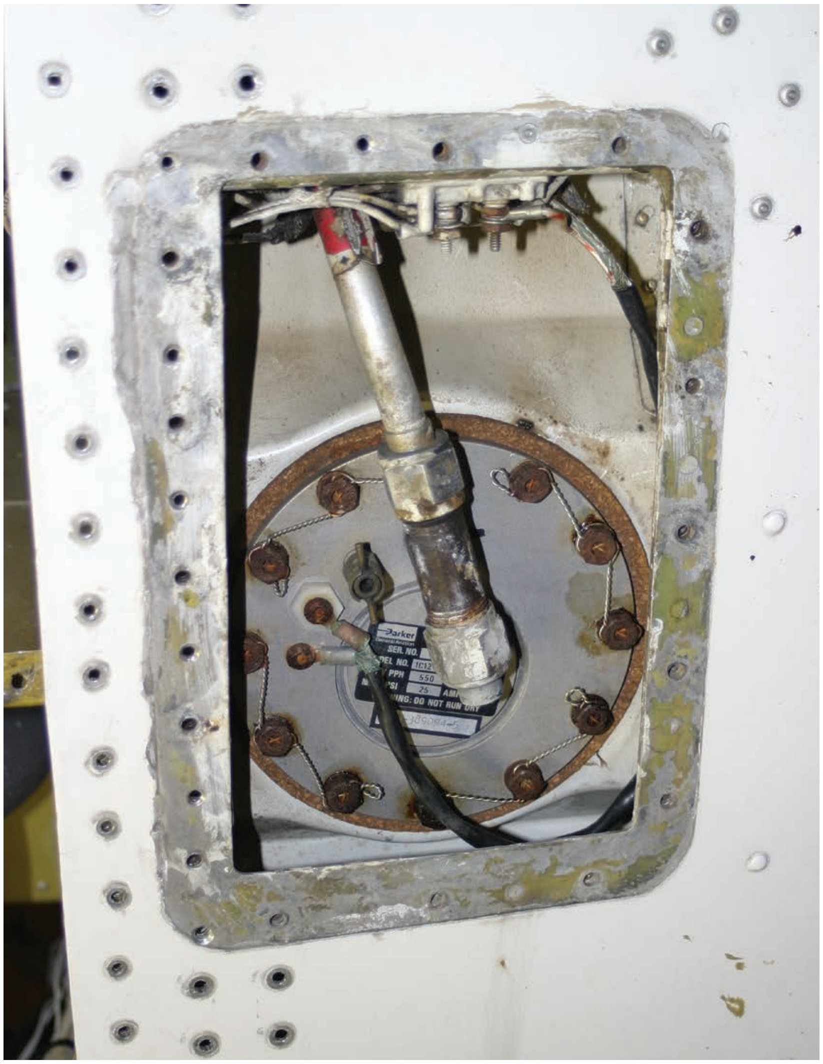


Figure 7-1-2. Cover plates must be removed to do a visual inspection. Failure to do so is to run the risk of missing something serious.

Corrosion Detection

The primary method of corrosion detection is visual inspection. Visual inspection must be relied upon to find corrosive attack during its initial stage. However, many situations exist where visual inspection is not feasible, and therefore other detection techniques must be used. These other techniques include liquid dye penetrants, magnetic particle, X-ray, and ultrasonic devices, all of which have achieved success in the detection of corrosion.

Visual Inspections

Visual inspections of metal surfaces can reveal several signs of corrosive attack.

The most visible sign of corrosive attack is corrosion deposits. Corrosion deposits of aluminum or magnesium compounds are generally a white or grayish-white powder, while the color of ferrous compounds varies from red to dark reddish-brown.

Other indications of corrosive attack are small, localized discolorations on the surface of the metal. Surfaces protected by paint or plating may only give indications of more advanced forms of corrosive attack by the presence of blisters in the protective film, indicating that the corrosion product has a greater volume than that of the consumed metal. Bulges in lap joints may be indicative of a buildup of corrosion products, although the corrosive attack is well advanced.

Often inspection areas are obscured by structural members, equipment installations or, for some other reason, they are awkward to check visually. Magnifying glasses, mirrors, and borescopes can provide the means to check obscured or difficult to reach areas. Ingenuity is encouraged, as long as the improvised inspection methods are thorough and safe.

A corrosion inspection is also difficult to accomplish if the cowling, fairings, and cover plates have not been removed. Figure 7-1-2 is an example of different types of corrosion that have been missed during several successive inspections.

Figure 7-2-1. An example of uniform surface corrosion.

Section 2

Types of Corrosion

Forms of Corrosion

There are many forms of corrosion. The form of corrosion depends on the metal involved and the corrosion-producing agents present.

Oxidation. One of the most simple forms of corrosion, and perhaps the one with which we are most familiar, is *dry corrosion*, or *oxidation*.

When aluminum is exposed to a gas containing oxygen, a chemical reaction takes place at the surface between the metal and the gas. In this case, two aluminum atoms join three oxygen atoms to form aluminum oxide: Al_2O_3.

If the metal is iron or steel (ferrous metal), two atoms of iron will join three atoms of oxygen and form iron oxide or rust: Fe_2O_3.

There is one big difference between iron oxide and aluminum oxide. If the film of aluminum oxide is unbroken, further reaction with the oxygen continues at a greatly reduced rate; indeed, it almost stops. Iron oxide, on the other hand, forms a porous or interrupted film, and the metal will continue to react with the oxygen in the air until the metal is completely eaten away.

Protection from oxidation. In order to protect iron from dry corrosion or rusting, the best procedure is to prevent oxygen from coming into contact with the surface. This may be done temporarily by covering the surface with oil or grease, or for more permanent protection, with a coat of paint.

Aluminum alloy may be protected from oxidation by the formation of an oxide film on its surface. The formation of this film is discussed later in this chapter in detail within methods of corrosion treatment under the headings of *anodizing* and *alodining*.

Uniform surface corrosion. Surface corrosion, as shown in Figure 7-2-1, appears as a general roughening, etching, or pitting of the surface of a metal, frequently accompanied by a powdery deposit of corrosion products. Surface corrosion may be caused by either direct chemical or electrochemical attack.

Occasionally, corrosion will spread under the surface coating and cannot be recognized by either a roughening of the surface or a powdery deposit. Instead, the paint or plating will be lifted off the surface in small blisters, which result from the pressure of the underlying accumulation of corrosion products.

A common type of uniform surface corrosion is caused by the reaction of metallic surfaces with airborne chlorine or sulphur compounds, oxygen, or moisture in the atmosphere. Often combinations of these agents may attack a surface simultaneously. Reactive compounds from exhaust

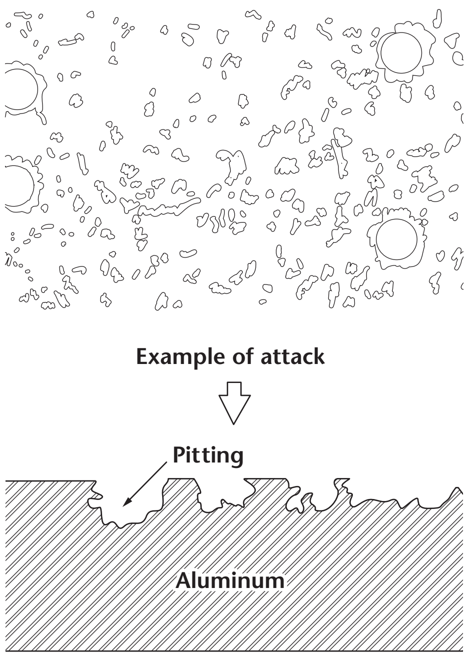


Figure 7-2-2. Pitting, as seen on the surface and in a magnified cross-section.

gases, as well as fumes from storage batteries, frequently cause uniform surface corrosion.

The amount of damage caused by uniform surface corrosion is ordinarily determined by comparing the thickness of the corroded metal with that of an undamaged specimen. A depth micrometer is used to measure the depth of the pits.

Pitting corrosion. Pitting corrosion is confined to very small areas of the metal surface, while the remainder of the surface is unaffected. The corrosion pits are often randomly located over the surface, however, some preferential attack may occur at the grain boundaries of the metal. A surface and cross-sectional example are shown in Figure 7-2-2.

Pitting results from the chemical action of moisture, acid, alkali, or saline solutions on the metal after the paint, surface oxide, or other protective film has either been removed or penetrated. Once pitting has begun, it is propagated by means of concentration cells or galvanic action.

The pits found in pitting types of corrosion usually have a rather short, well-defined edge with walls that run almost perpendicular to the surface of the metal.

All forms of pits have one thing in common regardless of their shape: They penetrate deeply into the metal and cause damage completely out of proportion to the amount of metal consumed.

Intergranular corrosion. *Intergranular corrosion* concentrates on the boundaries of the metal grains, first consuming the material between the grain boundaries and then attacking the grains themselves.

The damage from intergranular corrosion, like pitting corrosion, causes a loss of strength and ductility that is out of proportion to the amount of the metal destroyed. An example of intergranular corrosion is shown in Figure 7-2-3.

Aluminum alloys and some stainless steels are particularly susceptible to intergranular corrosion. A lack of uniformity in the grain of these metals is caused by changes that occur in the alloy during heating and cooling.

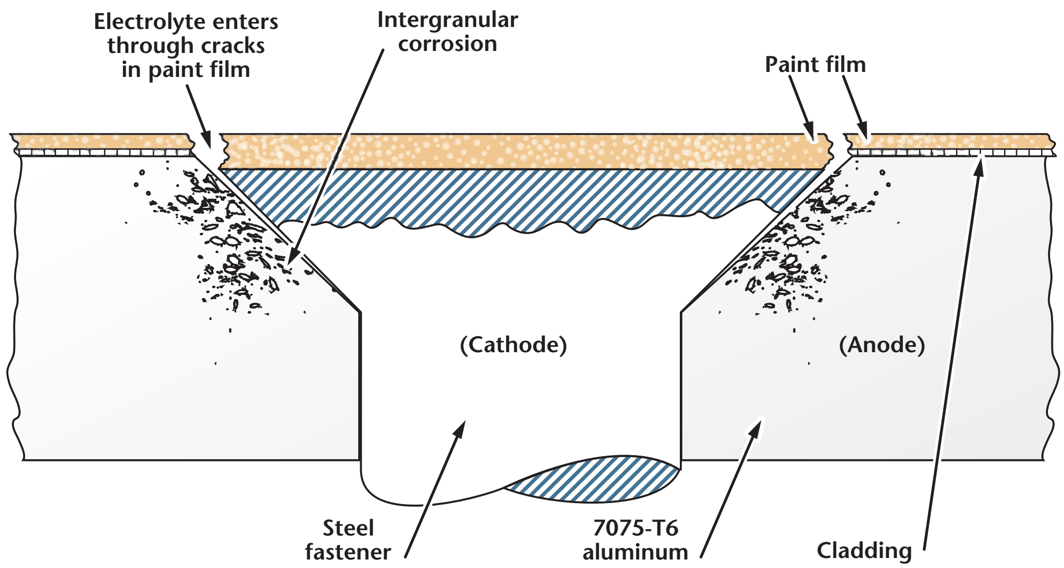


Figure 7-2-3. Intergranular corrosion of 7075-T6 aluminum, adjacent to a steel fastener.

Intergranular corrosion may exist without visible surface evidence, and is difficult to detect in its early stages. Ultrasonic and eddy current inspection methods provide the best success in detecting this particular form of corrosion.

Exfoliation. Exfoliation is a severely destructive form of intergranular corrosion, characterized by the actual leafing-out of corroded sections of metal away from the rest of the part (Figure 7-2-4).

Exfoliation corrosion is found most often on extruded parts. This is because the extrusion process elongates the grains of the metal. The corrosive attack on the grain boundary material produces corrosion products that take up more volume than that originally occupied by the unaffected grain boundaries, causing the part to swell.

By the time exfoliation corrosion is detected, the intergranular attack usually is so advanced that the static strength of the part is impaired because of the reduction of its effective cross-sectional area.

Galvanic corrosion. Galvanic cells may originate from localized differences of materials in the surface of an alloy, because the dissimilar metals in alloys provide a basis for galvanic action within the alloys themselves (Figure 7-2-5).

If an *electrolytic medium* is provided (like the condensation from a salt-air atmosphere), the metal can literally destroy itself.

The degree of attack depends on the relative activity of the two surfaces; the greater the difference in activity, the more severe the attack.

Of the materials listed in Table 7-2-1, some items are quite active and corrode easily. They require maximum protection. Other materials that are close together numerically are the least active, therefore requiring minimum protection.

Concentration cell corrosion. This type of corrosion occurs when two or more areas of metal surface are in contact with different concentrations of the same solution (Figure 7-2-6). There are two basic types of concentration cell corrosion: oxygen and metal ion.

In the case of *oxygen concentration cell corrosion*, the solution in contact with the metal surface will normally contain dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse into the solution, thereby creating a difference in oxygen concentration between two points. Typical locations of oxygen concentration cells are under either metallic or non-metallic deposits, such as dirt, on the metal surface and under faying surfaces, such as riveted lap joints. Oxygen cells can also develop under gaskets, wood, rubber, plastic tape, or other materials in contact with the metal surface.

With *metal ion concentration cell corrosion*, the solution may consist of water and ions of the metal that is in contact with the water. A high concentration of the metal ions will normally exist under faying surfaces where the solution is stagnant, and a low concentration of metal ions will exist adjacent to the crevice which is created by the faying surface. An electrical potential will exist between the two points; the area of the metal in contact with the high metal ion concentration will be anodic and will be corroded.

Figure 7-2-4. In this example the exfoliation is so advanced that the part is scrap.

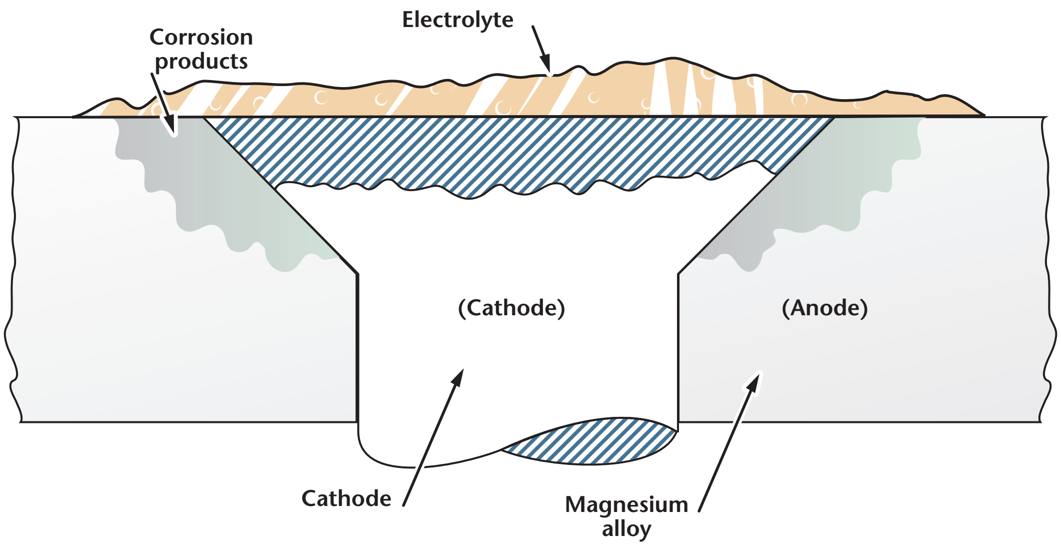


Figure 7-2-5. Galvanic corrosion of magnesium adjacent to steel structure.

Group number		Corroded end (anodic or least noble)												Protected end (cathodic or most noble)																	
	Group number	**1**	**1**	**2**	**3**	**3**	**3**	**3**	**4**	**5**	**5**	**5**	**5**	**6**	**6**	**8**	**9**	**9**	**10**	**12**	**12**	**12**	**13**	**13**	**13**	**13**	**14**	**14**	**14**	**14**	**14**
	Metal or alloy	**Magnesium**	**Magn. alloy**	**Zinc**	**1100**	**3003**	**6061-T6**	**Clad alloys**	**Cadmium**	**2017-T4**	**2014-T4**	**2024-T4**	**7075-T6**	**Steel wrought**	**Steel cast**	**50-50 Solder**	**Lead**	**Tin**	**Mang. bronze**	**Brasses**	**Alum. bronze**	**Copper**	**Nickel**	**Inconel**	**Type 410**	**Type 431**	**18-8 Cres**	**Titanium**	**Monel**	**Silver**	**Graphite**
1	Magnesium	0	0	1	2	2	2	2	3	4	4	4	4	5	5	7	8	8	9	11	11	11	12	12	12	12	13	13	13	13	13
1	Magn. alloy		0	1	2	2	2	2	3	4	4	4	4	5	5	7	8	8	9	11	11	11	12	12	12	12	13	13	13	13	13
2	Zinc			0	1	1	1	1	2	3	3	3	3	4	4	6	7	7	8	10	10	10	11	11	11	11	12	12	12	12	12
3	1100				0	0	0	0	1	2	2	2	2	3	3	5	6	6	7	9	9	9	10	10	10	10	11	11	11	11	11
3	3003					0	0	0	1	2	2	2	2	3	2	5	6	6	7	9	9	9	10	10	10	10	11	11	11	11	11
3	6061-T6						0	0	1	2	2	2	2	3	2	5	6	6	7	9	9	9	10	10	10	10	11	11	11	11	11
3	Clad alloys							0	1	2	2	2	2	3	2	5	6	6	7	9	9	9	10	10	10	10	11	11	11	11	11
4	Cadmium								0	1	1	1	1	2	2	4	5	5	6	8	8	8	9	9	9	9	10	10	10	10	10
5	2017-T4									0	0	0	0	1	1	3	4	4	5	7	7	7	8	8	8	8	9	9	9	9	9
5	2014-T4										0	0	0	1	1	3	4	4	5	7	7	7	8	8	8	8	9	9	9	9	9
5	2024-T4											0	0	1	1	3	4	4	5	7	7	7	8	8	8	8	9	9	9	9	9
5	7075-T6												0	1	1	3	4	4	5	7	7	7	8	8	8	8	9	9	9	9	9
6	Steel wrought													0	0	2	3	3	4	6	6	6	7	7	7	7	8	8	8	8	8
6	Steel cast														0	2	3	3	4	6	6	6	7	7	7	7	8	8	8	8	8
8	50-50 Solder															0	1	1	2	4	4	4	5	5	5	5	6	6	6	6	6
9	Lead																0	0	1	3	3	3	4	4	4	4	5	5	5	5	5
10	Tin																	0	1	3	3	3	4	4	4	4	5	5	5	5	5
12	Mang. bronze																		0	2	2	2	3	3	3	3	4	4	4	4	4
12	Brasses																			0	0	0	1	1	1	1	2	2	2	2	2
12	Alum. bronze																				0	0	1	1	1	1	2	2	2	2	2
13	Copper																					0	1	1	1	1	2	2	2	2	2
13	Nickel																						0	0	0	0	1	1	1	1	1
13	Inconel																							0	0	0	1	1	1	1	1
13	Type-410																								0	0	1	1	1	1	1
14	Type 431																									0	1	1	1	1	1
14	18-8 Cres																										0	0	0	0	0
14	Titanium																											0	0	0	0
14	Monel																												0	0	0
14	Silver																													0	0
14	Graphite																														0

Note: The larger the number, the greater the tendency for galvanic corrosion.

Table 7-2-1. Galvanic grouping of metals—the smaller the number, the less active.

If water is allowed to stagnate in a metallic structure, either an oxygen or metal ion concentration cell can develop. Small deposits of corrosion products may give an indication of the damage that has been sustained.

Stress corrosion. *Stress corrosion* occurs as the result of the combined effect of sustained tensile stresses and a corrosive environment. While stress corrosion cracking is found in most metal systems, it is particularly characteristic of aluminum, copper, certain stainless steels, and high-strength alloy steels (more than 240,000 p.s.i.). It usually occurs along lines of cold-working and may be transgranular or intergranular in nature. Aluminum alloy bellcranks with pressed-in bushings, landing gear shock struts with pipe-thread type grease fittings, clevis pin joints, shrink fits, and overstressed tubing B-nuts are examples of parts that are susceptible to stress corrosion cracking (Figure 7-2-7).

Crack initiation generally results from a physical breakdown of protective surface films and the subsequent corrosive attack on the part, in conjunction with the application of stress forces. One method for obtaining incrased resistance to stress corrosion cracking in some heat-treated aluminum alloy parts is to shot peen the surface to provide a uniform compressive stress on the surface.

Several elements determine crack propagation. Factors such as the alloy type, changes in the composition of the alloy or its environment, the type of heat treatment and the method of metal forming all contribute to the direction and length of the crack. Finally, for each type alloy, specific environmental conditions must exist before stress corrosion can occur.

Fretting corrosion. *Fretting corrosion* is a particularly damaging form of corrosive attack that occurs when two mating surfaces, normally at rest with respect to one another, are subject to slight relative motion. While the fit between two surfaces may be very tight, it is rarely tight enough to prevent oxygen or other corrosive agents from entering and attacking unprotected surfaces. Figure 7-2-8 is an example of fretting corrosion, commonly called *smoking rivets*.

Mechanical fretting and chemical corrosion in combined action is referred to as fretting corrosion. It is characterized by pitting of the surfaces and the generation of considerable quantities of finely divided debris. Since the restricted movements of the two surfaces prevent the debris from escaping very easily, an extremely localized abrasion occurs.

The presence of water vapor greatly increases this type of deterioration. If the contact areas are small and sharp, deep grooves resembling brinell markings or pressure indentations may be worn in the rubbing surface. As a result, this type of corrosion (on bearing surfaces) has also been called *false brinelling*.

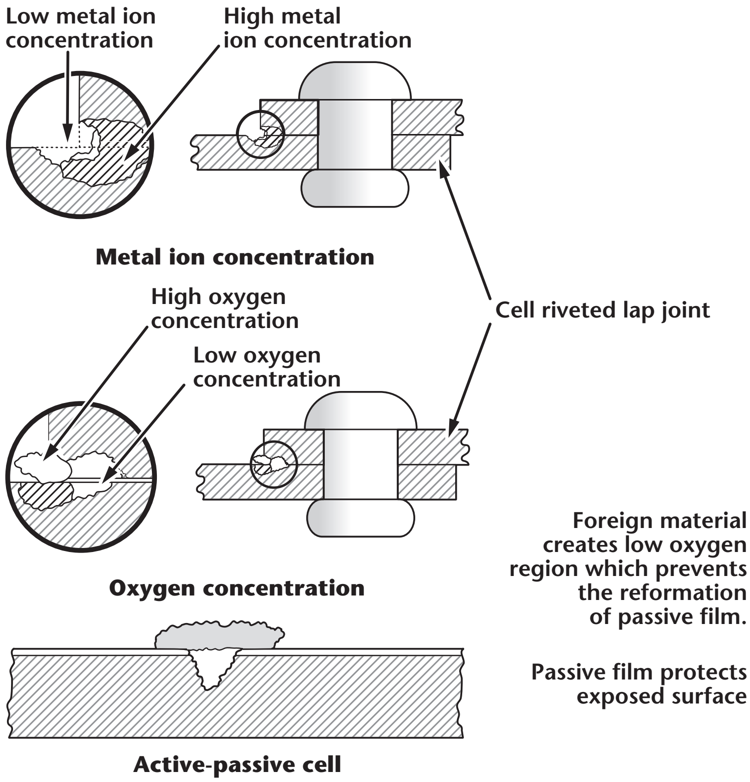


Figure 7-2-6. Concentration cell corrosion.

Filiform corrosion. Metals coated with organic coatings tend to undergo a type of corrosion resulting in numerous threadlike filaments of corrosion products under the coating. It is caused by the diffusing of oxygen and water through the coating, and is considered a special type of oxygen concentration cell corrosion.

One of the reasons for filiform corrosion has been the mistake of top coating a wash primer with an epoxy or polyurethane system before the acids in the primer where completely converted. Any ambient moisture that gets under the finish is then trapped and begins to react with the acids and causes filiform corrosion.

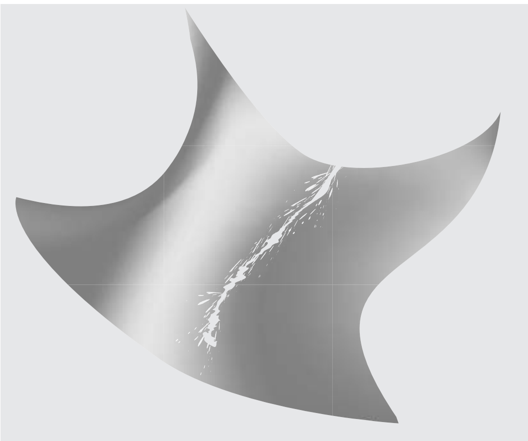


Figure 7-2-7. Stress corrosion cracking.

Figure 7-2-8. Fretting corrosion.

The effects of *filiform corrosion* can be prevented by storing the aircraft in a low-humidity environment (less than 65 percent relative humidity).

The progress of filiform corrosion can be markedly decreased by the use of coatings with a high resistance to diffusion by water.

Section 3

Corrosive Agents

Common Corrosive Agents

Substances that are capable of causing a corrosive reaction sometimes are called *corrosive agents*. The most common corrosive agents are acids, alkalis, and salts. The atmosphere and water, the two most common media for these agents, may sometimes tend to act as corrosive agents, too.

Acid. In general, moderately strong acids will corrode most of the alloys used in airframes. The most destructive are sulfuric acid (battery acid), halogen acids (hydrochloric, hydrofluoric, and hydrobromic), and organic acids found in the wastes of humans and animals.

Alkali. Although alkalis as a group are generally not as corrosive as acids, aluminum, and magnesium alloys are exceedingly prone to corrosive attack by many alkaline solutions, unless the solutions contain a corrosion inhibitor.

Particularly corrosive to aluminum are soaps that contain lye or potassium hydroxide. One alkali, ammonia, is an exception, because aluminum alloys are highly resistant to it. Magnesium alloys are also resistant to alkaline corrosive attack. In fact, they develop a protective film when exposed to caustic alkaline solutions.

Salt. While it may be difficult to generalize about salt as a corrosive agent, most salt solutions are good electrolytes and can promote corrosive attack. Some stainless steel alloys are resistant to attack by salt solutions, but aluminum alloys, magnesium alloys, and other steels are extremely vulnerable to solutions containing salt. Exposure of airframe materials to salt or salt solutions is extremely undesirable.

Mercury spills/corrosion damage. Once started, the corrosive action of mercury is rapid in both pitting and intergranular attack, and the destructive process is very difficult to control.

The presence of mercury and mercury salts in air cargo is a definite possibility. Loading, unloading, and general shifting of such cargo can and does result occasionally in damaged containers, cartons, electronic tubes, etc., with subsequent leakage of mercury on aircraft surfaces and structures.

Spillage of mercury or mercury compounds within an airplane requires immediate action to isolate and recover the substance to prevent possible corrosion damage and embrittlement of aluminum alloy structural components, stainless steels (300- and 400-series), and unplated brass components, such as cable turnbuckle barrels.

By a process known as *amalgamation*, mercury can penetrate any break in the finish (anodize/alodine), paint, or seal coating of a metal structural component. Bright, polished, shining, or scratched surfaces, as well as moisture, will hasten the process.

Mercury and mercury compounds attack the metal grain boundaries and seriously embrittle and reduce the strength of parts. Corrosive attack of freshly scratched aluminum alloy is very rapid, and complete penetration of sheet material is known to occur within 3 or 4 minutes.

Water. The *corrosivity* of water depends on the type and quantity of dissolved mineral and organic impurities and dissolved gases (particularly oxygen) in the water. Physical factors, such as water temperature and velocity, also have a direct bearing on the corrosivity.

The most corrosive of natural waters (sea and fresh waters) are those that contain salts. Water in the open sea is extremely corrosive, but waters in harbors are often even more so because they are contaminated by industrial waste and are diluted by fresh water.

The corrosivity of fresh water varies from locality to locality due to the wide variety of dissolved impurities that may be present in any particular area. However, soft water and rainwater are usually considered to be very corrosive. Hard waters tend to be less corrosive to most metals because they are alkaline, but some metals, such as alloys of aluminum and magnesium, seem to be more reactive to alkaline waters and corrode readily.

Air. The major *atmospheric corrosive agents* are oxygen and airborne moisture, both of which are in abundant supply. Corrosion often results from the direct action of atmospheric oxygen and moisture on metal, and the presence of additional moisture often accelerates corrosive attack, particularly on ferrous alloys. However, the air in the atmosphere is also cluttered with many other corrosive gases and contaminants. Two specific types, industrial and marine atmospheres, are unusually corrosive.

The air in industrial atmospheres contain many contaminants, the most common of which are partially oxidized sulphur compounds. When these sulphur compounds combine with moisture, they form sulphur-based acids that are highly corrosive to most metals. In areas where there are chemical industrial plants, other corrosive atmospheric contaminants may be present in large quantities, but such conditions are usually confined to a specific locality.

A marine atmosphere (an air mass over oceans, seas, or other large bodies of salt water) contains chlorides in the form of salt particles or droplets of salt-saturated water. Since saline moisture is an electrolyte, it provides an excellent medium for corrosive attack on aluminum and magnesium alloys, which are vulnerable to this type of environment.

Organic growths. Microorganisms, which contain water and iron oxides or mineral salts, live in jet fuels. Slime is formed by these fungoid creatures, which often serve as excellent electrolytes and promote corrosion.

From the standpoint of corrosion prevention, it is necessary to keep aircraft fuel tanks clean and use only clean, water-free fuel. Water condensate must be drained from the fuel tank frequently. Further, fuel storage facilities should be monitored to ensure that the fuel is clean.

Biocide treatment may be used for control of microorganisms in jet fuel tanks. Complete elimination of water and contaminants from the fuel all but prohibits tank corrosion; unfortunately, keeping a jet fuel tank totally free of water and debris isn't easily accomplished. Experience with fuel containing biocide has shown that, when used in the correct proportions, it is effective in eliminating many types of microbial growth, thus reducing tank corrosion.

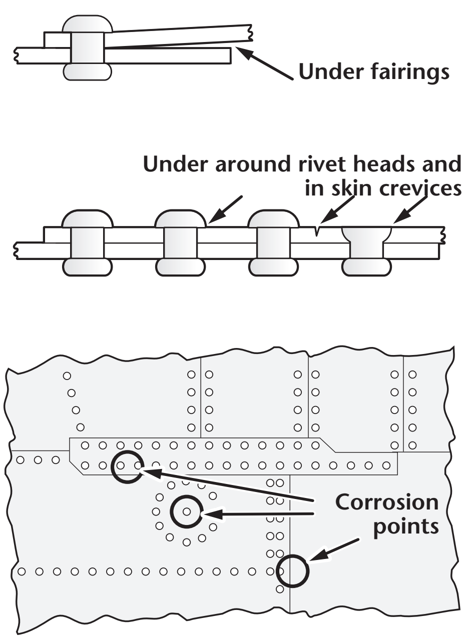


Figure 7-4-1. Exhaust trail area corrosion points.

Section 4

Corrosion-Prone Areas

Discussed briefly in this section are most of the corrosion-prone areas common to all aircraft. However, this coverage is not necessarily complete and may be amplified and expanded to cover the special characteristics of a particular aircraft model by referring to the applicable maintenance manual.

Engine exhaust and exhaust trail areas. Both jet and reciprocating engine exhaust deposits are very corrosive and give particular trouble where gaps, seams, hinges and fairings are located down the exhaust path, and where deposits may be trapped and not reached by normal cleaning methods.

Special attention should be paid to areas around rivet heads and in skin crevices, as shown in Figure 7-4-1. Fairings and access plates in the exhaust areas should be removed for inspection.

Exhaust deposit build-up in remote areas such as internal and external empennage surfaces should not be overlooked. Build-up in these areas will usually be slower and sometimes completely absent; it can be a problem on some aircraft.

Battery compartments and battery vent openings. Despite improvements in protective paint finishes and methods of sealing and venting, battery compartments continue to be corrosion problem areas. Fumes from overheated electrolytes are difficult to contain and will spread to adjacent cavities and cause a rapid, corrosive attack on all unprotected metal surfaces.

Battery vent openings on the aircraft skin should be included in the battery compartment inspection and maintenance procedure. Regular cleaning and neutralization of acid deposits will minimize corrosion.

Lavatories and food service areas. Deck areas behind lavatories, sinks, and ranges where spilled food and waste products may collect, if not kept clean, are potential trouble spots. Even if some contaminants are not corrosive themselves, they will attract and retain moisture and, in turn, cause corrosive attack. Carefully inspect bilge areas located under galleys and lavatories, clean these areas frequently, and keep paint touched-up.

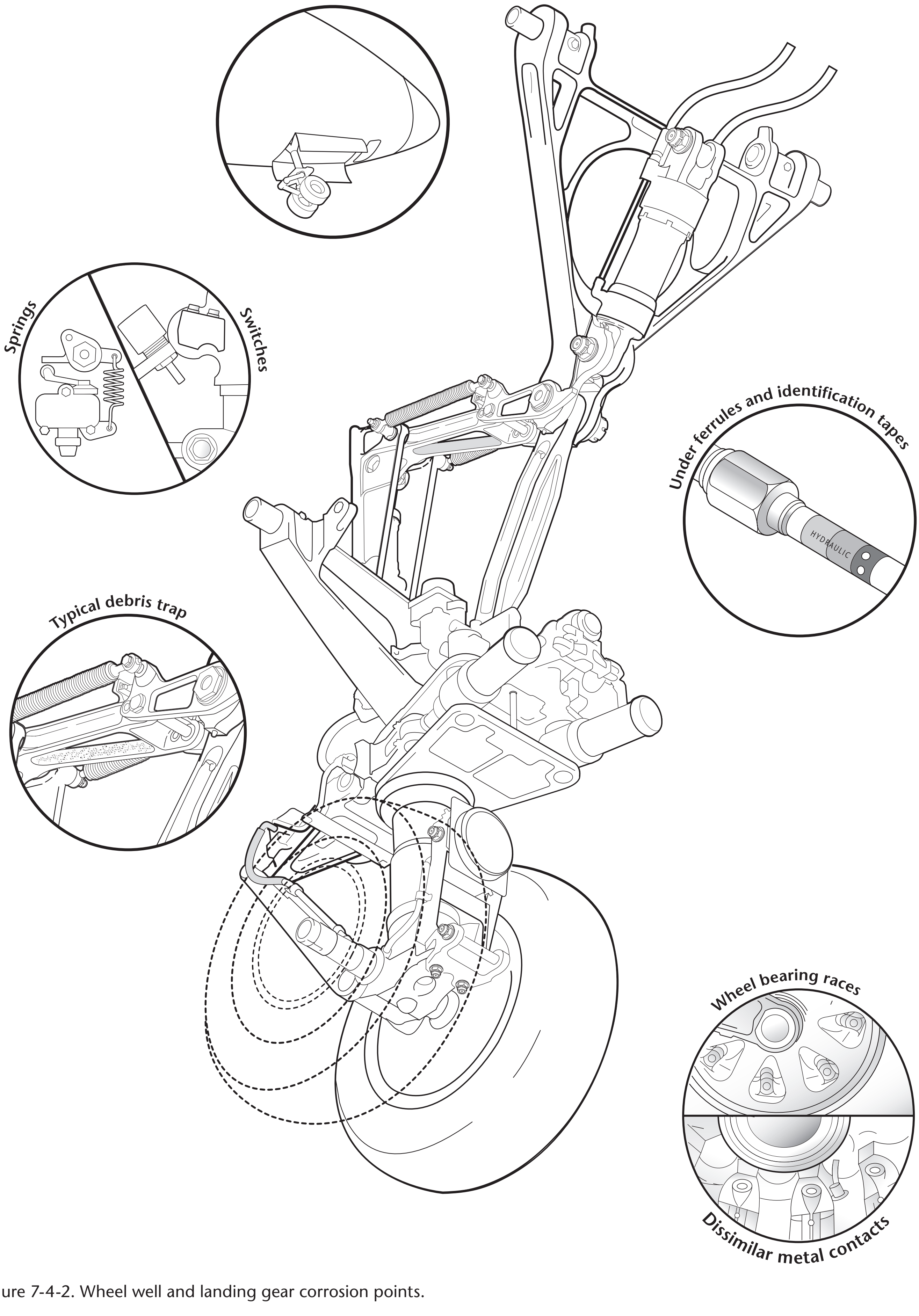


Figure 7-4-2. Wheel well and landing gear corrosion points.

Particular attention must be paid to areas around human waste disposal openings on the aircraft exteriors. Human waste products and the chemicals used in lavatories are very corrosive to the common aircraft metals. Clean these areas frequently, and keep the paint touched-up.

Wheel well and landing gear. This area probably receives more punishment than any other area on the aircraft because of mud, water, salt, gravel, and other flying debris that is picked up from ramps, taxiways and runways, and thrown by the tires.

Because of the many complicated shapes, assemblies, and fittings found in the wheel well and landing gear areas, complete area paint film coverage is difficult to attain.

A partially applied preservative tends to mask corrosion rather than prevent it. Due to heat generated by braking action, preservatives cannot be used on some main landing gear wheels. During inspection of this area, pay particular attention to the following trouble spots, as illustrated in Figure 7-4-2.

- Magnesium wheels—especially around bolt heads, lugs, and wheel-web areas—particularly for the presence of entrapped water or its effects
- Exposed rigid tubing, especially at B-nuts and ferrules, under clamps and tubing-identification tapes
- Exposed position-indicator switches and other electrical equipment
- Crevices between stiffeners, ribs, and lower skin surfaces, which are typical water and debris traps

External skin areas. External aircraft surfaces are readily visible and accessible for inspection and maintenance. Even here, certain types of configurations or combinations of materials become troublesome under certain operating conditions, and inspection of these areas requires special attention.

Relatively little corrosion trouble is experienced with magnesium skins if the original surface finish and insulation are adequately maintained. Trimming, drilling, or riveting destroys some of the original surface treatment, which is never completely restored by touch-up procedures. Any inspection for corrosion should include all magnesium skin surfaces, with special attention to edges, areas around fasteners, and cracked, chipped, or missing paint.

Corrosion of metal skin joined by spot-welding is caused by the entrance and entrapment of corrosive agents between the layers of metal.

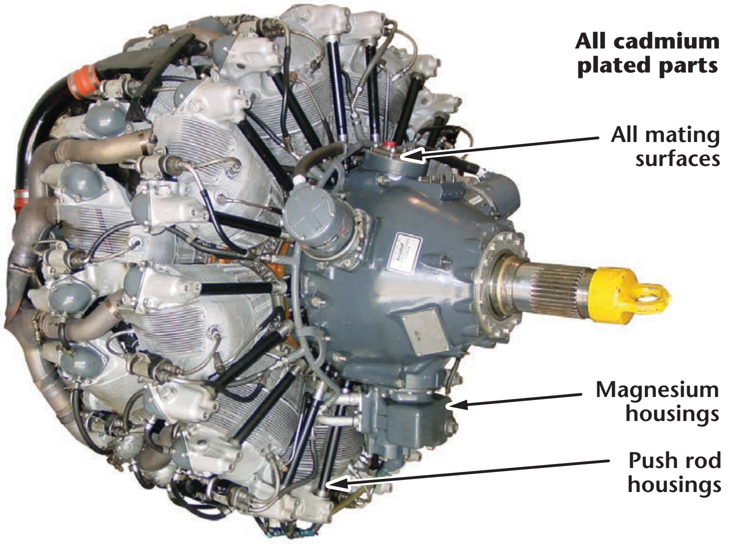


Figure 7-4-3. Illustration of engine frontal-area corrosion points on a reciprocating engine.

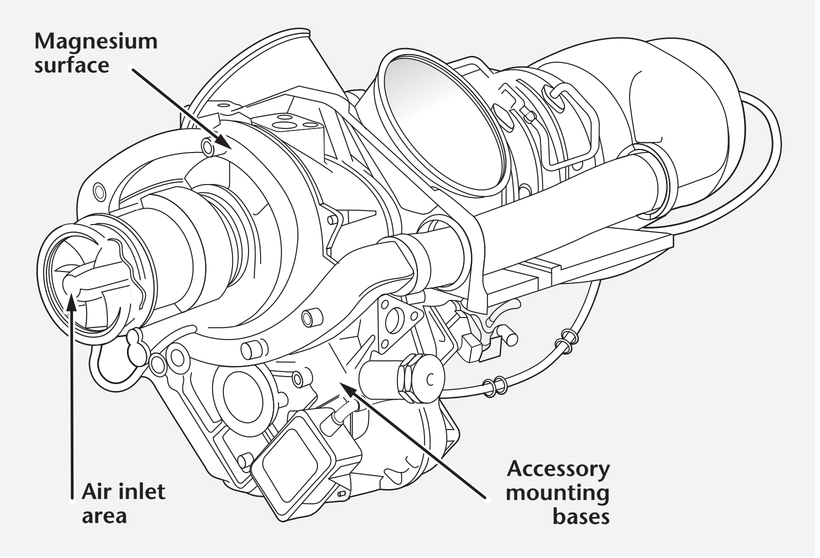


Figure 7-4-4. Turbine engine frontal-area corrosion points.

This type of corrosion is evidenced by corrosion products appearing at the crevices through which the corrosive agents enter. More advanced corrosive attacks cause skin buckling and eventually spot-weld fracture.

Skin buckling, in its early stages, may be detected by sighting along spot-welded seams or by using a straightedge. The only technique for preventing this condition is to keep potential moisture entry points, including seams and holes created by broken spot-welds, filled with a sealant or a suitable preservative compound.

Engine frontal areas and cooling air vents. These areas are being constantly abraded with airborne dirt and dust, bits of gravel from runways, and rain erosion, all of which tend to remove the protective finish. Inspection of these areas, shown in Figures 7-4-3 and 7-4-4,

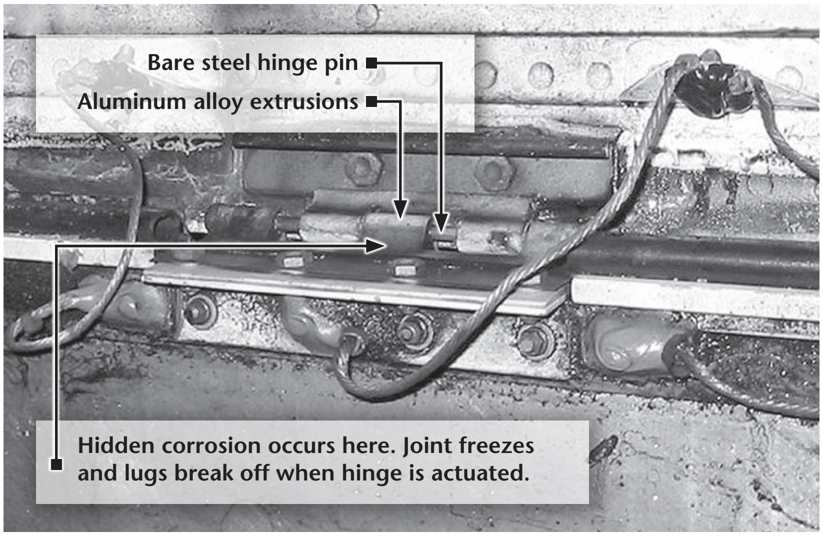


Figure 7-4-5. Piano-hinge corrosion points.

should include all sections in the cooling air path, with special attention to places where salt deposits may have built up during marine operations. It is imperative that incipient corrosion be inhibited and that paint touch-up and hard film preservative coatings be maintained intact on seaplane and amphibian engine surfaces at all times.

Inaccessible Areas

Fuel tanks. Because fuel tanks are usually located inside wing and fuselage structures, it is often difficult to gain access to inspect fittings and other hardware on the outside of the tank for corrosion. In addition, fuel tanks are targets for bacterial growth, particularly in tanks used for turbine fuels. While inspection inside the tank may be extremely difficult or impossible, bacterial growth can be controlled with the use of growth-inhibiting additives added to the fuel when refueling.

Piano hinges. As can be seen in Figure 7-4-5, piano-type hinges are prime spots for corrosion due to the dissimilar metal contact between the steel pin and aluminum hinge. They are also natural traps for dirt, salt, or moisture. Inspection of hinges should include lubrication and actuation through several cycles to ensure complete lubricant penetration.

Wing-flap and spoiler recesses. Dirt and water may collect in flap and spoiler recesses and go unnoticed because they are normally retracted. For this reason, these recesses are potential corrosion problem areas.

Bilge areas. These are natural sumps for waste hydraulic fluids, water, dirt, and other debris. Residual oil quite often masks small quantities of water that settle to the bottom and set up a hidden chemical cell.

Seaplane and amphibian aircraft bilge areas are protected by small bags of *potassium dichromate inhibitor* suspended near the low point in each bilge compartment. These crystals dissolve in any wastewater and tend to inhibit the attack on exposed metal surfaces.

Inspection procedures should include replacement of these bags when most of the chemical has been dissolved.

Water entrapment areas. Corrosion will result from entrapped water. With the exception of sandwich structures, design specifications usually require that the aircraft have drains installed in all areas where water collects. In many cases, these drains are ineffective either due to improper location or because they are plugged by sealants, extraneous fasteners, dirt, grease, or debris. Potential entrapment areas are not a problem when all drains are functioning and the aircraft is maintained in a normal ground attitude. It only takes the plugging of a single drain hole or the altering of the level of the aircraft to result in a corrosion problem if water becomes entrapped in one of these "bathtub" areas. Daily inspection of low-point drains would be practical.

Engine-mount structures. Because of their purpose and location, engine-mount structures are subjected to extremes of heat, vibration, and torque from the engine and its accessories. To withstand the tortures placed on mount structures, most engine mounts are manufactured from welded tubular steel. Therefore, engine-mount structures are inspected and treated for corrosion in much the same manner as other tubular steel airframe components (push/pull tubes, airframe structural tubing, tubular landing gear, etc.). To protect the inside from corrosion a coating of hot linseed oil is often used. Particular attention must be paid to areas where moisture or other contaminants could possibly get inside the tubing, such as threaded, riveted, or welded areas. Where economically feasible, corroded tubing should be cleaned, the structural integrity of the material tested through the use of magnaflux, radiography, or other suitable test procedure. It should then be treated to prevent a recurrence of the same or similar corrosion. Where the cost is prohibitive, the alternative is replacement of the part. In some cases, parts of the engine-mount structure can be individually replaced. In other cases, the entire mount assembly must be replaced.

Control cables. All control cables, whether plain carbon steel or corrosion-resistant steel, should be inspected to determine their condition at each inspection period. Cables should be inspected for corrosion by random cleaning of short sections with solvent-soaked cloths. If external corrosion is evident, tension should be relieved and the cable checked for internal corrosion. Cables with internal corrosion should be replaced. Light external corrosion should be removed with a stainless steel wire brush. When corrosion products have been removed, recoat the cable with preservative.

Welded areas. Many types of fluxes used in brazing, soldering, and welding are corrosive, and they chemically attack the metals or alloys with which they are used. Therefore, it is important that residual flux be removed from the metal surface immediately after the joining operation. Flux residues are *hygroscopic* in nature; that is, they are capable of absorbing moisture from the air, and unless carefully removed, tend to cause severe pitting.

Weld decay is another form of intergranular corrosion. It occurs because the process of welding often produces an undesirable heat treatment adjacent to the welded area, in turn producing separate phases of the metal, one of which may be preferentially attacked under adverse environmental conditions.

Electronic Equipment

Electronic and electrical package compartments cooled by ram air or compressor bleed air are subjected to the same conditions common to engine and accessory cooling vents and engine frontal areas. While the degree of exposure is less because of special design features that limit the amount of air passing through them, which reduces water accumulation, this is still a troublesome area that requires special attention.

Circuit breakers, contact points, and switches are extremely sensitive to moisture and corrosive attack and should be inspected for these conditions as thoroughly as design permits. If design features hinder examination of these items while in the installed condition, advantage should be taken of component removals for other reasons, with careful inspection for corrosion required before reinstallation.

Engine Preservation

A common method of preventing corrosion on aircraft engines that are put into storage is to coat inside surfaces with preservative oil.

Start with cylinder preservation. Remove the top spark plugs and spray atomized MIL-46002, Grade 1 preservative oil through the spark plug hole with the cylinder at bottom center. Repeat this for each cylinder. Then stop the crankshaft with no cylinder at top center. Re-spray each cylinder to thoroughly coat all cylinder surfaces by moving the spray nozzle from top to bottom. Then replace the spark plugs. Most engine manufactures recommend spraying two ounces of the preservative oil into the oil filler tube to preserve the interior parts. Seal all engine openings such as the exhaust, breather, carb intake, etc., with suitable plugs, moisture proof tapes, or whatever is applicable. Placard the engine with the reference, "DO NOT TURN CRANKSHAFT," as this will break the corrosion protective seal in the cylinders.

Section 5

Removal and Treatment of Corrosion

Corrosion Treatment

In general, any complete corrosion treatment involves cleaning and stripping of the corroded area, removing as much of the corrosion products as practicable, neutralizing any residual materials remaining in pits and crevices, restoring protective surface films, and applying temporary or permanent coatings or paint finishes.

Early corrosion removal. Corrosion should be removed as soon as it appears, rather than waiting until it becomes large enough to deal with more easily. Waiting can result in expensive repairs, while corrective action at the first sign of corrosion is very inexpensive.

Surface cleaning and paint removal. The removal of corrosion necessarily includes removal of surface finishes covering the attacked or suspected area. In order to assure maximum efficiency of the stripping compound, the area must be cleaned of grease, oil, dirt, or preservatives. This preliminary cleaning operation is also an aid in determining the extent of corrosion spread, since the stripping operation will be held to the minimum consistent with full exposure of the corrosion damage. Extensive corrosion spread on any panel should be corrected by fully treating the entire section (Figure 7-5-1).

Cleaning materials. The selection of the type of materials to be used in cleaning will depend on the nature of the matter to be removed. Dry cleaning solvent may be used for removing oil, grease, or soft preservative compounds. For heavy-duty removal of thick or dried preservatives, other compounds of the solvent-emulsion type are available. See Table 7-5-1 for abrasives that may be used for corrosion removal. In addition, most maintenance manuals will have a section listing cleaning materials approved by that

Materials or metals to be processed	Restrictions	Operation	(Abrasive paper or cloth)			Abrasive fabric or pad	Aluminum	Stainless steel	Pumice (350 mesh or finer)	Abrasive wheel
			Aluminum oxide	Silicon carbide	Garnet					
Ferrous alloys	Does not apply to steel heat-treated to strengths of 220,000 p.s.i. and above	Corrosion removal or fairing	150 Grit or finer	180 Grit or finer	—	Fine to ultrafine	X	X	X	X
		Finishing	400 Grit	—	—	—	X	X	X	—
Aluminum alloys (except clad aluminum)	Do not use silicon carbon abrasive	Corrosion removal or fairing	150 Grit or finer	—	7/0 Grit or finer	Very fine and ultraFine	X	—	X	X
		Finishing	400 Grit	—	—	—	X	—	X	—
Clad aluminum	Sanding limited to the removal of minor scratches	Corrosion removal or fairing	240 Grit or finer	—	7/0 Grit or finer	Very fine and ultraFine	—	—	X	X
		Finishing	400 Grit	—	—	—	—	—	X	—
Magnesium alloys	—	Corrosion removal or fairing	240 Grit or finer	—	—	Very fine and ultraFine	X	—	X	X
		Finishing	400 Grit	—	—	—	X	—	X	—
Titanium	—	Cleaning and finishing	150 Grit or finer	180 Grit or finer	—	—	—	X	X	X

Table 7-5-1. Abrasives for corrosion removal.

manufacturer. The manual will also have a section listing the commercial names of the cleaning materials and a name and address of the manufacturer. In short, they don't allow many excuses for not using the correct cleaning materials.

> **NOTE:** When cleaning aluminum and aluminum alloys, using steel wool or steel brushes will result in dissimilar metal contamination. Use aluminum wool and brushes on aluminum. Brass brushes are also acceptable.

Paint stripper. The use of a general-purpose, water-rinse stripper is recommended for most applications. Wherever practical, paint removal from any large area should be accomplished outside (in open air), preferably in shaded areas. If inside removal is necessary, adequate ventilation must be assured. Synthetic rubber surfaces, including aircraft tires, fabric, and acrylics, must be thoroughly protected against contact with paint remover. Care must also be exercised in using paint remover around gas- or water-tight seam sealants, since this material will tend to soften and destroy the integrity of these sealants. Mask off any opening that would permit the stripping compound to get into aircraft interiors or critical cavities. Paint stripper is toxic and contains ingredients harmful to both skin and eyes. Rubber gloves, aprons of acid-repellent material, and goggle-type eyeglasses should be worn if any extensive paint removal is to be accomplished, and always refer to the proper Material Safety Data Sheet (MSDS). The following is a general stripping procedure:

1. Brush the entire area to be stripped with a cover of stripper to a depth of 1/32 to 1/16 inch. Any paintbrush makes a satisfactory applicator, except that the bristles will be loosened by the effect of paint remover on the binder, and the brush should not be used for other purposes after being exposed to paint remover.

2. Allow the stripper to remain on the surface for a sufficient length of time to wrinkle and lift the paint. This may be from 10 minutes to several hours, depending on both the temperature and humidity, and the condition of the paint coat

being removed. Scrub the surface with a bristle brush saturated with paint remover to further loosen finish that may still be adhering to the metal.

3. Reapply the stripper, as necessary, in areas that remain tight or where the material has dried, and repeat the above process. Only non-metallic scrapers may be used to assist in removing persistent paint finishes.

4. Remove the loosened paint and residual stripper by washing and scrubbing the surface with water and a broom or brush. If water spray is available, use a low- to medium-pressure stream of water directly on the scrubbing broom or brush. If steam-cleaning equipment is available and the area is sufficiently large, cleaning may be accomplished using this equipment, together with a solution of steam-cleaning compound. On small areas, any method may be used that will assure complete rinsing of the cleaned area (Figure 7-5-2).

Figure 7-5-1. Removal of oil and surface dirt with bristle brush.

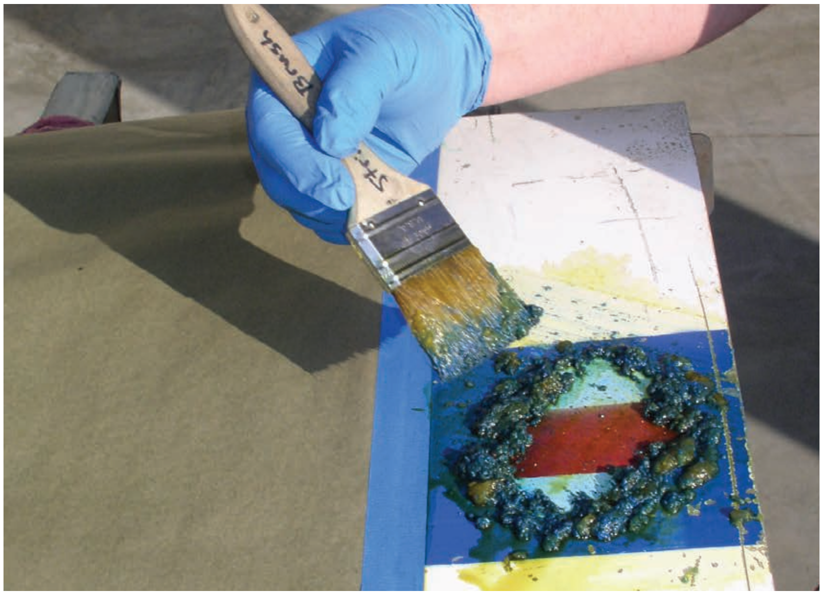


Figure 7-5-2. Cleaning and paint stripping.

Treatment of Aluminum Alloys

Corrosion of aluminum and aluminum alloys. Corrosion attack on aluminum surfaces is usually quite obvious, since the products of corrosion are white and generally more voluminous than the original base metal. Even in its early stages, aluminum corrosion is evident as general etching, pitting, or roughness of the aluminum surfaces.

NOTE: Aluminum alloys commonly form a smooth surface oxidation, which is from .001 to .0025 inch thick. This is not considered detrimental, as such a coating provides a hard shell barrier to the introduction of corrosive elements. Such oxidation is not to be confused with the severe corrosion discussed in this chapter.

General surface attack of aluminum penetrates relatively slowly, but it is speeded up in the presence of dissolved salts. Considerable attack can usually take place before serious loss of structural strength develops. However, at least three forms of attack on aluminum alloys are particularly serious:

- Penetrating pit-type corrosion through the walls of aluminum tubing
- Stress-corrosion cracking of materials under sustained stress
- Intergranular attack characteristic of certain improperly heat-treated aluminum alloys

Corrosion of aluminum. In general, aluminum corrosion can be more effectively treated in place than corrosion occurring on other structural materials used in aircraft. Treatment includes the mechanical removal of as much of the corrosion by-products as practicable and the inhibition of residual materials by chemical means, followed by the restoration of permanent surface coatings. Table 7-5-2 shows typical corrosion removal and treatment procedures for aluminum alloys.

Treatment of unpainted aluminum surfaces. Relatively pure aluminum has considerably more corrosion resistance than the stronger aluminum alloys. Advantage is taken of this by cold rolling a thin sheet of relatively pure aluminum over the base aluminum alloy. This is called *cladding*, and the resultant alloy is *Alclad*. The protection obtained is good, and the Alclad surface can be maintained in a polished condition.

	Step 1	Step 2	Step 3	Step 4
Type of corrosion	Cleaning to remove foreign matter	Paint stripping (when applicable)	Corrosion removal	Surface treatment (when applicable)
Light or heavy pitting or etching of aluminum (clad)	Remove foreign matter with cleaner MIL-Spec: C-25769.	Readily accessible areas: strip with stripper MIL-Spec: R-25134. Confined areas: strip with solvent.	Remove corrosion with brightener MIL-Spec: C-25378 or remove by mechanical method.	Apply chromate conversion coating MIL-Spec: C-5541.
Intergranular or exfoliation corrosion of aluminum	Same as above	Same as above	Remove corrosion by mechanical method.	Same as above
Light or heavy corrosion on small aluminum parts (removable for treatment)	Painted parts: Clean and strip in solution of paint/varnish remover MIL-Spec: R-7751. Unpainted parts: Clean with MIL-Spec: C-5543 or vapor degreaser.	Not required if cleaning is accomplished with paint and varnish remover MIL-Spec: R-7751.	Remove foreign matter with cleaner phosphoric-chromate acid solution.	Immerse in chromate conversion coating MIL-Spec: C-5541.
Stress corrosion cracking of aluminum	N/A	See step 1.	See step 1.	See step 1.

Table 7-5-2. Typical corrosion removal and treatment procedures for aluminum alloys.

In cleaning such surfaces, however, care must be taken to prevent staining and marring of the exposed aluminum and, more importantly from a protection standpoint, to avoid unnecessary mechanical removal of the protective Alclad layer and the exposure of the more susceptible aluminum alloy base material.

Remove oil and surface dirt with any suitable mild cleaner prior to abrasive cleaning of aluminum surfaces.

Polishing Aluminum

Metal polish intended for use on clad aluminum aircraft surfaces must not be used on treated aluminum, since it is abrasive enough to actually remove the protective film. It effectively removes stains and produces a high, lasting polish on unpainted Alclad. If a surface is particularly difficult to clean, a cleaner and brightener compound for aluminum can be used before polishing to shorten the time and lessen the effort necessary to get a clean surface (Figure 7-5-3).

Treat any superficial corrosion using an inhibitive wipe-down material. An alternate treatment is processing with a solution of sodium dichromate and chromium trioxide. Allow these solutions to remain on the corroded area for 5-20 minutes, and then remove the excess by rinsing and wiping the surface dry with a clean cloth.

Hand polishing. Brighteners are a spray or wipe-on/hose-off type of chemical. They are readily available from most aircraft supply stores. They do a pretty good job of removing oxidation but do not give a chrome-plated look. That takes some elbow grease.

An excellent material to use for polishing spinners and such is a commercial product called Flitz. Flitz is a wadding presoaked with metal polish. By following directions on the container, spinners will shine like chrome.

Machine polishing. Making an entire airplane shine like chrome is a daunting task, especially when it is a transport-type airplane. Even then, some airlines still polish them. They do not polish them by hand. The same polishing machines used for automobiles are used for airplanes — only the polish is different.

> **CAUTION:** Overly ambitious machine polishing can take the cladding off a piece of aluminum sheet. That will make the material harder to protect from future corrosion. Polished airplanes are also harder to wash without streaking. You must use the correct soap and lots of rinse water.

Overcoat the polished surfaces with waterproof wax.

Painting. Aluminum surfaces that are to be subsequently painted can be exposed to more severe cleaning procedures and can also be given more thorough corrective treatment prior to painting. The following sequence is generally used:

1. Thoroughly clean the affected surfaces of all soil and grease residues prior to processing. Any general aircraft-cleaning procedure may be used.
2. If residual paint films remain, strip the area to be treated. Procedures for the use of paint removers and the precautions to observe were mentioned earlier in this section, under *Surface cleaning and paint removal*.

Treat superficially corroded areas with a 10 percent solution of chromic acid and sulphuric acid. Apply the solution by swab or brush. Scrub the corroded area with the brush while it is still damp (Figure 7-5-4). While chromic acid is a good inhibitor for aluminum alloys, even when corrosion products have not been completely removed, it is important that the solution penetrate to the bottom of all pits and underneath any corrosion that may be present. Thorough brushing with a stiff fiber brush should loosen or remove most existing corrosion and assure complete penetration of the inhibitor into crevices and pits. Allow the chromic acid to remain in place for at least 5 minutes, then remove the excess by flushing with water or wiping with a wet cloth. There are several commercial chemical surface-treatment compounds, similar to the type described above, which may also be used.

Dry the treated surface and restore recommended permanent protective coatings as required, in accordance with the aircraft manufacturer's procedures (Figure 7-5-5). Restoration of paint coatings should immediately follow any surface treatment performed. In any case, make sure that corrosion treatment is accomplished or is reapplied on the same day that paint refinishing is scheduled.

Treatment of anodized surfaces. Anodizing is a common surface treatment of aluminum alloys. When this coating is damaged in service, it can be only partially restored by chemical surface treatment. Therefore, any corrosion correction of anodized surfaces should avoid destruction of the oxide film in the unaffected area. Avoid the use of steel wool, steel wire brushes, or severe abrasive materials.

Aluminum wool, aluminum wire brushes, or fiber bristle brushes are the approved tools for cleaning corroded anodized surfaces. Care must be exercised in any cleaning process to avoid unnecessary breaking of the adjacent protective film.

Take every precaution to maintain as much of the protective coating as possible. Otherwise, treat anodized surfaces in the same manner

Figure 7-5-3. Hand-polish Alclad surfaces.


Figure 7-5-4. Treat corroded aluminum surfaces.


Figure 7-5-5. Dry the treated surface.

Figure 7-5-6. Mechanical removal of corrosion from steel surfaces.

as other aluminum finishes. Chromic acid and other inhibitive treatments tend to restore the oxide film.

Treatment of intergranular corrosion. As mentioned before, intergranular corrosion is an attack along grain boundaries of improperly or inadequately heat-treated alloys, resulting from precipitation of dissimilar constituents following heat treatment. In its most severe form, actual lifting of metal layers (exfoliation) occurs. More severe cleaning is a must when intergranular corrosion is present. The mechanical removal of all corrosion products and visible delaminated metal layers must be accomplished to determine the extent of the destruction and to evaluate the remaining structural strength of the component. The following processes can be used as a means of repairing this type of corrosion:

- Use metal scrapers, rotary files, or abrasive steels to assure that all corrosion products are removed and that only structurally sound aluminum remains.
- Rotary files must be sharp to insure that they cut the metal without excessive smearing. A dull cutting tool will smear the metal over corrosion cracks or fissures and give the appearance that corrosion has been removed.
- Carbide-tip rotary files or metal scrapers should be utilized, since they stay sharp longer. Blasting is not a satisfactory method to remove intergranular corrosion.
- Inspection with a 5- to 10-power magnifying glass or the use of dye penetrant will assist in determining if all unsound metal and corrosion products have been removed.
- When complete removal has been attained, blend or fair out the edges of the damaged areas. Blending, where required, can best be accomplished by using aluminum-oxide-impregnated, rubber-base wheels.
- Chemically inhibit the exposed surfaces completely and restore paint coatings in the same manner as on any other aluminum surface.
- Any loss of structural strength in critical areas should be evaluated by engineers. Further, if damage exceeds the permissible limit chart in the handbook of structural repair for the aircraft model involved, the manufacturer should be contacted.

Treatment of Ferrous Metals

Mechanical removal of iron rust. The most practical means of controlling the corrosion of steel is the complete removal of corrosion products by mechanical means and the restoration of corrosion-preventive coatings. Except on highly stressed steel surfaces, the use of abrasive papers and compounds, small power buffers and buffing compounds, hand wire brushing or steel wool are all acceptable clean-up procedures (Figure 7-5-6). However, it should be recognized that in any such use of abrasives, residual rust usually remains in the bottom of small pits and other crevices. It is practically impossible to remove all corrosion products by abrasive or polishing methods alone. As a result, once a part has rusted, it usually corrodes again more easily than it did the first time.

Chemical surface treatment of steel. There are approved methods for converting active rust to phosphates and other protective coatings. The use of phosphoric acid-proprietary chemicals are examples of such treatments. However, these processes require shop-installed equipment and are impractical for field use. Other commercial preparations are effective rust converters where tolerances are not critical and where thorough rinsing and neutralizing of residual acid is possible. These situations are generally not applicable to assembled aircraft, and the use of chemical inhibitors on installed steel parts is not only undesirable but very dangerous. The danger of entrapment of corrosive solutions and the resulting uncontrolled attack, which could occur when such materials are used under field conditions, outweigh any advantages to be gained from their use.

Corrosion removal from steel parts. If possible, corroded steel parts should be removed from the aircraft. When it is impossible to remove the part, observe the aircraft's preventative preparations and safety precautions. No chemical removal or chemical-conversion coatings are allowed on steel parts. An example of corrosion-removal techniques for steel is as follows:

1. Positively identify the metal as steel and establish its heat-treatment value.
2. Clean the area to be reworked.
3. Strip the paint in the area, if needed.
4. Remove all degrees of corrosion damage from steel that has been heat treated at a low level of hardness. Corrosion removal on steel treated to a high level of hardness should be accomplished only by dry abrasive blasting, which is described later.
5. Mechanically remove all degrees of corrosion from steel parts heat treated at a low level of hardness as follows:
   a. Use goggles or a face shield to preclude injury from flying particles. Protect adjacent areas to prevent additional damage from corrosion products removed by this mechanical process.
   b. Remove heavy deposits of corrosion products by alternating between a stainless steel hand brush and dry-abrasive blasting. Exercise extreme care to prevent overheating the surfaces when using power tools on high-stress steels.
   c. Remove residual corrosion by hand sanding or with approved hand-operated power tools. Select an appropriate abrasive from Table 7-5-1.
   d. The surface is highly reactive immediately following corrosion removal; consequently, primer coats should be applied within an hour after sanding. Then remove all corrosion that's visible through a magnifying glass.
   e. Blend depressions resulting from rework, as covered in Figures 7-5-7 and 7-5-8. Then surface finish with 400-grit abrasive paper.
   f. Clean the reworked area, being careful never to use kerosene or petroleum-based solvents.
   g. Determine the depth of the faired depressions, as required, to ensure that rework limits have not been exceeded.
   h. Apply protective finish or specific organic finish, as required. Remove masking and protective covering.

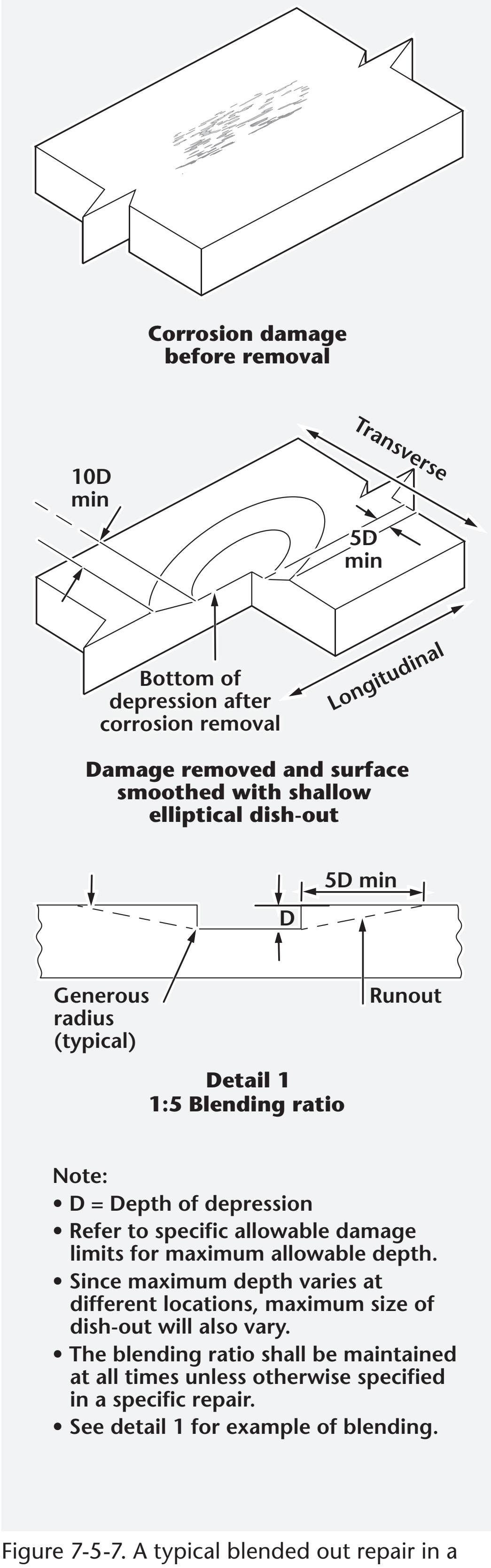


Figure 7-5-7. A typical blended out repair in a corroded area.

Removal of corrosion from highly stressed steel parts. Any corrosion on the surface of a highly stressed steel part is potentially dangerous, and the careful removal of corrosion products is required. Surface scratches or changes in surface structure from overheating can also cause sudden failure of these parts. Corrosion products must be removed by careful processing, using mild abrasive papers such as rouge, or fine-grit aluminum oxide, or fine buffing compounds on cloth buffing

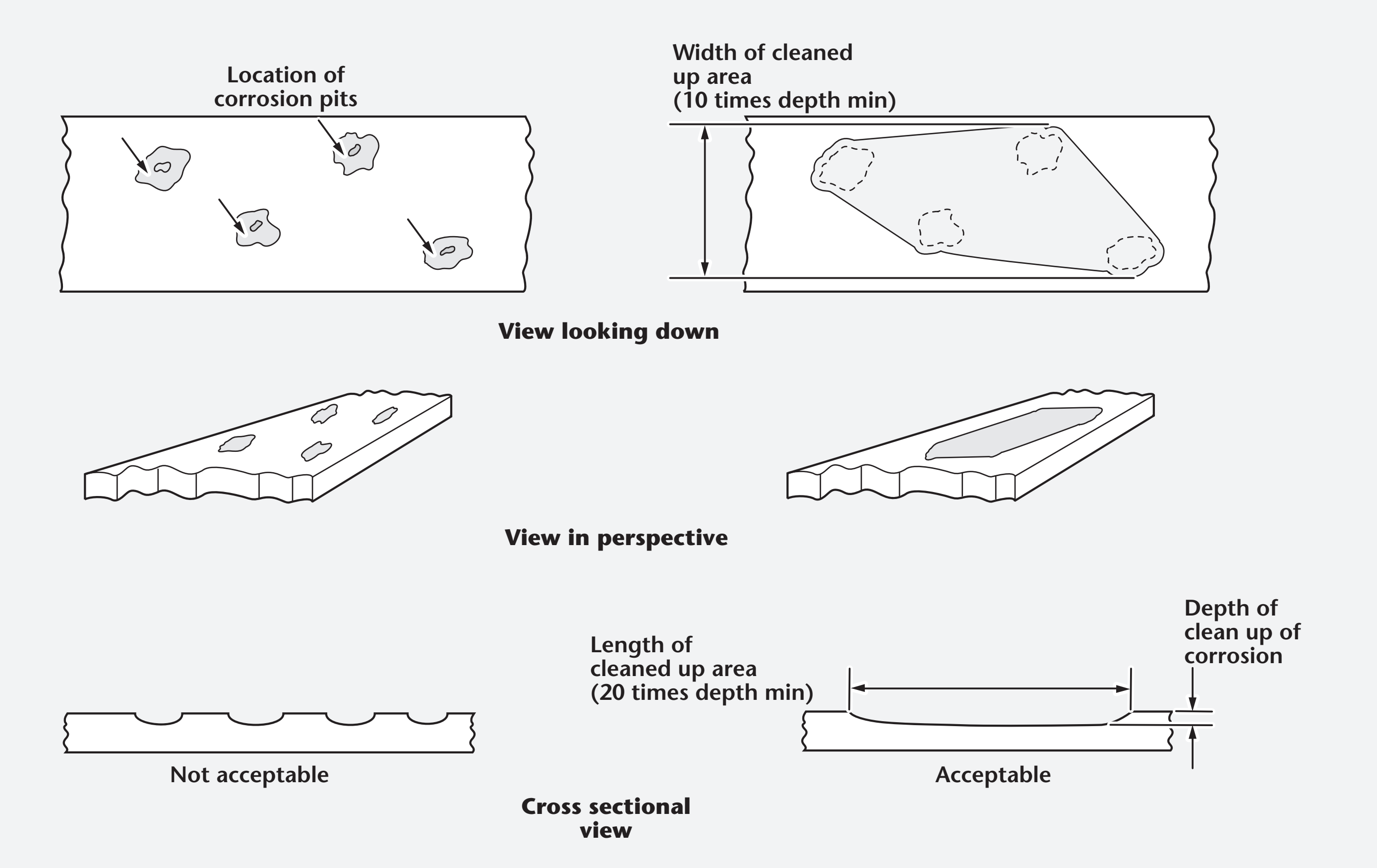


Figure 7-5-8. Example of acceptable clean-up of corrosion pits.

wheels. It is essential that steel surfaces not be overheated during buffing. After careful removal of surface corrosion, protective paint finishes should be reapplied immediately.

Special Treatment of Stainless Steel Alloys

Do not use chemical cleaners on stainless steels. Stainless steels are of two general types: magnetic and nonmagnetic. Magnetic steels are of the *ferritic* or *martensitic* types and are identified by numbers in the 400 series. Corrosion often occurs on 400 series stainless steels. Nonmagnetic steels are of the austenitic type and are identified by numbers in the 300 series. They are much more corrosion resistant than the 400 series steels, particularly in a marine environment.

Austenitic steels. Austenitic steels develop corrosion resistance by an oxide film, which should not be removed even though the surface is discolored by its presence. The original oxide film is normally formed at time of fabrication. If any deterioration or corrosion does occur on austenitic steels and the structural integrity or serviceability of the part is affected, it will be necessary to remove and replace the part.

Treatment of Magnesium Alloys

Corrosion of magnesium alloys. Magnesium is the most chemically active of the metals used in aircraft construction and is, therefore, the most difficult to protect. When a failure in the protective coating does occur, the prompt and complete correction of the coating failure is imperative if serious structural damage is to be avoided.

Magnesium attack is probably the easiest type of corrosion to detect in its early stages, since magnesium corrosion products occupy several times the volume of the original magnesium metal destroyed. The beginning of attack shows as a lifting of the paint films and white spots on the magnesium surface. These rapidly develop into snow-like mounds or even *white whiskers*. Reprotection involves the removal of corrosion products, the partial restoration of surface coatings by chemical treatment, and a reapplication of protective coatings.

Treatment of wrought magnesium sheet and forgings. Magnesium skin attack will usually occur around edges of skin panels, underneath hold-down washers, or in areas physically damaged by shearing, drilling, abrasion, or impact. If the skin section can be removed easily, this should be done to assure complete inhibition and treatment. If insulating washers are involved, screws should be loosened sufficiently to permit brush treatment of the magnesium under the insulating washer. Complete mechanical removal of corrosion products should be practiced insofar as practicable (Figure 7-5-9).

Such mechanical cleaning should be limited to the use of stiff, hog-bristle brushes and similar non-metallic cleaning tools, particularly if treatment is to be performed under field conditions. Any entrapment of steel particles from steel-wire brushes or steel tools or contamination of treated surfaces by dirty abrasives can cause more trouble than the initial corrosive attack. Corroded magnesium may generally be treated as follows:

1. Clean and remove the paint from the area to be treated (use caution when using paint strippers on magnesium).
2. Using a stiff, hog-bristle brush, break loose and remove as much of the corrosion products as possible. Steel-wire brushes, carborundum abrasives, or steel cutting tools should not be used.
3. Treat the corroded area liberally with a chromic acid solution to which has been added sulphuric acid and work into pits and crevices by brushing the area while still wet with chromic acid (using a non-metallic brush).
4. Allow the chromic acid to remain in place for 5-20 minutes before wiping up the excess with a clean, damp cloth. Do not allow the excess solution to dry and remain on the surface; paint lifting will be caused by such deposits.
5. As soon as the surfaces are dry, restore the original protective paint.

Treatment of installed magnesium castings. Magnesium castings, in general, are more porous and more prone to penetrating attack than wrought magnesium skins. However, treatment is, for all practical purposes, the same for all magnesium areas. Engine cases, bellcranks, fittings, numerous covers, plates, and handles are the most common magnesium castings.

When attack occurs on a casting, the earliest practicable treatment is required if dangerous corrosive penetration is to be avoided. In fact, engine cases submerged in salt water overnight can be completely penetrated. If it is at all practicable, parting surfaces should be separated to effectively treat the existing attack and prevent its further progress. The same general treatment sequence for magnesium skin should be followed.

Figure 7-5-9. Careful removal of corrosion from a highly stressed magnesium part.

If extensive removal of corrosion products from a structural casting is involved, a decision from the manufacturer may be necessary to evaluate the adequacy of structural strength remaining. Specific structural repair manuals usually include dimensional tolerance limits for critical structural members and should be referred to, if any question of safety is involved.

Section 6

Corrosion Prevention

Cleanliness

It is important that aircraft be kept thoroughly clean of deposits containing contaminating substances such as oil, grease, dirt, or other foreign materials.

Avoid damage to aircraft by not using harmful cleansing, polishing, brightening, or paint-removing materials. Use only those compounds that conform to existing government or established industry specifications, or products that have been specifically recommended by the aircraft manufacturer as being satisfactory for the intended application. Observe the product manufacturer's recommendations concerning use of their agent.

Chemical cleaners. Chemical cleaners must be used with great care in cleaning assembled aircraft. The danger of entrapping corrosive materials in faying surfaces and crevices counteracts any advantages in their speed and effectiveness. Use materials that are relatively neutral and easy to remove.

Battery acid. Spilled battery acid is removed by using sodium bicarbonate (baking soda) or sodium borate (Borax), 20 percent by weight dissolved in water. After the acid is neutralized, remove alkali salts completely by flushing the area with large quantities of water to prevent corrosion. An application of acid-proof paint to the structure surrounding the battery may be an effective control for this type of corrosion.

A boric acid solution is used to neutralize electrolyte from a nickel cadmium battery. Areas that have been affected by this electrolyte should be cleaned with this solution, allowed to dry, and then painted with an alkali-resisting paint.

Corrosion-Inhibiting Film

By covering materials with protective coatings of corrosion-inhibiting film, corrosion is often prevented. Care must be taken when handling materials coated with a protective film to prevent penetration or breaking of the film covering.

Anodizing and related processes. In anodizing, aluminum alloys are placed in an electrolytic bath, causing a thin film of aluminum oxide to form on the surface of the aluminum. This is resistant to corrosion and affords a good paint base. Other processes that do not provide as good a corrosive protection as anodizing are, however, good paint bases. These processes are:

- Alkaline cleaning, followed by chromic acid dip
- Alcoholic phosphoric acid cleaner
- Alkaline dichromate treatment

Plating. Steels are commonly plated with other metals to prevent corrosion. *Plating* is accomplished by placing the material in an electrolytic bath where metal from the plating solution is deposited on it. The various metals used in plating vary in the corrosion protection that they afford steel. For instance, cadmium and zinc corrode before the steel; hence, slight breaks or cracks through the plating of these metals will not result in rusting of the exposed steel since the surface metal is corroded and protects the steel. Chromium does not protect steel by this method, because steel will corrode before the chromium and thus depends on the tightness of the plating for its protection.

Phosphate rustproofing. This process is commercially known as *Parkerizing*, *Bonderizing*, or *Granodizing*. The coating placed on the part is used to protect steel parts after machining and before painting.

Chrome-pickle treatment. Magnesium parts that have been immersed or brushed with a solution of nitric acid and sodium dichromate will be protected for temporary storage. The coating also serves as a bond for subsequent organic finishes. Sealed *chrome-pickle treatment* is used on magnesium parts for long-term protection. Diluted chromic acid is a touch-up treatment. It is less critical to apply and can be applied over previously applied thin chromate films.

Dichromate treatment. The dichromate treatment consists of boiling magnesium parts in a solution of sodium dichromate. This treatment provides a good paint base and protective qualities on all standard wrought magnesium alloys except the magnesium-thorium alloys HK31A, HM21A, and HM31A. No coating forms on these alloys. Acid pickling of the magnesium surface prior to application of the dichromate treatment is required if maximum corrosion resistance of the finish is expected.

Stannate immersion treatment. This treatment deposits a layer of tin, as a protective paint base, on magnesium parts containing inserts and fasteners of a dissimilar metal such as brass, copper, or steel. This treatment cannot be used with parts containing aluminum inserts or fasteners, because the high alkalinity of the bath attacks the aluminum.

Galvanic anodizing treatment. This is an electrolytic process used to provide a paint base and corrosion-preventive film on magnesium alloys containing manganese.

Cladding. Aluminum alloys that are susceptible to corrosion are frequently clad with pure aluminum. Slight pits, scratches, or other defects through the cladding material will not result in corrosion of the core, since the pure aluminum on the edges of the defect will be preferentially corroded, protecting the core.

Metal spraying. Metal is melted and sprayed on the surface to be protected, providing a sealing film. Extra care must be taken to properly prepare the surface to prevent peeling of the sprayed coating.

Organic coatings. Zinc chromate primer, enamels, chlorinated rubber compounds, etc., are organic coatings commonly used to protect metals.

Dope-proofing. When doped fabrics are applied over an organic-finished metal struc-

Contacting metals	Aluminum alloy	Cadmium plate	Zinc plate	Carbon and alloy steels	Lead	Tin coating	Copper and alloys	Nickel and alloys	Titanium and alloys	Chromium plate	Corrosion-resisting steel	Magnesium alloy
Aluminum alloy				X	X	X	X	X	X	X	X	X
Cadmium plate				X	X	X	X	X	X	X	X	X
Zinc plate				X	X	X	X	X	X	X	X	X
Carbon and alloy steels	X	X	X				X	X	X	X	X	X
Lead	X	X	X				X	X	X	X	X	X
Tin coating	X	X	X				X	X	X	X	X	X
Copper and alloys	X	X	X	X	X	X						X
Nickel and alloys	X	X	X	X	X	X						X
Titanium and alloys	X	X	X	X	X	X						X
Chromium plate	X	X	X	X	X	X						X
Corrosion-resisting steel	X	X	X	X	X	X						X
Magnesium alloy	X	X	X	X	X	X	X	X	X	X	X	

Areas marked with an "X" indicate contacts that will result in electrolytic corrosion.

Table 7-6-1. Dissimilar-metal contacts that will result in electrolytic corrosion.

ture, the dope will have a tendency to loosen the finish on the metal. For this reason, organic coatings on the metal are usually covered with a dope-proof paint, metal foil, or with cellulose tape to prevent the dope from striking through.

Dissimilar Metal Insulation

Protection of dissimilar metal contacts. Certain metals are subject to corrosion when placed in contact with other metals. This is commonly referred to as *electrolytic corrosion* or *dissimilar-metals corrosion*. Contact of different bare metals creates an electrolytic action when moisture is present. If this moisture is saltwater, the electrolytic action is accelerated. The result of dissimilar-metal contact is oxidation (decomposition) of one or both metals. The chart shown in Table 7-6-1 lists the metal combinations requiring a protective separator. The separating materials may be metal primer, aluminum tape, washers, grease, or sealant, depending on the metals involved.

Contacts not involving magnesium. All dissimilar joints not involving magnesium are protected by the application of a minimum of two coats of zinc chromate primer, in addition to normal primer requirements. Primer is applied by brush or spray and allowed to air-dry six hours between coats.

Contacts involving magnesium. To prevent corrosion between dissimilar-metal joints in which magnesium alloy is involved, each surface should be insulated with at least two coats of zinc chromate. Next, a layer of pressure-sensitive, 0.003 inch thick vinyl tape is applied smoothly and firmly enough to prevent air bubbles and wrinkles. To avoid creep-back, the tape is not stretched during application. When the thickness of the tape interferes with the assembly of parts, where relative motion exists between parts, or when service temperatures above 250°F (121°C) are anticipated, the use of tape is eliminated and extra coats (a minimum of three) of primer are applied.

Mechanical corrosion removal by blasting. Abrasive blasting is a process for cleaning or finishing metals, plastics, or other materials by directing a stream of abrasive particles against the surface of the parts. Abrasive blasting is used for the removal of rust and corrosion and for cleaning prior to further processing, such as painting or plating.

Section 7

Aircraft Cleaning

Washing an airplane is like washing a car, only more difficult. Unlike a car, you have to work upside down on the underside of the surfaces. Depending on the size and complexity of the airplane, it will take some time to do a good job. A small general aviation airplane can be washed with a long-handled wash brush, auto wash detergent, and some elbow grease. Washing a Boeing 747 will take tens of thousands of dollars worth of machinery and work stands. Several special Mil Spec cleaning compounds designed for specific purposes will be required, not to mention a fairly large crew of people who should be trained to do the job.

Not only that, there are specific procedures that every large airplane manufacturer wants you to undertake before washing its airplane type. Basically, these consist of:

- **Chocking and blocking.** Airplanes must not roll during washing or personnel and equipment damage will likely result.
- **Taping.** Tape closed all static air ports. with masking tape, and cover all pitot tube openings with masking tape. Check all fuel vent tubes, and tape them if necessary.
- **Securing.** Check all fuel caps for security.
- **Closing.** Check all windows and doors. They should be closed and secure.
- **Opening.** Check all low-point drain holes. They should be open.

CAUTION: Remove all tape and residue after the aircraft has been cleaned. Leaving tape over the pitot or static ports will cause flight instruments to malfunction.

Figure 7-7-1. When taping a flush static port, fold back a piece of tape against itself. When applied, it will have a small tab that can be used to remove it. This also makes the taping more noticeable and harder to miss when time for removal.

Make sure there are enough ladders and work stands available before starting the job. The best wash job you can do is one where the airplane is wet from start to finish. Just like in washing a car, you end up with fewer streaks than if any surface is allowed to dry.

Static ports. A cautionary word about *static ports* and *pitot tubes;* they have to be taped or covered to keep water out of the instrument plumbing (Figure 7-7-1). While each instrument system should have a low-point drain in the static and pressure lines, not all do. Even if they do, it is not always sufficient to simply drain any stray water out of the tubing. Shop air pressure must not be used to blow out the lines. Shop air pressure in a pitot static system will destroy any instrument it comes in contact with, most of them explosively.

A more likely error is forgetting to remove the tape. If the pilot doesn't catch it during preflight, then the flight instruments will not work, which could result in an accident.

Before actually starting a wash job, there is an important thing most people forget to think of. What kind of a wash job do you want to do?

If you simply "get everything clean," there will be about an hour of drying out the bearings and bushings in the landing gear alone. Everything must be dried, wiped down, applied with corrosion preventative, and the bearings and bushings must be re-lubed before calling the job complete. You need to allow enough time for re-lubrication, because it is not good to let it go and try to do it the next day. To let it go is simply asking for corrosion to start forming. If the airplane makes a flight before being dried out and re-lubed, excess wear will result.

Washing sequence. The sequence of operations is important, because it can save you some time. Most people have a tendency to start at the top. Because water runs downhill, it is a natural instinct to start at the top. Thorough training demands that the under-surfaces of the aircraft are washed first. Starting on the top of a surface will result in water and detergent running over the edges and down the lower surface. Thus, certain places will be covered with wash solution for a lot longer time than others, in essence causing a much longer soaking time. It will cause streaks that are difficult to remove later. When you wash your car, do the same thing. Start at the bottom and you will have less trouble removing streaks later.

Washing Equipment

While a small airplane can be washed using nothing more than a wash brush and a bucket, larger airplanes take a bit more equipment to do a good job.

Power scrubbers. For large surfaces that have contamination from air pollution, it takes some scrubbing to get them clean. A real timesaver worth using is a power scrubber. There are air-powered rotating scrub brushes that will do an excellent job and are worth the expense and effort. They work well for removing exhaust tracks not "baked on."

Pressure washers. Some manufacturers state flatly that pressure washers are not to be used on their airplanes. Their reasoning is that an untrained operator can destroy a very expensive paint job very quickly. Other manufacturers will allow them. If you use one, there are some simple rules to follow that will make the process more successful:

- Use a nozzle size that will reduce the pressure to something reasonable. The machine may be capable of producing 1,450 p.s.i., but 500-600 p.s.i. might be a more manageable pressure.
- Never spray at a 90° angle. A 30-45° angle will actually work better. Also, it isn't so hard on the paint. Wing leading edges and areas around landing gear tend to pick up small chips in the paint. Direct pressure may cause the paint finish to begin peeling. Indirect pressure held in one area for too long can do the same thing. Never aim the spray at any area that looks like it may have a chip in the paint.
- Never spray directly into the edge of a faying surface. This includes sheet lap joints. Likewise, never spray directly into the edge of an inspection plate or removable panel. Even if the water doesn't enter the interior, it will enter the crevice and start to establish the potential for corrosion.
- Do not spray into a control bearing or a landing-gear bushing. Clean them by hand and re-lubricate after the wash is complete. Spraying either directly will damage the seals.
- Do not spray directly into any brake system part. Clean them by hand. Hitting the parts of a brake system with a pressure washer is asking for trouble. If it is winter, the parts may freeze and cause an accident.
- Wheel seals are designed to keep grease in, not to keep under-pressure water out. If water enters the bearing cavity, the wheel will have to be removed, the wheel bearings cleaned and repacked, and everything reassembled. It could take longer than the wash on a small airplane.
- It is possible to damage a sealed control-rod bearing so badly that it will need to be replaced. If you have to spray around one, protect it first. A 4 inch square piece of heavy-duty aluminum foil, wrapped tightly around the installed rod end, will protect it nicely. Remember to remove it.
- Control-surface bearings are easy to damage. The same process as outlined above will generally work nicely for installed control-surface bearings.

Most problems caused by misuse of pressure washers come from simply not thinking through the job before beginning the work. As with any job, there are three priorities:

1. Personal/personnel safety
2. Avoiding damage to aircraft and equipment
3. Accomplishing the job correctly and thoroughly

Steam cleaners. These are now largely relegated to the overhaul shop and not normally part of the maintenance process. They do not work well on a wash ramp.

Cleaning Materials

Most manufacturers have a list of approved cleaning products. Many will specify a good automotive wash. All will want to see a pH balance at or close to neutral (7). Most will also stress never to use anything that has a pH of 11 or more. A pH of 11 is too acidic and will damage aluminum surfaces.

There will also be several prohibitions against using household spray cleaners. Many of the most popular can cause hydrogen embrittlement.

Upholstery materials are an exception. Hand-held upholstery shampoo machines work wonders and are quick and easy to use. Just don't spill anything, and be careful what you use on the carpets. There is an aluminum floor underneath.

Figure 7-7-2. Engine oil leaks can make a real mess of a tricycle-geared airplane. Oil leaks can also shorten the life of the nose-wheel tire.

Figure 7-7-3. All airplanes leave an exhaust track somewhere on the structure. If not removed regularly, the stain will start corrosion of the structure from the combustion byproducts present.

Mil Spec materials. Most manufacturers will list a *Mil Spec* cleaning chemical. While Mil Spec numbers can be confusing and cumbersome in the field, there is a good reason for their use. Over the life of an airplane, commercial products will change several times. Many of the name brand products are nothing like what they were originally. By using the Mil Spec number, the manufacturer can assure a standard.

If the manufacturer lists a Mil Spec number and no commercial equivalent, the Mil Spec product is what you must use. Using anything else is a violation of the FARs and will result in a leveling of full blame on the technician should anything go wrong.

Specific Procedures

There are a few things that are generally done in a very specific way for very specific reasons. It is important when cleaning the following areas with a potentially flammable cleaner that you use a cotton fiber wiping cloth to avoid static build. Do not use a synthetic fiber cloth due to the build up of static electricity that could cause a spark and start a fire.

Solid materials. Dirt, mud, and grease containing solid soils should always be removed before starting a wash job. Use of a wash brush runs the risk of severely scratching the finish. At the very least, a greasy wash brush will result.

Hydraulic oil leaks. Hydraulic oil should be cleaned up as quickly as it is discovered. In particular, Mil 5606 will attract dirt and form a nasty film that, when dried, will be very difficult to remove. If it leaks over a brake system, it can cause a caliper to freeze up from accumulated dirt.

Skydrol will soften or discolor most finishes. If it is cleaned up as soon as it is discovered, there is normally no damage to the finish. Leave a surface wetted with Skydrol for any appreciable amount of time, and you will be doing some paint touch-up.

Engine oil. Even though they make a mess, minor engine oil leaks are not a real disaster. Half a cup of oil spread over the cowling and the fuselage belly will look like a massive leak. Oil leaks should be cleaned up as soon as discovered, and the source found and corrected, but they tend not to do damage to the painted surfaces.

Engine oil will, however, damage rubber parts, especially tires. On many small, tricycle-geared airplanes, it seems that the nose wheel and strut are always covered with some amount of oil. The cowling should be removed and cleaned, and the strut and tire/wheel combination needs to be cleaned as well. Removing oil from the tires is more important than most people seem to think. Because repair can be costly and time consuming, owners tend to let minor leaks go for too long (Figure 7-7-2).

Exhaust track. The burned and unburned hydrocarbons in fuel leave a long, brownish-grey stain down the fuselage on just about any single-engine airplane. On multi-engine aircraft, it either goes across the wing or down the cowling. Not only does the streaked stain look bad, it is a precursor to corrosion. It also gets harder to remove and stands a bigger chance of corroding the skin the longer it is allowed to remain. Needless to say, it is best to clean the stains on a regular basis.

A good detergent mixture will generally suffice. Should that fail, a cleaning solvent mixture is the next best thing. As shown in Figure 7-7-3, the only real way to get the job done is to get on a creeper and start scrubbing.

Magnesium Engine Parts. Magnesium engine parts are cleaned by washing them with a commercial solvent, soaking them in a decarbonizer, and removing remaining deposits with a scaper or grit blast.

Fuel leaks. Not only do fuel leaks make a mess, they are dangerous and need immediate attention.

Acrylics and Rubber. Aliphatic naptha is recommended for the cleaning of acrylics and rubbers. It should not be confused with aromatic naptha, which is toxic and attacks acrylic and rubber products.

Windshields. There is a whole separate process for cleaning windshields and Plexiglas® or Lexan® windows. The short list follows:

- On large aircraft with glass cockpit windows a squeegee or sponge may be used to clean off the dirt (Figure 7-7-4).

- Never wash a windshield or window with the wash broom. Start by flooding it with water until dust and accumulated dirt are softened or flushed away. Then wet your hand and, while still flooding the surface with water, gently rub the surface to remove dust and dirt. Nothing else should be done until the rest of the cleaning process has been completed.

- Use a cleaner designed for aircraft windshields, as shown in Figure 7-7-5. Read the instructions on the product and make sure to use only clean, soft cloths for the cleaning process. Anything else (including shop towels) will produce fine-line scratches. Pick up a rag with dust on it, and you will see every move you made because of the fine scratches in the windshield.

- Windshield cleaner has a wax in its composition. This wax has approximately the same light-refraction abilities as the windshield material. By filling the fine scratches with wax, the scratches seem to disappear, or at least become less noticeable.

- Store windshield cleaning rags in a closeable plastic bag until next use.

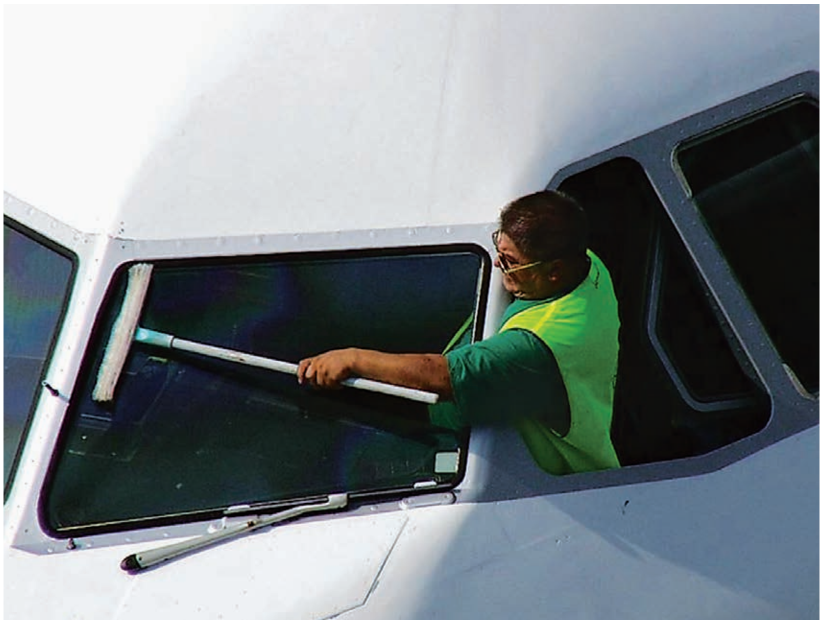


Figure 7-7-4. Cleaning an aircraft's windshield requires great care—use of a dusty cloth or marred implement will result in fine scratches and markings all over the surface being cleaned. *Photo courtesy of Marcus Kroegler*

Figure 7-7-5. Cleaners designed specifically for use on an aircraft's Plexiglas windows ensure scratch-free cleaning when used with an appropriate cloth.

Disposal. Certain parts of the U.S. have very strict rules about wash and rinse water. So strict, in fact, that there are some places where rinse water disposal is almost impossible. Be aware of the local rules and follow the ordinances.

8

Fluid Lines and Fittings

Section 1

Tubing Fabrication and Maintenance

Learning Objectives

REVIEW
- Types, fittings and assemblies of tubes and hoses

DESCRIBE
- Tubing and hose fabrication methods and tools

EXPLAIN
- Maintenance practices for tubing and tube assemblies and hose and hose assemblies

Tubing and Tube Assemblies

Tubing assemblies are used to transport liquids or gas (usually under pressure) between various components of the aircraft system. Tube assemblies are used in aircraft for fuel, oil, breathing oxygen, instruments, hydraulic, and vent lines. Aircraft tubing has a 37° flare.

Types of Tubing

The tubing used in the manufacture of rigid tubing assemblies is sized by outside diameter (OD) and wall thickness. Outside diameter sizes are in sixteenth-inch increments; the number of the tube indicates its size in sixteenths of an inch. Thus, No. 6 tubing is 6/16 or 3/8 inch; No. 8 tubing is 8/16 or 1/2 inch, etc. Wall thickness is specified in thousandths of an inch. The most common types of tubing are the corrosion-resistant steel tubing for high pressure and the aluminum alloy tubing for high pressure and general-purpose depending on thickness.

Corrosion-resistant steel tubing. Corrosion-resistant steel tubing (CRES) is used in high-pressure hydraulic systems (3,000 p.s.i. and above) such as landing gear, wing flaps, and brakes. The tubing does not have to be annealed for flaring or forming. The flared section is strengthened by cold working and consequent strain hardening.

Left. From inside a wheel well, it is obvious that hose and tubing inspection and maintenance can be a major item. As with all complete systems, just follow one line at a time.

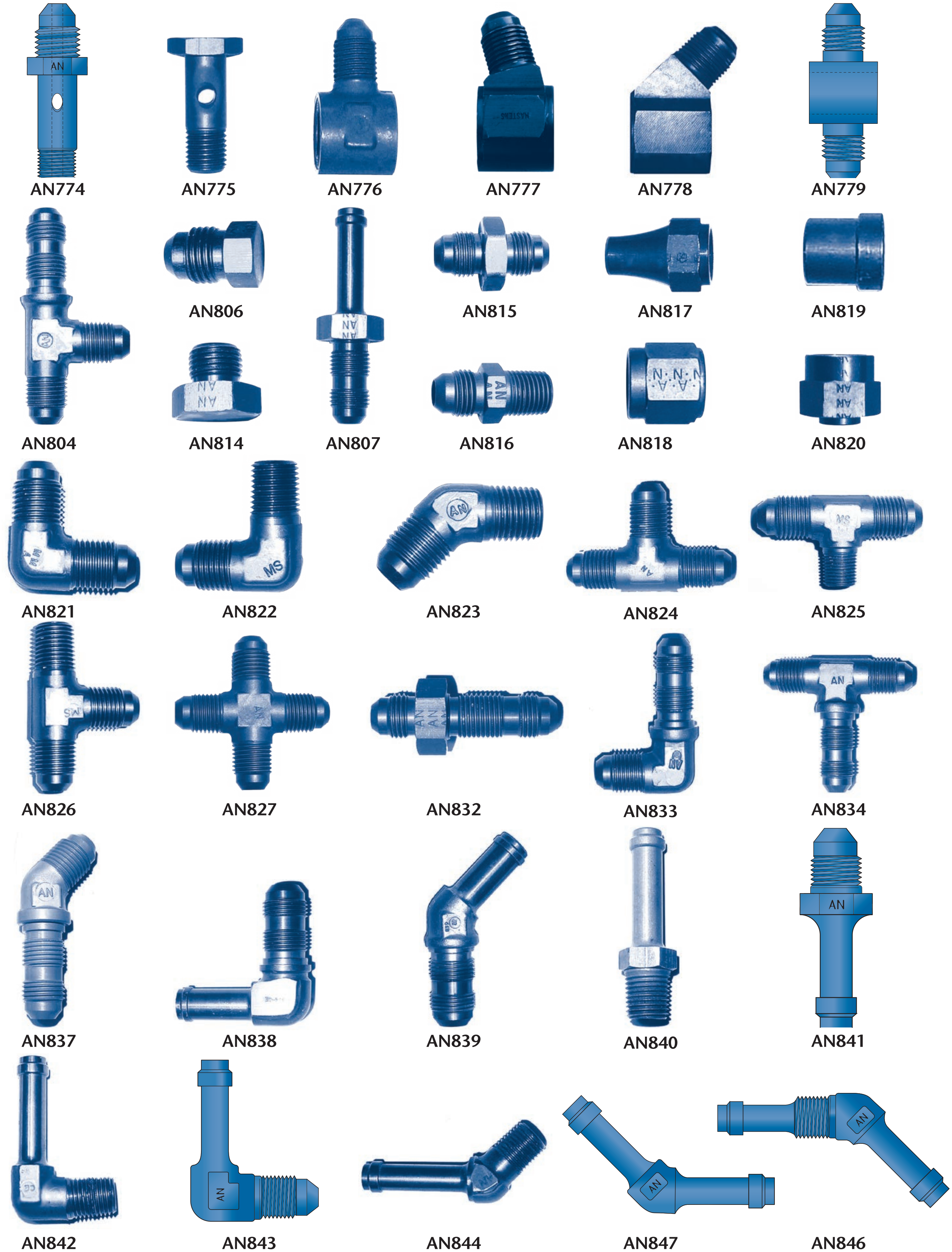


Figure 8-1-1. Typical styles of AN fittings.

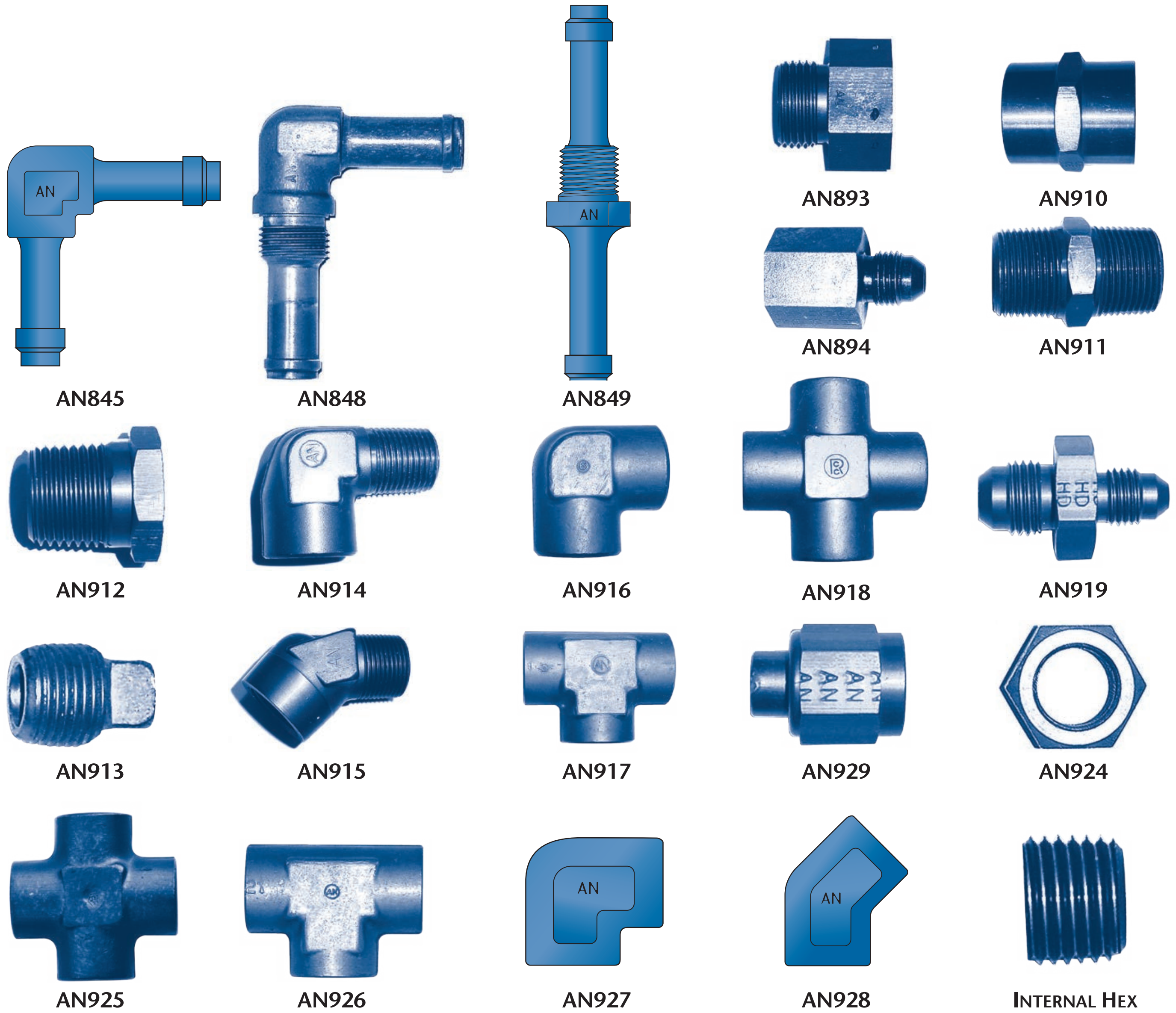


Figure 8-1-1. Typical styles of AN fittings (cont'd).

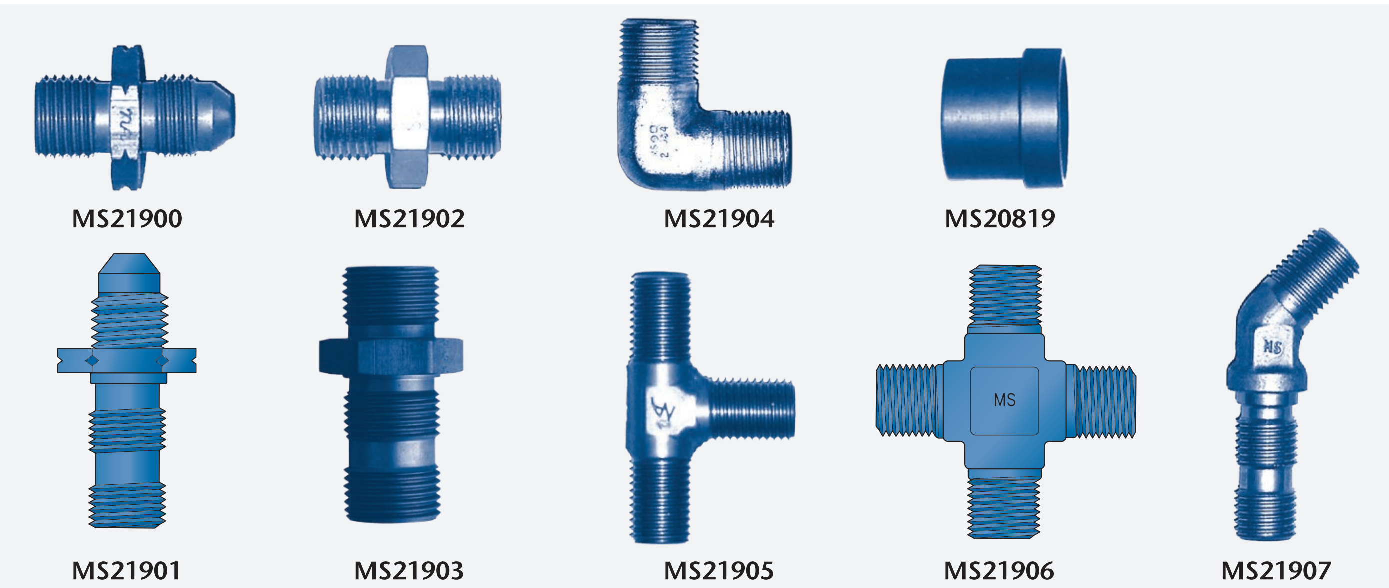


Figure 8-1-2A. Typical styles of MS fittings.

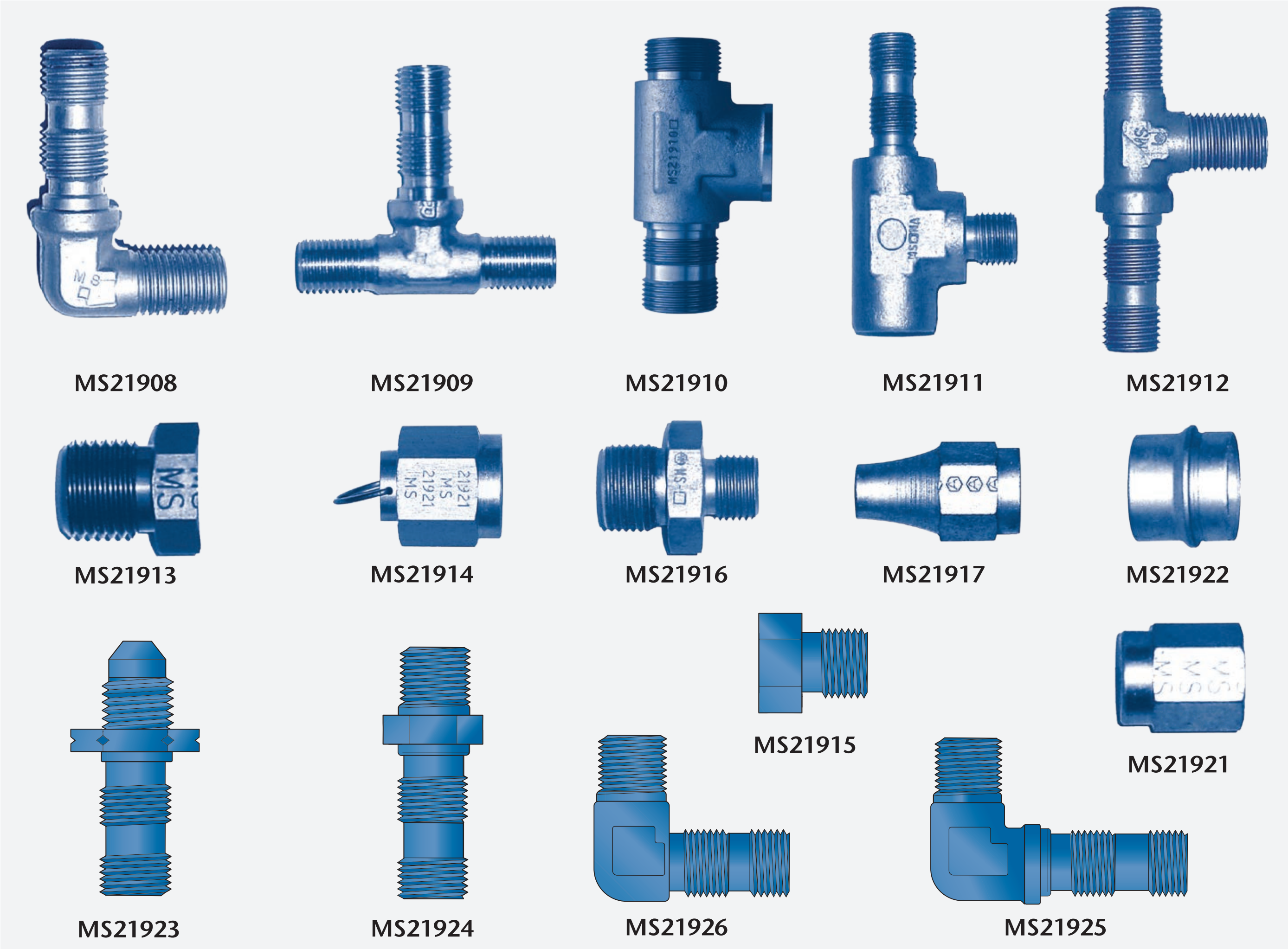


Figure 8-1-2A. Typical styles of MS fittings (cont'd).

Aluminum alloy tubing. Aluminum alloy tubing is used for both high-pressure and general-purpose lines. Use of aluminum alloy tubing is limited in certain areas of aircraft hydraulic systems. Refer to the applicable manual and the illustrated parts breakdown to determine the correct tubing for a particular system.

Special tubing. Corrosion-resistant steel 21-6-9 and titanium alloy 3AL-2.5V are used in some special circumstances. Repair and fabrication of assemblies using these materials may require special procedures. Refer to the applicable manufacturers recommendations for specific details.

Tube fitting color codes	
Material or finish	Color
Aluminum alloy	Blue
Carbon steel	Black
Corrosion resistant steel	Natural
Aluminum-bronze	Cadmium plate
Titanium	Natural to grey, depending on type and intended use

Table 8-1-1. AN/MS tube fitting color codes.

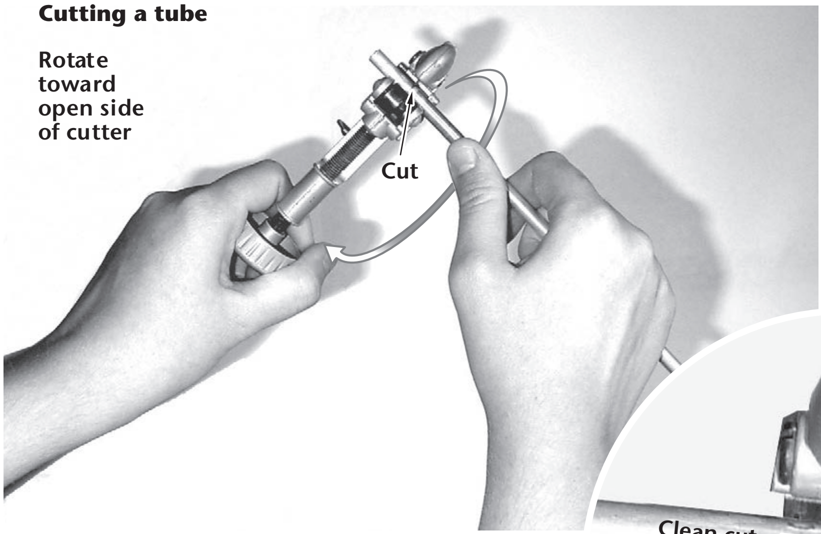
Figure 8-1-2B. AC fittings are no longer used.

Tube Fittings

Fittings for tube connections are made of aluminum alloy, titanium steel, corrosion-resistant steel, brass, and bronze. Fittings are made in many configurations and styles. The usual classifications are; flared-tube fittings, flareless-tube fittings, brazed, welded, and swaged fittings (refer to Figure 8-1-1 through Figure 8-1-3). Refer to Table 8-1-1, for identification of fitting material.

Tubing Fabrication

Fabrication of tube assemblies consists of tube cuttings, deburring, bending, and tube joint preparation. The procedures found in this chapter are for instructional purposes and cover MS and AN fittings only. AC fittings are no longer used (Figure 8-1-2B). Permaswage, Dynatube, Rynglok, and other connector systems that require specialized tooling are not covered.



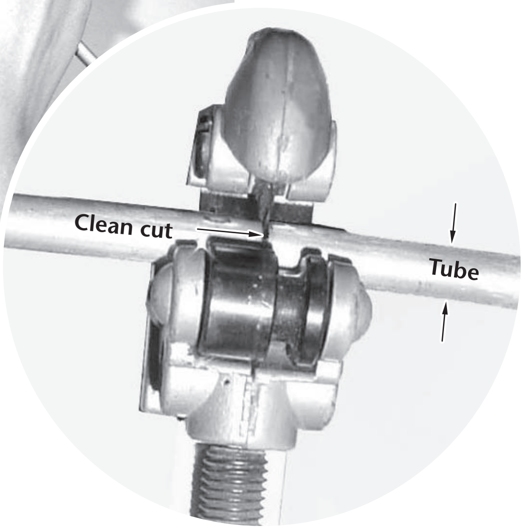


Figure 8-1-3. Standard tube cutter.

Figure 8-1-4. Using a standard tubing cutter produces a square cut, but does require deburring.

Expansion and contraction of straight runs of tubing will cause excessive pressure on the assembly. Provide enough bend in the tubing to take up the changes in length caused by environment and operating conditions.

> **NOTE:** When fabricating tube assemblies, always refer to the manufacturers specifications for both material type and fabrication procedures.

Tube cutting. When you cut tubing, the objective is to produce a square end free from burrs. Tubing should be cut with a standard tube cutter.

Standard tube cutter. Place the tube in cutter with cutting wheel at the point where the cut is to be made. Apply light pressure on tube by tightening adjusting knob. Too much pressure applied to the cutting wheel at one time may deform the tubing or cause excessive burrs.

Rotate the cutter toward its open side (Figures 8-1-3 and 8-1-4). As the cutter is rotated, adjust the tightening knob after each complete turn to maintain light pressure on the cutting wheel.

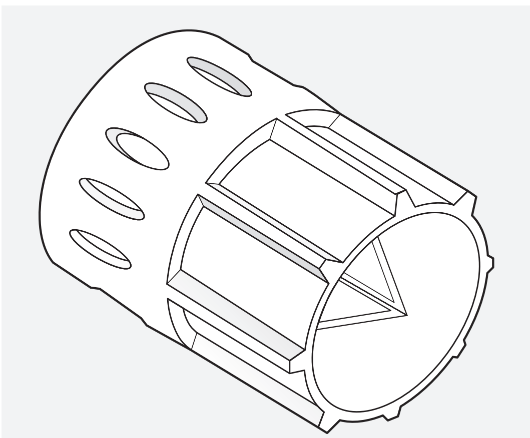


Figure 8-1-5. Standard deburring tool.

If a standard tube cutter is unavailable, a fine-tooth hacksaw should be used to cut tubing. A convenient method for cutting tubing with a hacksaw is to place the tube in a flaring block and clamp the block in a vise. After cutting the tube with a hacksaw, remove all saw marks by filing the tube.

Tube deburring. After you cut the tubing, remove all burrs and sharp edges from inside and outside of tube with deburring tools, (Figure 8-1-5) making sure that no foreign particles remain inside the tube.

You should avoid excessive deburring, which can cause too deep a chamfer on tube ID. The chamfer should not exceed one-half wall thickness of tubing. Relax the pressure and rotate the deburring tool several times to produce a smooth surface. Check the tube end to see if it is completely deburred. If tube end appears satisfactory, remove the deburring tool from the tube.

Tube bending. The objective in tube bending is to obtain a smooth bend without flattening the tube. The maximum amount of flattening allowed in a a bend is 25 percent of the tube's outer diameter. Acceptable and unacceptable bends are shown in Figure 8-1-6. Tube bending is usually done using a mechanical or hand-operated tube bender. In an emergency, soft, non-heat-treated aluminum tubing smaller than 1/4 inch in diameter may be bent by hand to form the desired radius.

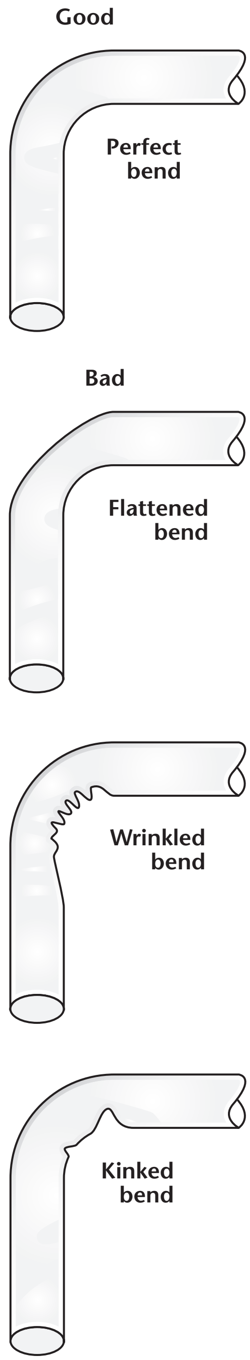


Figure 8-1-6. Acceptable and unacceptable tubing bends.

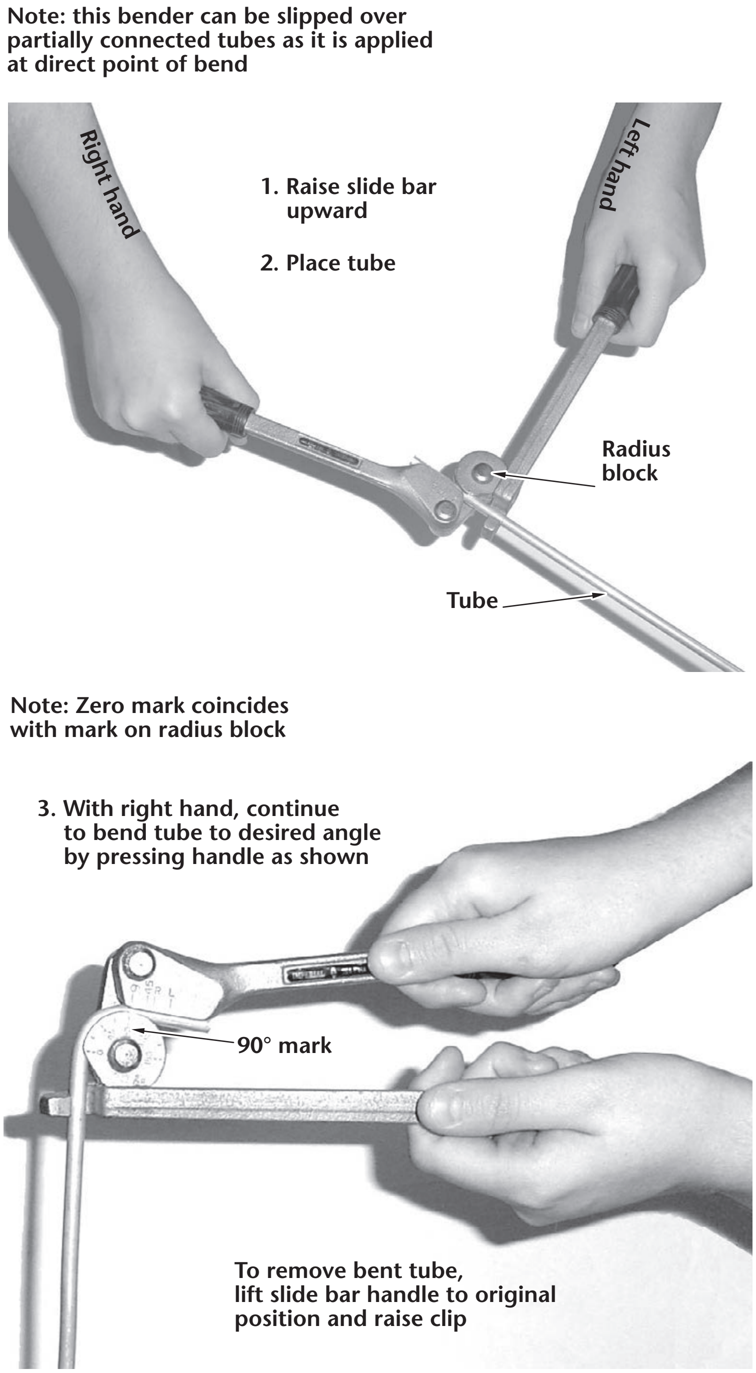


Figure 8-1-7. Bending tubing with hand-operated tube bender.

Hand tube bender. The hand-operated tube bender, shown in Figure 8-1-7, consists of a handle, radius block, clip, and a slide bar. The handle and slide bar are used as levers to provide the mechanical advantage necessary to bend tubing. The radius block is marked on degrees of bend ranging from 0 to 180 degrees. The slide bar has a mark that is lined up with the zero mark on the radius block. The tube is inserted in the tube bender, and after lining up the marks, the slide bar is moved around until the mark on the slide bar reaches the desired degree of bend on the radius block.

Mechanically operated tube bender. The tube bender, shown in Figure 8-1-8, is a heavy duty bench model. This tube bender is designed for use with larger diameter tubing as well as aircraft grade, high-strength, stainless steel tubing, as well as all other metal tubing. It is designed to be fastened to a bench or tripod, and the base is formed to provide a secure grip in a vise.

The simple hand bender shown in Figure 8-1-7 uses the handle and slide bar as levers to provide the mechanical advantage necessary to bend the tubing, while the mechanical operated tube bender employs a hand crank and gears. The forming die is keyed to the drive gear and secured by a screw (Figure 8-1-8).

The forming die on the mechanical tube bender is calibrated in degrees similar to the radius block of the hand-type bender. A length of replacement tubing may be bent to a specified number of degrees or it may be bent to duplicate the bend in the damaged tube or pattern. Duplicating the bend of a damaged tube or pattern is accomplished by laying the pattern on top of the tube being bent and slowly bending the new tube to the required bend.

> **NOTE:** Certain types of tubing are more elastic than others. It may be necessary to bend the tube past the required bend to allow for springback. Before hand bending large aluminum tubing, it should be packed with sand, shot, or aluminum powder and both ends closed with protective closures to minimize kinking or flattening of the bends. Where sand, shot, or aluminum powder is used, wash or blow out all the particles after the bend is complete. Any remaining particles can cause serious damage to component parts.

Tube joint preparation. The two major tube joints are the flared fitting and the flareless fitting. Preparation for these tube joints differ.

Flared fitting. There are two types of flared tubing joints—the single-flared joint and the double-flared joint. Most single- and double-flared joints are secured with a combination of a nut and a sleeve. The nut tightens the line to the fitting while the sleeve protects the flare and prevents the nut from wiping, ironing, or otherwise damaging the flared section of the tubing. The single-flared tube joint is used on all sizes of steel tubing and 5052 aluminum alloy tubing that conforms to Federal Specification WW-T-700/6 with 1/2 inch or larger outside diameter:

Use the tube flaring tool (Figure 8-1-9) to prepare tube ends for flaring.

- Check tube ends for roundness, square cut, cleanliness, and be certain there are no draw marks or scratches. Draw marks can spread and split the tube when it is flared.

- Use a deburring tool to remove burrs from the inside and outside of the tubing.
- Remove all filings, chips, and grit from the inside of the tube. Clean the tube.
- Slip the fitting nut and sleeve onto the tube.
- Place the tube into the proper size hole in the grip die. Make sure the end of the tube extends 1/64 inch above the surface of the grip die.
- Center the plunger over the end of the tube, tighten the yoke setscrew to secure the tube in the grip die and hold the yoke in place.
- Loosen the setscrew and remove the tube from the grip die.
- Check to make sure that no cracks are evident and that the flared end of the tube is no larger than the largest diameter of the sleeve being used.

The double-flare tube joint is used on all 5052 aluminum alloy tubes with less than 3/8 inch or less outside diameter, except when used with NAS 590 series tube fittings, NAS 591 connectors, or NAS 593 connectors. Aluminum alloy tubing used in low-pressure oxygen systems or corrosion-resistant steel used in brake systems is normally double flared. Double flaring reduces the chance of cutting the flare by overtightening. When fabricating oxygen lines, make sure that all tube material and tools are kept free of oil and grease. Use the tube flaring tool (Figure 8-1-10) to prepare tube ends:

- Check tube end for roundness, square cut, and cleanliness, and be certain there are no draw marks or scratches.
- Select the proper size die blocks, and place one-half of the die block into the flaring tool body with the countersunk end towards the ram guide.
- Install the nut and sleeve, and lay the tube in the die block with 1/2 inch protruding beyond the countersunk end.
- Place the other half of the die block into the tool body, close latch plate, and tighten the clamp nuts finger tight.
- Insert the upset flare punch in the tool body with the gauge end toward the die blocks. The upset flare punch has one end counterbored, or recessed, to gauge the amount of tubing needed to form a double-lap flare. Insert the ram, and turn it until the upset flare punch contacts the die blocks and the die blocks are set against the stop plate on the bottom.

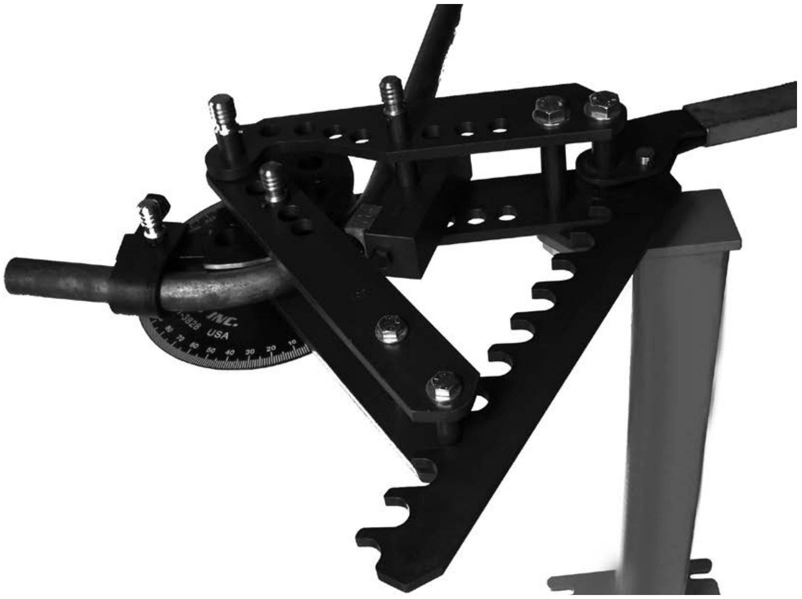


Figure 8-1-8. Mechanically operated tube bender. *Photo courtesy of JD Squared, Inc.*

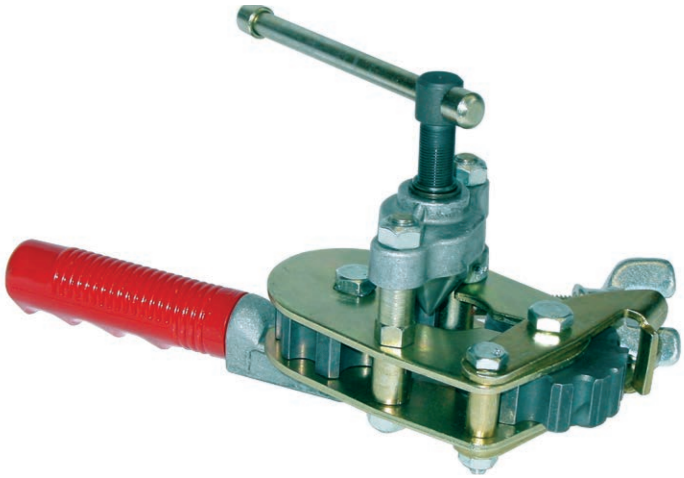


Figure 8-1-9. Tube flaring tool (single-flare).

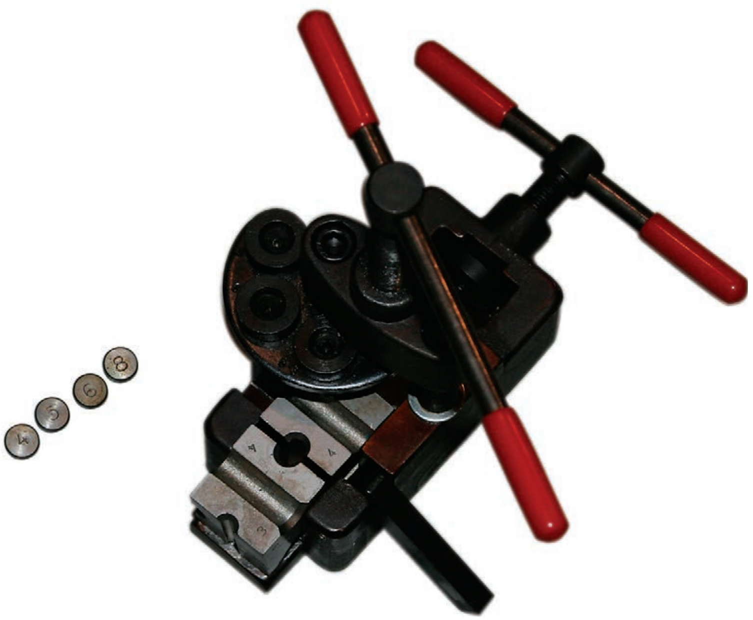


Figure 8-1-10. Tube flaring tool (double-flare).

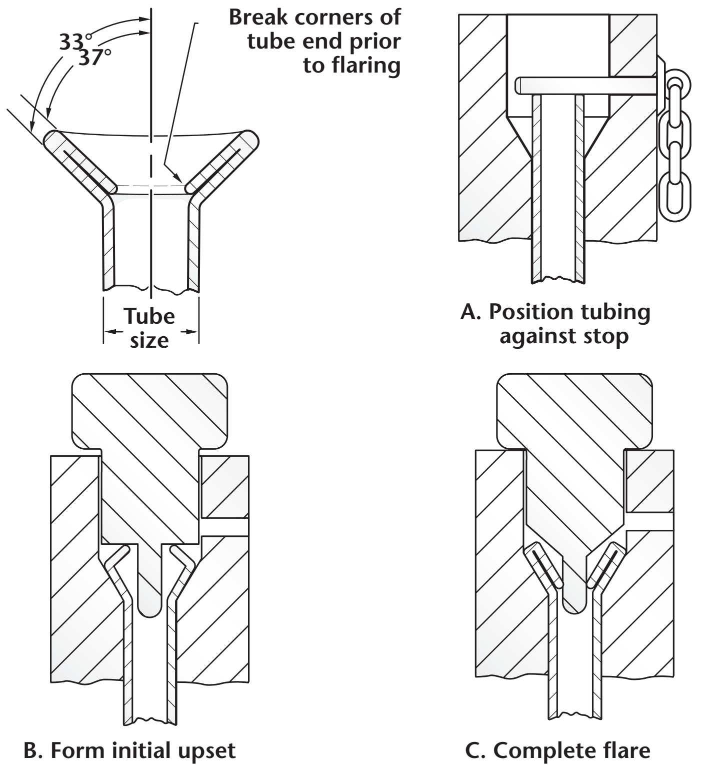


Figure 8-1-11. Double flares are formed with a special impact tool. The die should not be struck hard.

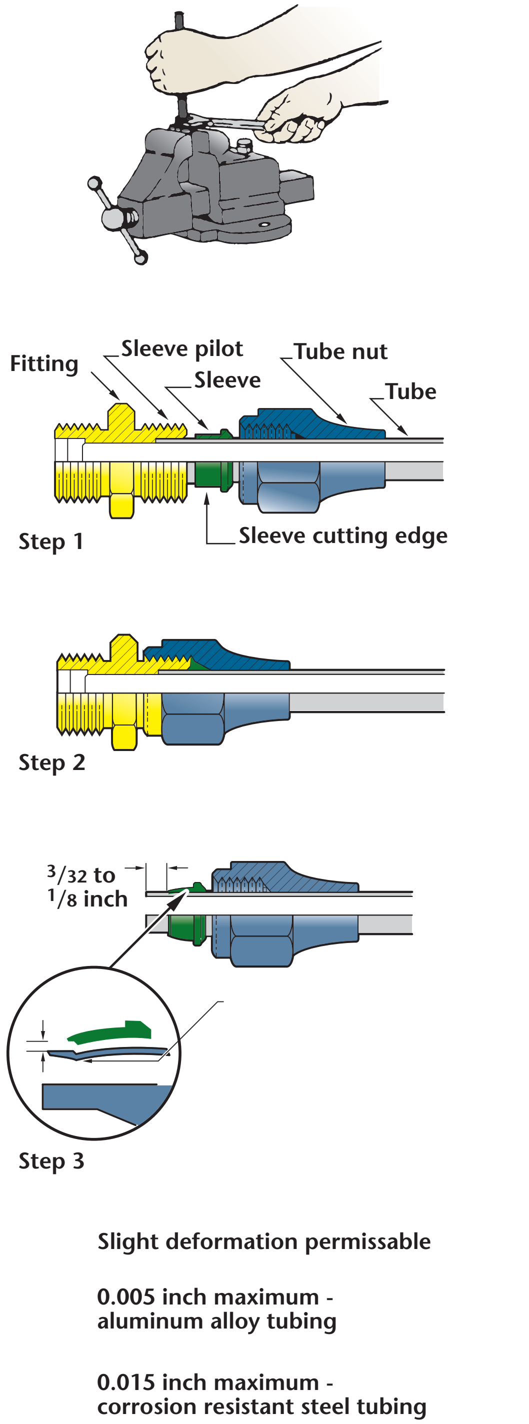


Figure 8-1-12. Presetting flareless-tube assembly.

- Use a wrench to tighten the latch plate nuts alternately, beginning with the closed side, to prevent distortion of the tool. Reverse the upset flare punch; insert the upset flare punch and ram it into the tool body.
- Tap lightly with a hammer or mallet until the upset flare punch contacts the die blocks.
- Remove the upset flare punch and ram. Insert the finishing flare punch and ram.
- Turn the ram lightly until a good seat has been formed (Figure 8-1-11).
- Check the seat at intervals during the finishing operation to avoid overseating.

Flareless fitting. In preparing tube ends for flaring the sleeve is set onto the tubing. Presetting is necessary to form the seal between the sleeve and the tube without damaging the connector. Presetting should always be accomplished with a presetting tool, such as the one shown in Figure 8-1-12. These tools are machined from tool steel and hardened so that they may be used with a minimum of distortion and wear.

Special procedures are used in the presetting operation:

- Select the correct size presetting tool or a flareless fitting body.
- Clamp the presetting tool or flareless fitting body in a vise.
- Slide a nut and then a sleeve onto the tube, and make sure the pilot and cutting edge of the sleeve points toward the end of tube.
- Lubricate fitting threads, tool seat, and shoulder sleeve (Table 8-1-2).
- Place the tube end firmly against the bottom of the presetting tool seat, while slowly

System lubricant	
Specification	**Specification number**
Hydraulic	MIL-H-5606
Fuel	MIL-H-5606
Oil	MIL-O-6032 or MIL-L-23699
Freon	MIL-L-6085A
Pneumatic	MIL-G-4343
Oxygen	MIL-T-27730A

Table 8-1-2. Thread lubricants.

Tube size	Approximate tube projection-inches
2	7/64
3	7/64
4	7/64
5	5/32
6	11/64
8	3/16
10	13/64
12	7/32
16	15/64
20	1/4
24	1/4
32	9/32

Table 8-1-3. Tube projection from sleeve pilot.

screwing the nut onto the tool threads with a wrench until the tube cannot be rotated with thumb and fingers. At this point the cutting edge of the sleeve is gripping the tube and preventing tube rotation; the fitting is ready for the final tightening force needed to set the sleeve on the tube.

- Tighten the nut to the number of turns specified in the maintenance manual (MM).

After presetting, unscrew the nut from the presetting tool or flareless fitting body; check the sleeve and tube (Figure 8-1-13). Sleeve cutting lip should be imbedded into the tube's outside diameter between 0.003 inch and 0.008 inch, depending on size and tubing material. A lip of tube material will be raised under the sleeve pilot. The sleeve pilot should contact or be quite close to the outside diameter of tube. The tube projection from the sleeve pilot to the tube end should be as listed in Table 8-1-3. The sleeve should be bowed slightly. The sleeve may rotate on tube and have a maximum lengthwise movement of 1/64 inch. The sealing surface of the sleeve, which contacts the 24° angle of fitting body seat, should be smooth, free from scores, and should not show lengthwise or circular cracks. Minimum internal tube diameter should not be less than values shown in Table 8-1-4.

Beading

Beaded tubing and hose clamps are not a fastening system that is in common use today, but are frequently found in older low pressure systems, (i.e., vacuum systems, dry sump reciprocating engine oil systems, and some gravity fuel systems). Tubing may be beaded with a hand beading tool or with machine beading rolls. The method to be used depends on the diameter and wall thickness of the tube and the material from which it was made.

The hand beading tool is used with tubing having 1/4 to 1 inch outside diameter. The bead is formed by using the beader frame with the proper rollers attached. The inside and outside of the tube are lubricated with light oil to reduce

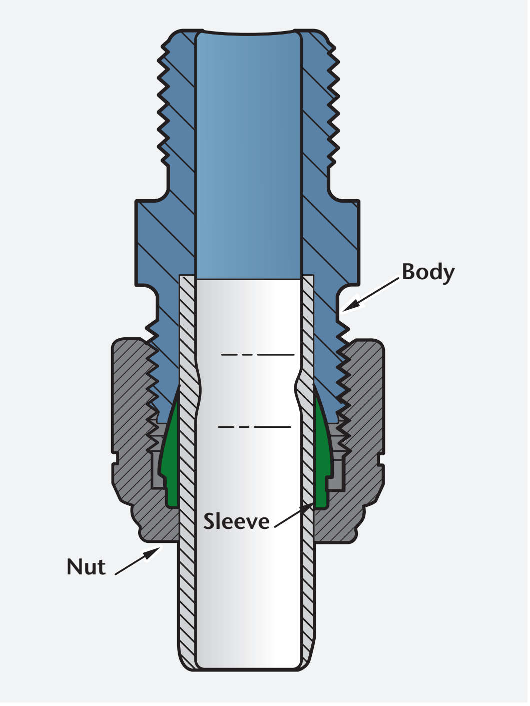


Figure 8-1-13. Preset sleeve.

Tube OD	6061 Aluminum		1/8 Hard stainless		Annealed stainless	
	Wall	Min Id	Wall	Min Id	Wall min	Id
1/8	0.020	0.060	0.016	0.070	0.020	0.060
5/16	0.049	0.180	0.022	0.225	0.035	0.225
3/8	0.049	0.240	0.025	0.290	0.049	0.270
1/2	0.065	0.330	0.028	0.400	0.058	0.380
5/8	0.083	0.420	0.035	0.485	0.065	0.475
3/4	0.095	0.530	0.042	0.610	0.083	0.590
1	0.065	0.830	0.065	0.840	0.083	0.800

Table 8-1-4. Minimum inside diameter of tubing.

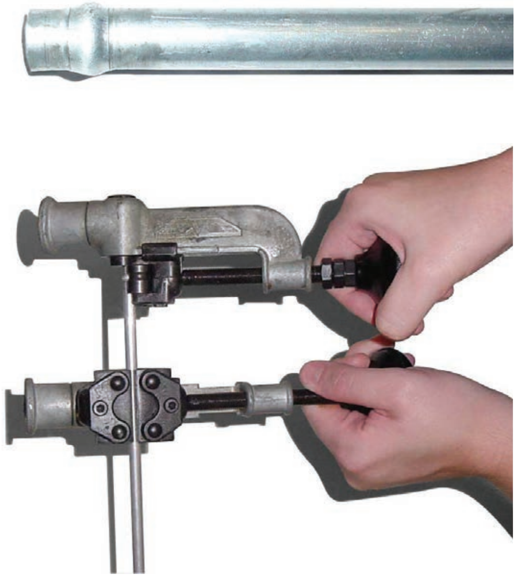


Figure 8-1-14. Forming a bead using a beading tool is similar to using a tubing cutter.

the friction between the rollers during beading. The sizes, marked in sixteenths of an inch on the rollers, are for the outside diameter of the tubing that can be beaded with the rollers.

Separate rollers are required for the inside of each tubing size, and care must be taken to use the correct parts when beading. As shown in Figure 8-1-14, the hand beading tool works somewhat like the tube cutter in that the roller is screwed down intermittently while rotating the beading tool around the tubing. In addition, a small vise (tube holder) is furnished with the kit.

Other methods and types of beading tools and machines are available, but the hand beading tool is used most often. As a rule, beading machines are limited to use with large diameter tubing, over 1-15/16 inch, unless special rollers are supplied. See Figure 8-1-15 for several examples of beading tools.

Proof Pressure Testing

There is no FAA requirement in AC 43.13-1B for pressure testing a fabricated metal line. However, some aircraft manufacturers may specify that fabricated replacement tube assemblies should be proof pressure tested. As a guide, the pressure test for fabricated hose assemblies is at least 1.5 times the system pressure.

> **NOTE:** This figure varies upon change of wall thickness for a given size. Do not use these dimensions as an inspection standard but rather as an approximation of proper tube projection.

The fluid medium for proof pressure testing of all tube assemblies except oxygen systems should be a liquid medium such as hydraulic fluid, water, or oil. It is suggested that oxygen tubing be tested using dry nitrogen and inspected for leaks while the tubing is submerged in water.

Many aircraft manufactures have a specific cleaning procedure for oxygen lines that have been fabricated or repaired. The information should be located in ATA 20-30-00 Airplane Structure Cleaning Solvents.

Protective Paint Finish

Most tube assemblies do not require paint as a protective finish. Titanium or stainless steel tubing does not require primer or paint except in areas of dissimilar metals. The primary reason for this is that cracked or damaged paint systems establish a differential oxygen concentration cell, which may result in tubing or fitting corrosion damage. Do not paint interior surfaces of airspeed indicator tubing, oxygen, or other plumbing lines. When using bonding clamps on metal tubing, remove any paint or anodizing from the tube where the clamp will attach. This will ensure a low-resistance connection.

Interior tube assemblies may require a protective finish of two coats of zinc chromate, using application techniques as specified in a MM. Protective finishes for exterior tube assemblies should be the same as for exterior aircraft surfaces.

Identification

Fabricated tube assemblies should be identified before installation or storage. All information from the identification tag of the removed tube assembly should be transferred to the tag on the replacement tube assembly. Identify the tube assemblies by ink stamping or stenciling the part number, manufacturer's code, and other required data on tube assemblies. Apply a protective coat of clear varnish over the markings. To aid in the rapid identification of the various tubing systems and operating pressure, each fluid line in the aircraft is identified by strips of tape around the line near each fitting.

These identifying media are applied at least once in each compartment. Identification tapes are applied to all lines less than 4 inches in diameter except cold lines, hot lines, lines in oily environment, and lines in engine compartments where there is a possibility of the tape being drawn into the engine intake. In these cases, and all others where tapes should not be used, painted identification is applied to the lines.

Identification tape codes indicate the function, contents, hazards, direction of flow, and pressure in the fluid line. These tapes are applied in accordance with FAA regulations and MIL-STD-1247C. This military standard was established to standardize fluid line identification throughout the aviation industry.

The function of a line is identified by use of a tape, approximately 1 inch wide, upon which words, colors, and geometric symbols are printed. Functional identification markings, as provided in MIL-STD-1247C, are the subject of international standardization agreements. Any tube that carries physically dangerous material will additionally be marked with tape displaying the letters PHDAN.

The function of the line is printed in English across the colored portion of the tape. Even a non-English-speaking person can troubleshoot or maintain the aircraft if he or she knows the code but cannot read English. The right-hand one-fourth of the functional identification tape contains a geometric design rather than the color(s) or word(s). Figure 8-1-16 shows the different tapes used in identifying tubing.

For convenience in distinguishing one hydraulic line from another, each line may be designated as to its function within the system. In general, the various hydraulic lines are designated as follows:

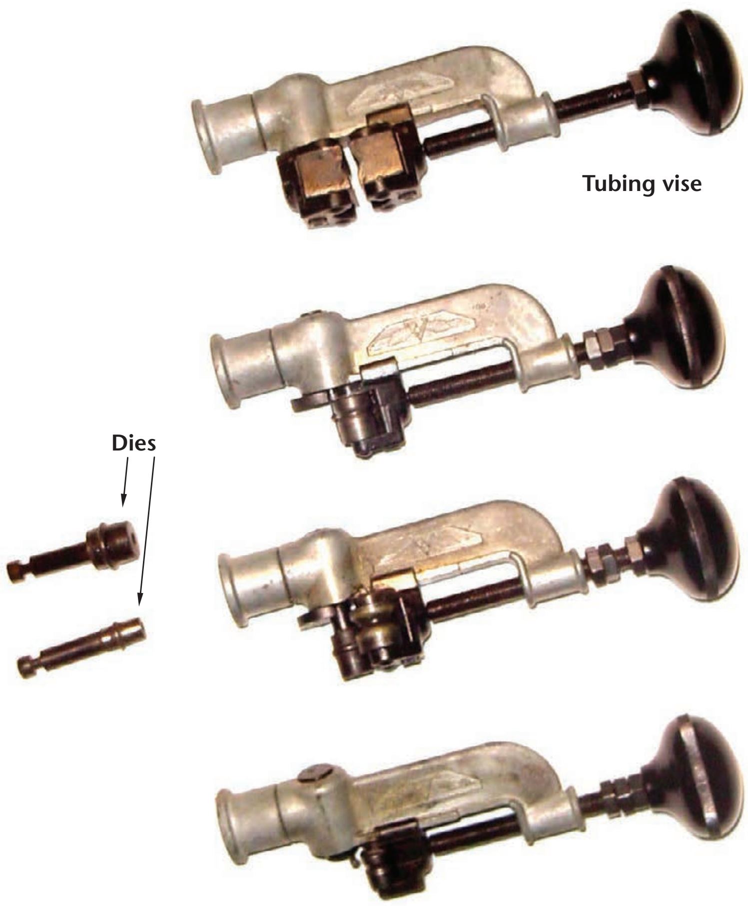


Figure 8-1-15. A beading tool set includes different tools for diferent sizes of tubing. One of the tools is a tubing vise.

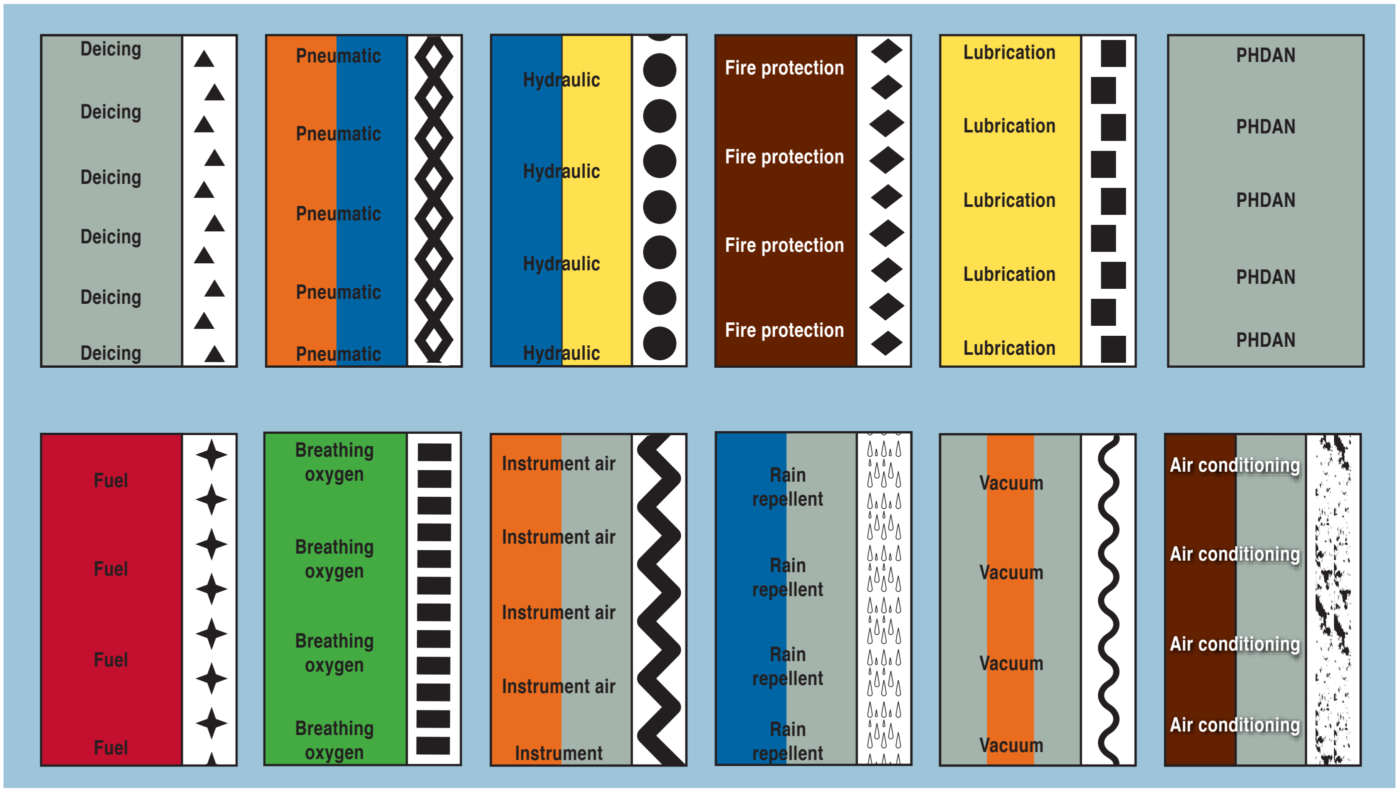


Figure 8-1-16. Color-coded functional identification tapes.

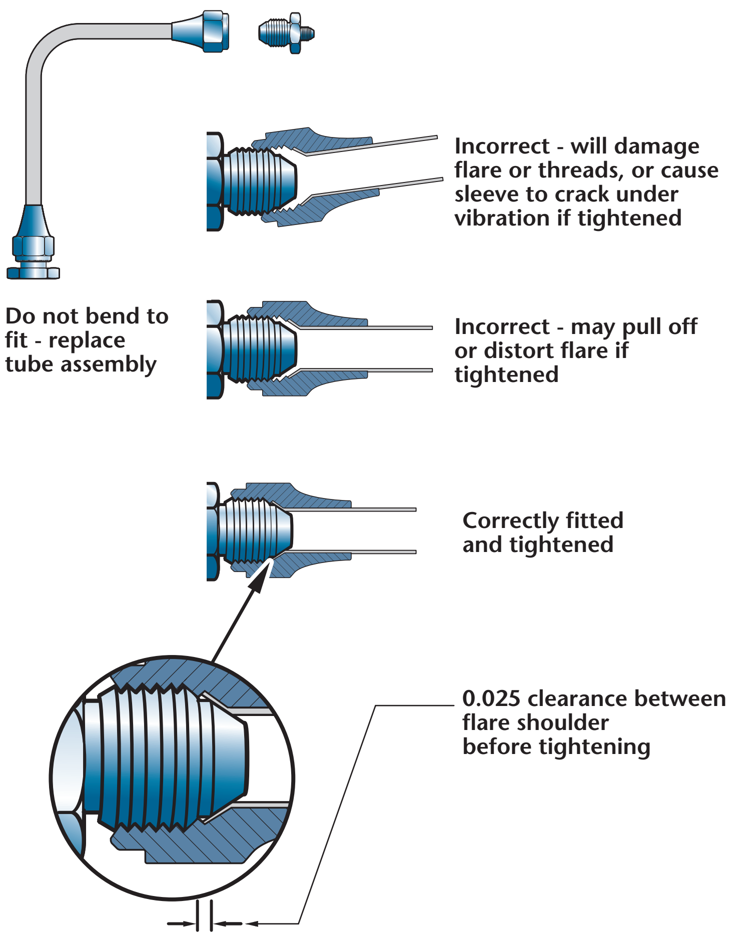


Figure 8-1-17. Correct and incorrect methods of installing flared fittings.

- **Supply lines.** Lines that carry fluid from the reservoir to the pumps are called supply (or suction) lines.
- **Pressure lines.** Lines that carry only pressure are called pressure lines. Pressure lines lead from the pumps to a pressure manifold, and from the pressure manifold to the various selector valves, or they may run directly from the pump to the selector valve.
- **Operating lines.** Lines that alternately carry pressure to an actuating unit and return fluid from the actuating unit are called operating lines, or working lines. Each operating line is identified in the aircraft according to its specific function; for example, LANDING GEAR UP, LANDING GEAR DOWN, FLAPS UP, FLAPS DOWN, etc., as the case may be.
- **Return lines.** Lines that are used to return fluid from any portion of the system to the reservoir are called return lines.
- **Vent lines.** Lines that carry excess fluid overboard or into another receptacle are called vent lines.

Storage

Fabricated tubing and tube assemblies requiring storage for any length of time should be provided with protective closures at each end. Do not use pressure-sensitive tape as a substitute for protective closures. Oxygen tube assemblies require protection of the entire assembly in addition to protective closures at end fittings.

Tubing and Tube Assemblies Maintenance

Maintenance of tube assemblies is limited to inspection, removal, installation, repair, and replacement. Inspections are performed during fabrication, installation, and on in-service equipment. During fabrication, inspect bulk tubing and fittings before and during fabrication of a tube assembly. Before replacing a defective tube assembly, find the cause of failure, and inspect the tube assembly before and after its installation.

Inspect in-service tube assemblies at regular intervals in accordance with applicable maintenance instructions. When you inspect the tube and tube assemblies for damage, look for chafing, galling, or fretting, which may reduce the ability of tubing to withstand internal pressure and vibration. Replace tubing that shows visible penetration of the tube wall surface caused by chafing, galling, or fretting.

Tubes that have damage (nicks, scratches, or dents) caused by careless handling of tools are acceptable if they meet the following requirements: Any dent that has a depth less than 20 percent of the tubing diameter is acceptable unless the dent is on the heel of a short bend radius.

A nick or scratch that has a depth of less than 10 percent of the wall thickness of aluminum, aluminum alloy, or steel tubing should be reworked by burnishing with hand tools before it is acceptable. Any aluminum, aluminum alloy, or steel tubing carrying pressures greater than 100 p.s.i. with nicks or scratches greater than 10 percent of wall thickness should be replaced.

Inspect each fitting before it is installed. Any sign of a crack, deep wrench mark, hex shoulders rounded excessively, or any permanent mark in the seal area of the flare, are reasons for rejection. Visually or flow check to make sure that fitting passage or passages are free from obstructions.

Installation

Installation of tube assemblies involves a pre-installation check before tube assemblies can

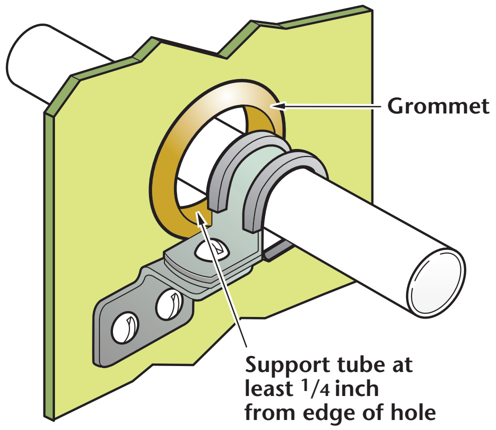


Figure 8-1-18. Cushioned steel clamp MIL-C-85052.

be installed. Before you install tube assemblies, check to make sure there are no dents, nicks, and scratches; that the assembly contains the correct nuts and sleeves; that there is a proper fit, where fitting is flared; that a proof pressure test is performed on each assembly; and that the assemblies are clean.

To install tube assemblies, hand screw the nuts onto mating connectors. Align the tube assembly in place so that it will not be necessary to pull it into place with the nut. Tubing that runs through cutouts should be installed to avoid scarring when the tubing is worked through a hole. If the tube assembly is long, tape the edge of cutouts before installing the assembly. Torque the nuts. Apply a protective coating to the remaining non-sealed joints after tubing is installed. For disconnected non-sealed joints, apply MIL-S-8802, followed by appropriate paint system, if required. Correct and incorrect flared tube assemblies are shown in Figure 8-1-17.

Leakage of a flared tube assembly is usually caused by the following:

- Flare distorted into the nut threads
- Sleeve cracked
- Flare out of round
- Flare cracked or split
- Inside of flare rough or scratched
- Connector mating surface rough or scratched
- Connector threads or nuts are dirty, damaged, or broken

CAUTION: If an aluminum alloy flared tube assembly leaks after it has been tightened to the required torque, disassemble it for repair or replacement. If a steel flared tube assembly leaks, it can be tightened one-sixteenth turn beyond the noted torque. If the assembly continues to leak, it should be disassembled for repair or replacement. Do not tighten a nut when there is pressure in the line. Do not overtighten a leaking aluminum alloy assembly. Overtightening may severely damage or cut off tubing flare or damage sleeve or nut.

When you install flareless tube assemblies, proceed as follows:

- Make sure no nicks or scratches are evident and the sleeve is preset. Tighten the nut by hand until resistance to turning develops.
- If it is impossible to use fingers to run nut down, use a wrench.
- Look out for the first signs of bottoming.
- Do not use pliers to tighten tube connectors.
- Final tightening should begin at the point where the nut begins to bottom.
- Use a torque wrench if fitting is accessible and torque the fitting.
- Loosen and completely disconnect the nut if the leak continues. Replace the nut and retorque. If the fitting still leaks, something needs to be replaced.
- Inspect fitting components for scores, cracks, foreign material, or damage from previous overtightening.
- Reassemble fitting.
- Finger tighten nut and repeat wrench tightening. It is important to tighten tube fitting nuts properly.
- A fitting wrench or an open-end wrench should be used when tightening connections.

All hydraulic tubing should be supported from rigid structures by cushioned steel clamps MIL-C-85052 or multiple tube block clamps (Figure 8-1-18). Hydraulic tubing support clamps should be installed and maintained in the positions described in the MM.

Unless otherwise specified, where tubing is supported to structure or other rigid members, a minimum clearance of 1/16 inch or where related motion of adjoining components exists, a minimum clearance of 1/4 inch is to be maintained. Table 8-1-5 shows the maximum allowable distance between supports. Flexible grommets or hose should be used at points where the tubing passes through bulkheads.

Repair

Tube repair is divided into two categories: temporary and permanent. Temporary repairs are made with splice sections fabricated with flared ends or preset MS sleeves. The splice sections

Tubing outside diameter (in inches)	Distance between supports (in inches)	
	Aluminum alloy	Steel
1/8	9-1/2	11-1/2
3/16	12	14
1/4	13-1/2	16
5/16	15	18
3/8	16-1/2	20
1/2	19	23
5/8	22	25-1/2
3/4	24	27-1/2
1	26-1/2	30-1/2
1-1/4	28-1/2	31-1/2
1-1/2	29- 1/2	32-1/2

Table 8-1-5. Maximum distance between supports for aluminum tubing.

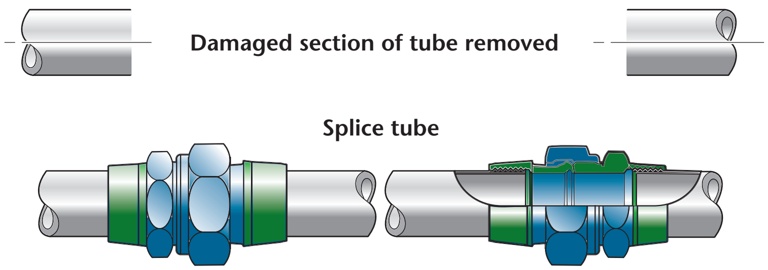


Figure 8-1-19. Temporary tubing repair.

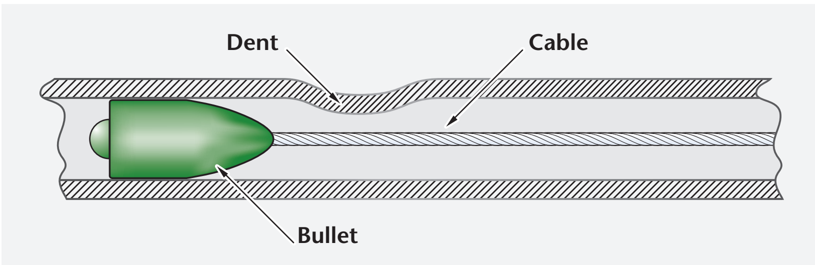


Figure 8-1-20. This method of removing small dents requires that the bullet can enter and exit both ends of the tubing.

Figure 8-1-21. Fitting damaged by abrasion to the point it is unuseable.

are to be replaced by a permanent repair or new tubing assembly at the next major inspection. Temporary or emergency repairs should be limited to cases that are due to unavailability of equipment, material, or unusual circumstances. (Figure 8-1-19).

Cut and remove the damaged section of tubing. Remove the rough edges of the remaining tube ends. Clean the tubing ends with a lint-free wiping cloth. Position the AN818 nuts and AN819 sleeves on the tubing ends. Flare the tubing. Install AN815 unions. Position the AN818 nuts and AN819 sleeves on the new section. A new section is not required when the length of the union is longer than the damaged section. Install the new section of tubing and tighten the AN818 nuts.

Some minor surface damages to tubing are acceptable, as described in inspection of tubing damage. A nick that is not deeper than 10 percent of the wall thickness of aluminum, aluminum alloy, or corrosion-resistant steel is acceptable after being reworked by burnishing with hand tools. Small dents may sometimes be removed by drawing a die, called a bullet, through the tube (Figure 8-1-20).

Damaged fittings. Figure 8-1-21 shows typical fitting damage caused by abrasion. This type of damage is not repairable. Most aircraft manufacturers do not have, or do not publish, standards for repair of damaged fittings. Fittings that are damaged should be replaced. Attempting to use a damaged fitting because "it doesn't look that bad" will, in the long run, cause increased maintenance expenses down the road. Not to mention the fact that it might not be legal.

Section 2

Hose Fabrication and Maintenance

A corporate or airline type aircraft may have hundreds of feet of fluid and air lines and various hardware and seals. The maintenance of these lines frequently involves fabrication and replacement of hose and hose assemblies. To be able to select the proper type of hose and hose assemblies and their hardware, you will need a basic knowledge of the type, size, and material from which items are to be made.

Hose and Hose Assemblies

Hose assemblies are used to connect moving parts with stationary parts and in locations subject to severe vibration. Hose assemblies are heavier than aluminum-alloy or CRES tubing and deteriorate more rapidly. They are used only when absolutely necessary. Hose assemblies are made up of hose and hose fittings. A hose consists of multiple layers of various materials. An example of the hose most often used in medium-pressure applications is shown in Figure 8-2-1.

Types of Hose

There are two basic types of hose used in aircraft and related equipment. They are synthetic rubber and polytetrafluoroethylene, commonly known as Teflon®, or PTFE. Bulk hose identification will vary with the materials from which the hose is constructed. PTFE hose is compatible with phosphate ester hydraulic fluid.

Synthetic rubber hose. Synthetic rubber hose has a seamless synthetic rubber inner tube covered with layers of cotton and wire braid and an outer layer of rubber impregnated cotton braid. The hose is provided in low-, medium-, and high-pressure types. Synthetic rubber hose (if rubber-covered) is identified by the indicator stripe and markings that are stenciled along the length of the hose. The indicator stripe (also called the lay line because of its use in determining the straightness, or lie, of a hose) is a series of dots or dashes. The markings (letters and numerals) contain the military specification, the hose size, the cure date, and the manufacturer's identification. The lay line and identification marks may be colored white, yellow, or red. This information is repeated at intervals of 9 inches (Figure 8-2-1).

Size is indicated by a dash followed by a number (referred to as a dash number). The dash number does not denote the inside or outside diameter of the hose. It refers to the equivalent outside diameter of rigid tube (sized in sixteenths (1/16) of an inch) with which the hose is used. A dash 8 (-8) mates to a number 8 rigid tube, which has an outside diameter of one-half inch (8/16). The inside of the hose is not one-half inch, but slightly smaller to allow for tube thickness.

The cure date is provided for age control. It is indicated by the quarter of the year and year. The year is divided into four quarters.

- 1st quarter — January, February, March
- 2nd quarter — April, May, June
- 3rd quarter — July, August, September
- 4th quarter — October, November, December
- An example of the date marking would be 2Q06

Synthetic rubber hose (if wire-braid covered) is identified by bands wrapped around the hose at the ends and at intervals along the length of the hose (Figure 8-2-2). Each band is marked with the same information as is marked on the hose.

Teflon hose. The Teflon hose is made up of a tetrafluoroethylene resin, which is processed and extruded into a tube shaped to a desired size. It is covered with stainless steel wire, which is braided over the tube for strength and protection. The advantages of this hose are its operating temperature range, its chemical inertness to all fluids normally used in hydraulic and engine lubrication systems, and its long life. Teflon hose is normally only available in medium-pressure or high-pressure types. These are complete assemblies with factory-installed end fittings. The fittings may be either the detachable type or the swaged type. When failures occur, replacement should normally be made on a complete assembly basis.

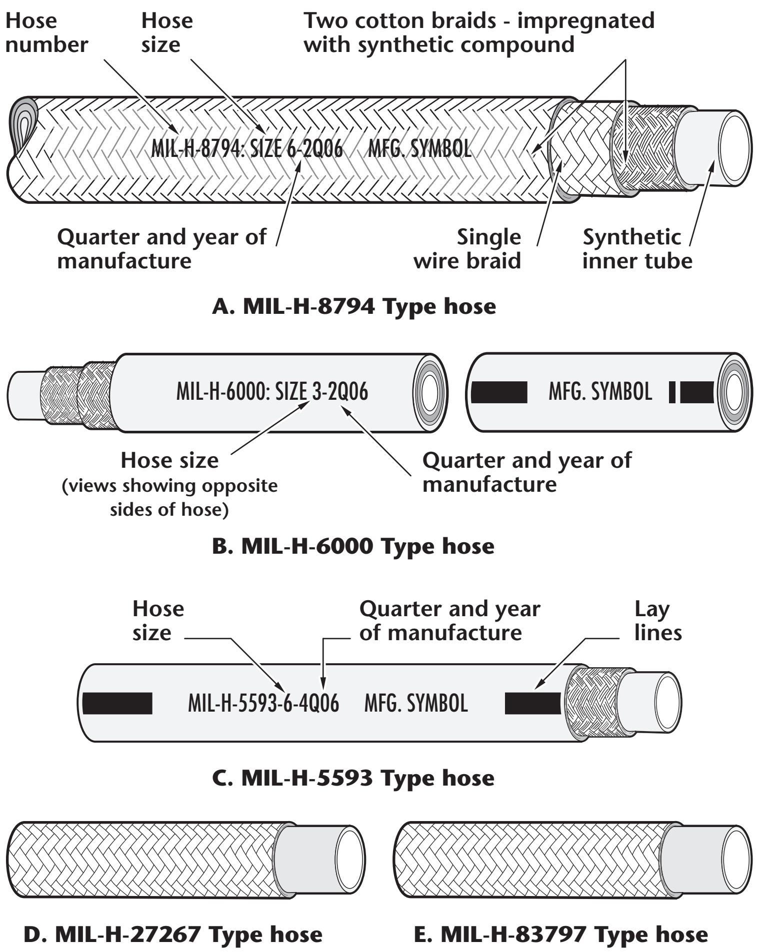


Figure 8-2-1. Medium pressure synthetic rubber hoses.

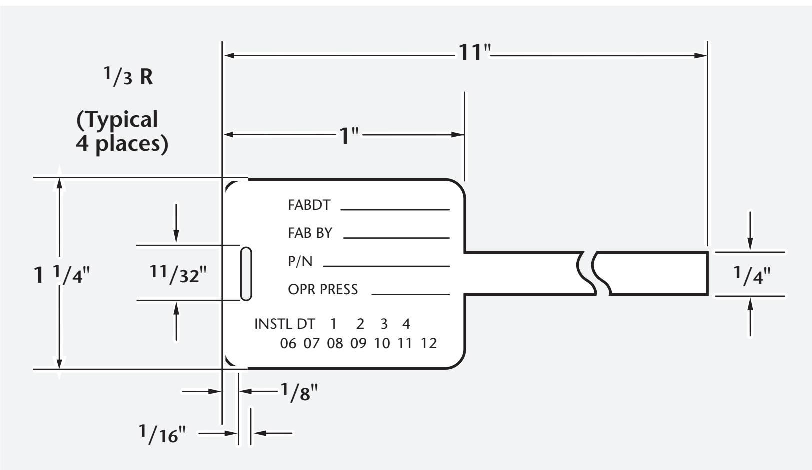


Figure 8-2-2. Wire-covered hose identification band.

Figure 8-2-3. Identification band on wire braid-covered hose assembly.

Teflon hose is identified by metal bands or pliable plastic bands at the ends and at 3 foot intervals. These bands contain the hose military specification number, size indicated by a dash (-) and a number, operating pressure, and the manufacturer's identification (Figure 8-2-3).

Hose Assembly

Hose fittings are designed and constructed in accordance with Military specifications (Mil. spec.) and standard drawings for particular hose configurations and operating pressures. Fittings designated by a military standard drawing number have a particular dash number to indicate size. The fitting dash number does not designate a size in the same manner as a hose dash number. The fitting dash number corresponds to the dash number of the hose so that both will match at the critical dimensions to form a hose assembly.

Materials used in the construction of fittings vary according to the application. Materials include aluminum, carbon steel, and corrosion-resistant steel. Fittings that qualify under one Mil. spec. may be produced by several manufacturers. Two methods or styles are used to secure the hose fitting to the hose. They are the reusable and swage, or crimp, style.

Reusable style Teflon hose. The preferred reusable style has modified internal threads in the socket to grip the hose properly. The fitting can be disassembled from a hose assembly and reused on another hose, provided it passes an inspection for defects. Reusable style fittings are authorized replacement fittings for replacement hose assemblies.

Swage (crimp) style. Some hose assembly manufacturers use a swage, or crimp, style. This style requires the socket to be permanently deformed by an electric- or hydraulic-powered machine. The deformed socket and related hardware are to be scrapped after they are replaced.

Hose Fittings

Hose fittings are assemblies of separate parts. These parts are the nipple, the socket, the swivel nut or flange, and the sleeve. The nipple is the part that fits the inside diameter of the hose. Nipples have three configurations for the hose-to-tube or component surface-sealing portion. They are the flared, flareless, and flanged configurations. The socket fits over the outside diameter of the hose and secures one end of the nipple to the hose. The swivel nut or flange secures the other end of the nipple to the mating connection in the fluid system. Figure 8-2-4A, 8-2-4B, and 8-2-4C show typical hose end fittings.

For Teflon hose, some manufacturers have a sleeve in addition to the nipple, socket, and nut or flange. Each manufacturer may have unique characteristics and tolerances that prevent interchangeability between parts. Do not intermix nipples and sockets from one manufacturer to another.

Hose fittings are identified by applicable Mil. spec. and manufacturer's name or trademark on fittings and nuts. Flared or flareless fittings and nuts are color coded to show materials or hose fittings and sleeves (Table 8-2-1).

All hose assemblies are identified by tags, bands, or tapes (Figure 8-2-5). Some identifications are permanently marked while others are removable. Removable tags, bands, or tapes should not be installed on hose assemblies located inside fuel and oil tanks or in areas of an aircraft where tags, bands, or tapes could be drawn into the engine intake. Hose assemblies are either commercially manufactured or locally fabricated.

Commercially Manufactured Hose Assemblies

Commercially manufactured hose assemblies are made from synthetic rubber or Teflon. The assemblies are identified by a band near one end of the assembly. This band identities the assembly manufacturer's code or trademark and Mil. spec. part number, including dash size, operating pressure (in pounds per square inch, p.s.i.), date of assembly (in quarter and year), hose manufacturer identification (if different from assembly manufacturer), and the cure date of the hose manufacturer (in quarter and year).

The assembly date is indicated by the letter A, followed by the quarter of the year, the letter Q, and ends with the last two digits of the year. For example, hose assemblies fabricated during June 2006 are marked A2Q06. When a decal or band is used that states "assembly date," the A may be omitted. Assembly date information is also indicated on the unit and its packaging.

Commercially manufactured Teflon hose assemblies are identified by a permanently marked and attached band on the assembly. The band contains the assembly manufacturer's name or trademark; hose manufacturer identification; hose assembly part number; operating pressure in p.s.i., pressure test symbol (PT), and the date of hose assembly manufacture (in month and year). It is best NOT to remove the tags or you will lose all identification for that hose assembly.

Use labels to identify hose assemblies located in areas where a tag may be drawn into an engine intake or where hose assemblies are covered

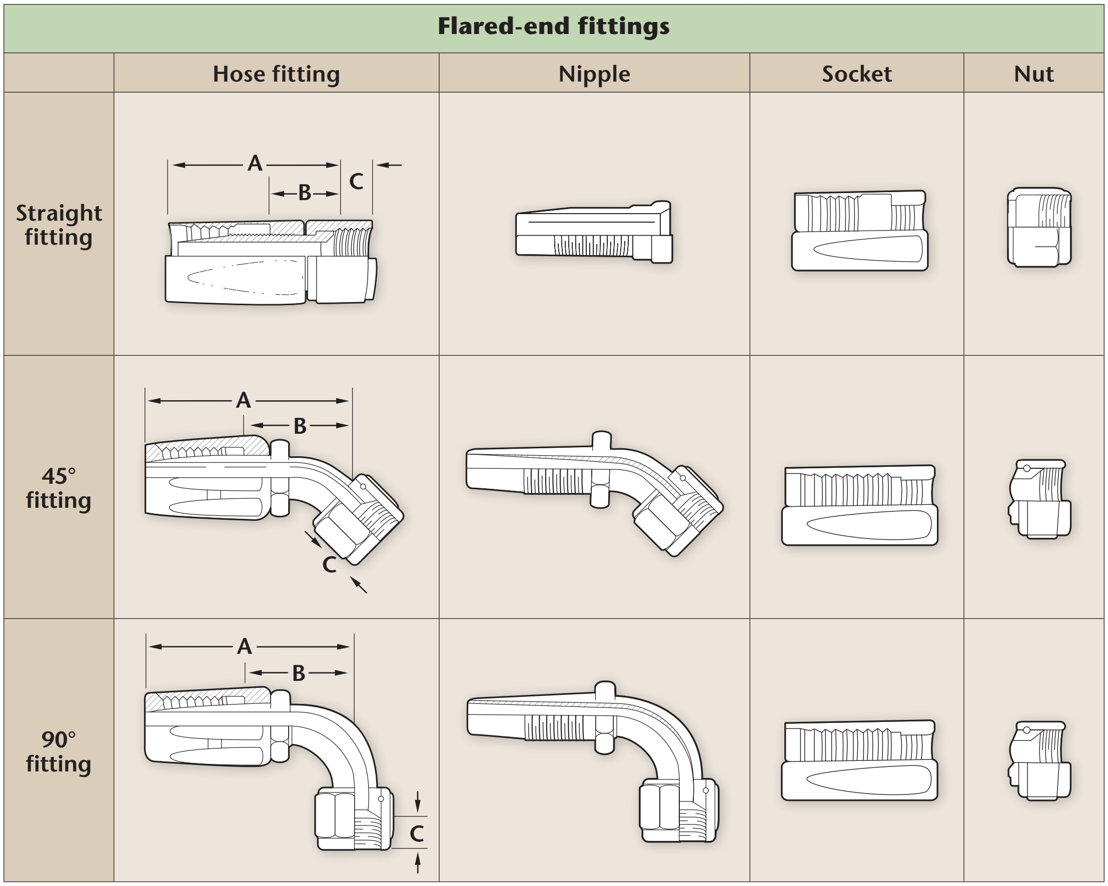


Figure 8-2-4A. Flared-end fittings.

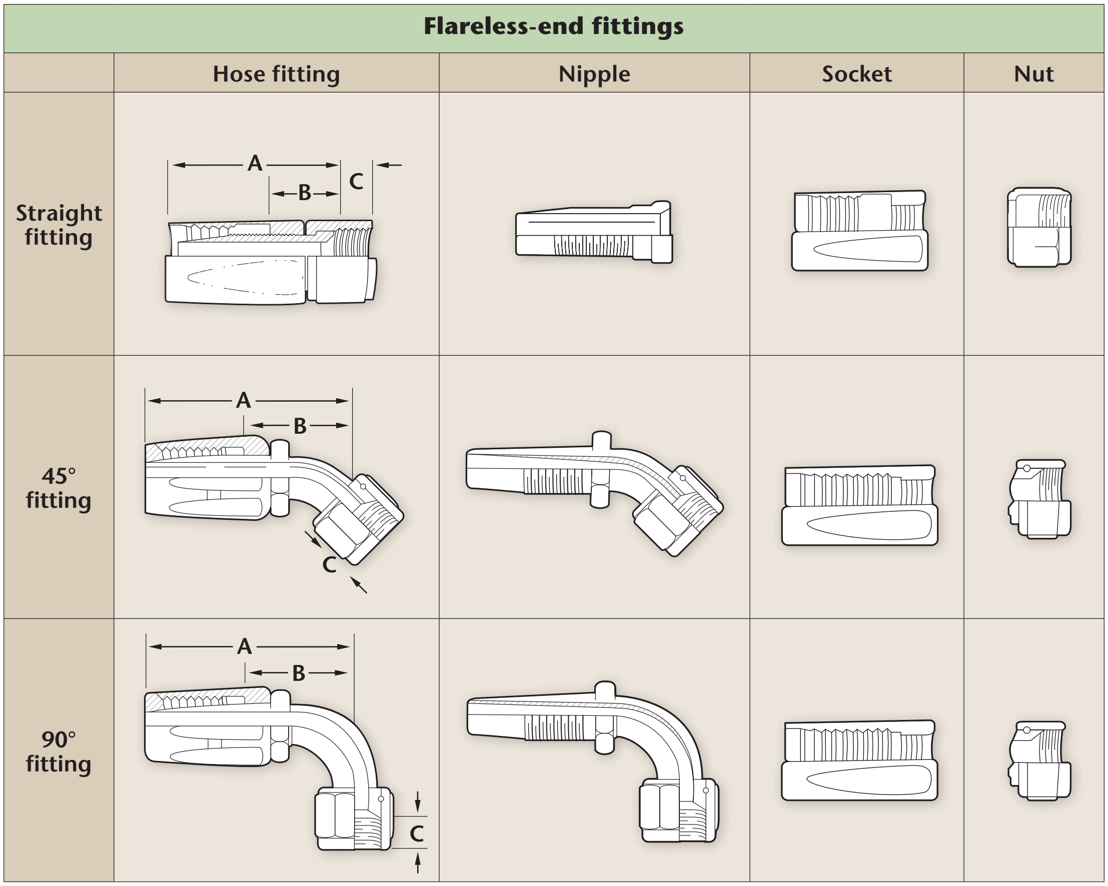


Figure 8-2-4B. Flareless-end fittings.

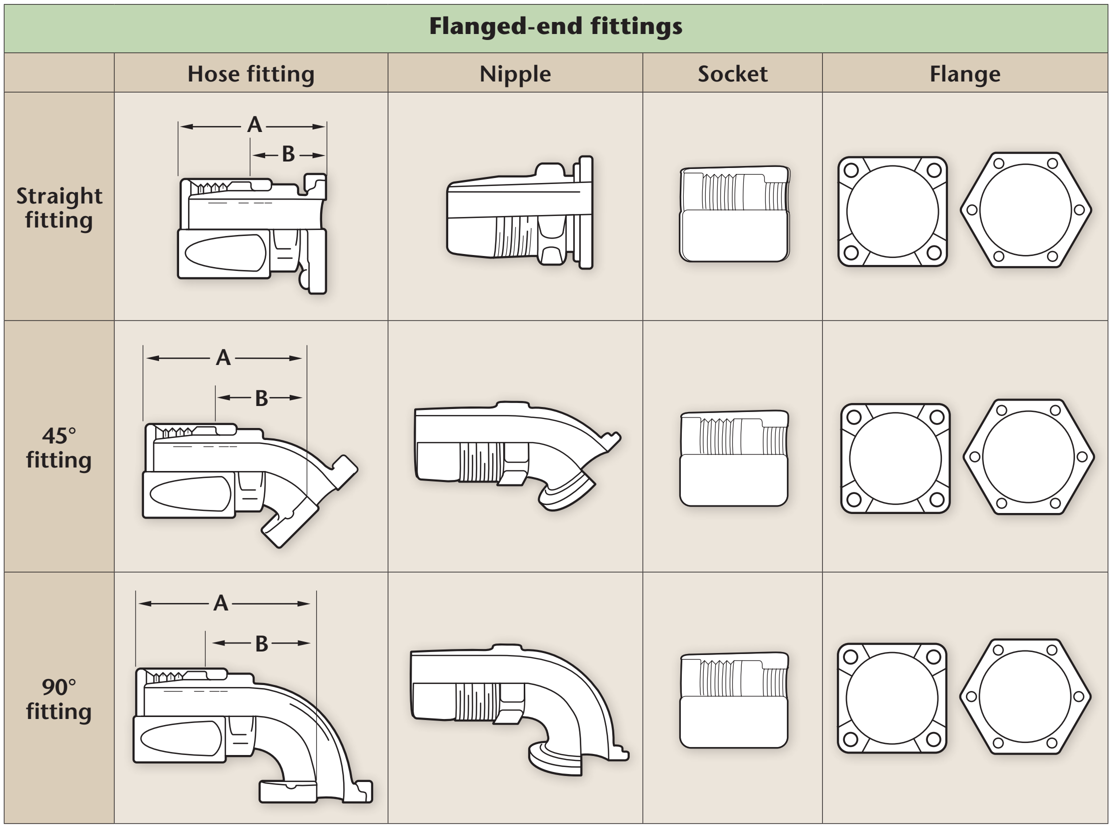


Figure 8-2-4C. Flanged-end fittings.

Flared fittings MIL-F-5509	Color	Material code
Aluminum alloy 2014 and 2024(1)	Blue	D (Optional)
Aluminum 7075(1)	Brown	W(T-73)
Steel	Black	
Copper based alloys	Natural cadmium plate (if applicable)	
Corrosion resistant steel	None	
Class 304		J
Class 316		K
Class 347		S
Titanium alloys	Gray	T

Table 8-2-1. Hose fitting color and material code.

with heat-shrinkable tubing. Place the label 1 inch from the socket and apply a 2-1/2 inch piece of clear, heat-shrinkable tubing, MIL-R-46846, type V, over the label and hose. Function and hazard labels can be applied in the same manner as described above.

Fabrication

Fabricating hose assemblies from bulk hose and reusable end fittings requires some basic skills and a few hand tools. The skills required are the ability to follow step-by-step instructions and to use the required hand tools.

Equipment and tools. The basic hand tools that are required to fabricate hose assemblies up to

	Fitting P/N	Hose size (dash number)										
		-3	-4	-5	-6	-8	-10	-12	-16	-20	-24	-32
Straight flared	MS27616		0.92		1.02	1.06						
	MS27053	0.70	0.74	0.77	0.81	0.93	1.05	1.13	1.30	1.44	1.66	
	MS28760		0.79		0.99	1.10	1.19	1.35	1.59			
	MS18085	0.42	0.41	0.42	0.47	0.58	0.63	0.61	0.67	0.79	0.86	
	MS24587	0.60	0.60	0.70	0.77	0.94	1.00	1.00	0.94	0.99	1.09	1.24
	MS27404		0.46		0.55	0.68	0.73					
	MS87018	0.64	0.65	0.70	0.76	0.94	0.99	1.00	1.16	1.34	1.44.	1.62
	MS83798/1	0.74	0.74	0.76	0.84	0.97	1.05	1.11	1.34	1.54	1.70	
NOTES: Cut-off factor for one fitting.												

Table 8-2-2. Hose cutoff factor (in inches).

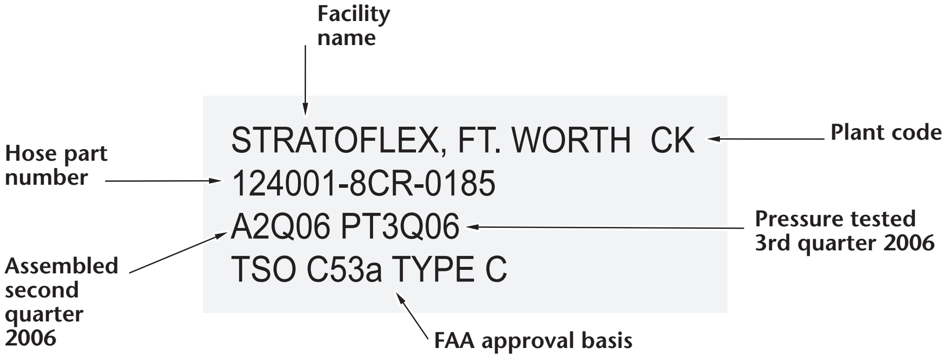


Figure 8-2-5. Hose assembly identification tags.

3,000 p.s.i. operating pressure are a bench vise, a hose cutoff machine, open end wrench sets, a sharp knife, slip joint pliers, an oil can for lubricating oil, a marking pencil, a small paint brush, masking or plastic electrical tape, a steel ruler, a thickness gauge (leaf type), and a protractor.

Mandrels are special hand tools (Figure 8-2-6) that are not required but are recommended for fabricating hose assemblies. During hose assembly fabrication, mandrels can be used to protect sealing surfaces, support inner tubes, and guide fitting nipples into hoses.

The use of a mandrel also reduces the possibility of damaging the hose during installation of the nipple. If the nipple is misaligned it will cut a shaving from the inside of the hose. A common, and potentially very dangerous, method of removing the cut piece of rubber is to take a piece of rod or tubing and try to poke it loose. During this process a flap of hose liner can be cut without ever knowing or seeing it. The hose then contains a one-way flapper valve that is waiting to create a failure of fluid flow.

Procedures. When failure occurs in a flexible hose equipped with swaged end fittings, the unit is generally replaced without attempting a repair. The correct length of hose, complete with factory-installed end fittings, is ordered from a supplier or drawn from inventory.

When failures occur in hose assemblies equipped with reusable style end fittings, the fabrication of the replacement unit is the function of the Aviation Maintenance Technician. Undamaged end fittings on the old length of hose may be removed and reused; otherwise, new fittings must be drawn from inventory along with a sufficient length of hose.

The first step is to determine the necessary hose size and length from Table 8-2-2 and Figure 8-2-7. Once the hose length is determined, add 5 to 8 percent to allow for expansion or contraction from both temperature changes and pressure

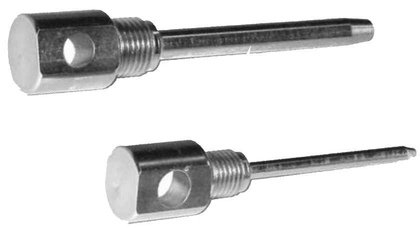


Figure 8-2-6. Mandrel kit.

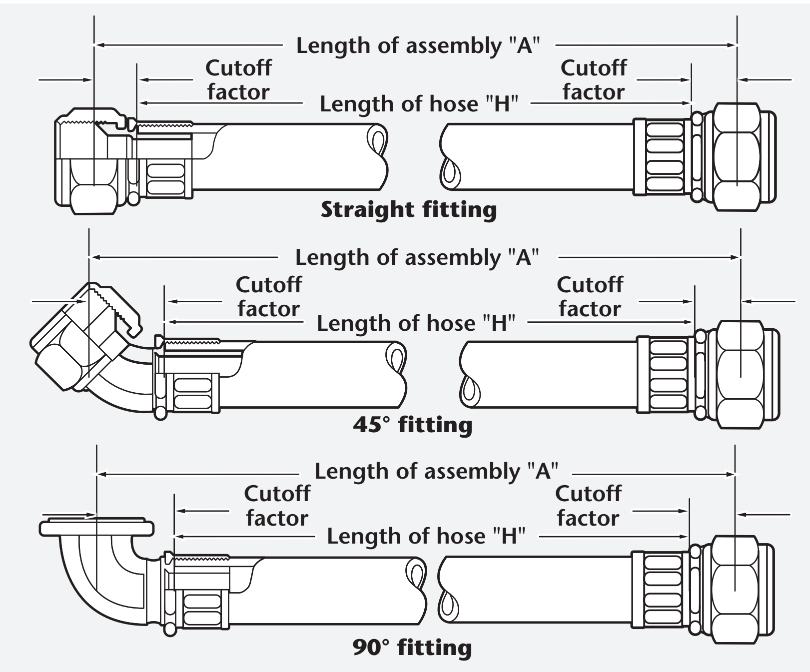


Figure 8-2-7. Determining hose assembly length.

application. Wrap the circumference of the hose with masking or plastic electrical tape at the cutoff to prevent flare-out of braid if the hose outer cover is wire braid. Hose with rubber or fabric outer cover does not require wrapping with tape. Measure the hose to the required length and cut off the required length, making sure it is square, using a cutoff machine. Blow the hose clean with filtered shop air after cutting. Remove the tape and the clamp socket in a vise (Figure 8-2-8).

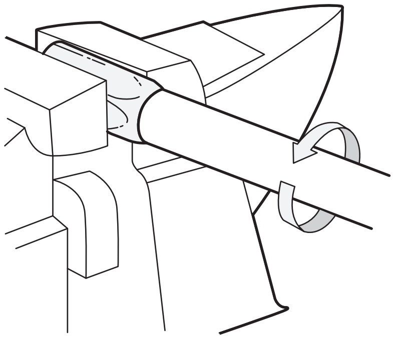


Figure 8-2-8. Hose insertion.

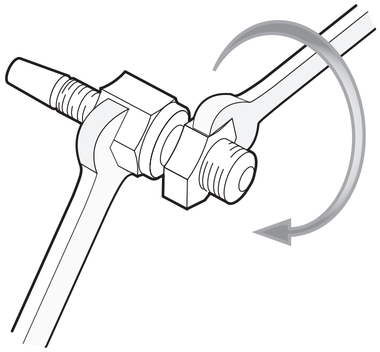


Figure 8-2-9. Nipple and nut assembly.

Do not overtighten a vise on thin-walled lightweight fittings. Screw the hose counterclockwise into the socket using a twisting, pushing motion until the hose bottoms on the socket shoulder. Back the hose out 1/4 turn. Assemble the nipple and nut with a standard adapter of the same size and thread. Lubricate the inside bore of the hose and the outside surface of the nipple with hydraulic fluid, MIL-H-5606, MIL-H-83282, or MIL-H-6083.

Clamp the socket with the hose into a vise. Insert the nipple assembly into the hose and socket by using a wrench on the hex of the insertion tool. Turn the nipple assembly clockwise until the nut-to-socket gap is between 0.005 and 0.031 inch. The gap allows the nut to turn freely about its axis (Figure 8-2-9). Remove the insertion tool from the assembly. Repeat the procedure for hose assemblies with straight fittings on both ends.

Preformed Hose Assemblies

Medium-pressure Teflon hose assemblies are sometimes preformed to clear obstructions and to make connections using the shortest possible hose length. Since preforming permits tighter bends that eliminate the need for special elbows, preformed hose assemblies save space and weight. Preformed hose assemblies must be procured from a qualified commercial source.

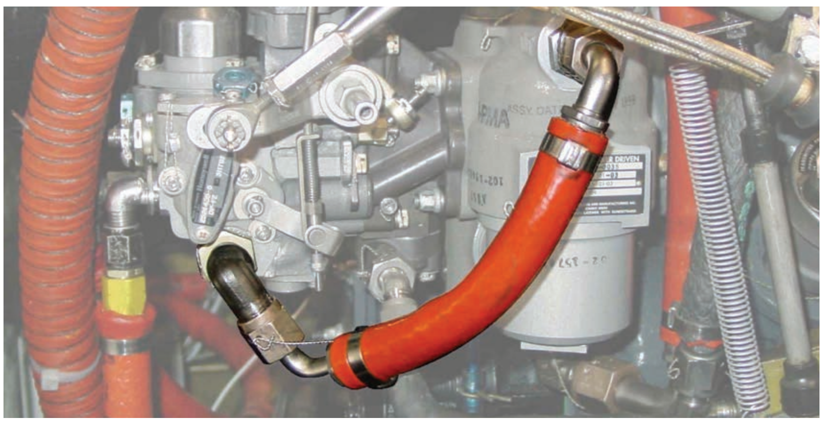


Figure 8-2-10. Firesleeve.

Protective fire sleeves. Some hose assemblies are located in areas (i.e. engine compartments, nacelles, and some wheel wells) where temperatures exceed the capabilities of the hose material. The FAA requires that protective fire sleeves should be installed (Figure 8-2-10) over these hose assemblies. Fire sleeves do not increase the service temperature of hoses, but protect the hose from direct fire long enough to allow the appropriate action to be taken. The sleeve is composed of fiberglass. It is impregnated and overlaid with a flame-resistant silicone rubber.

> **CAUTION:** Hose ends may be salvaged from old hoses. They are perfectly good to use if they pass an inspection. However, if the salvage hose is more than 20 years old and has a firesleeve, there is a chance the firesleeve could contain asbestos. Be sure you know the difference before you start dismantling a hose of unknown age.

Cleaning. Fabricated hose assemblies should be cleaned and visually inspected for foreign material before and after proof testing. Cleaning should be done with an approved cleaning fluid or a detergent solution.

In cleaning hose or hose assemblies, the cleaning procedures used depend upon the cleaning material selected for. Normally each manufacturer will specify approved cleaning materials. These should be listed in the MM under ATA 20-30-00. Do not use commercial soaps and cleaners unless they are specifically approved by the airframe manufacturer. To do so may risk the possibility of damage to the hose material.

Cleaning oxygen hoses. Almost all manufacturers that use a piped oxygen system will have very specific instructions that apply to hose and tube replacement, testing, cleaning, as well as storage. ALWAYS refer to these instructions.

Proof pressure testing. Observe all safety rules when you proof pressure test hose assemblies, and proceed as follows to proof pressure test hose assemblies.

Clean hose assembly. Select test media from Table 8-2-3. Select proof pressure. Test one hose assembly at a time. Several hose assemblies that require the same proof pressures may be tested together, if they are connected in series with adapters.

Unless otherwise directed, a manifold hose assembly that contains different sizes or types of hose will be tested at the lowest proof pressure required by any one size or type contained in the manifold. Arrange hose assemblies as close to the horizontal position as possible. Allow trapped air to escape when testing hose assemblies in a liquid test medium.

When testing an air or gas medium, test hose assemblies underwater so that trapped air can escape from the hose's braided outer covers. Hose assemblies with a fire sleeve do not require the underwater test. Tighten the pressure cap. Apply proof pressure for a minimum of 30 seconds, but no longer than 5 minutes. Check leakage while maintaining proof pressure.

After the completion of the proof pressure test, drain the hose assembly and clean. Install the protective closures. Install the identification tag. Prepare the hose assembly for installation or storage.

Pressure Test Stands

As previously stated, all flexible hose manufactured in the shop must be hydraulic or pneumatic pressure tested prior to installation in the aircraft.

Some aircraft manufacturers may give standard pressures for testing; most refer to FAA specifications. Advisory Circular 43.13-1B states that fabricated hoses must be tested to 1.5 times system pressure. A new commercially fabricated hose assembly can be operationally checked after installation in the aircraft by using system pressure in lieu of pressure testing.

Most maintenance facilities have an existing method of testing assembled hoses. Be sure to get checked out on it's operation and follow all safety procedures. Any hose assembly failing the pressure test can be very dangerous to personnel and property.

Hose and Hose Assembly Maintenance

Maintenance of hose and hose assemblies at the shop level is limited to contamination control, preventive maintenance, removal, installation, or replacement. Proper maintenance practices can minimize the problems that might occur with regard to hose and hose assemblies.

Hose type	Test media
Hydraulic	Water, MIL-H-5606 or Skydrol 500 B-4, type II
Pneumatic or gaseous	Water, MIL-H-5606, nitrogen (clean, dry and oil-free), air (clean, dry and oil-free) or MIL-H-46170, type II
Oil	Water or nitrogen (clean, dry and oil-free)
Coolant	Water
Fuel (non-self-sealing)	Water, MIL-H-5605 or Skydrol 500 B-4, type II
Fuel (self-sealing)	Water, air (clean, dry and oil-free) or nitrogen (clean, dry and oil-free)
Air	Water or air (clean, dry and oil-free)
Instrument	Water or nitrogen (clean, dry and oil-free)

Table 8-2-3. Proof pressure test media.

Maintenance Practices

Do not use hose or hose assemblies as foot or hand holds. Do not lay hose or hose assemblies where they may be stepped on or run over by vehicles. Do not lay objects on hose or hose assemblies. Turn the swivel nut when loosening or tightening fittings. Hold the socket only to prevent the hose assembly from turning. Perform all necessary turnoff or shutdown procedures as outlined in the applicable maintenance instruction manuals before removing any hose or hose assembly. Cover open ends of hose, hose assemblies, and fittings with protective closures. Make sure hose, hose assemblies, and connection points are cleaned before installing.

Preventive maintenance. Preventive maintenance consists of periodic inspection and correction of hose and hose assembly faults. In this process, you must check for leaks, wear, and deterioration. Special attention must be paid to hose or hose assemblies and clamps.

Checking for leaks. Hose or hose assemblies should be replaced when leaks are found to be caused by damage to any part of a hose or hose assembly; poor seating or damaged threads of the socket or nipple assembly, which causes the fitting to leak; or excessive torque. If a leak appears in the swivel nut area, check that the swivel nut is properly torqued. If necessary, disconnect the fitting and check for contamination or damage. If the leak persists after cleaning and the swivel nut is properly torqued, replace the hose assembly. If that doesn't work, replace the fitting.

Checking for wear and deterioration. Check hose and hose assemblies for signs of wear and deterioration. Replace any hose or hose assembly when a chafe guard appears worn or shows signs of cracking; when a fire sleeve is worn through, torn, cut, or oil soaked; when a hose or hose assembly has weather protective coatings or sleeves that are worn, cracked, or torn, thus exposing the hose or hose assemblies to corrosion.

Checking hose or hose assembly installations. Check hose or hose assembly installations carefully. Proper routing and clamping is mandatory. If retaining wires on swivel nuts are backed out, replace the hose assembly. Look for kinks or twists. Observe the lay line, if possible. A kinked hose or hose assembly must be replaced. A twisted hose or hose assembly may be relieved by loosening clamps and swivel nuts and then straightening the hose by hand. Retorque the swivel nuts and tighten the clamps. A preformed hose or hose assembly may have a smaller bend radius. Do not attempt to straighten preformed hose or hose assemblies. Excessive bends or signs of chafing may be due to loose, oversize, or worn clamps. Replace oversized or worn clamps, and tighten the clamp without squeezing the hose.

Checking clamps. Check the clamps to make sure they are the correct type and size, that the position of the hose is correct within the clamp, and that the cushion material is positioned correctly. Reposition hose and clamps as needed. Cushion material should NOT lodge between end tabs of a closed clamp. Do not use clamps with fuel-resistant cushioning unnecessarily, as this type of cushioning material deteriorates rapidly when exposed to air.

Removing Hose or Hose Assemblies

Hose or hose assembly removal procedures must include contamination control procedures as well as actual removal procedures to prevent contamination to the opened system.

Contamination control procedures. Perform contamination control procedures before removing any hose or hose assemblies. Use approved solvents and clean, lint-free cloths to clean the affected area and wipe down fittings to remove excessive contaminants. Use a suitable container to catch spilled fluid. Have replacement hose, hose assemblies, or protective closures on hand for installation when disconnecting hose or hose assemblies. If immediate hose replacement is not practical, cap or plug hose or hose assembly ends immediately after disconnecting.

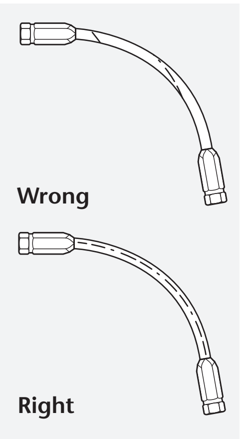


Figure 8-2-11. Hose twist.

Removal procedures. Once contamination control has been accomplished, begin removal of hose and hose assemblies. Remove all supporting clamps from hose or hose assembly. Remove lockwire (if present) from swivel nuts. Turn swivel nuts only to disconnect hose assembly. Loosen nuts carefully to avoid damage. Disconnect the hose assembly by using two open-end wrenches. One is to grip and prevent turning of the fitting to which the hose assembly is connected, and the other is to loosen the swivel nut.

Hose and hose assemblies (particularly Teflon®) have a tendency to become set to shape in service. Some Teflon hose assemblies are deliberately preformed during the fabrication process. Do not attempt to straighten a preformed hose. Protect the preformed areas from distortion by a restrainer. The restrainer may be of wire, metal, plastic forms, or any other suitable device to retain the preformed configuration.

Install the protective closures to seal open parts of hydraulic lines and ends of removed hose or hose assemblies.

Installing Hose or Hose Assemblies

Before beginning installation procedures, there are guidelines to remember about installing hose or hose assemblies. The replacement hose or hose assembly must be a duplicate of the one removed in length, outside diameter, material, type, contour, and associated markings.

Fluid used as a lubricant for fitting installation should be spelled out in the MM. If it is not, use only the fluid that the particular hose will contain. To use anything else is to risk cross contamination. Compatible oil, approved for the purpose, may be used on all other types of fuel, oil, and coolant hose installations.

When installing or handling hose or hose assemblies, it is possible to sustain hand injuries or damage to the hose if it is kinked. Take care to prevent situations where injuries or kinking can occur. A hose that is bent to a smaller radius than specified might cause kinking. Minimum bend radii are contained in either the MM or in FAA AC 43.13-1B.

Also a preformed hose assembly, or one that has become set-to-shape in its operating position, is straightened or handled without a protective restraint, or a hose or hose assembly that is twisted during handling, removal, or installation can easily cause kinking.

Pre-installation procedures. Check hose or hose assembly before installing it to make sure that identification bands and protective closures are present as required after proof pressure testing. Inspect hose for proper type and size and for signs of aging, such as deterioration in the form of cracks, discoloration, hardening, weather checking, or fungus.

Check the braid for broken wires. The hose manufacturers' information will specify an acceptable number of broken wires. Any number above that is cause for rejection. Inspect for broken wires where kinking is suspected. Evidence of internal restriction of tube due to collapse, kinking, wire-braid puncture, or other damage can be found by using one of the following methods of inspection:

- For straight hose assembly, insert a light at one end and visually inspect from the opposite end.
- For elbow fitting on both ends (practical for larger sizes only), insert flexible inspection light into one end and visually inspect from the opposite end using a small, angled, dental-type mirror.
- Inspect for any separation of covers or braids from inner tube, or from adjacent covers or braids.
- Look for flaring or fraying of braid. Look for blisters, bubbles, or bulging. Inspect for corrosion. A hose that has carbon steel wire braid is subject to corrosion, which may be detected as brownish rust coloration penetrating the outer braid.
- Inspect end fittings for proper type and size, corrosion and cleanliness, nicks, scratches, or other damage to the finish that affects corrosion resistance.
- Look for damage to threaded areas, damage to cone-seat sealing surfaces damage to flange fittings, warping of flange, and for nicks or scratches on the sealing surface or gasket.

Installation Procedures. Remove the protective closures from hydraulic lines, hose, or hose assemblies. When possible, install hose or hose assemblies so that identification markings are visible. Install hose or hose assemblies without twisting, chafing, or overbending (Figure 8-2-11). Observe the bend radius. Greater bend radius is preferred where possible. Install hose or hose assemblies with a slight bow or slack to compensate for contraction pressure on the line (Figure 8-2-12).

When connecting hose or hose assemblies to an engine or an engine-mounted accessory, provide 1-1/2 inches of slack or a suitable bend between the last point of support and the engine or accessory attachment. Finger tighten swivel connector nuts to avoid stripping threaded areas of fittings. Before applying final torque to end fittings, make sure hose assemblies are properly aligned and free of twists and kinks. Complete tightening by using torque values specified in the applicable MM. Table 8-2-4 is a guide for installation torque of flared and flareless fittings.

> **NOTE:** Torque values based on lubrication with fluid MIL-H-5606 or MIL-H-83282 prior to installation.

Hold fitting stationary with one wrench, and use torque wrench to tighten swivel nut.

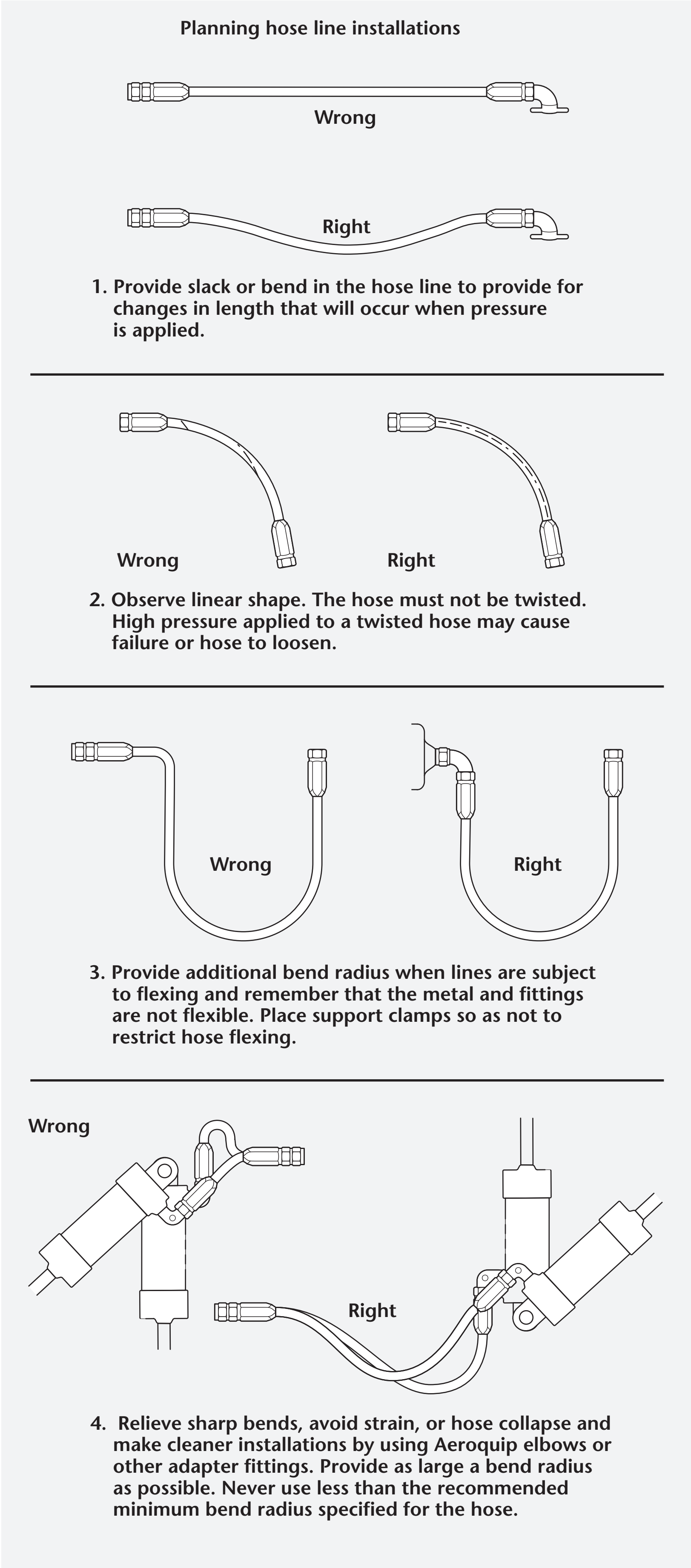
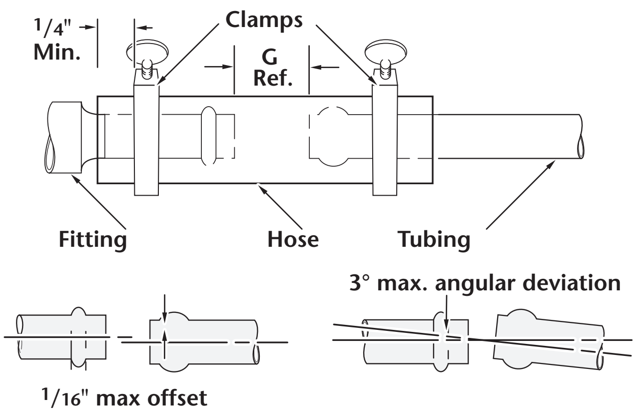


Figure 8-2-12. Hose slack.



Minimum gap "G" shall be 1/2" or tube OD/4, whichever is greater. Maximum gap "G" is not limited except on suction lines using other than self-sealing hose. On such suction lines, maximum "G" shall be 1 1/2 inch or one tube in diameter, whichever is greater.

Figure 8-2-13. Hose clamp mounting.

	Flared		Flareless	
Hose size	Min	Max	Min	Max
-2	75	85	20	30
-3	95	105	25	35
-4	135	145	50	65
-5	170	190	70	90
-6	215	245	110	130
-8	430	470	230	260
-10	620	680	330	360
-12	855	945	460	500
-16	1,140	1,260	640	700
-20	1,520	1,680	800	900
-24	1,900	2,100	800	900
-32	2,660	2,940	1,800	2,000

Table 8-2-4. Swivel nut installation torque (in.-lb.) for flared and flareless fittings.

When applying final torque, hold hose manually to prevent rotation and scoring of the fitting's sealing surface. Lockwire the swivel nut (if applicable). Support flexible hose or hose assemblies by routing and clamping hose or hose assembly securely to avoid abrasion and kinking where flexing occurs (Figure 8-2-13).

Overtightening clamps will squeeze or deform the hose (cold flow). Cushion-type clamps should be used to prevent hose chafing (Figure 8-2-13). Make sure support clamps do not restrict hose travel or subject hose or hose assembly to tension, torsion, compression, or sheer-stress during flexing cycles. Where flexing is required in an installation, bend the hose in the same plane of movement to avoid twisting. Ensure that the minimum bend radius is greater by a factor of "N" than the minimum bend radius for a nonflexing hose for hose assemblies required to flex at a bend (Table 8-2-5).

Hose Service Life

Some hoses or hose assemblies are fabricated from age-sensitive materials and have a specific shelf life, up to 32 quarters (8 years) from the date of acceptance by the consumer (shop, parts house, etc.) from the hose manufacturer. By establishing a time limit, a hose manufacturer is only limiting the time the hose is in storage.

Due to the dramatically different environments to which a hose assembly can be subjected, a hose manufacturer cannot predict an operational life. Only an aircraft manufacturer can do that. Many, indeed most, hose installations do not have mandatory retirement times. Instead, they are *on condition*. On condition means that as long as the hose assembly can pass an inspection it is airworthy.

A maintenance shops' incoming materials inspection procedures and inventory control systems should be able to track hose shelf life with little effort. The service life, if applicable, should be spelled out in the aircraft MM. It should also spell out the approved method of complying with any service life requirements.

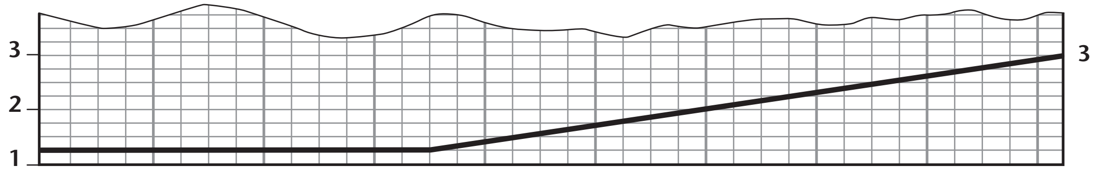
> **NOTE:** Teflon® (PTFE) rubber hose and hose assemblies do not have shelf life limitations.

Rejection standards. Rejection and replacement of hose or hose assemblies after inspections are based on the standards normally specified in the applicable maintenance instruction manual or maintenance requirement cards. Where rejection standards are not specifically outlined or if doubt exists as to the acceptability of a hose or hose assembly, replace the hose or hose assembly.

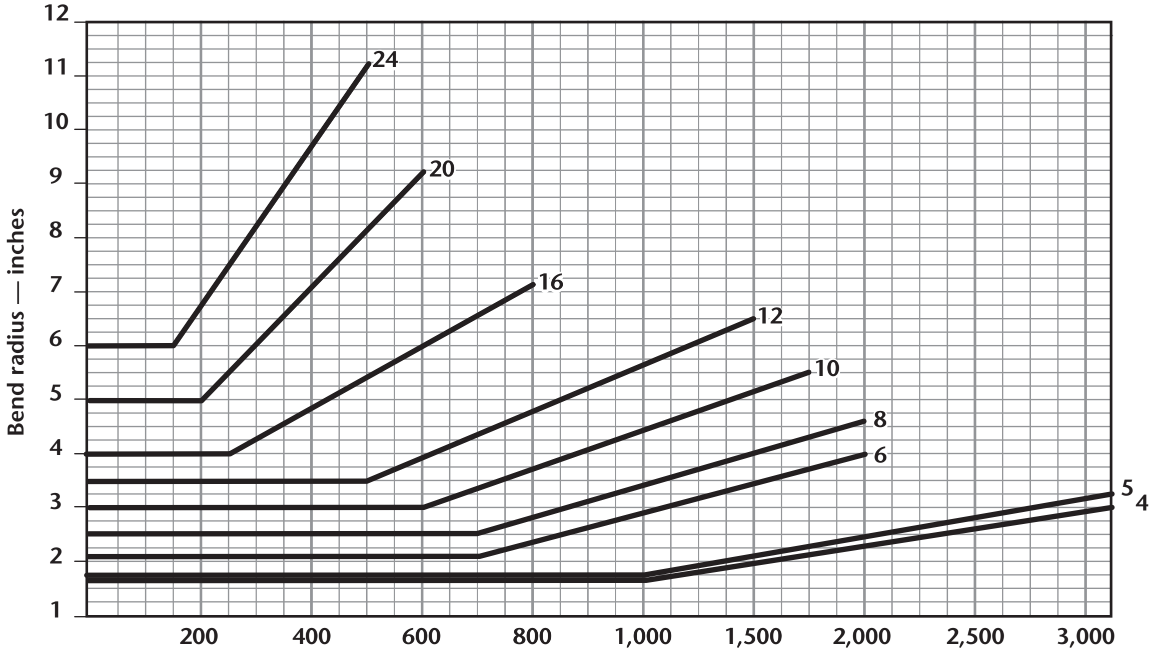
Storage

Hose and hose assemblies fabricated from age-sensitive materials are subject to deterioration by oxygen, ozone, sunlight, heat, moisture, or other environmental factors. These types of hoses and hose assemblies should be stored in a dark, cool, dry place protected from circulating air, sunlight, fuel, oil, water, dust, and ozone (ozone may be generated in an atmosphere where electricity is discharged through oxygen or ambient air). Store hose or hose assemblies by sealing both ends of bulk hose. Cap or plug each hose or hose assembly. Store hose or hose assemblies on racks that support and protect them. Store hose or hose assemblies so that the oldest items are used first.

> **CAUTION:** Improper storage (such as in piles) causes accelerated deterioration due to both heat and moisture factors.



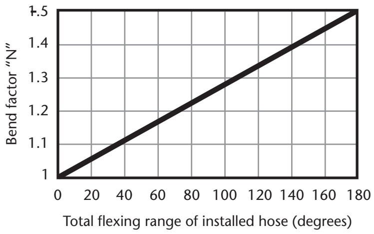
Inside bend radii vs. operating pressure MIL-H-8794 hose with no flexing



Operating pressure — pounds/sq. in (-3 to -24 inclusive)

Minimum bend radii for -32, -40, and -48 at all pressures are as follows:

-32	**13.25″**
-40	**24″**
48	**33″**

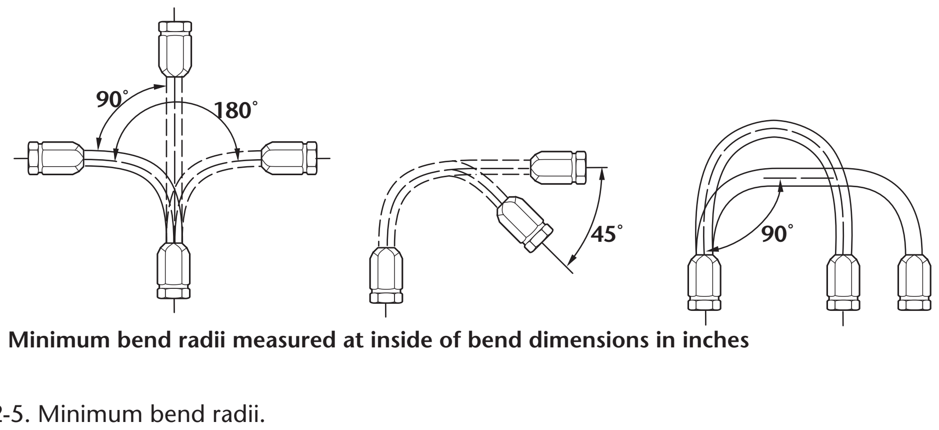


MIL-N-8788 hose with no flexing

Dash no.	Bend radii
4	3.000
5	3.375
6	5.000
8	5.750
10	6.500
12	7.750
16	9.625

Minimum bend radius of hose under flexing conditions = "N" no flexing
Bend radius of either MIL-H-8794 or MIL-H-8788 hose

Example: for MIL-H-8794 hose -12 size at 1,500 p.s.i. and having a flexing range of 60° minimum bend radius = 1.16 x 6/5 = 7.5 inches (measured at inside of bend).



Minimum bend radii measured at inside of bend dimensions in inches

Table 8-2-5. Minimum bend radii.


DUNCAN AVIATION
Airframe

9

Aircraft Inspection

On March 31, 1931, a Fokker F10-A aircraft crashed near Cottonwood Falls, Kansas, killing all eight passengers aboard. The flight had encountered severe weather, and witnesses said the aircraft's right wing broke off before the Fokker hit the ground (Figure 9-0-1). The cause of the crash was traced to two factors. Poor wing design caused the wing and aileron to flutter in flight, putting excessive stress on the main wing spar, which was made of wood. The wood spar deteriorated over time because of accumulated stress and exposure to water, and it eventually failed. The second factor concerned the lack of inspection of the aircraft's wing structure. At this time in aviation history, detailed structural inspections simply didn't exist.

Aircraft accidents were common in the 1920s and early 1930s. What set this one apart was the fact that among the crash victims was Notre Dame football coach Knute Rockne. Rockne was a well-known public figure and was beloved by many Americans. Public outcry over his death led to the formation of the Civil

Left. This technician checks for signs of stress cracking or corrosion on the airfoil's leading edge. *Photo courtesy of Duncan Aviation*

Learning Objectives

REVIEW
- Aircraft inspection tools and techniques
- Oxygen system inspection tasks
- Required inspections

DESCRIBE
- Task-specific inspection methods
- Inspection concerns for aging aircraft

EXPLAIN
- Nondestructive testing procedures
- Damage tolerant design
- How to inspect for and identify corrosion

Figure 9-0-1. Public pressure over the crash involving Knute Rockne led to the formulation of the CAA and to airplane certification.

Figure 9-0-2. Aircraft Type Certificate No. 2 was issued to the Boeing 40A. It was the first transport-type aircraft certified under the new CAA rules.

Aeronautics Agency, forerunner of the Federal Aviation Administration (FAA). The CAA was instrumental in developing regulations that required, among other things, periodic aircraft inspections (Figure 9-0-2). These early events have led to the complex maintenance and inspection techniques that you will use in your career as an aviation maintenance technician.

There are two reasons we perform aircraft inspections. The first, obviously, is safety. Continuous development and improvement of inspection programs have given us the safest air transportation system in the world. The second reason is economics. By finding small defects before they become serious, repair costs are greatly reduced. Reliability monitoring allows us to leave components in service longer and replace them just before they fail, lowering costs for parts and avoiding expensive aircraft downtime.

Section 1

Inspection Programs

Aircraft inspection programs are designed to suit both the aircraft and the aircraft operator. As an example, an annual inspection on a Cessna 152 might take an experienced technician one day to perform and another day or two to repair any discrepancies found. Doing a C check on a Boeing 747, on the other hand, would require six or eight weeks, three shifts a day, with 40 or so technicians per shift. During this type of check, the airplane is parked in a maintenance bay (Figure 9-1-1), allowing full access. In order to suit the inspection program to the aircraft, the Federal Aviation Regulations (FARs) set inspection requirements based on aircraft weight and complexity.

Basic Aircraft Inspection Programs

Annual inspections. According to FAR 91.409, aircraft with gross takeoff weights of 12,500 lbs. or less are basic aircraft. Basic aircraft include reciprocating engine-powered aircraft, some turbine-powered rotorcraft, and single-engine turbine-powered fixed-wing aircraft. A Cessna 152 is considered a basic aircraft for inspection purposes since it weighs less than 12,500 lbs. and is piston powered. If the aircraft is not used for hire, it requires only an annual inspection.

An annual inspection must be performed on this aircraft once every 12 calendar months. This means that if an annual was performed on May 3 2006, the next annual is due by the end of May in 2007. The inspector must use a checklist that covers the items listed in FAR 43 Appendix D. Appendix D covers only the minimum required inspection items, and a technician will typically use a checklist provided by the aircraft manufacturer specific to the model being inspected.

An annual inspection can be performed only by an airframe and powerplant mechanic holding an inspection authorization rating. The IA must perform the annual himself; he cannot supervise another person performing the inspection. A certificated repair station that is rated for the particular aircraft being inspected may also perform annuals.

If the inspector finds no discrepancies on the annual, he makes an entry in the aircraft logbook stating this and signing the aircraft off as airworthy. If discrepancies are found, they must be entered into the aircraft logbook. Any discrepancies found must be corrected, with the corrective action entered in the aircraft logbook, before the aircraft is returned to service. If any discrepancies are not corrected, the inspector must give the owner a written list of those discrepancies and sign off the annual inspection as unairworthy. Correction of the discrepancies returns the aircraft to an airworthy status. Under certain circumstances, the owner may fly the aircraft to have the repairs performed at another location by obtaining a special flight permit.

FAR Part 43 Appendix D describes the scope and detail of annual and 100-hour inspections. The items listed are the minimums that must be covered in an inspection. Inspection personnel usually use forms provided by the aircraft manufacturer as they are specific to the aircraft type and cover it in much more detail.

100-hour inspections. Suppose the same Cessna 152 is used for hire: flight instruction for example. FAR 91.409 requires that it be inspected every 100 flight hours in addition to receiving an annual inspection. The scope and detail of the 100-hour inspection is the same as the annual for a given aircraft. However, unlike the annual, the 100 hour can be performed by a mechanic holding an A&P license without an IA rating.

This inspection must be performed every 100 hours of operation. If the inspection cannot be performed immediately after the aircraft passes 100 hours, FAR 91.409 allows the aircraft operator to exceed this deadline by up to 10 hours in order to fly the aircraft to the place where the inspection will be performed. However, any hours over the 100 hour limit are deducted from the next interval. For example, if the inspection takes place at 103 hours, the next inspection is due 97 flight hours later.

Progressive inspections. Some aircraft operators find it inconvenient to ground their aircraft for several days to perform annual or 100-hour inspections. FAR 91.409 allows them to split the inspections into small portions that are performed at shorter intervals. The scope and detail of the annual or 100-hour inspection does not change when performed progressively. In other words, a complete annual inspection is accomplished during each 12 calendar months. The operator must submit his progressive inspection program to the FAA, which must approve the program before it is started. An A&P technician who does not have an IA rating may perform progressive inspections as long as an IA supervises the inspection.

Complex Aircraft Inspection Programs

Continuous inspections. Complex aircraft are those with gross takeoff weights greater than 12,500 lbs., any turbine-powered aircraft having more than one engine, and some turbine-powered rotorcraft. This would include most corporate and regional airline aircraft and all major airline aircraft. Because of their size and complexity, it is impractical to perform a complete inspection at a single maintenance visit. As a result, continuous inspection programs are developed to maintain airworthiness while minimizing aircraft downtime.

It is up to the aircraft owner or operator to select the continuous inspection program he will use. FAR 91.409(f) gives several options. An aircraft operator may use a continuous airworthiness inspection program currently in use by a person holding an air carrier operating certificate issued under Part 121, 127, or 135. The operator may create his own continuous inspection program and have it approved by the FAA. Lastly, the operator can use a current inspection program recommended by the aircraft manufacturer — this is the option most commonly used. In practice, an aircraft operator will modify the manufacturer's program over time to suit the operator's own needs. As a result, while the inspection programs at different airlines perform the same functions on the same aircraft models, the particulars of the different inspection programs will often be quite different.

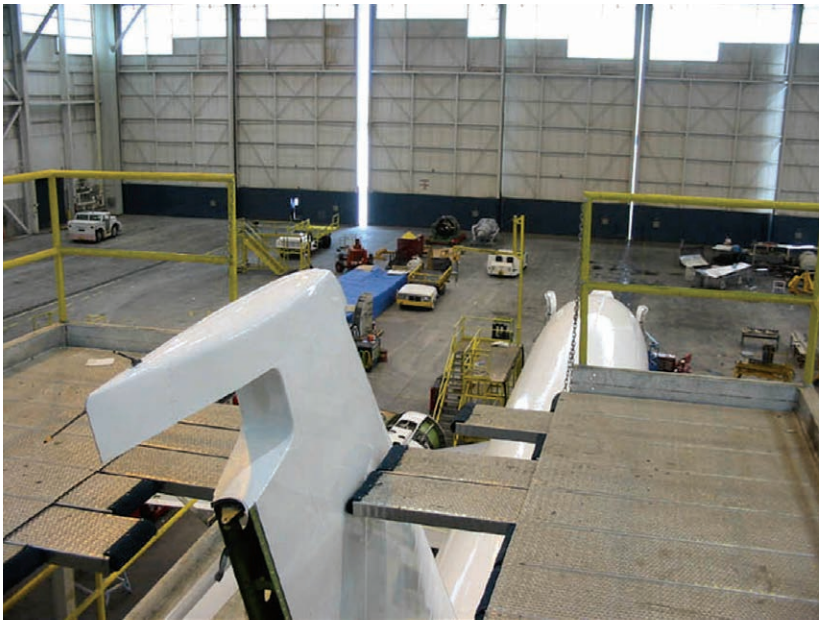


Figure 9-1-1. A Boeing airplane in a maintenance bay.

Inspection Intervals

The goal of any inspection program is to ensure continuous airworthiness. Since a modern transport aircraft is so large, inspections must be split up to keep aircraft downtime to a minimum. The following schedule of inspection intervals is typical of those used by large U.S. carriers.

Service or termination check. A basic inspection performed daily when the aircraft is overnighting. Typically, one technician checks items such as tires, brakes, lights, and the general condition of the interior. Any flight discrepancies logged that day will be repaired or deferred.

A check. An A check is a bit more in-depth than a service check and is generally performed after 60 flight hours, about once a week. One or two technicians perform more detailed inspection and functional checks on an overnight stay. The aircraft is not removed from service.

B check. B checks are more intensive and are usually performed once a month or every 300 to 500 flight hours. Routine servicing requires the removal of panels and cowlings, and operational checks of aircraft systems are more involved. B checks are performed by crews of technicians and take anywhere from 100 to 300 man-hours, sometimes with the aircraft out of service for a short period.

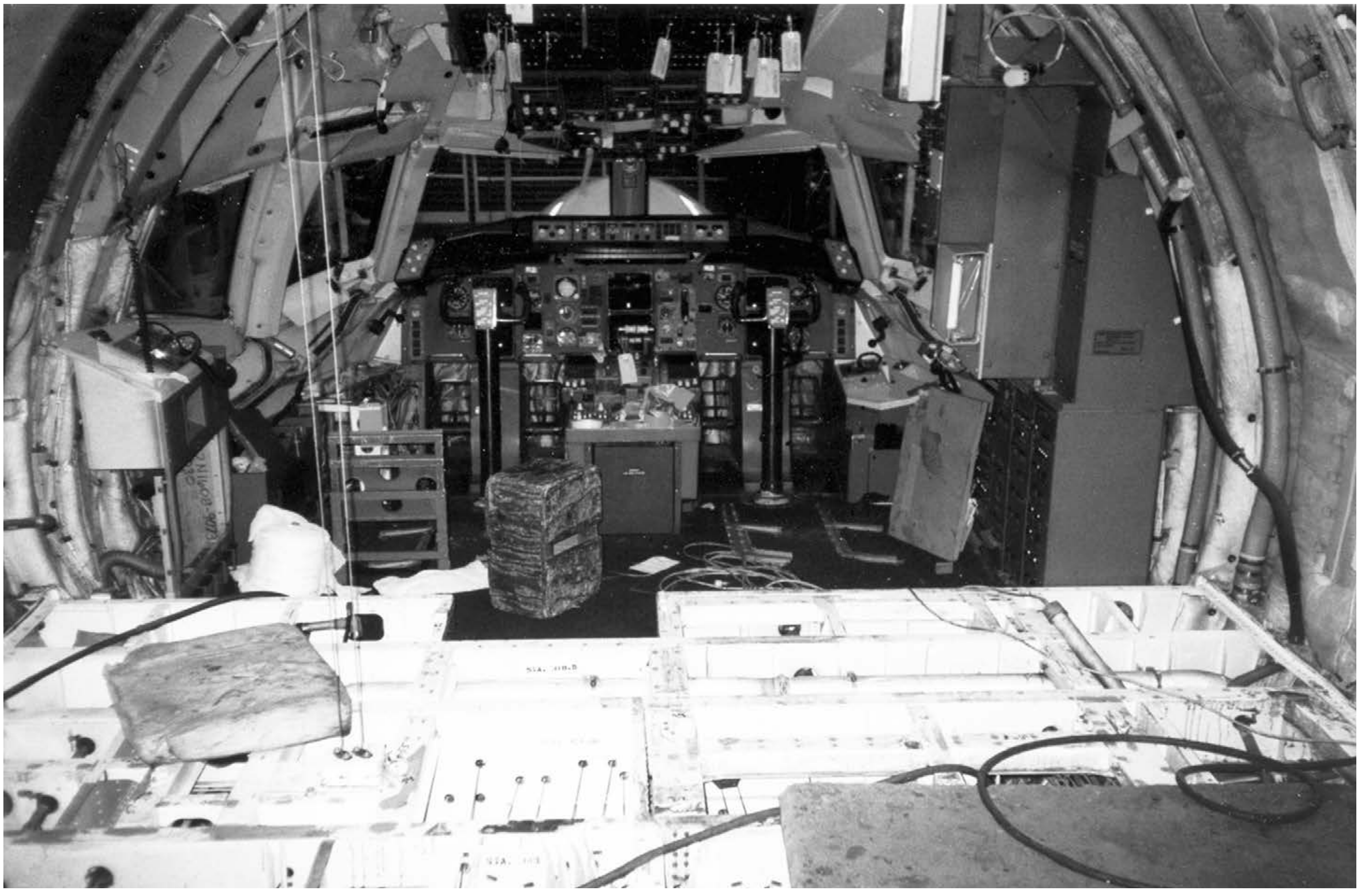


Figure 9-1-2. The forward cabin area on a Boeing 757 is exposed to liquids from the galley and lavatory. Since corrosion is more likely to occur in this area, it is inspected more frequently on C checks.

C check. A C check is a major inspection that covers the airframe, engines, and systems. C checks are performed once a year, or about every 3,000 to 5,000 flight hours. Some airlines categorize these inspections as C1, C2, up to C7. A C1 inspection typically is less in-depth and requires less disassembly of panels and cowlings, and may take a week to perform. C2, C3, and C4 inspections may cover different areas of the aircraft structure, with repeat inspections of areas prone to damage or corrosion.

A C7 check is much more thorough and requires complete removal of fixed panels and fairings and replacement of time-controlled components. The aircraft interior will be removed, and seats, galleys, lavatories, and sidewalls will be repaired as required. Figure 9-1-2 shows a forward cabin section stripped of panels. This is necessary to complete a through corrosion inspection. A C7 check can ground an aircraft for anywhere from four to eight weeks and requires multiple crews working three shifts around the clock.

D check. A D check is a major overhaul of an entire aircraft. It is performed approximately every 10 years or 30,000 flight hours. The airframe is completely gutted and all damaged structure is repaired or replaced. A D check can easily ground an aircraft for three months or more. Very few maintenance bases are equipped for this level of work.

Maintenance Program Logic

Maintenance steering group. The regulatory environment that governs air transport is changing. In the past, inspection programs operated in ways that were neither cost-effective nor as effective as they could be. It is important to know and understand both the history and future of aircraft inspection.

In the 1940s and 1950s, air carriers believed each component on a transport aircraft needed periodic disassembly and inspection. Time limits were established for servicing and inspections, and the entire aircraft was periodically disassembled, overhauled, and reassembled in an effort to achieve the highest level of safety. This was the origin of the first primary maintenance process that we call *hard-time* (HT).

As the industry grew and aircraft became more complex, hard-time maintenance programs became inefficient and uneconomical. They caused too much downtime. In 1968 representatives from airlines and manufacturers formed a committee to address the complexity of the new Boeing 747 aircraft and develop effective inspection and maintenance programs for it. The committee was called the *Maintenance Steering Group – 1st Task Force*, or *MSG-1*. The group determined that many components did not require periodic overhaul on a fixed-time basis, and doing so was wasteful of time and money. As a result, they developed a second primary maintenance process that was called *on-condition* (OC).

On-condition maintenance dispensed with periodic disassembly and overhaul and used visual inspection, measurements, and tests to determine if a component or assembly was airworthy. Experience showed that inspection intervals were often too long or too short, but the regulations governing the maintenance program made it very difficult to change the intervals. To correct this, the FAA, manufacturers and airlines developed a system to monitor component and system reliability. *Reliability control systems* watch a component's mechanical performance to keep failure rates below a certain threshold.

The analytical nature of reliability control showed some systems and components did not respond to the hard-time or on-condition processes. This led to a third process that eliminates servicing or inspection to determine serviceability. Instead, mechanical performance is monitored and analyzed, but no limits or mandatory actions are required. This process is called *condition monitoring* (CM).

Both industry and regulators saw the value in the 747 MSG-1 program and wanted to apply it to other aircraft. Procedures that were specific to the 747 were deleted to produce a universal document applicable to other new aircraft. This new document included condition monitoring processes and was called *MSG-2*. The purpose of the MSG-2 program is to develop a maintenance program acceptable to the FAA, aircraft operators, and manufacturers. The objective of this maintenance program is to maintain the inherent design levels of reliability and operating safety in an aircraft, and to do this at the minimum practical cost.

The MSG-2 program uses decision tree logic to determine which components are *maintenance significant items.* Then, the MSG-2 decision logic asks five questions to determine which process—hard time, on-condition, or condition monitoring—to use. Aircraft such as the Boeing 727 and 737-200 and -300 use MSG-2 logic in their maintenance programs.

In the late 1970s, a third task force determined that the MSG-2 program had shortcomings and produced a third program, MSG-3. This program is applied to Boeing 757, 767, 777, and higher series 737 aircraft, and to Airbus 320, 330, and 340 series aircraft. Instead of maintenance processes—HT, OC, or CM—MSG-3 lists two sets of tasks, scheduled tasks and unscheduled tasks. Scheduled tasks are:

- Lubrication/Servicing (LU/SV)
- Operational/Visual Check (OP/VC)
- Inspection/Functional Check (IN/FC)
- Restoration (RS)
- Discard (DS)

Unscheduled tasks are derived from:

- The scheduled tasks (nonroutines)
- Reports of malfunctions (pilot or maintenance reports)
- Data analysis (reliability)

The MSG-3 system first breaks down an aircraft system to its basic components and asks how a component failure would affect function of the entire system. A decision tree is then applied to determine which maintenance task should be applied to the component.

It is beyond the scope of this section to go into further detail of the MSG logic system. However, when you enter the field as an aircraft maintenance technician you will be using maintenance programs developed under these guidelines. It is important that you understand how improvements in maintenance programs directly lead to increased safety, reliability, and lower operating costs.

Section 2

Basic Inspection Tools and Techniques

In your career as an aircraft maintenance technician, you will use a wide variety of tools to inspect aircraft. The most basic are your five senses. All of the inspection techniques discussed here simply expand your senses of sight, hearing, and touch.

Radiographic techniques, such as X-rays, allow you to see inside metal castings to discover cracks and corrosion.

Ultrasonic equipment enhances your sense of hearing to detect the unique way that a cracked part transmits sound.

Figure 9-2-1. An AMT uses a flashlight and mirror to inspect inside a panel in the cramped conditions of an air conditioning bay.

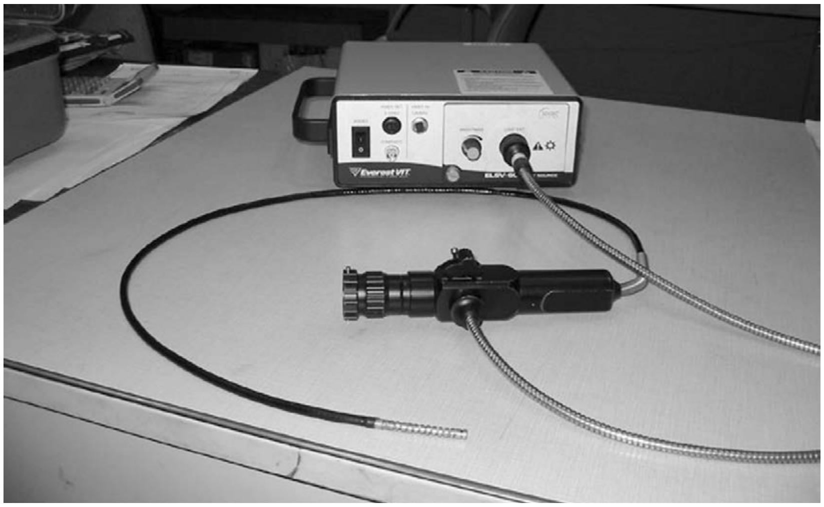


Figure 9-2-2. This borescope unit consists of a light source, probe, and viewer. It is nothing more than an extension of your eyes.

With experience you will develop judgment and insight; these will be your most effective tools in discovering hidden, troublesome problems. All the tooling we will discuss here are simply aids to make your job easier.

Visual inspection. Whether you are performing an inspection or troubleshooting, it is almost always best to proceed from the simplest level and then go to the more complex. Direct visual observation is the simplest, most common, and cost-effective inspection method used in aviation. A strong flashlight, an inspection mirror, and a magnifying glass are all that you require in most instances. Modern airframes and engines are equipped with numerous access panels that can be removed to allow direct visual inspection. Figure 9-2-1 is an example of an inspection behind a removable panel. This allows you to quickly and efficiently view most critical areas.

Some areas have limited access and will require further disassembly and stronger light sources such as drop lights or borescopes. A *borescope*, Figure 9-2-2, consists of a flexible fiber optic cable, or probe, with a lens and light source at its tip. The probe can reach deep into tight areas and show the inspector the condition of hidden structures. Borescope inspections are commonly done on turbine engines.

You will use other senses during an inspection. Touch components, shake them, test their security of mounting. Pull gently on fluid and hydraulic lines to detect looseness or broken mounts. Run your fingers on tubing or stringers—your sense of touch can detect differences of several thousandths of an inch. Use your sense of smell. Electrical shorts produce a distinctive burned odor. If you smell hydraulic fluid or fuel and there are no open lines in the area, suspect a leak. Use your ears to detect rattles and bumps as you tug on things. The easiest way to find a loose seat assembly in a transport aircraft is to pull on it and listen for a light tapping.

Inspecting complex assemblies. On a complex unit such as an engine (Figure 9-2-3), the total number of items to be checked can overwhelm you. It is helpful to select one system and trace it from beginning to end. For example, on a turbine engine, start at an ignition exciter unit. Touch the unit and push and pull on it to check the security of its mounts. Look for obvious damage from impact, fluid leakage, or electrical faults. Trace the igniter wires, flex them, check their mounting clamps for security and condition. Follow them to the igniter plugs. Check the plugs for general condition and proper safety. Gently pull on the leads where they enter the igniter to see if they are loose. Serious operational problems are often traced to loose wires or cannon plugs. Touch, push, pull, feel, watch, and listen.

Advanced Inspection

Your senses have limited sensitivity and sometimes require help. While you can detect minute differences in metal thickness with your fingers, you will need a micrometer or caliper to determine exactly how thick it is. Precision measuring tools can be as simple as a six-inch ruler or as complex as an ultrasonic micrometer.

Measuring Tools

Micrometers. *Micrometers* are one of the most commonly used precision measuring tools. They can measure length, width, and thickness,

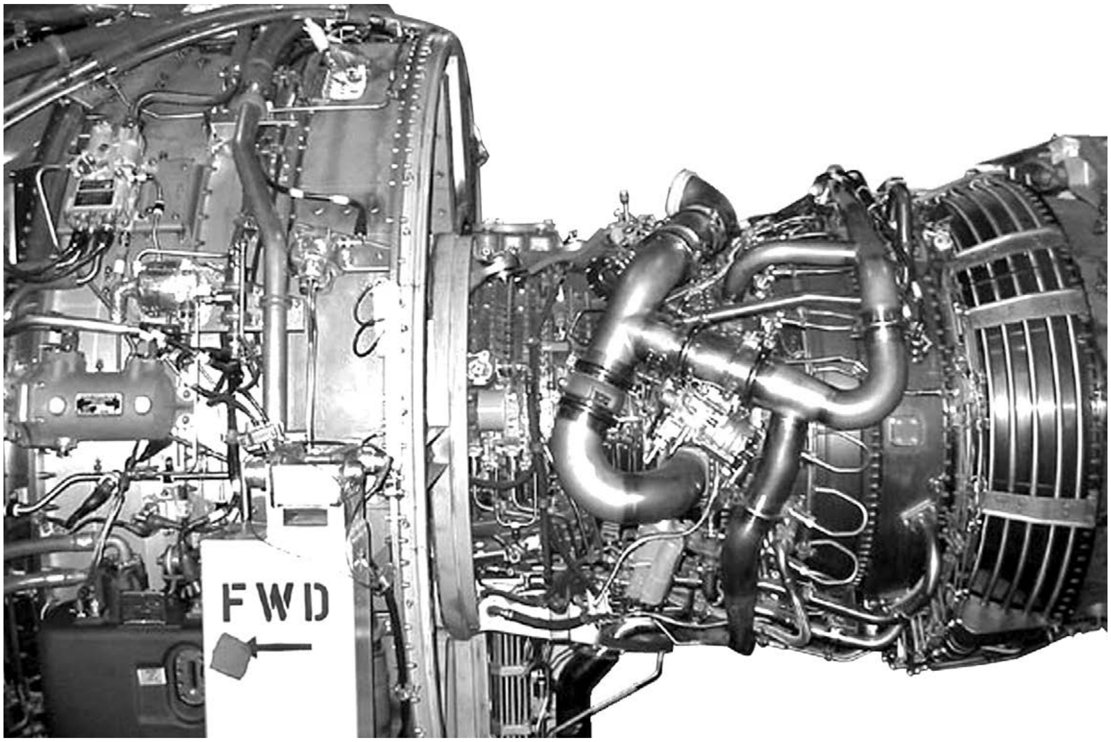


Figure 9-2-3. When inspecting a complex assembly like this, it is helpful to focus on a single system.

are extremely accurate and are easy to use. Figure 9-2-4 shows a basic micrometer.

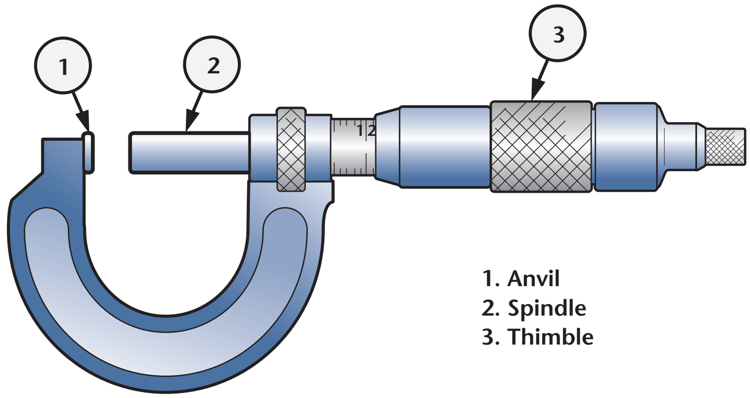


Figure 9-2-4. A basic micrometer is very simple: it is based on a precision-threaded thimble that moves in and out 0.025 inch with each revolution.

A micrometer measures objects between two surfaces: a fixed anvil and a moveable spindle. The thimble is part of the spindle and is threaded. It fits into the micrometer body (called the *barrel*) that is also threaded. When the thimble is turned, the spindle moves in and out.

Some micrometers have digital readouts that display the dimension of the part being measured. Other micrometers use markings engraved on the barrel and spindle that allow you to read the dimension being measured. This requires a bit of skill and a little computation. Look at the micrometer in Figure 9-2-5.

Note the marks on the barrel. Each number above the line represents 0.10 inch, and each mark below the line represents 0.025 inch. The threads in the thimble and barrel are cut so that one turn of the thimble moves it exactly 0.025 inch, or one mark on the barrel. Four turns moves the thimble four marks, or 0.10 inch. The thimble is engraved with 25 equally spaced lines around its circumference. Each of these lines represents 0.001 inch, so one full turn of the thimble moves it 0.025 inch.

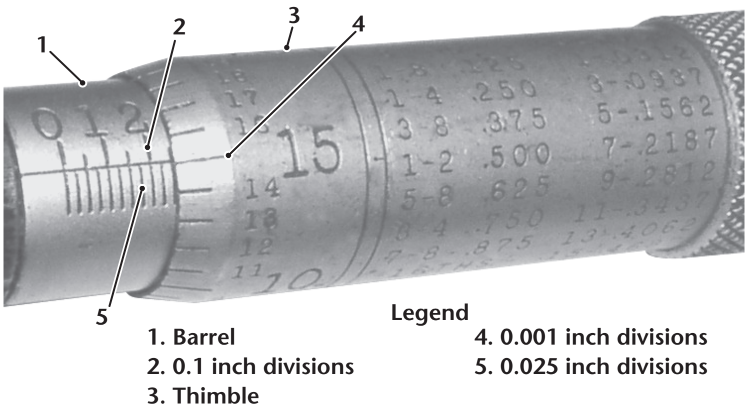


Figure 9-2-5. In this illustration, there are three different measurements indicated. To obtain the total measurement, they must be added.

To read the measurement in the illustration, first count the marks above the line. There are two marks visible, or 0.20 inch. Then count the marks below the line. There are two visible, so add 0.050 to the first measurement. The total so far is 0.250 inch. Next, count the marks on the

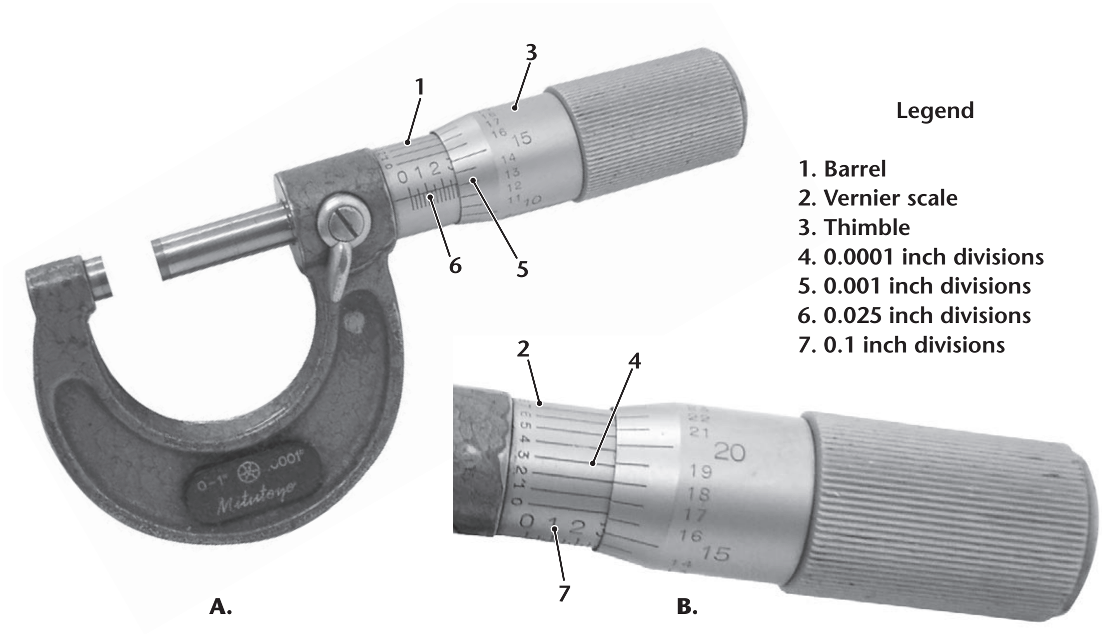


Figure 9-2-6. Micrometer vernier scales allow for measuring accuracy to 0.0001 inch.

thimble. The line is on the fifteenth mark, so add 0.015 thousandths. The total measurement shown is thus 0.265 inch.

Vernier micrometer. Sometimes we measure a part and the lines on the thimble do not line up. When more precision is required we use a *vernier micrometer* that is accurate to one ten-thousandth of an inch. Notice in Figure 9-2-6 that the vernier micrometer has additional lines engraved lengthwise in its barrel. Each line represents one ten-thousandth of an inch. To read a vernier, we match up a line on the thimble with a line on the barrel. In detail A, we have two 0.10 marks, three 0.025 marks, and 13 0.001 marks on the thimble. The total so far is 0.288 inch. Then, in detail B, we look for any two of the marks that line up. It looks like they line up at 2, which adds 0.0002 to our reading, for a total of 0.2882 inch.

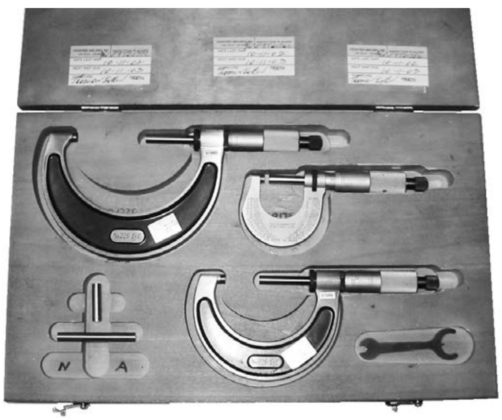


Figure 9-2-7. This micrometer set has 0- to 1-inch, 1- to 2-inch, and 2- to 3-inch micrometers. Sizes can go up to several feet.

Micrometers are available in many sizes to measure large and small parts. Figure 9-2-7 shows a standard set of 0- to 3-inch micrometers in a wooden case. Figure 9-2-8 shows a special micrometer for measuring deep offsets that a standard micrometer can not reach.

Micrometers are also available to measure irregularly shaped objects. You can use a number of accessories to make your micrometer even more versatile. Spindles are available with ball ends instead of flat ends. This allows measuring curved parts such as tubing. Blade contacts can be mounted on the thimble to measure grooves or threads.

Depth micrometers. These work on the same principle as regular micrometers, but are used to determine the depth of holes, borings, or a part's thickness after a repair. Figure 9-2-9 shows a depth micrometer set that uses interchangeable precision rods to extend its range.

Calipers. *Calipers* are another measuring tool frequently used in aviation. Calipers can measure thickness, diameter, length and depth. They are somewhat easier to use than micrometers. Calipers can measure everything a micrometer can without changing instruments. A typical caliper can measure dimensions from 0 to 6 inches.

Three types of caliper are available. *Vernier* calipers employ vernier scales similar to those on micrometers. Reading the scale is similar to the process for micrometers. As their name implies, *dial* calipers use a dial to provide the

Figure 9-2-8. This 0- to 1-inch micrometer is used to measure deeply offset structures.

Figure 9-2-9. This depth micrometer set has interchangeable spindles that allow measurement of deep holes.

0.025 and 0.001 readings, making the process much easier (Figure 9-2-10). *Digital* calipers provide a numerical readout of the measured dimension, eliminating any guesswork or visual error.

Dial indicator. *Dial* indicators are extremely versatile and can be set up to measure a variety of dimensions. The dial indicator shown in Figure 9-2-11 can be used as a depth micrometer to determine corrosion depth in metal structures. This dial indicator has a machined flat face and a pointed spindle.

A dial indicator, such as shown in Figure 9-2-12, is a standard type and is commonly use to measure the run-out of a shaft or the backlash of a gear set.

Section 3

Non-Destructive Testing

When aircraft prototypes are built and undergo testing, they are sometimes subjected to stress until they experience structural failure. This is known as destructive testing and is useful to determine the ultimate strength of a component, assembly, or design. While the process is necessary to find a part's practical strength limits, it is rarely used in the field.

Non-destructive testing (NDT) or non-destructive inspection (NDI) are methods of checking parts and structures to determine their integrity, composition, dimensions, or thermal, chemical, or physical properties without affecting the component's serviceability. NDI utilizes *dye penetrant, magnetic particle, ultrasonic,* and *radiographic* (X-ray) testing to find internal discontinuities, cracks, corrosion, and other flaws. Because of its effectiveness and relatively low cost, NDI is widely used in all facets of aviation.

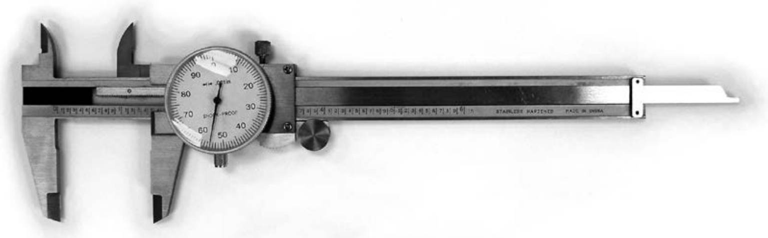
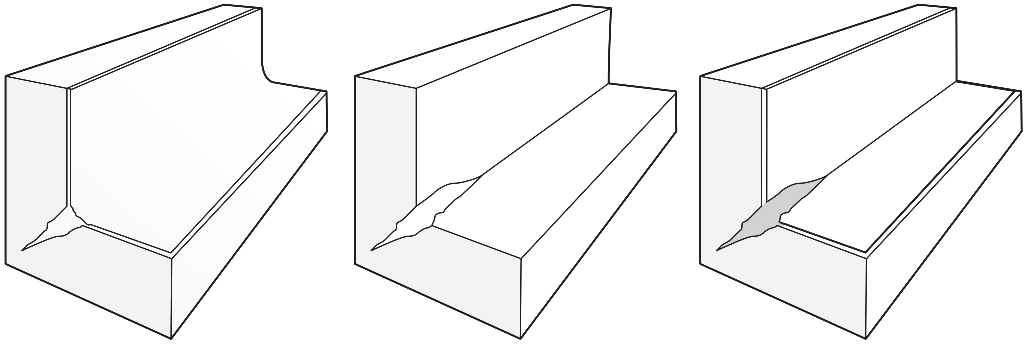


Figure 9-2-10. Vernier dial caliper.

Figure 9-2-11. This dial indicator is ideal for measuring corrosion damage. Other dial indicator styles are used for measuring chankshaft and propeller shaft run-out.

Figure 9-2-12. Standard dial indicators, using mounting adaptors, can be used to measure crankshaft runout.



A. Penetrant, applied to surface, seeps into discontinuity

B. Penetrant, removed from surface, but discontinuity remains full

C. Developer, acts as a blotter to draw the penetrant out of surface discontinuity and produce a visible indication

Figure 9-3-1. Penetrant and developer action on a cracked flange.

Dye Penetrant Inspection

Penetrant inspection is a quick, reliable, and inexpensive form of nondestructive testing that is very useful in finding defects that are open to a part's surface (Figure 9-3-1). It is accomplished by use of a highly penetrating liquid that is able to enter the surface openings of a crack or discontinuity. The dye may be a visible colored material or it can be fluorescent, but it will have low viscosity that allows it to enter surface cracks. After allowing sufficient time for this liquid to penetrate, the excess is cleaned off and a developer is applied. The developer may be a dry powder or a liquid. When it is applied to a treated area, the developer draws penetrant from a suspected defect and reveals the flaw.

This method is limited by the fact that it cannot detect cracks or flaws below a part's surface. In addition, it cannot be used on materials with rough surfaces or those that are highly absorbent such as rubber, plastic, and some synthetic materials. While this method does not require a high degree of skill, successful penetrant inspection does demand thorough precleaning of test areas, proper use of penetrant and developer solutions, and careful inspection of the treated area to find flaw indications and determine their severity.

Types of penetrant. There are two types of penetrant material: *visible dye* and *fluorescent dye*. Visible or color contrast penetrants have a red dye dissolved in the penetrating liquid. Visibility is improved by use of a white developer, which provides a high contrast background for the bright red penetrant when viewed under white or natural light. Fluorescent dyes are similar to visible dyes, but instead of visible dye they use a fluorescent material that glows brightly when exposed to *ultraviolet* (black) light. The advantage of fluorescent dye is that very small quantities of dye provide highly visible indications of flaws.

Penetrant materials are further classified as *water-soluble* and *post-emulsifying*. Water-based penetrants are removed using water and have the advantages of easy cleanup and the ability to be used on materials that may be damaged by strong solvents. Post-emulsifying penetrants require an emulsifier to remove the penetrant prior to developer application. This method has the advantage of allowing better removal of unneeded penetrant without disturbing the penetrant held within the defect. This results in more precise flaw detection.

Procedures for Penetrant Inspections

Before beginning a penetrant procedure, the technician must first determine what the component or structure is made of. Cleaning agents and penetrants can have adverse effects on certain materials. For example, strong alkali cleaners can damage magnesium and titanium alloys. In addition, the high temperatures that result from some cleaning and inspection procedures can damage many materials (Table 9-3-1).

The first step in dye penetrant inspection is cleaning. For this method to be effective, all parts to be inspected must be thoroughly cleaned and dried. Dirt, grease, or coatings such as paint or plating must be removed. This is accomplished by mechanical or chemical methods.

A number of cleaners are used in penetrant inspection:

Penetrant inspection pre-cleaning	
Mechanical methods	
Abrasive tumbling	Removing light scale, burrs, welding flux, braze stopoff, rust, casting mold, and core material; should not be used on soft metals such as aluminum, magnesium, or titanium.
Dry abrasive grit blasting	Removing light or heavy scale, flux, stopoff, rust, casting mold and core material, sprayed coatings, carbon deposits; in general any brittle deposit. Can be fixed or portable (may peen metal over defect).
Wet abrasive grit blast	Same as dry except, where deposits are light, better surface and better control of dimensions are required.
Wire brushing	Removing light deposits of scale, flux, and stopoff (may mask defect by displacing metal).
High pressure water and steam	Ordinarily used with an alkaline cleaner or detergent; removing typical machine shop contamination, such as cutting oils, polishing compounds, grease, chips, and deposits from electrical discharge machining; used when surface finish must be maintained.
Ultrasonic cleaning	Ordinarily used with detergent and water or with a solvent; removing adhering shop contamination from large quantities of small parts.
Chemical methods	
Alkaline cleaning	Removing braze stopoff, rust, scale, oils, greases, polishing material, and carbon deposits; ordinarily used on large articles where hand methods are too laborious; also used on aluminum for gross metal removal.
Acid cleaning	Strong solutions for removing heavy scale; mild solutions for light scale; weak (etching) solutions for removing lightly smeared metal.
Molten salt bath cleaning	Conditioning and removing heavy scale; not suitable for aluminum, magnesium, or titanium.
Mechanical methods	
Solvent wiping	Same as for vapor degreasing except a hand operation; may employ nonhalogenated (nonchlorinated) solvents; used for localized low-volume cleaning.

Table 9-3-1. Pre-cleaning methods for penetrant inspection.

- **Detergents.** Detergent cleaners are water-soluble chemicals that emulsify contamination and allow it to be washed away.
- **Solvents.** Solvents dissolve oil, grease, wax, sealants, paint, and other organic matter to ease removal by rinsing or wiping.
- **Alkalis.** Alkaline cleaners consist of chemical solutions that remove contaminants by chemical action or displacement.
- **Salt baths.** Molten salt baths are used to remove heavy scale and oxides from low-alloy steel, nickel, and cobalt-based alloys and some stainless steels. They cannot be used on aluminum, titanium, or magnesium alloys.
- **Acids.** Acid solutions are used to remove rust, scale, corrosion products, and dry contamination.
- **Etching.** Etching chemicals contain a mixture of acids or alkalis with inhibitors. They are used to remove a thin layer of surface material, usually caused by a mechanical process that could seal or reduce the opening of any discontinuities. The type of etching solution used depends on the part material and condition.

Crack detection. Detection and indication of any defect depends on the flow of dye penetrant into what may be only a microscopic crack. Such flow cannot take place if the crack is already filled with carbon, oil, engine varnish, dirt, paint, oxide plating or similar coatings that cover or fill the defect. Therefore, unless

Material	Form	Type of discontinuity	Water-washable penetration time (minutes)	Post-emulsified penetration time (minutes)[1]
Aluminum	Castings	Porosity	5 to 15	52
		Cold shuts	5 to 15	52
	Extrusions and forgings	Laps	N/R	10
	Welds	Lack of fusion	30	5
		Porosity	30	5
	All	Cracks	30	10
		Fatigue cracks	N/R	30
Magnesium	Castings	Porosity	15	52
		Cold shuts	15	52
	Extrusions and forgings	Laps	N/R	10
	Welds	Lack of fusion	30	10
		Porosity	30	10
	All	Cracks	30	10
		Fatigue cracks	N/R	30
Steel	Castings	Porosity	30	102
		Cold shuts	30	102
	Extrusions and forgings	Laps	N/R	10
	Welds	Lack of fusion	60	20
		Porosity	60	20
	All	Cracks	30	20
	All	Fatigue cracks	N/R	30
Brass and bronze	Castings	Porosity	10	52
		Cold shuts	10	52
	Extrusions and forgings	Laps	N/R	10
	Brazed parts	Lack of fusion	15	10
		Porosity	15	10
	All	Cracks	30	10
Plastics	All	Cracks	5 to 30	5
Glass	All	Cracks	5 to 30	5
Carbide-tipped tools		Lack of fusion	30	5
		Porosity	30	5
		Cracks	30	20
Titanium and high temperature alloys	All	Cracks	N/R	20 to 30
All metals	All	Stress or intergranular corrosion	N/R	240

[1] For parts having a temperature of 60°F (16°C) or higher.

Table 9-3-2. Minimum penetration time for penetrants.

the part is clean and free from foreign matter, reliable inspection may not be accomplished.

After the part is thoroughly cleaned and dried, the penetrant can be applied. It can be sprayed, brushed, or a part can be immersed in a penetrant solution. After the penetrant is applied, the part is set aside to drain. The length of time the part is allowed to drain (*penetration time or dwell time*) and the position of the part during draining are extremely important factors for reliable penetrant inspection. The smaller the defects in a part, the longer the penetration time required since penetrant takes more time

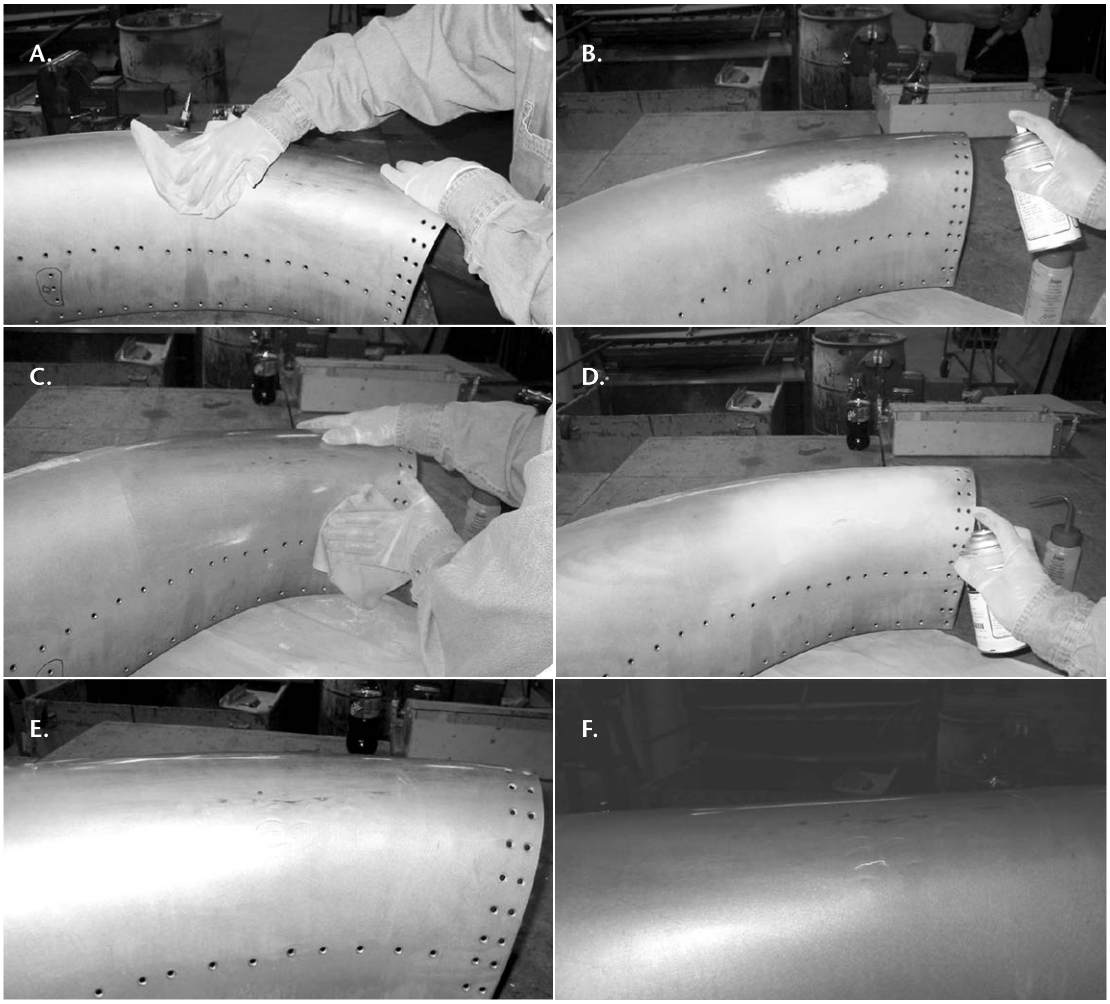


Figure 9-3-2.
(A) The technician cleans the area to be inspected.

(B) Apply the penetrant using a spray can.

(C) After allowing the correct time for penetration, all traces of the penetrant must be removed.

(D) Apply the developer using a spray can. Normally, the correct amount is about half as much as the penetrant.

(E) The damaged area after the excess developer has been removed.

(F) The crack is revealed under ultraviolet light. This crack could not be repaired and the part was scrapped.

to enter extremely fine apertures. Longer penetrant time or further penetrant applications may be required for questionable parts to ensure full indication of defects (Table 9-3-2.)

After allowing the correct penetrant time, remove excess penetrant from the part's surface. Excess penetrant can cause false indications and a loss of contrast between indications of discontinuities and the background during inspection. Removal may require washing or spraying the part with a cleaning solution or wiping the part clean with a solvent-moistened cloth. If removal of excess penetrant involved water or other cleaning solutions, the part must be dried prior to application of developer. Figure 9-3-2 illustrates a typical dye penetrant inspection using an ultraviolet light.

Developer can be applied wet or dry by dipping, brushing, spraying, or dusting. If wet developers are used, the part must be drained and allowed to dry. After the developer has been applied, allow a period of time for the developer to set. This dwell time will depend on the type of developer used and the type of defect. Sufficient time must be allowed for an indication to form, but too much time lets penetrant bleed into the developer in such quantities as to cause a loss of definition. Developer dwell time varies from a few minutes up to an hour, and is generally about half the penetrant dwell time.

Types of Indications

The component is now ready for inspection. Dye penetrant inspections are performed using either visible light or ultraviolet (black) light. Both methods are equally effective. There are five general types of indications to be aware of:

- **Continuous line.** Cracks, cold shuts, and forging laps show up as continuous lines. A crack will appear as a sharp or faint jagged line, a straight line, or an intermittent line. Cold shuts usually appear as smooth, straight narrow lines. Scratches and die marks also appear as straight lines, but the bottom of the discontinuity is usually visible.
- **Intermittent line.** The same defects that appear as straight lines may also appear as intermittent lines. This occurs when a

defect is partially closed at the surface by metal working such as machining, forging, extruding, or grinding.

- **Rounded areas.** Circular defects indicate porosity caused by gas holes or pinholes or a generally porous metal depending on the extent of the indication. Deep crater cracks in welds frequently show up as rounded indications, since there is a large amount of dye penetrant entrapped, although the actual defects may be irregular in outline.
- **Small dots.** This indication results from a porous condition of the metal. This porosity can be caused by small pinholes or coarse grains from casting.
- **Diffuse or weak indications.** Diffuse indications may be caused by a porous surface, insufficient cleaning, incomplete removal of dye penetrant, or excess developer. Weak indications spread over a wide area should be viewed with suspicion and are cause for repeating the operation.

Interpretation of Indications

If a dye penetrant inspection results in flaw indications, these indications must be correctly evaluated to determine the cause and extent of the defect. Five types of defects are generally encountered:

- **Fine, tight surface cracks.** Such cracks may be shallow or deep, but their most significant characteristic is a very small and tight surface opening.
- **Broad, open surface defects.** These may be shallow or deep. Because of their width, too much penetrant may be removed during the cleaning process, leading to incorrect indications.
- **Porosity.** Generally, porosity defects are characterized by cavities below the surface, which are connected to the surface by minute channels. Porosity is frequently found in aluminum and magnesium castings.
- **Shrinkage.** Microscopic shrinkage in magnesium castings can be opened to the surface by machining or etching and is very hard to distinguish from cracks.
- **Leaks or through cracks.** These are cracks, which open from one surface to another.

False Indications

When using dye penetrant, the technician must be aware of the possibility of false indications. False indications are generally caused by poor cleaning, poor developer removal, or press-fit parts.

If all the surface penetrant is not completely removed in the washing or rinse operation, the remaining penetrant can produce false indications. This condition is easy to identify since the penetrant will cover broad areas instead of the sharp patterns found in true indications. When accumulations of penetrant are found, the entire part must be cleaned and reprocessed. Similarly, excess developer left on a part because of poor cleaning can cause false indications, particularly at keyways, threads, and sharp fillets. Since heat-treating or fatigue cracks often occur at these locations, it is essential that they be checked very carefully.

The joint areas of press-fit parts can retain penetrant and give false indications. For example, if a wheel is press-fitted onto a shaft, penetrant will show an indication at the fit line. This is normal since the parts are not welded together, but creates a problem since penetrant from the press fit can bleed out and mask true defects.

Defects, especially microscopic ones, may not be detected if cracks are filled with oil, dirt, or other matter that keeps the penetrant from entering the crack. Cleanliness is extremely important for this method of nondestructive inspection.

Ultrasonic Inspection

Ultrasonic inspection is a versatile form of nondestructive inspection in widespread use in aviation. It can be used to inspect parts for internal and external flaws. Ultrasonic inspection units can test materials from a fraction of an inch to several feet in thickness. They can be used as micrometers to determine the thickness of a part. Ultrasonic inspection equipment is also used to perform leak checks on a wide variety of aircraft components and systems.

Ultrasonic inspection has many advantages and few drawbacks. It can detect surface and subsurface flaws. It is effective on most materials including metals, plastics, and composites. Test equipment is highly portable and requires access to only one side of a part or structure. This method's main disadvantage is that it is subject to *dead zones* or *no inspection zones* where flaws cannot be detected.

Ultrasonic Test Equipment

A typical ultrasonic inspection unit consists of a *control unit* and a *probe*, or *transducer*. The control unit houses a signal generator, timing circuits, controls, display, and power supply. The transducer is a small handheld device that changes electrical signals from the control unit into sound waves. It also detects sound signals and changes them into electrical signals. In addition, ultrasonic inspection requires the use of a *liquid couplant* applied between the transducer and the target material. This couplant provides a direct path for the sound waves and eliminates signal contamination.

If the transducer makes direct contact with the test material, it is called *contact testing*. A couplant must be selected that provides sufficient viscosity and surface wetting of the part to maintain good transmission of the ultrasonic signal. Contact testing employs a portable test unit with a handheld transducer and has the advantage of being very portable. An alternate method is called *immersion testing*, where the test material and the transducer are immersed in a liquid such as oil or water. Immersion testing can be performed in a fixed installation using an immersion tank, or performed in the field with a portable setup using a water column spray.

Principles of Operation

Sound. What we know as sound is the vibration of air particles. When you listen to a radio, the radio's speakers vibrate the air at a certain frequency (tone) and amplitude (volume). These vibrations pass through the air to your ears. Sound vibrations, or waves, behave in the same way as light waves. When you clap your hands inside a large room, the echo you hear is the sound energy of your clapping bouncing off the building's walls and returning to your ears. Ultrasonic inspection is based on this phenomenon.

The term *ultrasonic* refers to sound waves at frequencies above the range of human hearing, about 20,000 Hz. All materials such as air, metal, and plastic transmit sound energy. Ultrasonic inspection relies on the principle that different materials transmit sound waves at different velocities. An ultrasonic test unit generates sound waves that are directed into a part. If there are no defects in the part, the sound waves pass through the part at the same speed. However, if the part is flawed or cracked, the sound waves vary in velocity as they pass through the flaw. This change in velocity is detected and measured by the ultrasonic test unit, which then provides a visual signal of the flaw. As light reflects from a mirror, sound waves can also be reflected by flaws or cracks within a part.

Longitudinal waves. Sound waves are introduced into materials in different ways to detect different kinds of flaws. The sound from your radio's speakers travels in the form of *longitudinal* waves, or waves that travel parallel to the direction of the sound beam. Longitudinal

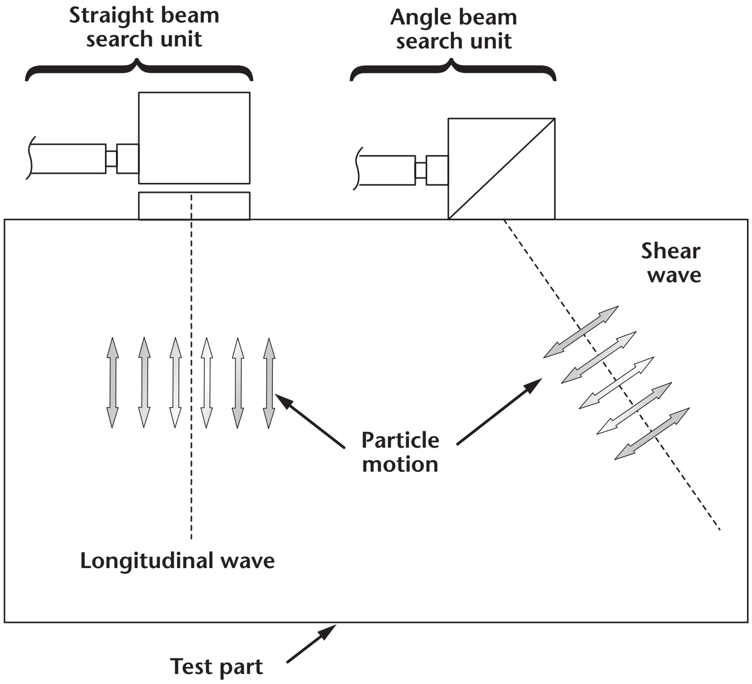


Figure 9-3-3. Longitudinal and shear wave modes.

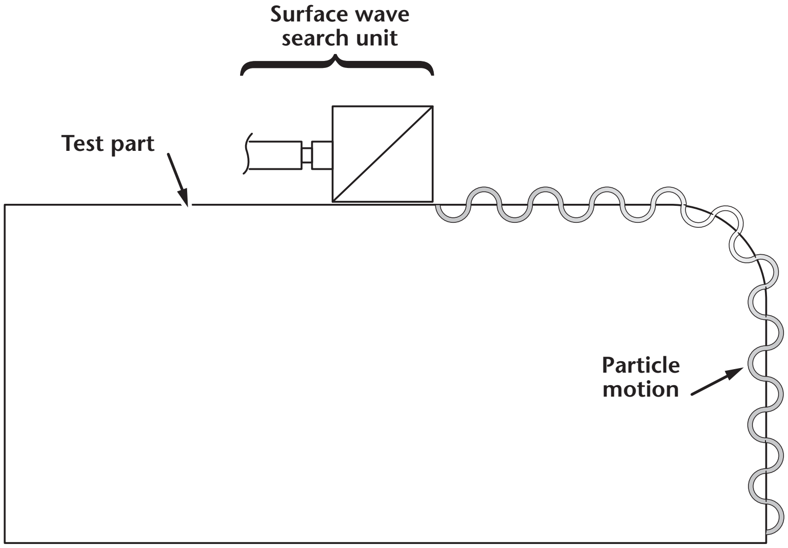


Figure 9-3-4. Surface wave mode.

waves are used in the *straight beam inspection* method, generally on objects 1/2-inch or thicker.

Transverse waves. Another type of wave propagation is called *transverse* or *shear* propagation. Shear waves are perpendicular to the direction of the sound beam. Shear waves are used in the *angle beam inspection* method that, as its name implies, introduces sound waves into a test part at an angle. This method allows inspection of irregularly shaped components or areas of limited access. This is because angle beams can travel through a part by bouncing from surface to surface. Angle beam inspections are well suited for cylindrical objects, for areas around fastener holes and for inspection of skins for cracks. Both longitudinal and shear waves are illustrated in Figure 9-3-3.

Surface waves. A third type of sound wave is the *surface* wave, or *Rayleigh* wave. Surface waves (Figure 9-3-4) are confined to a thin layer of a part's surface. Surface waves will travel around curves; reflections occur only at sharp corners on the surface. They are therefore most suitable for detecting surface flaws such as cracks and machining lines.

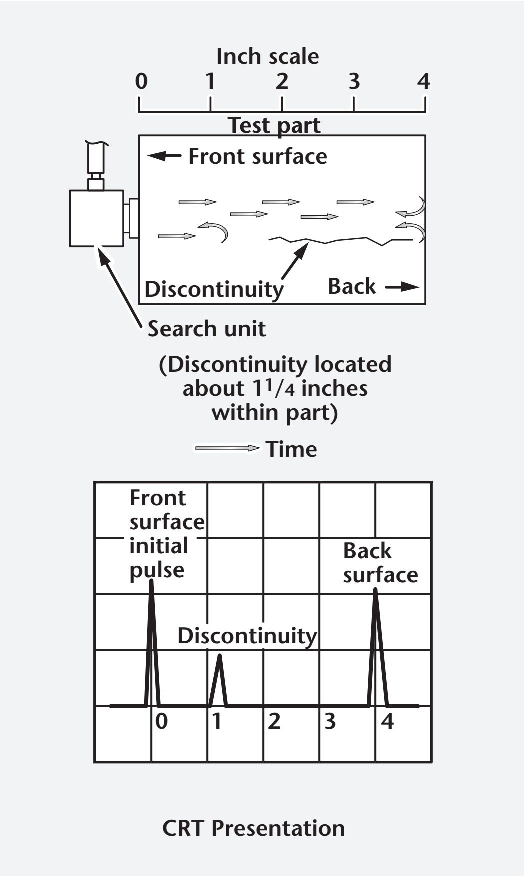


Figure 9-3-5. Typical pulse-echo display for contact inspection.

There are two ways to perform ultrasonic inspections, depending on how the ultrasonic signal is received by the transducer. They are the *pulse-echo system* and the *through-transmission system*.

Pulse echo. The pulse-echo system employs a transducer that transmits and receives ultrasonic signals. The transducer is held on a component's surface and emits an ultrasonic pulse. If the component contains no discontinuities, the pulse travels through the part until it reaches the far side, called the backwall, which reflects the pulse back to the transducer. However, if there is a flaw within the part, part of the sound pulse will bounce off the flaw and return to the transducer. The test unit measures the time difference between the pulses reflected from the flaw and the backwall, measures the relative distance of the flaw from the backwall and shows the information on the display (Figure 9-3-5).

Through-transmission. The through-transmission method (Figure 9-3-6) uses separate transmitter and receiving units that are placed on opposite sides of a component. Any discontinuities block the passage of sound, which causes a reduction in the received signal. With this method, echoes from discontinuities cannot be seen on the display and, therefore, depth information on the discontinuities cannot be determined.

Ultrasonic Thickness Measurement

Many aircraft repairs require the technician to remove material from a damaged part. After the repair is made, the material must be measured to make sure is still within limits. In most cases it is easy to use a micrometer or caliper to measure thickness. However, on large parts or complex assemblies it is not possible to use these tools. One alternative is an *ultrasonic thickness gauge* or *ultrasonic micrometer.*

Ultrasonic thickness gauges work on the same pulse-echo principle used in ultrasonic flaw detection. The test unit must first be calibrated for the material to be tested. A signal generator within the test unit produces an electrical signal that is sent to a transducer, or probe. The transducer changes the electrical signal into a high-frequency sound pulse and directs it into the target material. The sound pulse travels through the material until it reaches its backwall, which reflects the sound pulse back to transducer. Figure 9-3-7 shows a technician testing an aircraft window.

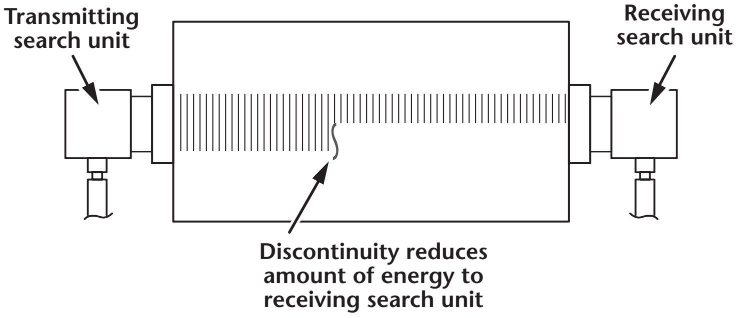


Figure 9-3-6. Through-transmission inspection.

Ultrasonic Leak Testing

In addition to finding cracks, discontinuities, and corrosion in aircraft parts, ultrasonic test equipment is used to detect leaks in a variety of aircraft systems and components. When pressurized gas flows through a leak, it produces sound of both audible and ultrasonic frequencies. Larger gas leaks generate lower-frequency sound that you can hear without assistance or with equipment such as microphones or stethoscopes. Smaller gas leaks produce sound at higher frequencies, generally in the range of 30,000 to 50,000 Hz. While this is above the range of human hearing, these frequencies travel easily through air and can be detected by ultrasonic leak detectors. Larger leaks make more noise and can be detected at greater distances. For example, leakage rates of 0.1 cubic centimeters per second can be detected at a distance of 2 feet, while rates of 10 cubic centimeters per second are detectable 20 feet away. Since the detector is sensitive only to ultrasonic frequencies, it is not affected by background noise and can be used while equipment is being operated.

Figure 9-3-7. Standard practice allows aircraft maintenance technicians to polish out small cracks and pits in aircraft windows. Here an inspector uses an ultrasonic test unit to find the thickness of a repaired window in an emergency escape hatch.

Unlike other ultrasonic test equipment, ultrasonic leak detectors are passive. This means that they do not generate ultrasound but only sense the ultrasound generated by a leaking system or component. Leak detectors can use a microphone to pick up signals at a distance or contact probes to detect internal component leakage. Leak indications are displayed visually on a meter or audibly as a tone in a headset. To find a leak, the probe is pointed at the test component and moved around suspected leak areas. You are trying to find fluctuations in the meter reading or changes in the audible tone. When fluctuations are noted, maximize the meter reading by pointing the probe directly at the suspected leak area. The leak will generally be located in front of the probe when the meter reading or tone volume is at a maximum.

This testing method has a wide variety of applications. It can be used to check for leaks in operating pneumatic systems, air conditioning systems, fuel systems, or any other system using pressurized air or liquids. Contact probes can detect internal leakage in hydraulic components. Ultrasound can also detect leaks and determine the rate of leakage in aircraft tire assemblies and emergency escape slides.

Tap Testing

Tap testing is a widely used inspection technique that can detect delamination and debonding in aircraft structures. Figure 9-3-8 shows a technician using a special hammer to tap test for delamination. It is particularly effective in finding flaws in composite structures. The procedure consists of lightly tapping a part's surface with a coin or small hammer. Metal is preferable to plastic, especially on composite structures. Defect-free structure produces a sharp ringing sound, while disbonded areas will give a hollow, flat, or "dead" sound. By alternately tapping known good areas and then testing suspect areas, the inspector can easily detect the difference in sound quality that reveals defects. While this method requires experience and skill on the inspector's part, it is easily learned and is accurate and inexpensive.

Figure 9-3-8. A composite technician tap tests a radome to detect delamination and disbond.

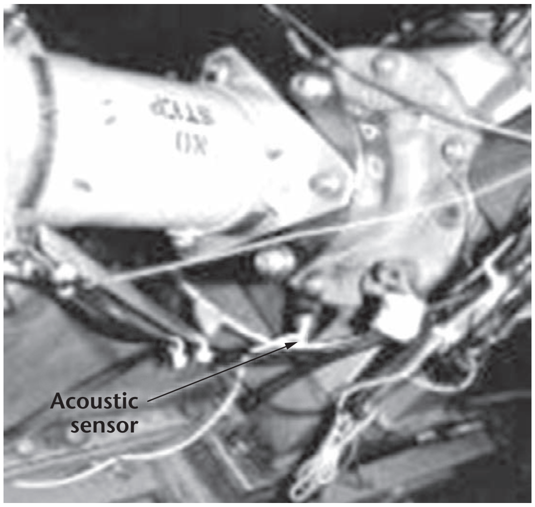


Figure 9-3-9. An acoustic sensor mounted to a helicopter gearbox. The acoustic emission test will be conducted with the engine operating.

Acoustic Emission Testing

Acoustic emission testing is a form of nondestructive inspection that detects the sounds made by structures under conditions of stress. Acoustic sensors similar to those used in ultrasonic inspection are placed at random locations on a component (Figure 9-3-9). Stress is then applied to the component; the stress can be bending stress, torsional (twisting) stress, or pressure. The stress causes the component to emit sound waves that are picked up by the acoustic sensors. If the component contains flaws such as cracks or corrosion, the flaws produce different sound emissions that are detected by the sensors.

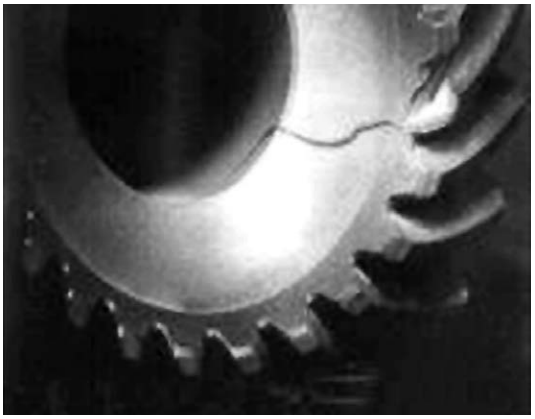


Figure 9-3-10. Crack detected in gear by acoustic emission inspection.
Photo courtesy of Physical Acoustics Company

Figure 9-3-10 is a photo of a cracked gear and is an excellent example of the types of flaws that are readily found using acoustic emission testing. While the same crack could be found with other methods, this is one of the best for these types of flaws.

Thermography

Thermography is a form of nondestructive inspection that detects the relative amounts of heat in components to detect flaws such as cracks and corrosion. It can be used on materials such as composite structures, or it can be applied to units in operation such as the motor shown in (Figure 9-3-11). In the case of composite structures, heat is applied to the part being tested. Discontinuities will have different rates of thermal conductivity, which are easily detected and displayed by the thermographic test unit.

The bearings in engines or motors produce increasing amounts of friction and heat as they wear. Thermographic inspection can detect this heat as the motor is running.

Eddy Current Inspection

Eddy current inspection is a form of nondestructive inspection that is used frequently throughout the aircraft industry. It is used to detect cracks, pitting, discontinuities, and corrosion in metals both on the surface and below the surface. In addition, eddy currents are used to determine the composition of alloys, a mate-

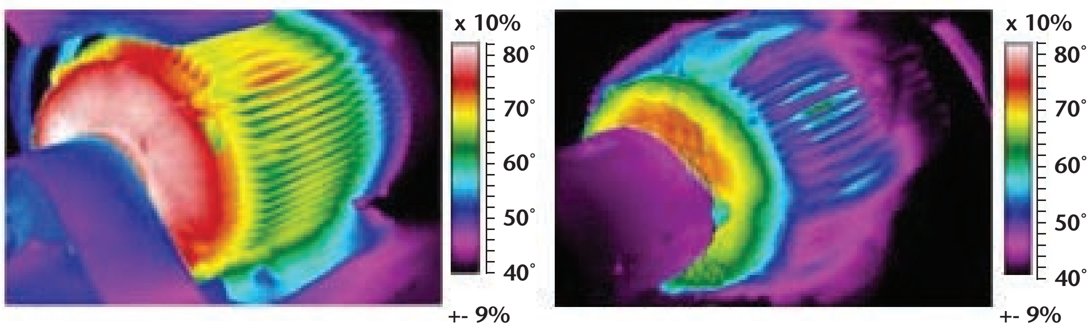


Figure 9-3-11. These thermographic images show that the thermal patterns of these motors are similar, but there is a marked overall temperature rise on the motor on the left, indicating discontinuity.
Photo courtesy of Infrared Training, Inc.

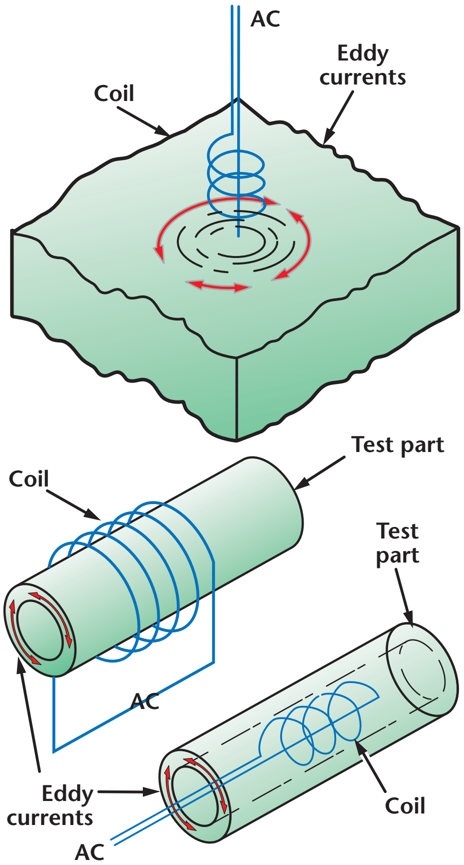


Figure 9-3-12. Alternating current creates a constantly changing magnetic field. When it is held near a conductor, this magnetic field induces eddy currents in the conductor.

Figure 9-3-14. A sample of different eddy current test probes.

rial's heat-treat condition and damage caused by exposure to excessive temperature. Eddy current equipment is portable, making it ideal for inspections in the field. There are limitations for eddy current inspections, since the component being tested must be an electrical conductor. Also, eddy current inspection cannot accurately detect flaws that are parallel to the part's surface.

Operating Principles. Eddy currents are electrical currents induced in a conductor by a changing magnetic field. As you recall from your study of electricity, when alternating current passes through a coil it develops a magnetic field around the coil. When the coil is placed next to a component that is an electrical conductor, eddy currents are induced in the component. These eddy currents are circular and perpendicular to the direction of the magnetic field (Figure 9-3-12).

If a material is composed of a uniform alloy and contains no discontinuities, the eddy currents

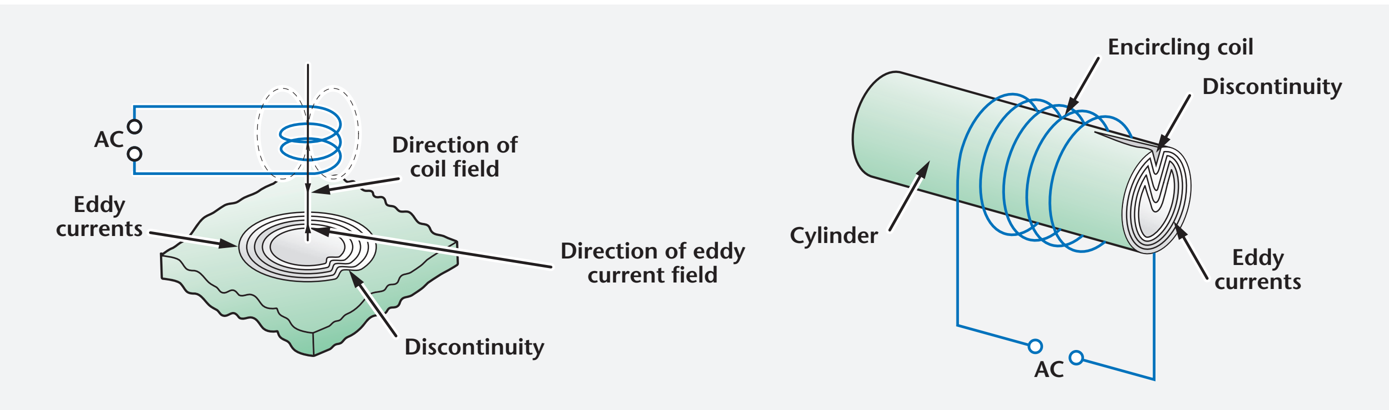


Figure 9-3-13. Discontinuities, such as cracks, change the conductor's permeability and disrupt the induced eddy currents.

induced within the material will be uniform. However, if the material is cracked, corroded, or contains contaminants, these flaws change the material's permeability or its resistance to magnetic fields. As a result, these flaws produce disruptions in the induced eddy currents that are detected by the eddy current probe, as shown in Figure 9-3-13.

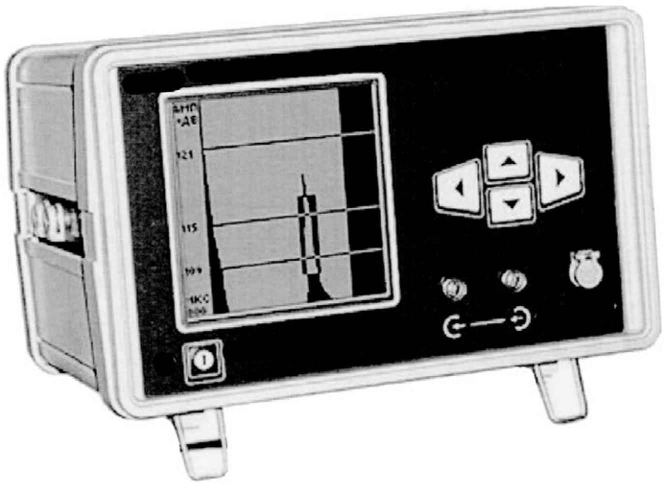


Figure 9-3-15. A typical eddy current test unit.

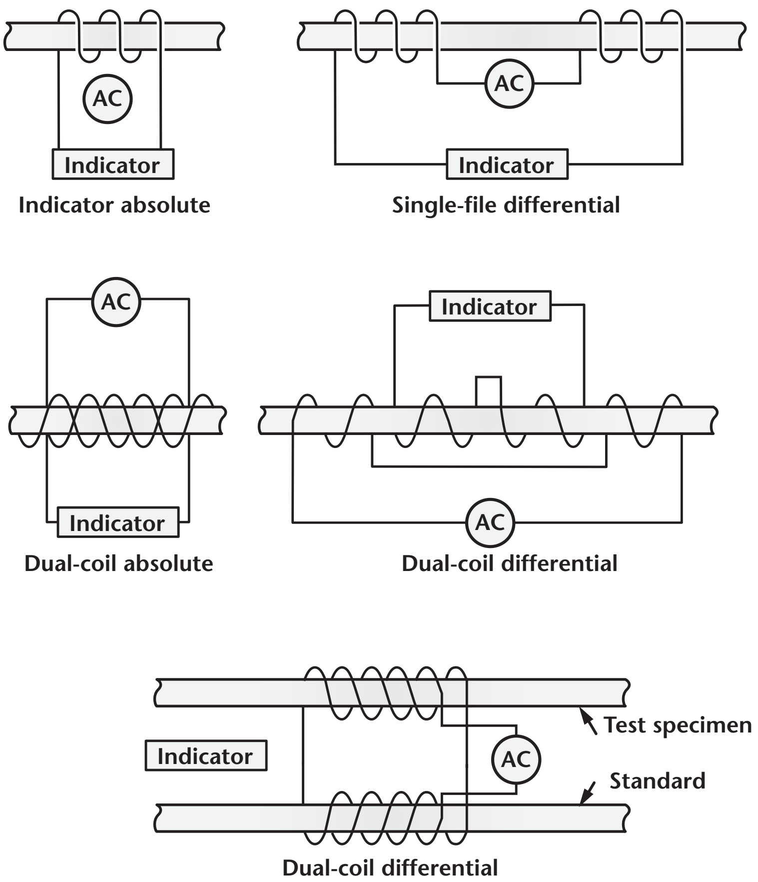


Figure 9-3-16. Single coils induce eddy currents in the tested area of a single part. Dual coil units compare the tested area to a reference standard (an area known to be defect-free).

General Procedures

A typical eddy current test unit consists of four basic parts. A coil assembly or probe induces eddy currents into the part being inspected and detects changes in eddy current flow. In some applications, a single probe performs both functions. However, it is more common to use one coil to induce current flow and use other coils as detectors. Figure 9-3-14 illustrates a variety of test probes. The second component is an oscillator that provides alternating current at a selected frequency to the test probe. The frequency used depends on the type of defect suspected and the material being inspected. Frequencies can vary from 50 Hz to greater than 6 MHz.

A signal processor converts changes in eddy current magnitude and distribution from the probe into signals that are processed and displayed. The processor employs a bridge circuit set to provide a zero output when no flaws are present. Presence of a flaw results in an unbalance of the bridge, producing a signal that is amplified and analyzed in the processor circuit. The processing circuit then sends a signal to an output display (Figure 9-3-15) for interpretation by the inspector.

There are three general types of operation for eddy current coil assemblies—absolute, differential, or driver/receiver (Figure 9-3-16.) Absolute probes consist of a single coil that induces a signal in the area immediately adjacent to the coil. This method develops a signal based only on the signal received from the tested component. Differential probes, on the other hand, consist of two or more coils and operate by comparing the response of one coil to the response of another. Normally, one coil is used to test a part while the other coil develops a signal from a known good part or from a reference standard. By comparing the two signals the inspector can detect discontinuities in the tested part.

Driver/receiver probes utilize a driver coil physically separated from one or more receiver coils. The driver coil induces eddy currents within the tested part. A common setup for the receiver coils is for one receiver coil to be adjacent to the inspected part and the other coil to be removed from the part but still near the driver coil. The eddy current instrument is then adjusted to zero. Then, as the area interrogated by the first coil changes, the display output changes to show the change in the area being inspected.

Radiographic Inspection

Radiographic inspection uses the same principles and techniques found in medical X-ray testing. Just as medical X-rays find broken bones, high-energy *X-rays* and *gamma rays* are used to detect flaws in aircraft structures and components. In radiographic testing, a radiation source directs X-ray or gamma ray radiation into a test component. A photographic film is placed opposite the radiation source so that the radiation passes through the component and strikes the film. Flaws within the component absorb some of the radiation passing through them, resulting in an image on the film. This is called *differential absorption*.

Radiographic inspection has several advantages over other inspection methods. It can detect both surface and subsurface flaws and can be used on ferrous and nonferrous metals, ceramics, and plastics. It can penetrate deep within complex assemblies, such as the rotating cores of turbine engines and wing and stabilizer attach fittings, and detect flaws. Radiographic inspection can determine any significant variations in a material's composition.

Real-time radiography, which substitutes an electronic sensor for photographic film, provides a video image of operating components. However, radiographic inspection has some important drawbacks. The high energy level of the radiation employed can kill living tissue, produce genetic mutations, and cause serious injury or death to exposed personnel.

Radiographic inspection is expensive since it requires specialized equipment and training for inspectors. The setup for radiographic inspection can be very time consuming. Radioactive materials must be stored in secure areas, and strict record keeping and accountability for these materials is mandatory.

Principles of Radiography

Electromagnetic radiation. X-rays and gamma rays are forms of electromagnetic radiation, as are visible light, ultraviolet light, radio waves, and cosmic rays. The most distinguishing characteristic of X-rays is their short wavelength. The penetrating power of X-rays is dependent on their wavelength in an inverse relationship; that is, the shorter the wavelength, the higher the energy, and vice-versa, as illustrated in Figure 9-3-17. Visible light can pass through sheets of paper but is unable to penetrate metal. X-rays, because of their shorter wavelength and much higher energy, can pass through metal with ease. For our purposes, X-rays and gamma rays will be treated the same, although their sources are different. The main difference is that gamma ray sources are physically small and provide access to small spaces.

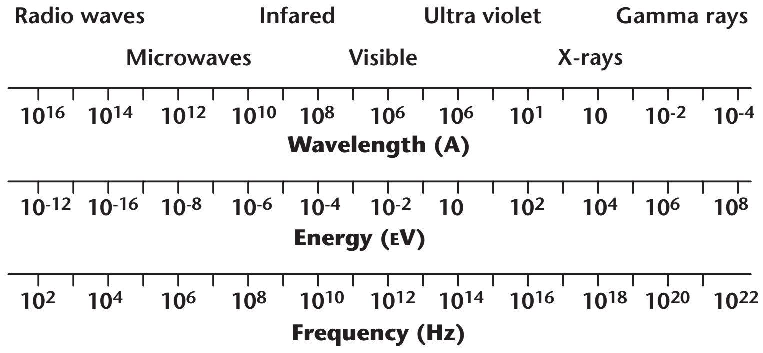


Figure 9-3-17. Electromagnetic spectrum.

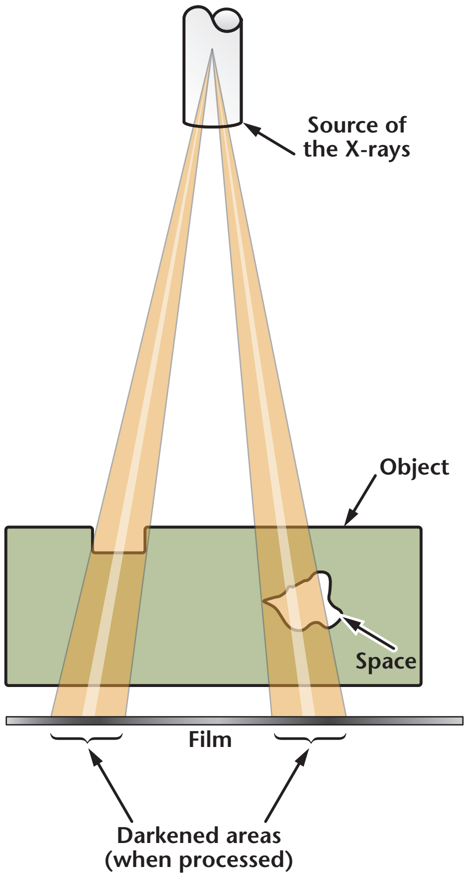


Figure 9-3-18. The radiation that passes through a discontinuity, or a thinner area, retains more energy and creates a darker image on the film.

X-rays and gamma rays share some characteristics with visible light but are very different in most ways. They are invisible to humans and are *reflected* or *refracted* to a much smaller degree than is visible light. X-rays and gamma rays expose (darken) photographic film and both cause certain substances to emit light (fluoresce).

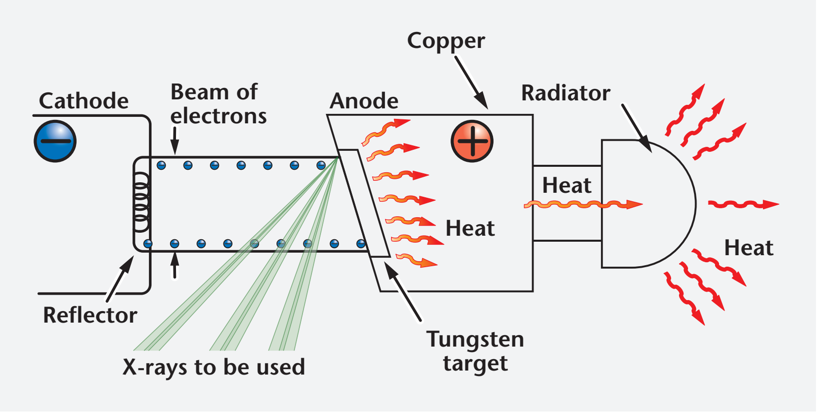


Figure 9-3-19. Fundamentals of an X-ray tube.

They are absorbed or scattered differently by different materials, and it is this property that is most important to their use in NDT.

As X-rays pass through a given material, the material, depending on its density and makeup, absorbs a certain amount of energy. A material discontinuity, such as a void or change in configuration, changes a material's effective thickness and, thus, changes the amount of radiation absorption (Figure 9-3-18). Since all radiation that is absorbed or scattered within a material is transmitted, the amount of transmitted radiation varies with localized changes in effective material thickness.

It is this transmitted radiation intensity that is usually used to find material defects. If the material discontinuity shown in Figure 9-3-18 were a foreign material inclusion, it would also cause a change in the apparent composition of the material and again result in a change in the transmitted radiation intensity. The degree of this change would depend on relative effects of the base material and the included material on the applied radiation.

Methods of Generating Radiation

X-rays. X-rays used in radiographic inspection are generated by the interaction of high-energy electrons or ions with matter. A typical X-ray tube houses a cathode emitter and a target anode in a vacuum tube. The cathode is a tungsten filament that emits electrons when heated. This filament is housed in a reflector in much the same way as a flashlight. The reflector focuses the electron beam and directs it to the target. The X-ray tube is illustrated in Figure 9-3-19. The target anode usually consists of a piece of tungsten that is mounted at a 45° angle and embedded in a copper rod, which acts as a heat dissipater. When current is applied to the cathode filament, it emits a high-energy electron beam that strikes the tungsten target. As electrons hit the target, they cause the target material to emit energy in the x-ray spectrum through the side of the x-ray tube.

Gamma rays. As you recall from your study of physics, an atom consists of *protons*, *neutrons*, and *electrons*. A stable atom will have a certain number of protons and neutrons in its *nucleus*. Sometimes an atom of a given element will have more or fewer neutrons than it should. Such an atom is called an *isotope*. Isotopes are unstable and seek to return to a stable condition by converting neutrons to protons, by converting protons to neutrons, or by ejecting an *alpha particle* (two neutrons and two protons) from the nucleus. The atom is seeking a stable neutron-to-proton ratio. When a nucleus changes the number of its protons and neutrons, it releases energy in the form of *ionizing radiation*. One form of this energy is *gamma ray radiation*.

Radioactive isotopes such as *iridium-192* are used to produce gamma rays for aircraft inspections. Iridium-192 constantly emits gamma rays as its nuclei seek to reach a stable state, and the material will continue to do so until all its atoms are stable. Gamma rays contain about 10,000 times the energy of visible light. It is this high energy that allows them to penetrate the heavy metal castings found on many aircraft components.

General Radiographic Procedures

A radiographic inspection must be sensitive enough to detect small defects. This is achieved by using a radiation beam of the proper power, directing the beam in correct alignment with the plane of the likely flaw, and obtaining sharp images through proper geometrical setup of the shot and control of secondary radiation. These factors are determined by the thickness, composition, and density of the test material, the size and shape of the object, and the type of defect to be detected.

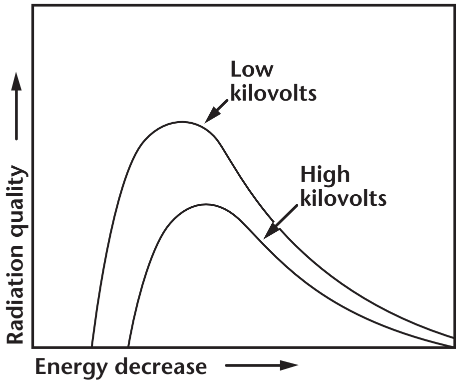


Figure 9-3-20. The left line represents a lower voltage applied for a longer time. It will produce an X-ray image with superior contrast than the lower voltage shorter time exposure.

Radiation energy is selected depending on the density of the tested material. For thin sections of less-dense materials such as honeycomb structure, low energy radiation produces final radiographic images of good contrast. On the other hand, dense, massive castings such as turbine engine cores require radiation of sufficient penetrating capacity to produce an image within a reasonable period of time. Excessive radiation reduces contrast in the final image. An example is shown in Figure 9-3-20.

The geometrical setup of the equipment used in the shoot has a great effect on image quality. Improper setup can result in image distortion, fuzziness and loss of resolution. In general, five factors should be considered when setting up a shot:

- The X-rays should proceed from as small a local spot as circumstances allow.
- The distance between the source and the object should be as great as practical.
- The film should be as close as possible to the object being radiographed.
- The central beam should be as nearly perpendicular to the beam as possible.
- As far as the object's shape will allow, the plane of suspected flaws in the object should be parallel to the film.

Whenever X-rays interact with a material, *unwanted absorption*, *scattering*, or *penetration* can occur. Scattered radiation can present a problem since it may expose the X-ray film with false images. Exposure due to scatter is called *fog* and substantially reduces image contrast. Scatter can be caused by unwanted objects in the radiation beam, by radiation from objects behind the film (called *backscatter*), or by characteristics of the test specimen itself. Figure 9-3-21 shows sources of scatter. Scatter can be controlled by placing lead shielding in critical areas of the test piece. Lead sheets placed behind the film can reduce or eliminate backscatter.

Special Radiographic Techniques

Fluoroscopy. Up to this point we have discussed radiographic inspections that produce permanent records on film. An alternative to film radiography is fluoroscopy. Fluoroscopy is based on the ability of X-rays and gamma rays to produce fluorescence in some materials. Fluorescence is the property of some materials that causes them to emit visible light when subjected to radiation. Fluoroscope inspection has the advantage of providing an instantaneous visible image of a component's interior. It operates on the same principles as film radiography; the only difference is that the fluoroscope screen takes the place of photographic film.

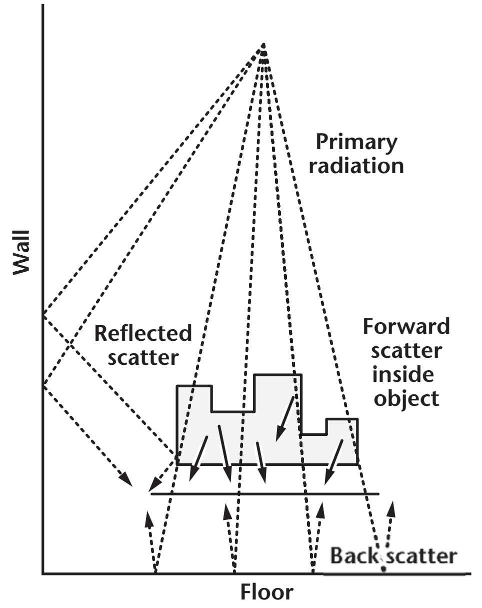


Figure 9-3-21. Backscatter from a number of sources can cause poor image quality.

Computed tomography (CT). *Computed tomography* is a radiation inspection that can provide density and geometric images of cross sections of a test component. It derives from the CAT scan technology used in medical applications and uses a computer to construct an image of a cross-sectional plane through an object. CT information is derived from a large number of observations of radiation intensity over many different viewing angles. This method allows the inspector, in effect, to slice open the test object, examine its internal features, perform dimensional inspections, and identify any material or dimensional defects that may exist. A major advantage of CT inspection is that internal structures are not hidden or shaded by other structures that may be in the beam path. In addition, CT inspections can detect density variations and locations within the inspected material. This method's main disadvantage is that it requires full access to the tested part, which must be small enough to fit inside the CT scanner.

Radiation Safety

Radiation is one of the most serious hazards you will face when you work as an aircraft maintenance technician. The radiation levels used in aviation are far greater than those found in medical applications. Exposure to ionizing radiation can kill you or cause serious injuries that will shorten your life. It is extremely important that you understand the nature of the risks and take all possible precautions.

Three factors determine your level of exposure to ionizing radiation. The first is time. Obviously, the more time you spend near a radiation source, the higher dosage you will receive. Radiographic testing is designed to keep exposure times to a minimum, and inspection personnel are limited in the amount of time they can spend doing these inspections. The second factor is distance. The farther away you are from a radiation source, the less your exposure. Test equipment using high levels of ionizing radiation is controlled remotely to keep inspection personnel as far away as possible from the radiation source. The last factor is shielding. The more material between the radiation source and your body, the less exposure you receive. When not in use, radioactive materials are stored in heavily shielded containers to limit exposure to personnel in the area.

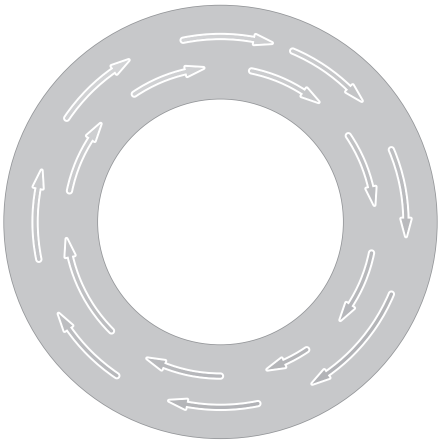


Figure 9-3-22. Horseshoe magnet, fused into a ring.

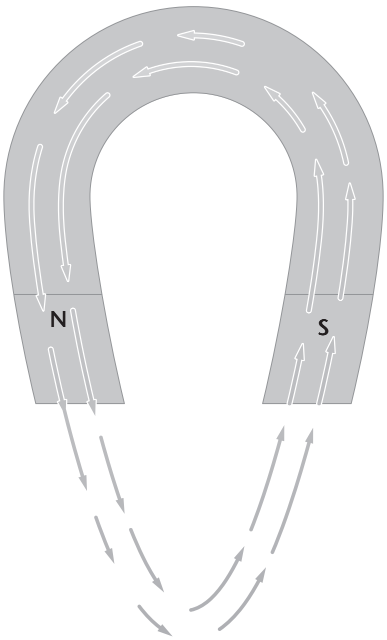


Figure 9-3-23. Horseshoe magnet.

Devices called *dosimeters* measure personnel exposure levels. Three types of dosimeters currently in use are the *thermoluminescent dosimeter*, or TLD, the *electronic personal dosimeter* and the *digital/personal alarm dosimeter* (PAD). A thermoluminescent dosimeter consists of a material that, when exposed to radiation, is excited by the radiation to a higher energy state. When this material is later heated, it falls back to its original energy state and emits light. The amount of light emitted is directly related to the amount of radiation the TLD received. By measuring this light, the dose received by the individual wearing the dosimeter can be determined.

An electronic personal dosimeter contains circuitry that detects radiation and records the amount of exposure in its memory. The PAD has a display to show total radiation received. In addition, the PAD provides an audible signal or *chirp* when exposed to radiation to alert the wearer of its presence. Both types of dosimeter allow permanent records to be kept of total exposure.

Magnetic Particle Inspection

Magnetic particle inspection is a form of NDI that can detect flaws on the surface or just below the surface of alloys composed of iron or steel. The part to be tested is first magnetized by electric current to induce a magnetic field within the part. Next, a fine iron oxide powder is applied to the part's surface and forms patterns along the lines of magnetic flux induced in the part. Any disruption or break in the part will cause a disruption in the magnetic field and will be revealed by change in the pattern of the oxide powder.

Some definitions are needed to understand magnetic particle inspection.

Indication. An *indication* is an accumulation of magnetic particles held by a magnetic leakage field to the surface of a part.

Discontinuity. A *discontinuity* is an interruption of the normal physical structure or configuration of a part.

Defect. A *defect* is a discontinuity that interferes with the usefulness of a part.

Principles of Magnetism

As you recall from your study of physics, magnetism is the property of some metals, primarily iron and its alloys, to attract each other. Most metals are affected by magnetism to some degree, but only iron, steel, cobalt, nickel, and their alloys, called *ferromagnetic* materials, are sufficiently affected for the application of magnetic particle inspection. The ease with which a part can be magnetized is called its *permeability.* A metal such as aluminum that is difficult to magnetize is said to have low permeability, while metals like soft iron that magnetize easily have high permeability.

To understand how magnetic particle inspection works, look at the drawing of the lines of magnetic force, or magnetic flux, in a circular magnet. The magnetic flux lines are contained within the magnet (Figure 9-3-22) and have little affect on ferromagnetic materials such as iron filings. However, if the circular magnet is cut to form a horseshoe magnet, (Figure 9-3-23) magnetic flux lines form between the magnet's north and south poles and exert a powerful magnetic attraction on iron filings. This is called flux leakage, and is the principle that allows magnetic particle inspection to help you detect defects in ferromagnetic components.

When a part is magnetized, it channels magnetic flux lines just like the circular magnet. If there are no cracks, breaks, or flaws in the part, no flux lines leave the part. If there are breaks or cracks at or near the surface, however, magnetic field strength is increased in the area of the defect. Magnetic particles applied to these areas form a pattern around the defect.

Magnetic field orientation. Proper orientation of the magnetic field is critical to reveal defects in a part. If the magnetic field is parallel to a flaw, the disruption in the field is minimized and the defect may escape detection. Best results are achieved when the magnetic field is at right angles to the suspected defect, causing maximum field disruption that creates a very visible indication. Two methods are used to achieve this. They are circular magnetization and longitudinal magnetization.

As you recall from your study of electricity, circular magnetic fields surround a conductor carrying electric current. The magnetic lines of force are circular and are at right angles to the direction of current flow. Circular magnetization uses this principle to detect radial discontinuities around edges of holes or openings in parts. It is also used to detect longitudinal flaws that lie in the same direction as the current flow (Figure 9-3-24).

Two methods are used to perform circular magnetization. In the direct contact or direct induction method, as shown in Figure 9-3-25, the component is mounted between two electrical contact plates and current is passed through the component. This method requires caution since the high amperages needed to induce the magnetic field can cause overheating, arcing, and burning of the part.

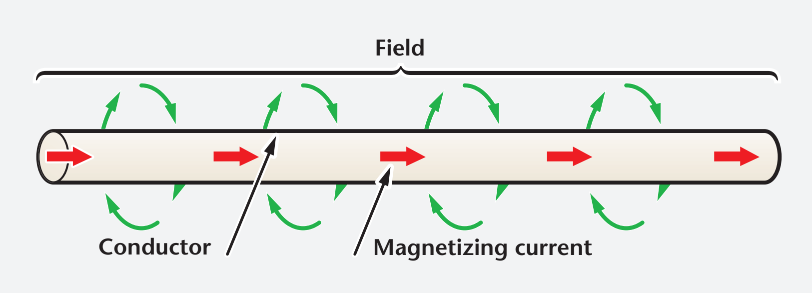


Figure 9-3-24. Magnetic field surrounding an electrical conductor.

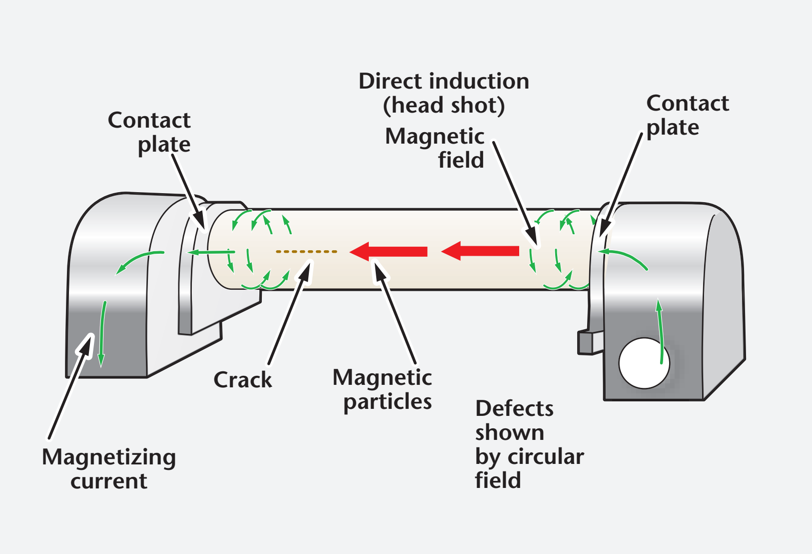


Figure 9-3-25. Circular magnetization.

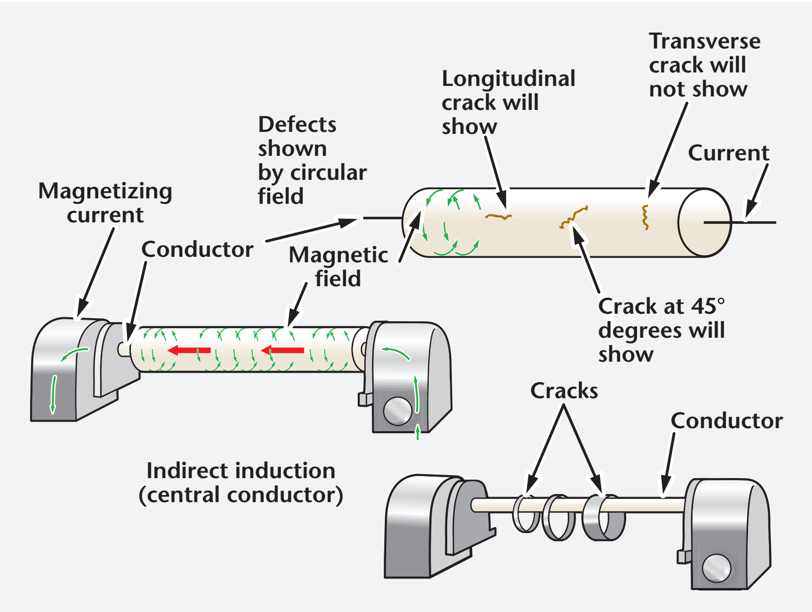
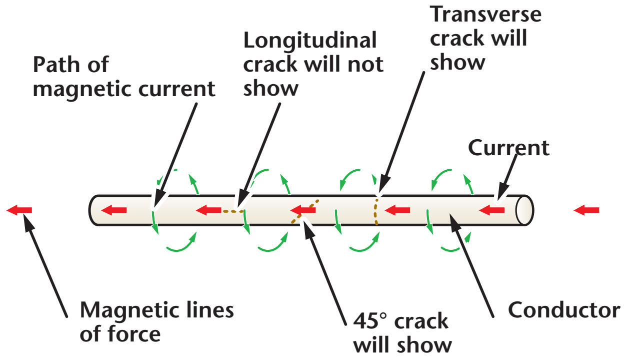
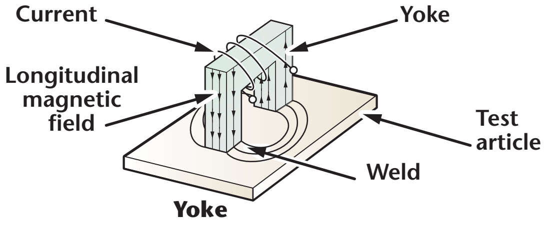
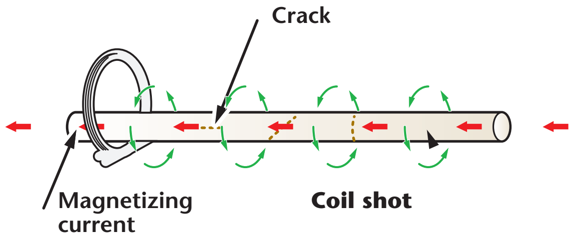


Figure 9-3-26. Using a central conductor to circularly magnetize a cylinder.

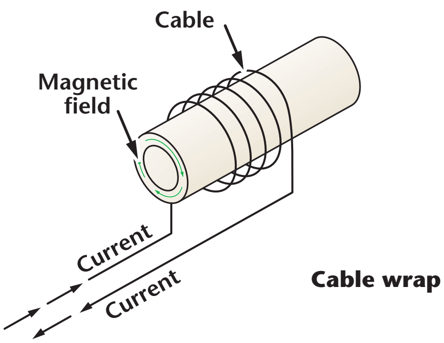




Yoke
Essentially a yoke is a temporary horseshoe magnet. It is made of low-retentivity iron that is magnetized by a small coil wound around its horizontal bar. Yokes are recommended for parts subject to arc burns and for spot inspection of large parts.



Coil shot
The usual way to longitudinally magnetize a part is to place the part lengthwise inside the bottom of the coil. Multiple inspections are neccessary on long paths because the effective field extends only 6 to 9 inches on either side of the coil.



Cable wrap
Cable wrapping a coil around large or heavy parts is a common practice. Cable length must be kept as short as practical to minimize cable-resistance loss and aid in obtaining higher current amperages. Normally, three to five turns are sufficient.

Figure 9-3-27. Longitudinal magnetization.

The indirect induction or central conductor method can be used with tubular or hollow parts to detect longitudinal discontinuities. The part is mounted over the circular conductor that is then magnetized, inducing a magnetic field in the part (Figure 9-3-26).

Longitudinal magnetization is used to detect circumferential discontinuities that lie at 45° or 90° to a part's axis. It is performed by placing the component to be tested in a strong magnetic field. While there are a number of ways to generate this field, a magnetizing coil, yoke, or cable are most frequently used. The coil method is very effective on long parts such as crankshafts. Figure 9-3-27 shows all three methods.

Current and particle magnetization. Two methods are used to magnetize components. The method used for a given part depends on the part's *magnetic retentivity* and the desired sensitivity of the inspection to be made. Retentivity refers to a metal's tendency to keep a magnetic field after the magnetizing current is removed. The two methods used are the *residual* method and the *continuous* method.

The residual method is used only when parts are magnetized with direct current and can only be used with parts that have sufficient retentivity to form adequate magnetic particle indications at discontinuities. When using this method, a part is magnetized and the indicating medium is applied after the magnetizing force has been removed. Residual inspection can be used with longitudinal or circular magnetization, using either direct contact or central conductor methods.

The residual method has the advantage of allowing a part or a group of parts to be magnetized and then inspected at a later time. It cannot be used to detect subsurface flaws, however, and is limited to parts with high retentivity.

The continuous magnetization method uses a magnetizing force that is active when the indicating medium is applied. In practice, current is applied for a few seconds up to several minutes, although leaving current on for long periods can overheat the part and damage the test equipment. The continuous method can be used in practically all circular and longitudinal magnetization procedures. It has the advantage of using AC or half wave rectified AC power. In addition, it is more sensitive than the residual method and is able to detect subsurface discontinuities. The choice of which method to use depends on the magnetic retentivity of the parts to be inspected, the desired sensitivity to be achieved and the availability of equipment.

Indicating Media and Application Methods

The particles used in magnetic particle inspection are made of magnetic elements, usually iron or iron oxides, that have high permeability and low retentivity. High permeability allows the particles to be easily magnetized by the low-level leakage fields at discontinuities, while low retentivity keeps the particles from becoming permanently magnetized, which would cause unclear indications. In addition to high permeability, the size of the particle is very important. Sizes vary from 0.0002-0.0006 inch. The smallest sizes are easily attracted to low-level leakage fields at very fine discontinuities, while larger particles can more easily bridge the strong leakage fields at coarse discontinuities. Magnetic particles are available in different colors including red, gray, yellow, and black and can be mixed with fluorescent dyes for use in ultraviolet (black) light inspection. Colors are chosen to provide the best contrast with the surface background of the part being inspected. The fluorescent method is used frequently because of its ability to highlight the smallest indications.

Magnetic particles can be applied wet or dry. Each method has certain advantages and disadvantages, and the application method depends on the part being inspected and the types of discontinuities you expect to find.

As its name implies, the dry application method requires no liquid carrier. Components being tested are magnetized and dry particles are then poured, brushed, or sprayed on, usually with a squeeze bulb or spray can. A spray gun similar to a paint gun utilizing compressed air can be used to cover larger areas (Figure 9-3-28). Dry application has several advantages. It is better for localized inspections of small areas, and it is suitable to mobile use since it needs no special application equipment. In addition, dry particles are more suitable for detecting subsurface discontinuities of moderate size.

The wet application method uses a low-viscosity liquid carrier such as oil, kerosene, or water mixed with an anticorrosion agent. After a part is magnetized, a liquid particle slurry is poured or sprayed onto the part, or the entire component can be immersed in a liquid bath. This application method offers the convenience of complete coverage of oddly shaped parts and is superior in detecting very fine and shallow defects such as fatigue cracks. However, the wet method is less portable than dry application, and drainage patterns of liquid particle slurry can hide or obscure actual flaw indications.

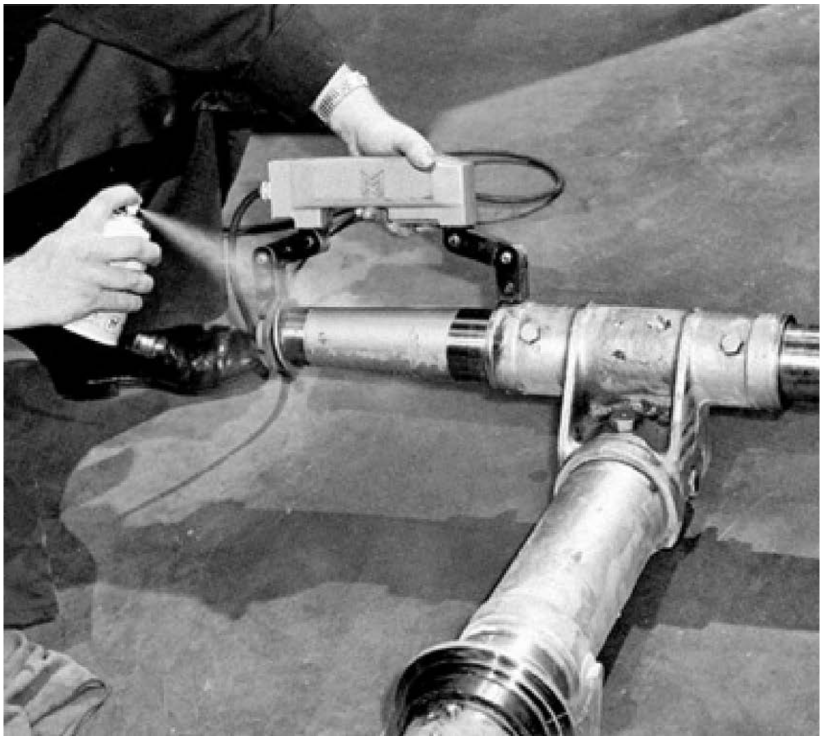


Figure 9-3-28. Field inspection of a nose wheel strut.

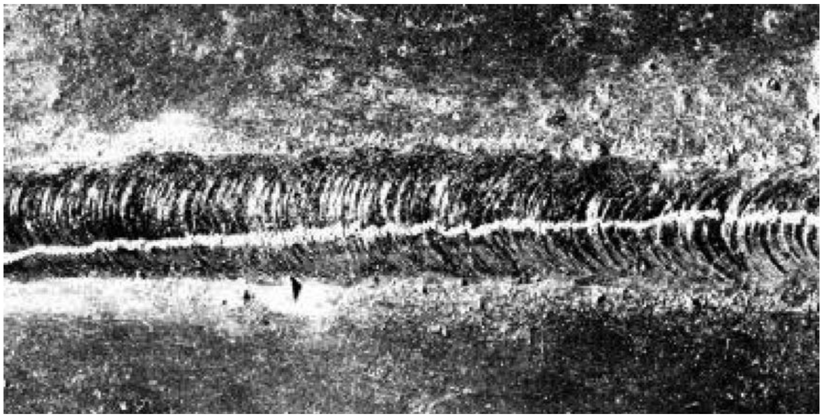


Figure 9-3-29. This pattern indicates a surface discontinuity. Notice the sharpness and definition of the magnetic particle accumulation.

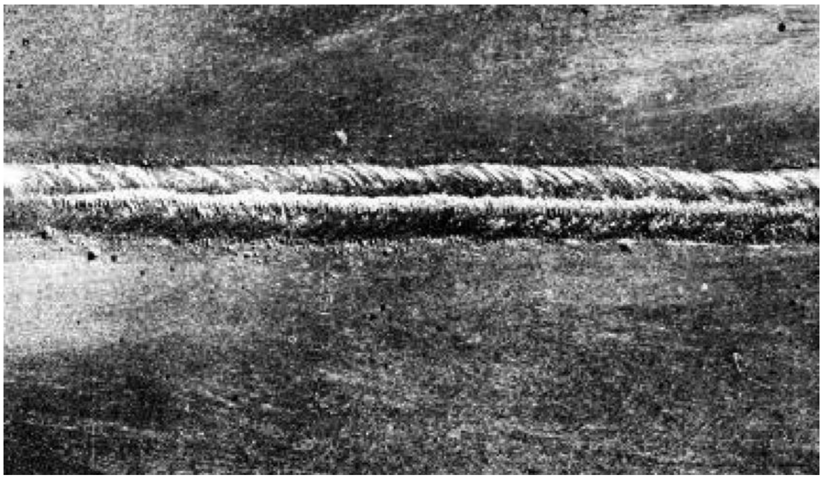


Figure 9-3-30. The pattern here is much broader and is characteristic of the indications formed over subsurface discontinuities.

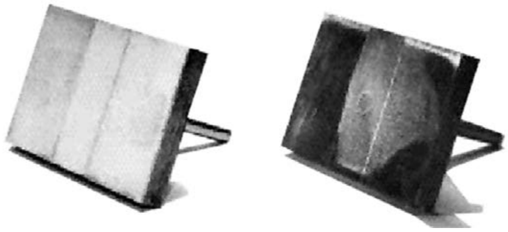


Figure 9-3-31. Magnetic indication of a forced fit.

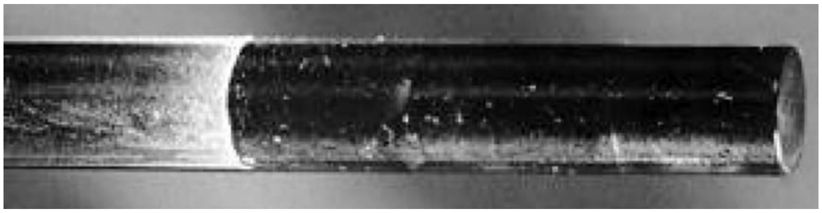


Figure 9-3-32. MPI at the weld between a soft and a hard steel rod.

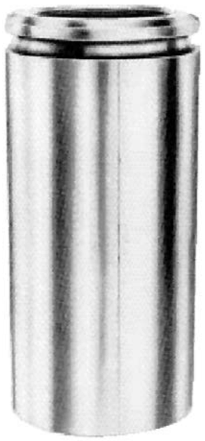


Figure 9-3-33. MPI of a subsurface stringer of non-metallic inclusions.

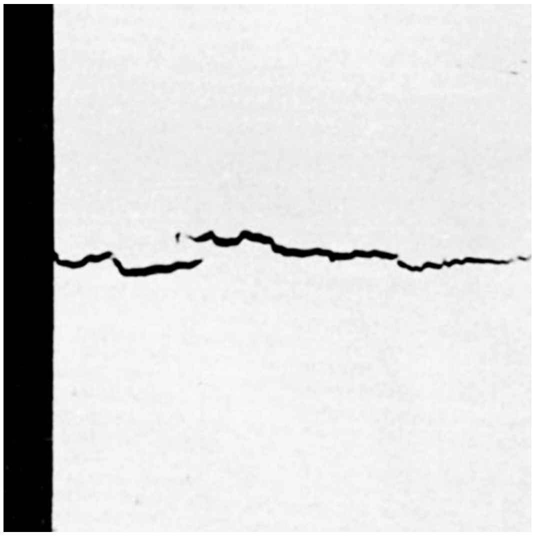


Figure 9-3-34. Magnetic particle indications of cooling cracks in an alloy steel bar.

Figure 9-3-35. MPI of quenching cracks, shown with dry powder.

Indication Interpretation and Evaluation

After you perform a magnetic particle inspection and have actual indications, you must interpret these indications to determine their cause. Then, the indication must be evaluated to determine its effect on the component's usefulness.

Figure 9-3-29 shows surface discontinuities that produce indications characterized by particles tightly held to the surface by a relatively strong magnetic leakage field. This indication will have sharp, well-defined edges and a noticeable buildup of particles. On the other hand, subsurface discontinuities, as in Figure 9-3-30, will display a fuzzy or indistinct particle accumulation. This is due to the weaker leakage field caused by subsurface flaws.

After determining an indication's source, you must interpret its nature and decide if it renders the component unserviceable. In general, there are two sources of indications—those caused by manufacturing processes that are not cause for concern, and those caused by wear, stress, or malfunction that effect a part's serviceability.

Many aircraft components contain parts with press fits, or interference fits in which parts are held together by friction. These seams will give magnetic particle indications, but the indications are simply showing a normal condition (Figure 9-3-31).

A similar indication can occur at welds. Indications can occur at the boundaries of welded dissimilar ferromagnetic metals because the metals have different permeabilities, even though the weld is perfectly sound. These indications, as shown in Figure 9-3-32, are not a cause to reject the part.

Some manufacturing processes result in defects that can cause MPI indications. *Non-metallic inclusions* are usually oxides, sulfates, or silicates found in metal castings. They are caused by poor manufacturing processes and can form stringers during rolling operations. These defects can affect a part's serviceability and are cause for rejection. Figure 9-3-33 shows such an item.

When alloy and tool steel bars are rolled and subsequently run out on a bed or table for cooling, uneven cooling can induce stresses severe enough to crack the metal bars. Such cracks are generally longitudinal and are not necessarily straight. They may be quite long and vary in depth along their length. Figure 9-3-34 shows that the magnetic particle indication of this flaw varies in intensity, being heaviest at points where the crack is deepest.

When steels are heated and quenched to produce desired properties for strength or wear, cracking may occur if the operation is not suited to the part's material and shape. The most common *quench cracks* occur when heated parts are cooled in a quenching medium (Figure 9-3-35). They occur at locations where a part changes cross-section, at fillets or notches, or at the edges of keyways or the roots of splines or threads. Cracks may also result from the too-rapid heating of a part that can cause uneven expansion.

Stress cracks occur when components are stressed beyond their design limits. This can happen due to accidents, impact, or overspeed conditions. For example, a propeller strike or sudden stoppage on a reciprocating engine may not result in immediate part failure but can cause serious damage that will lead to component breakage. Magnetic particle inspection can reveal these dangerous defects, as in Figure 9-3-36.

Demagnetization

Demagnetization is performed between successive magnetizations of the same part to allow defect detection in all directions. It must also be done at the completion of the magnetic particle inspection procedure to remove residual magnetism.

Either AC or DC can be used to demagnetize parts. In the AC method, the part is placed between the demagnetizing coils and moved slowly through the coils and about three or four feet past the coils. This is repeated several times until the part loses its residual magnetism. Figure 9-3-37 shows this process in action.

When the DC method is used, the part is placed in the same relative position as when it was magnetized and reverse DC current is applied. The current is gradually reduced to zero and the process is repeated until the residual magnetic field is depleted.

Section 4

Practical Inspection Techniques

Weld Inspection

Welds must be inspected for quality immediately after the welding operation is performed. The finished weld should be uniform in thickness and should taper smoothly into the base

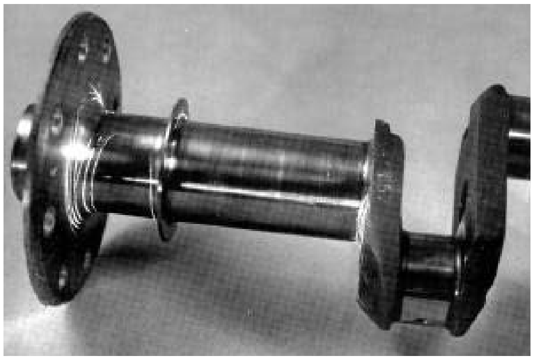


Figure 9-3-36. Fluorescent magnetic particle indications of cracks in crankshaft of small aircraft engine damaged in an accident.

metal. There should be no blowholes, porosity, or large globules. The base metal should display no signs of pitting, burning, cracking, or distortion.

Welded parts are subject to cracks and corrosion in service. Weld seams can be visually checked using a magnifying glass, but some form of nondestructive testing is more efficient. Dye penetrant is very effective at finding cracks in welded structures and has the advantages of being inexpensive and portable. Other NDT methods such as ultrasound, X-rays, and eddy current are also used to detect cracks and corrosion in welded structures. An example of X-ray inspection of welds is shown in Figure 9-4-1.

Hardware

Hardware should be inspected for general condition and obvious damage. This includes corrosion, wear, and impact damage. Self-locking fasteners are single-use items. Look for signs

Figure 9-3-37. Non-contact demagnetization.

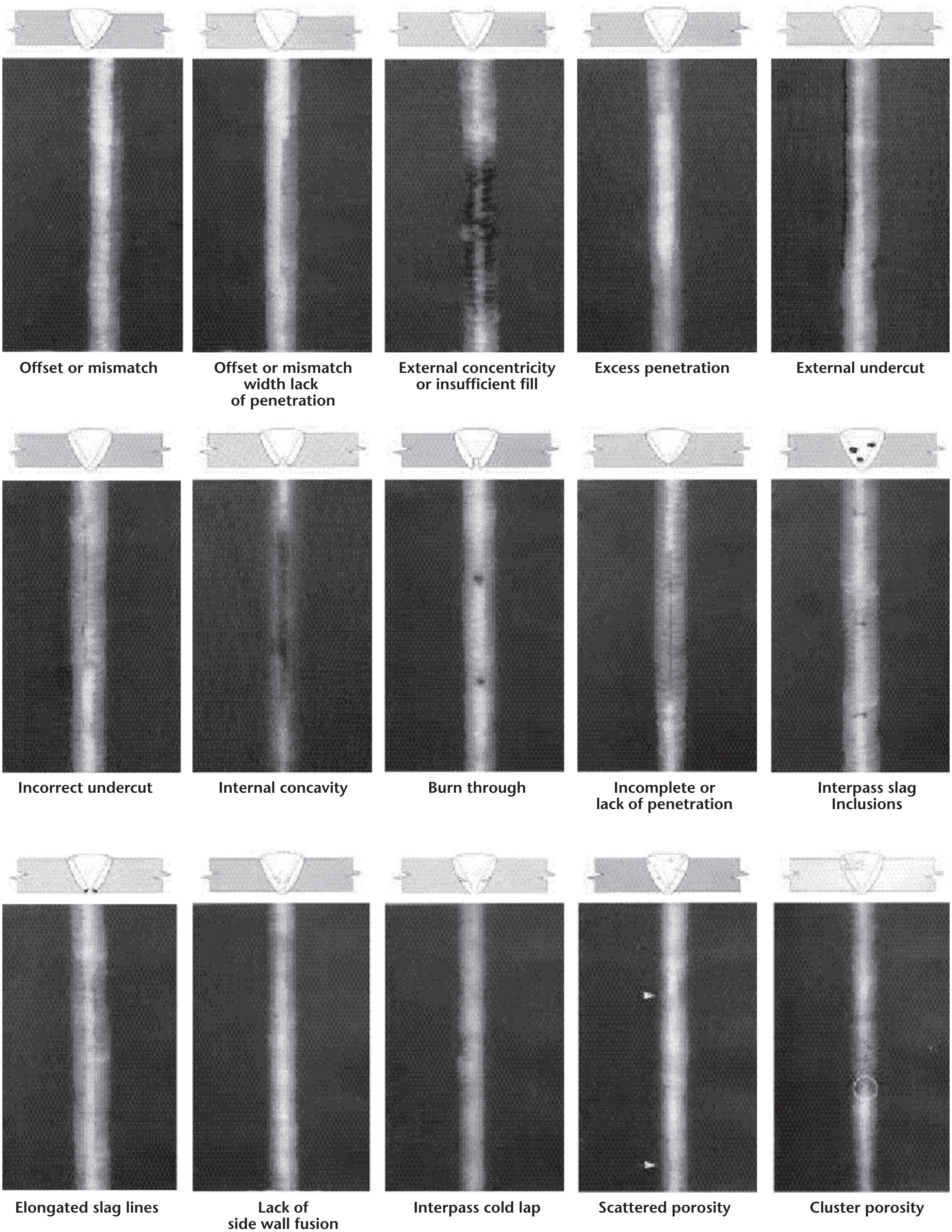


Figure 9-4-1. Radiographic examples of welds.

of excessive wear and looseness on self-locking nuts.

Observe the condition of bolt heads and fasteners. In areas around moving parts with little clearance, a shiny or gouged bolt head indicates that something is loose or worn. A greasy sludge or "mud" forms around bolt heads when the nut works loose or when the mount hole becomes elongated.

Rivets should be inspected for proper installation and tightness. A properly shot rivet will have no deformation on the shop head. The bucked shank should be uniform and flat, one times the rivet's diameter thick, and one-and-a-half times its diameter in width. Rivets should be tight in the surrounding structure. Flaked paint on or around a rivet could indicate looseness. On exterior surfaces, loose rivets will display *smoking*, a telltale streaking caused by exhaust and atmospheric gases.

Non-standard or *bogus* parts present a major threat to airworthiness when installed on aircraft. You must be vigilant when installing and inspecting hardware. Counterfeit parts often have a rough appearance or poor finish. Automotive and construction industry hardware have been found installed on aircraft. If possible, check the paperwork trail for any suspect hardware. Remember, if you install it, you own it.

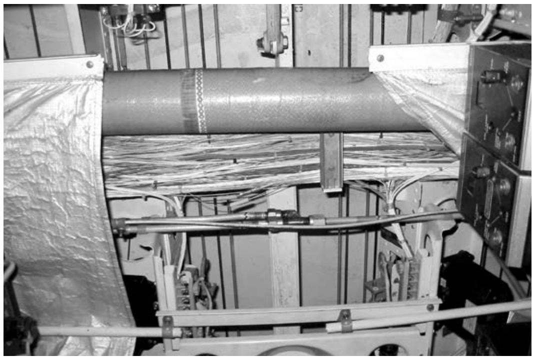


Figure 9-4-2. Flight control cables and wiring bundles are located directly below the passenger cabin floor panels. Wiring in this area is susceptible to impact damage and foreign object contamination.

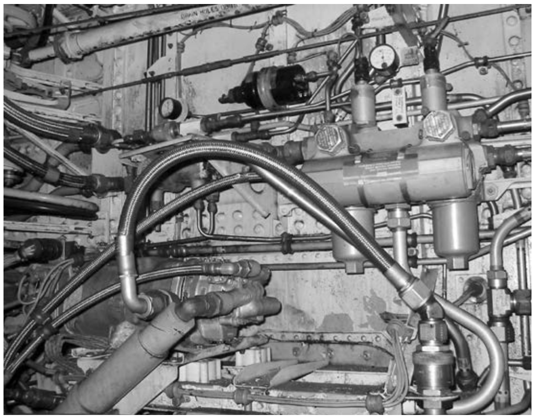


Figure 9-4-3. Hydraulic tubing and hoses in the main landing gear well of a Boeing 737 are particularly vulnerable to damage from stones, hail, and other debris.

Electrical Wiring

Swaged terminals are subject to fatigue from flexing caused by repeated removal and installation. Inspect terminals for signs of bending or cracking. Pull gently on the wire going into a terminal — the swaged attachment should be stronger than the wire.

Faulty aircraft wiring or insulation can lead to arcing, short circuits, and fires. Wiring is particularly vulnerable to damage caused by technicians performing maintenance and repairs. Metal chips, hardware, and solvent can contaminate wiring bundles and deteriorate insulation. Look for discolored insulation, arc tracking on insulation, and worn or missing insulation.

Wiring is sometimes bent and deformed when removing and installing other parts, and can be stepped on when floor panels have been removed. Be aware of this and look for wiring bundles that sag between their clamp supports or show kinks or abrupt bends. Figure 9-4-2 is an example of an under floor wiring bundle.

Hydraulic Components

Hydraulic systems consist of components such as pumps, valves, reservoirs, and actuators, and plumbing lines and fittings. Pumps, valves, and actuators frequently develop leaks in service. Before locating the source of a leak, the area around the component should be cleaned and the system serviced. Suspect components should then be observed while the system is operating. This often requires that flight control surfaces be moved through their full range of travel, which presents a safety hazard to personnel.

Hydraulic plumbing often runs through areas subject to abrasion and foreign object damage. Landing gear wells, for example, receive impact damage from ice, rocks, sand, and other debris. The same is true for wing leading edges and flap wells. Check plumbing in these areas for dents, kinks, bends, and other obvious damage. Again, leak checks will sometimes require you to inspect these components while the hydraulic system is pressurized.

Figure 9-4-4. A maintenance technician checks a pressurized cabin for leaks.
Photo courtesy of UE Systems, Inc., Elmsford, NY

Aircraft hydraulic systems operate at pressures up to 3,000 p.s.i.

> **CAUTION:** Never allow any part of your body to get close to areas where leakage may be occurring while the system is operating. Pinhole leaks in lines and components may not be visible, but they can cut your skin like a razor. Injuries caused by fluid injection frequently require that the affected area be amputated.

When you suspect a pinhole leak from a line or component, move a piece of paper or cardboard around the area. The paper will absorb hydraulic fluid and help locate the leak. Figure 9-4-3 is a typical area that needs frequent inspection.

Figure 9-5-1. A portable oxygen bottle used on passenger aircraft by flight attendants.

Pneumatic Systems

Pressurized pneumatic system lines and components can be leak checked using a leak detecting solution. Soapy water, for example, can be sprayed over a suspect area. If a leak is present, soap bubbles will form at its source. Ultrasonic leak detectors (Figure 9-4-4) are available that can *hear* the telltale sounds produced by leaking components, even while the aircraft's engines are operating.

Section 5

Oxygen System Inspection

Oxygen system inspection presents unique problems to the technician. While oxygen itself is not a flammable gas, it is an oxidizer and can cause some materials to ignite spontaneously. When working around oxygen systems, you must take extra care to make sure your hands and tools are free from grease.

> **CAUTION:** If grease is exposed to pure oxygen, it will ignite. There are documented cases of pilots putting lip balm on their lips and then donning an oxygen mask. The lip balm, which contained petroleum products, ignited when exposed to pure oxygen.

Types of oxygen systems. There are two types of oxygen systems used in aviation. The first uses oxygen gas compressed in cylinders. In a fixed system the oxygen bottle is mounted in a remote location with tubing routed to the points of use in the flight deck and the passenger compartment. With this type of system, the oxygen cylinders must be checked for obvious damage and security of mounting.

All oxygen cylinders require periodic recertification and pressure tests. Inspection is only outlined here. See the section on *Oxygen Systems* for cylinder inspection requirements. Make sure the cylinder is within its inspection limit.

Oxygen system plumbing must be checked for security and obvious damage. This would include bends and kinks in the tubing. Fittings should be checked for tightness. Special leak check solutions that are inert when exposed to oxygen should be used to leak check fittings. This procedure should also be done any time the system is opened for servicing. FAA AC 43.13-1B paragraph 9-47 through 9-51 contain more complete inspection and recertification requirements. Additional information will be included in the applicable aircraft maintenance manual (MM).

Passenger aircraft have individual oxygen masks for each passenger in case of cabin decompression. They are usually contained in a *passenger service unit* (PSU) above each seat. The oxygen system components in each PSU should be inspected periodically for condition. They should be inspected for correct packing in accordance with the MM to assure they will deploy properly when the system is actuated.

Portable oxygen bottles (Figure 9-5-1) are used aboard passenger aircraft to allow flight attendants to aid passengers in distress. They should be inspected for correct pressure, cleanliness, and signs of obvious damage.

The second type of oxygen system uses oxygen generators in place of compressed gas (Figure 9-5-2). An *oxygen generator* consists of a chemical compound that, when ignited by a percussion cap, burns and releases pure oxygen gas. Oxygen generators become extremely hot when activated, so exercise caution when handling them. Inspect oxygen generators for proper safety of the igniter and signs of damage. They will change color when they have been activated.

Because an oxygen generator is classified as a pyrotechnic device, it has special handling requirements that must be followed. Be sure to read and understand all instructions before attempting work on, or around, any pyrotechnic device. An oxygen generator has special regulations relating to shipment and disposal. Follow them.

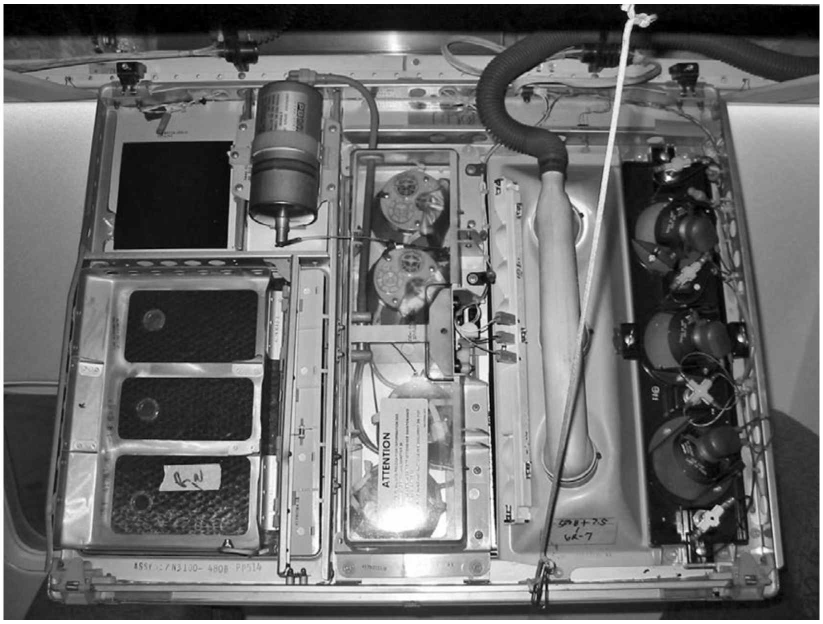


Figure 9-5-2. This PSU panel uses a solid oxygen generator (visible at the top, left of center) to supply four passenger oxygen masks.

Section 6

Damage-Tolerant Design Concepts

The Lockheed Electra L-188 is a turboprop transport aircraft that bridged the era between piston-powered propeller aircraft and pure jets (Figure 9-6-1). The prototype first flew in 1957, and the

Figure 9-6-1. The Lockheed Electra L-188 first saw service in June, 1959. It was the largest turboprop airplane in service and was billed as the replacement for the aging piston-powered fleet. Hidden design flaws soon put an end to its promising future.

Figure 9-7-1. The structural failure of the upper cabin of an Aloha Airlines 737-200 was the event that put national focus on aging aircraft and corrosion inspections. *Photo courtesy of NTSB*

aircraft was put into service by numerous airlines soon after. However, a hidden design flaw would soon become apparent, dooming the aircraft's commercial popularity.

On September 29, 1959, an Electra operated by Braniff Airways was en route from Houston to Dallas at 15,000 feet when structural failure caused the left wing to separate from the aircraft that subsequently crashed. Six months later on March 17, 1960, another Electra operated by Northwest Orient Airlines suffered a similar fate when its right wing separated in flight.

The cause of these accidents was traced to defective engine mounts. Vibration caused the engine mount to fail. The engine then began an oscillation in its nacelle, setting up a violent flutter in the wing that caused it to separate from the fuselage. The entire sequence took less than 60 seconds. This is an example of *catastrophic failure*.

The Electra accidents and others led aircraft designers to focus on ways to prevent one component failure from causing the loss of an entire aircraft. This is called *failsafe design.*

Failsafe design allows a structure to retain its required residual strength for a period of use after the failure of a principle structural element. As an example, the engine on a Boeing 737-300 is held on to its nacelle by three cone bolts. These bolts are designed to break if the engine develops excessive vibration from a disk failure, allowing the engine to separate from the wing. While this is a serious occurrence, the aircraft can still be flown safely and landed.

A key element of failsafe design is *damage tolerance*. Damage tolerance is the characteristic of a structure or component that allows it to retain its required residual strength for a period of use after the item has sustained a given level of corrosion, fatigue, or accidental damage.

Damage tolerance based inspections are developed by a manufacturer or operator based on an engineering evaluation of likely sites where damage could occur. They are also developed considering expected stress levels, material characteristics, and projected damage growth rates. It is important to understand that this concept allows an aircraft to continue in operation with a known level of deterioration. By knowing the damage is present, how quickly it is likely to spread and the failsafe nature of its design, the operator can schedule its repair at the lowest possible cost without compromising safety.

Section 7

Aging Aircraft

In April of 1988, an Aloha Airlines 737-200 series aircraft cruising at 24,000 ft. suffered an explosive decompression and lost a significant amount of its roof and skin structure (Figure 9-7-1). A flight attendant was swept from the aircraft and, miraculously, was the only fatality. The National Transportation Safety Board (NTSB) determined the accident was caused by structural failure induced by metal fatigue. Investigators found numerous cracks and corrosion, despite the fact that the operator followed an approved maintenance program. Contributing factors included improper maintenance inspection, inadequate supervision of maintenance personnel, and inadequate surveillance by the FAA.

When jet-powered aircraft first entered service, the effects of metal fatigue were not fully understood. The first jet in commercial service, the DeHavilland Comet, experienced in-flight fuselage failure. Three Comets were lost because of this, and aircraft manufacturers redesigned aircraft to reduce metal fatigue. However, the Aloha incident illustrated that strong design was not enough; older airframes require more thorough inspection and maintenance.

In response to the Aloha accident, and others, the FAA developed its *National Aging Aircraft Research Program* to study how age affects aircraft and develop plans to maintain airworthiness. The program focused on 10 first- and second-generation aircraft such as the Boeing 707, 727, 737, and 747. In addition, the FAA divided the aircraft into separate areas. The two we are interested in are structures and electrical systems.

The FAA determined there are three kinds of damage that lead to failure. The first is *corrosion damage*, obviously caused by the process of corrosion or oxidation. The spread of corrosion, once discovered in an aircraft structure, is fairly easy to predict since it spreads with the passage of time. An aircraft operator must develop a *corrosion prevention and control program* (CPCP) for his or her aircraft based on history for the particular aircraft. Inspection intervals should and will be adjusted based on the success of the CPCP.

The second type of damage is *fatigue damage*. The repeated flexing of structural components, typically as a result of turbulence, takeoff, and landing, causes fatigue damage in the form of cracks. The cracks caused by fatigue tend to spread at a predictable rate. Fatigue damage is not time-dependent like corrosion but instead relates to aircraft cycles, the number of takeoffs and landings.

The third type of damage is *accidental damage*. Accidental damage results when aircraft are hit by ground vehicles or encounter severe hail during flight. It cannot be predicted, so an aircraft operator must include in his inspection program sufficient periodic inspections to detect damage sustained in accidents. It is important to note that one of the leading causes of accidental damage is, ironically, inflicted most often during the maintenance of the aircraft.

Technicians frequently cause damage while performing aircraft maintenance. One example the FAA has found concerns aircraft wiring. Wiring bundles run throughout the aircraft fuselage and are often found below floorboards. When floorboards are removed to repair aircraft floor structure, technicians sometimes step on the bundles, causing damage to insulation and stress on terminals. Aluminum chips from drilling get into wiring bundles and, over time, wear through wiring insulation and cause short circuits. This has been found to be a major concern in aging aircraft, and all technicians will encounter it at some point.

The FAA requires operators of aging aircraft to develop practices to assure the continued airworthiness of their aircraft through inspection, monitoring, and corrective maintenance.

The aging aircraft initiative will allow the continued operation of safe, reliable, and economical airplanes. Properly inspected and maintained aircraft have a very long service life. The Boeing B-52 aircraft first flew in the early 1950s, and the Air Force plans on operating the fleet into the 2040s.

Section 8

Corrosion Prevention and Control

Corrosion is the single greatest threat to the integrity of airframe structures. It is a natural chemical or electrochemical process that occurs on metals and metal alloys. Corrosion weakens the metals it attacks and, if left untreated, will cause metal parts to fail.

A number of factors promote the spread of corrosion. These include air pollution, the type of metal used in components, or the type of stress the metal is subjected to. However, unless a metal part suffers direct chemical attack by acid or a mercury spill, *corrosion will only occur in the presence of water and oxygen.*

Chemical corrosion. This occurs when a strong acid or base chemically dissolves metal. An example would be a piece of copper or zinc immersed in acid. The acid attacks and dissolves the metal until nothing is left. Aircraft are exposed to a number of corrosive chemicals. For example, aircraft batteries are a source of both strong acids and bases. In addition, acids can be produced in aircraft structures when certain conditions are present. It is common to find growths of microorganisms in aircraft fuel tanks. Certain bacteria have metabolisms that

Contacting metals	Aluminum alloy	Cadmium plate	Zinc plate	Carbon and alloy steels	Lead	Tin coating	Copper and alloys	Nickel and alloys	Titanium alloys	Chromium plate	Corrosion resisting steel	Magnesium alloys
Aluminum alloy												
Cadmium plate												
Zinc plate												
Carbon and alloy steels												
Lead												
Tin coating												
Copper and alloys												
Titanium and alloys												
Chromium plate												
Corrosion resisting steel												
Magnesium alloys												

Shaded areas indicate dissimiliar metal contact

Table 9-8-1. Differences in electrode potential among various structural materials.

cause them to secrete corrosive fluids. These fluids form acids that attack metal structures.

Electrochemical corrosion. *Electrochemical corrosion* occurs in the presence of different metals that have different susceptibilities to corrosion. The mechanism involved is similar to the way a primary cell works. As you recall from your study of electricity, a primary cell consists of an anode, or donor of electrons, a cathode, or receiver of electrons, and a conductive electrolyte. When a conductor completes the circuit between the anode and cathode, a chemical reaction occurs in the cell that produces electricity. As this process takes place the anode is slowly worn away by the chemical reaction. The same process occurs in electrochemical corrosion.

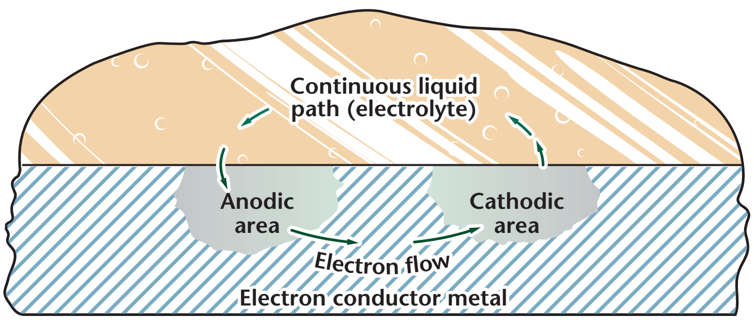


Figure 9-8-1. Water acts as an electrolyte when corrosion occurs on a metal structure.

A metal's *electrode potential* refers to the metal's ability to give up or receive electrons. Electrode potential is a function of a material's atomic structure; those with a high electric potential are strong electron donors while those with a low potential are poor electron donors. Refer to Table 9-8-1. Because of its atomic structure, gold is not a good electron donor. Since it is not very susceptible to corrosion, gold is frequently used as a coating on electrical system contacts. On the other end of the scale is magnesium, which is a strong electron donor. This property makes magnesium extremely susceptible to corrosion. However, its strength and light weight make it indispensable for certain aircraft applications.

Electrochemical corrosion takes place when two different metals come in contact, either directly or through a conductive electrolyte. The farther apart they are in their electrode potentials, the greater the degree of corrosion.

Moisture and oxygen are always present in the atmosphere. When metal is exposed to moisture, electrochemical corrosion has a place to start. One part of the metal surface will serve as a cathode, receiving electrons. Another part of the metal acts as an anode, giving up electrons. Corrosion will always take place at the anode, as shown in Figure 9-8-1.

A number of factors affect the spread of corrosion. If an aircraft is frequently operated near the ocean, the salt in the atmosphere increases the electrolyte action of the water and the corrosive process is more rapid. The same is true for air pollution. Sulfur and nitrogen compounds in the air dissolve in water and form acid compounds. These compounds attack structural components directly and provide a good electrolyte for electrochemical corrosion.

Types of Corrosion

Corrosion attacks aircraft structures in a variety of ways, depending on a component's composition and location.

Pitting corrosion. Pitting corrosion starts on the surface and extends down into the material. It is most common in aluminum and magnesium parts and is first noticeable as a white or gray powdery deposit on the surface. When the powdery deposit is cleaned away, tiny pits or holes can be seen in the surface. Pitting corrosion can spread vertically and horizontally from the area of initial surface attack, severely weakening the corroded part. The corrosion can spread rapidly. Subsurface damage, shown in Figure 9-8-2, can be dramatically worse than the surface appearance would lead you to believe.

Concentration cell corrosion. Crevice corrosion occurs at joints between metal parts. The joint can be a butt splice, a seam, or an assembly. When the protective finish or sealant between the metals deteriorates, water and air are allowed in. This creates a microenvironment where a corrosive process begins and spreads. In metal ion concentration cells, entrapped water forms a solution with ions from the metal structure. A high concentration of metal ions develops where the water solution is stagnant, while a low concentration of metal ions forms next to the crevice. An electrical potential difference exists between the two points. Metal in contact with the low concentration of ions is anodic and corrodes.

Oxygen concentration. Oxygen concentration cells occur when the solution in contact with the metal surface contains dissolved oxygen. An oxygen cell can develop at any point where the oxygen in the air is not allowed to diffuse into the solution, thereby creating a difference in oxygen concentration between the two points. The area of low oxygen concentration is anodic, and corrosion starts there.

Look at Figure 9-8-3 and contrast the normal bolt on top with the corroded lower bolt. Water exposure allowed an oxygen concentration to start that dissolved the threaded portion.

Figure 9-8-2. This magnesium casting was installed in a passenger door. Pitting corrosion formed on the lower edge of the gasket (removed) when the sealant became worn. The pitting is more than 0.1 inch deep.

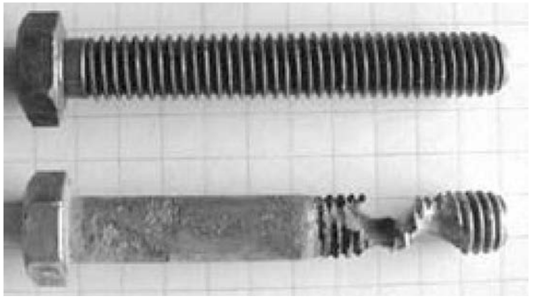


Figure 9-8-3. It is obvious how dangerous this condition can become.

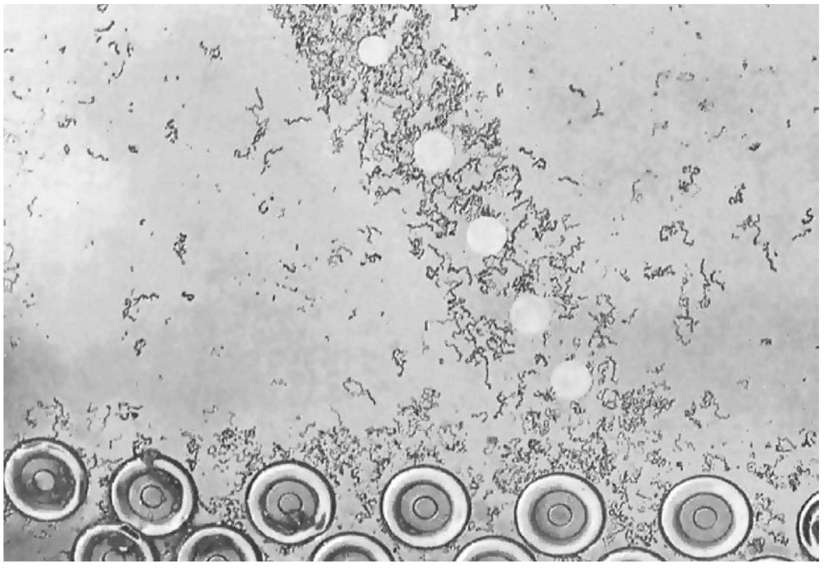


Figure 9-8-4. Filiform corrosion is a form of oxygen concentration cell corrosion that occurs under painted surfaces.

Filiform corrosion. Filiform corrosion (Figure 9-8-4) is a type of oxygen concentration cell corrosion that occurs on metal surfaces hav-

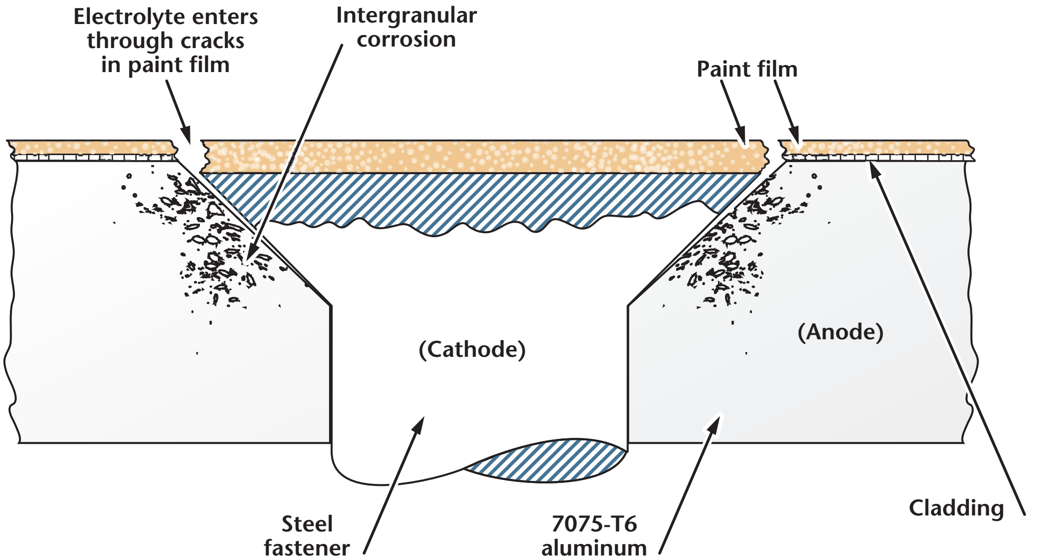


Figure 9-8-5. Intergranular corrosion of 7075-T6 aluminum adjacent to a steel fastener.

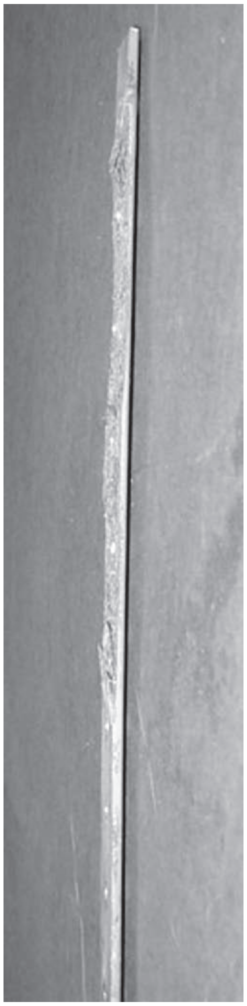


Figure 9-8-6. An example of exfoliation corrosion on a stringer section. The corrosion products have more than doubled the part's original thickness.

ing an organic coating. You can recognize it by its characteristic worm-like or thread-like trace of corrosion products beneath the paint film. Filiform corrosion occurs when the relative humidity is between 78 and 90 percent, and it most likely to occur under polyurethane finishes. If filiform corrosion is not removed, it can lead to another form, intergranular corrosion.

Intergranular corrosion. Intergranular corrosion is an attack on the grain boundaries of a metal. A magnified cross-section of an alloy will show the granular structure of the metal. This granular structure consists of thousands of individual grains, each of which has a clearly defined boundary that differs chemically from the metal within the grain. The grain boundary and the grain center can react with each other as anode and cathode when in contact with an electrolyte, resulting in rapid corrosion along the grain boundary. Intergranular corrosion is most likely to occur in high-strength aluminum alloys that have been improperly heat-treated. Figure 9-8-5 illustrates a typical area to look for this type of corrosion.

Exfoliation corrosion. Exfoliation corrosion (Figure 9-8-6) is an advanced form of intergranular corrosion characterized by the lifting up of a metal surface's grains by the force of expanding corrosion products occurring at the grain boundaries just below the surface. It is visible evidence of intergranular corrosion and is most often seen on extruded sections.

Galvanic corrosion. Galvanic corrosion, one of the most common types of corrosion, (Figure 9-8-7) occurs when two dissimilar metals make contact in the presence of an electrolyte. It also occurs when certain metals come in contact with carbon fiber reinforced plastic. Galvanic corrosion typically appears as a white or gray powdery substance on fittings, joints, or other structural interfaces.

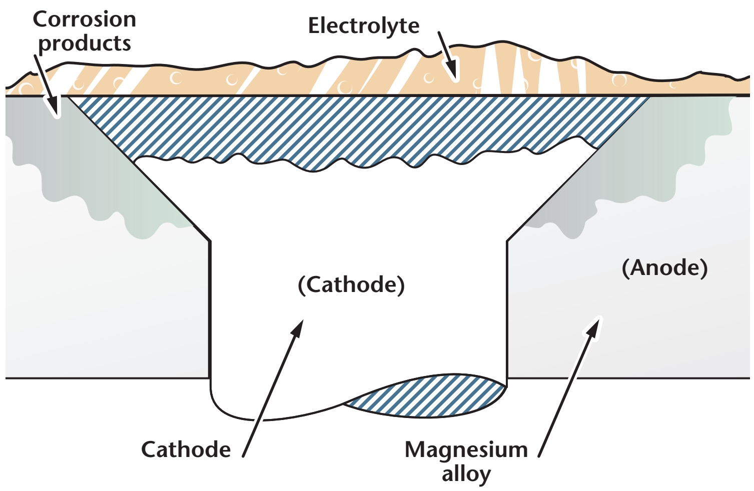


Figure 9-8-7. Galvanic corrosion of magnesium adjacent to steel structure.

Stress corrosion. Stress corrosion takes place when a metal part is subjected to a tensile load in a corrosive environment. Internal stress can be trapped in a component during manufacturing when the stress relief operation is omitted or performed improperly. It can be introduced after manufacturing by riveting, welding, press-fitting parts, or improper bolt tightening. For example, when a fastener is overtorqued, stress is introduced into the part. Figure 9-8-8 is an example of stress corrosion.

Fatigue corrosion. Fatigue corrosion involves the cyclic stress of a part in a corrosive environment. Metal parts can withstand cyclic stress indefinitely as long as the stress is below the part's design endurance limit. However, once this limit is exceeded, the part will eventually crack and fail from metal fatigue. When the stress limit is exceeded in the presence of a corrosive environment, component failure will occur much more rapidly, and can occur at stress levels well below those for which the part was designed.

Fatigue corrosion failure occurs in two stages. In the first stage, the combination of stress and corrosion weakens the metal structure and begins the formation of pitting and cracks. The damage will now continue even if the corrosive agent is removed. In the second stage, the cracks grow until the part fails in use, usually at a very low level of stress.

Fretting corrosion. Fretting corrosion happens when there is movement between two highly loaded surfaces that are not supposed to move against each other. Once this has begun, the rubbing action removes the protective coatings on both pieces of metal. With continued rubbing, metal particles sheared from the two surfaces combine with oxygen to form metal oxides. As these oxides accumulate, they cause further damage by abrasive action. The most common example of fretting corrosion is the "smoking rivet" found on engine cowlings and wing skins.

Corrosion Inspection

The importance of early corrosion detection cannot be overstated. If you find and repair corrosion at an early stage of its development there is less damage to the aircraft, the repair is less expensive to complete, downtime is reduced, and safety is not compromised. The longer corrosion is allowed to go untreated, however, the bigger the problem it creates.

Dye penetrant, eddy current, ultrasonic, and radiographic inspections are very effective in detecting corrosion damage. These methods are discussed in the section on nondestructive testing.

Visual inspection can be performed using a flashlight, magnifying glass, and inspection mirror. On painted surfaces, the appearance and integrity of the paint is your best indicator of the condition of the metal beneath. Corrosion can change the color of the paint or cause the paint to have a scaly or blistered surface. Look for blisters or paint that is chipping and flaking off the surface. Watch for damage to the paint or to adjacent sealant. Figure 9-8-9 shows what can happen when cracks or pinholes in these areas expose the metal underneath to water and oxygen, the first step in the corrosive process.

On bare metal surfaces corrosion will appear as a dulled or darkened area with a pitted surface. You may also observe white, gray, or reddish dust or particles.

Corrosive Agents

Corrosive agents are substances that cause a corrosive chemical reaction on metals. The most common corrosive agents are acids, alkalis (bases), and salts. The atmosphere and water, the two most common media for these agents, can sometimes act as corrosive agents themselves.

Acid. An acid is a chemical compound that gives up hydrogen ions when dissolved in water. Depending on the acid's strength, it can corrode most alloys used in aircraft structures. The most destructive are sulfuric acid, halogen acids (hydrochloric, hydrofluoric, and hydrobromic), and organic acids found in human and animal waste.

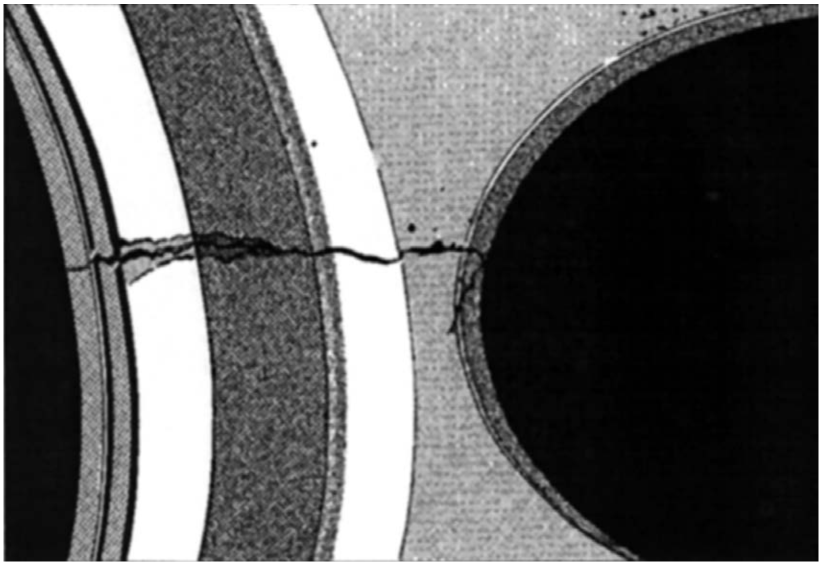


Figure 9-8-8. A typical example of cracking caused by stress corrosion.

Figure 9-8-9. This casting developed extensive corrosion when the built-up sealant cracked and allowed water to contact the metal. The part appeared sound until corrosion extended beyond the sealant.

Figure 9-8-10. Exposure to high heat and corrosive exhaust gases make engine exhaust areas susceptible to corrosion.

Figure 9-8-11. Exposure to water and food items makes galley areas especially prone to corrosion.

Alkalis. Alkalis, or bases, are chemical compounds that give up hydroxyl ions when dissolved in water. Aluminum is vulnerable to corrosive attack from lime, washing soda or lye, and potassium hydroxide, an electrolyte used in nickel-cadmium batteries. Aluminum and magnesium alloys are generally more resistant to alkali attack than to acid attack.

Salts. Salts are chemical compounds formed by the chemical reaction that occurs when acids are mixed with alkalis. Sodium chloride, or table salt, is a good example. Solutions containing salts are good electrolytes that actively promote corrosive attack on aluminum and magnesium alloys. Many stainless steel alloys are resistant to attack by salt solutions. Aircraft operated in saltwater environments are especially vulnerable to salt-induced corrosion.

Figure 9-8-12. The area below the floorboards around galleys and lavatories is a likely site for corrosion. The large object on the right is a potable water tank, with a main floor beam running vertically in this picture.

Mercury. Mercury is a heavy metallic element that is liquid at room temperatures and is highly corrosive to aluminum alloys, stainless steel, and brass. Through a process known as *amalgamation*, mercury chemically combines with these metals and produces severe corrosion. It can come in contact with aircraft structure through breaks in paint or other protective coatings, and when this happens the chemical attack is extremely rapid. Contamination results in pitting and intergranular attack, leaving the metal embrittled and weakened. Mercury and mercury compounds are frequently shipped on aircraft, and if spills occur, cleanup must be fast and thorough.

Water. Water acts as a corrosive agent on aircraft structures. The degree of corrosivity depends on the type and quantity of dissolved minerals, organic impurities, and gases in the water.

The most corrosive natural waters are those that contain salts. Water in the open ocean is extremely corrosive, but water in harbors are often more so because they are usually contaminated by industrial waste. The corrosiveness of fresh water varies depending on the kinds of dissolved impurities it contains. Certain industrial pollutants can make fresh water extremely corrosive.

Oxygen. The atmosphere contains oxygen, which when mixed with moisture in the air, acts as a corrosive agent. As with water, the presence of industrial pollutants greatly enhances the corrosiveness of the atmosphere around cities and industrial centers.

Organic growth. Organic growth includes bacteria and fungi that live in aircraft structures such as fuel tanks, water systems, and galleys. They promote corrosion in several ways. Some microorganisms produce corrosive agents as waste products, which attack metal structures directly. Bacterial growths can entrap water around the floor structures of galleys, hastening the spread of corrosion.

Corrosion-Prone Areas

Some areas of an aircraft structure receive little exposure to corrosive conditions and, thus, experience less corrosion damage. Other areas, however, are constantly exposed to corrosives and need much more frequent inspection.

On both turbine and reciprocating engines, the high heat and corrosive compounds of engine exhaust can cause problems for exhaust components and structures in the exhaust gas path. Pay particular attention to gaps, seams, hinges, and fairings in the exhaust gas path where deposits may be trapped and not reached by normal cleaning methods (Figure 9-8-10). This includes remote areas such as empennage structures.

Aircraft galley (Figure 9-8-11) and lavatory areas are some of the most corrosion-prone areas you will encounter.

Deck areas behind lavatories, sinks, and ranges where spilled food and waste products may collect, if not kept clean, are potential trouble spots. Even if some contaminants are not corrosive in themselves, they will attract and retain moisture and, in turn, cause corrosive attack. Figure 9-8-12 shows a potentially troublesome area. Carefully inspect bilge areas located under galleys and lavatories, clean these areas frequently, and keep paint touched up.

Aircraft battery electrolytes contain acid or strong alkali. As a result, battery compartments (Figure 9-8-13) and battery vent openings are frequently attacked by corrosion. Despite improvements in protective paint finishes and in methods of sealing and venting, battery compartments continue to be corrosion problem areas. Fumes from overheated electrolyte are difficult to contain and will spread to adjacent cavities and cause a rapid, corrosive attack on all unprotected metal surfaces.

Battery vent openings on the aircraft skin should be included in the battery compartment inspection and maintenance procedure. Regular cleaning and neutralization of acid deposits will minimize corrosion from this cause.

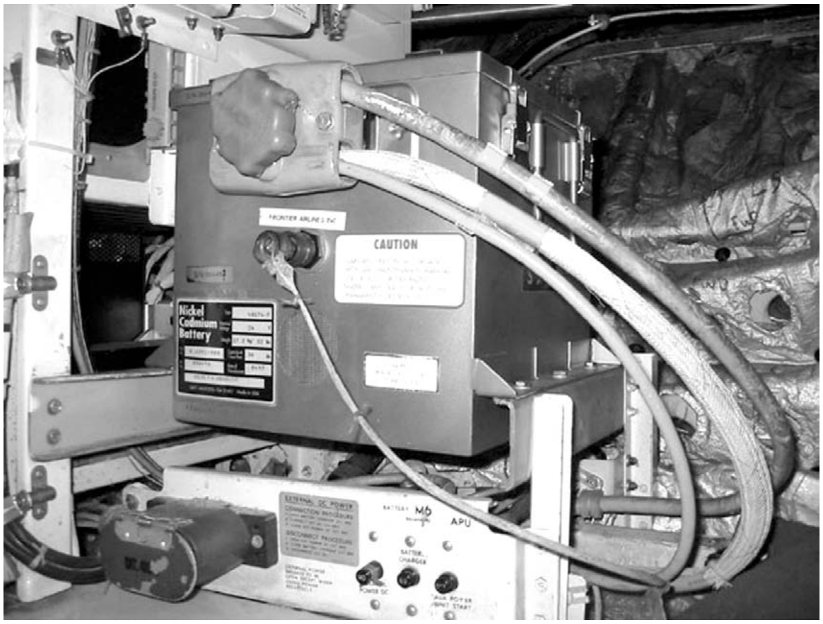


Figure 9-8-13. Areas adjacent to aircraft batteries should be checked for corrosion.

Landing gear and wheel wells probably receive more punishment than any other area on the aircraft because of mud, water, salt, gravel, and other flying debris that is picked up from ramps, taxiways, and runways and thrown by the tires. Because of the many complicated shapes, assemblies, and fittings found in the wheel well and landing gear areas, complete area paint film coverage is difficult to attain. A partially applied preservative tends to mask corrosion rather than prevent it. Due to heat generated by braking action, preservatives cannot be used on some main landing gear wheels. During inspection of this area, pay particular attention to the following trouble spots.

- Magnesium wheels, especially around bolt heads, lugs, and wheel-web areas, for the presence of entrapped water or its effects.
- Exposed rigid tubing, especially at B-nuts and ferrules, under clamps and tubing identification tapes.
- Exposed position indicator switches and other electrical equipment.
- Crevices between stiffeners, ribs, and lower skin surfaces, which are typical water and debris traps.

External aircraft surfaces are readily visible and accessible for inspection and maintenance. Even here, certain types of configurations or combinations of materials become troublesome under certain operating conditions and require special attention. One example is shown in Figure 9-8-14.

Figure 9-8-14. The two steel screws in this wing leading edge show signs of dissimilar metal corrosion.

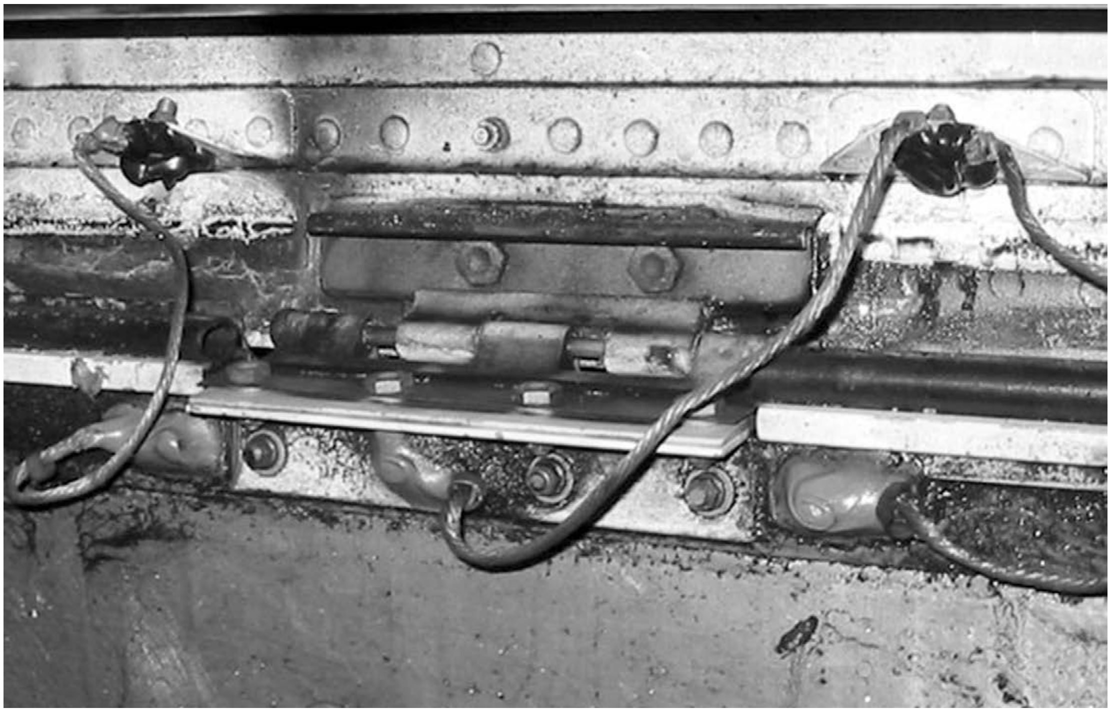


Figure 9-8-15. This piano hinge secures the air conditioning bay door to the fuselage on a Boeing 737. The hinge is aluminum, the pin is steel. It is common to find these hinges corroded.

Relatively little corrosion trouble is experienced with magnesium skins if the original surface finish and insulation are adequately maintained. Trimming, drilling, or riveting destroys some of the original surface treatment, which is never completely restored by touchup procedures. Any inspection for corrosion should include all magnesium skin surfaces with special attention to edges, areas around fasteners, and cracked, chipped, or missing paint.

Corrosion of metal skin joined by spot welding is the result of the entrance and entrapment of corrosive agents between the layers of metal. This type of corrosion is evidenced by corrosion products appearing at the crevices through which the corrosive agents enter. More advanced corrosive attack causes skin buckling and eventual spot-weld fracture. Skin buckling in its early stages may be detected by sighting along spot-welded seams or by using a straightedge. The only technique for preventing this condition is to keep potential moisture entry points, including seams and holes created by broken spot welds, filled with a sealant or a suitable preservative compound.

Figure 9-8-16. Flap recesses at wing trailing edge.

Inaccessible Areas

Because fuel tanks are usually located inside wing and fuselage structures, it is often difficult to gain access to inspect fittings and other hardware on the outside of the tank for corrosion. In addition, as was previously mentioned in this chapter, fuel tanks are targets for bacterial growth, particularly in tanks used for turbine fuels. While inspection inside the tank may be difficult or impossible, bacterial growth can be controlled with the use of growth-inhibiting additives added to the fuel when refueling.

Piano hinges are prime spots for corrosion due to the dissimilar metal contact between the steel pin and aluminum hinge. As you can see from Figure 9-8-15, they are also natural traps for dirt, salt, or moisture. Inspection of hinges should include lubrication and actuation through several cycles to ensure complete lubricant penetration.

Wing flap and spoiler recesses (Figure 9-8-16) accumulate grease, dirt, and water. These areas frequently go unnoticed because flaps and spoilers are normally retracted. For this reason, these recesses are potential corrosion problem areas.

Because of their purpose and location, *engine-mount structures* are subjected to extremes of heat, vibration, and torque from the engine and its accessories. To withstand the stresses placed on mount structures, most reciprocating engine mounts are manufactured from welded tubular steel. Therefore, engine-mount structures are inspected for corrosion and corrosion treated in much the same manner as other tubular steel airframe components, such as push/pull tubes, airframe structural tubing, tubular landing gear, etc. Particular attention must be paid to areas where moisture or other contaminants could possibly get inside the tubing, such as threaded, riveted, or welded areas. Where economically feasible, corroded tubing should be cleaned, the structural integrity of the material tested (through the use of magnaflux, radiography, or other suitable test procedure) and treated to prevent a recurrence of the same or similar corrosion. Where the cost is prohibitive, the alternative is replacement of the part. In some cases parts of the engine-mount structure can be individually replaced. In other cases the entire mount assembly must be replaced.

All *control cables,* whether plain carbon steel or corrosion-resistant steel, should be inspected to determine their condition at each inspection period. Cables should be inspected for corrosion by random cleaning of short sections with solvent-soaked cloths. Control cable access is easier in large airplanes (Figure 9-8-17) than in some smaller airplanes. If external corrosion is evident, tension should be relieved and the cable checked for internal corrosion. Cables with internal corrosion should be replaced. Light external corrosion should be removed with a stainless steel wire brush. When corrosion products have been removed, recoat the cable with preservative.

Many types of fluxes used in brazing, soldering, and welding are corrosive and will chemically attack the metals or alloys on which they are used. Therefore, it is important that residual flux be removed from the metal surface immediately after the joining operation. Flux residues are hydroscopic in nature; that is, they are capable of absorbing moisture, and unless carefully removed, tend to cause severe pitting.

Weld decay is a form of intergranular corrosion that attacks welds in stainless steel. It occurs because the process of welding often produces an undesirable heat treatment adjacent to the welded area (Figure 9-8-18), in turn producing separate phases of the metal, one of which may be preferentially attacked under adverse environmental conditions.

Electronic and electrical package compartments cooled by ram air or compressor bleed air are subjected to the same conditions common to engine and accessory cooling vents and engine frontal areas. While the degree of exposure is less because of a lower volume of air passing through and special design features incorporated to prevent water formation in the enclosed spaces, this is still a trouble area that requires special attention.

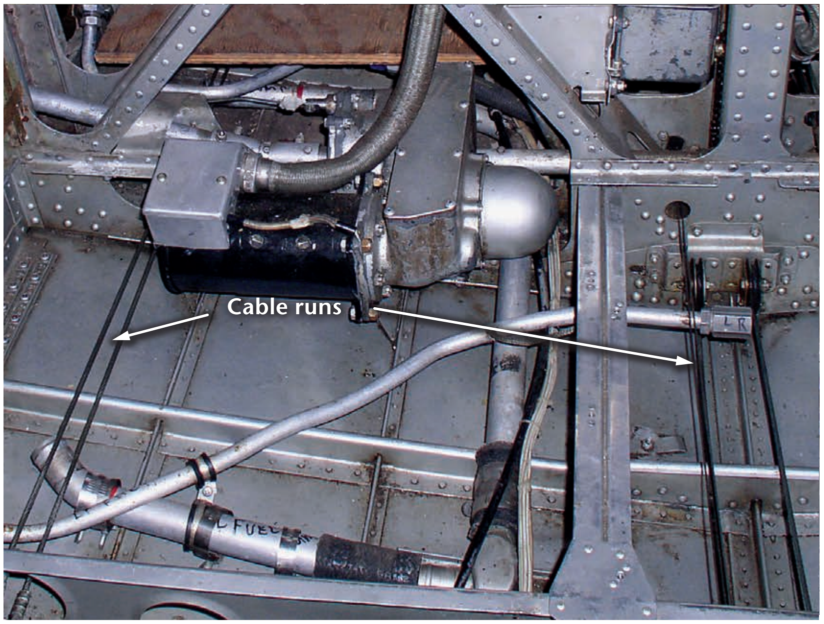


Figure 9-8-17. Most cable runs in large airplanes are accessible once the floorboards are removed.

Figure 9-8-18. Welding often produces an undesirable heat treatment adjacent to the welded area.

Figure 9-9-1. The leading-edge slat has been removed from the wing. Its reinstallation is a required inspection item.

Circuit breakers, contact points, and switches are extremely sensitive to moisture and corrosive attack and should be inspected for these conditions as thoroughly as design permits. If design features hinder examination of these items while in the installed condition, advantage should be taken of component removals for other reasons with careful inspection for corrosion required before reinstallation.

Section 9

Required Inspection Items

As you have seen, large, complex aircraft used in commercial air transport are subject to many different inspection and maintenance requirements.

An accident involving a large jet aircraft can cause severe loss of life and extensive property damage. Some aircraft systems and components are especially critical to safe operation of an aircraft. To ensure that these items are properly maintained and inspected, FAR 121.369 states that operators must include in their manuals a list of maintenance and alterations that must be inspected. These are called *required inspection items*, or *RIIs*. The regulation defines an RII as something that *"could result in a failure, malfunction, or defect endangering the safe operation of the aircraft, if not performed properly or if improper parts or materials are used."*

Engine installations, maintenance of pitot-static systems, repair and installation of major structural components, and the installation, rigging, and adjustment of flight controls are examples of required inspection items. An engine installation is an example. Before an engine is installed, an inspector who has been trained for RII items will check the engine, the mounts and pylon, the hardware used for installation, and the calibration of any special tooling, such as torque wrenches. The technician performing the installation has also inspected these same items. The inspector will witness the bolt torque procedure. The inspector must also inspect and sign off the complete installation and operational check. Figure 9-9-1 is an example of another RII item; in this case the leading edge of a wing. The same inspection process is required.

Test flights are sometimes required after major maintenance or repair. A technician and inspector will go on the test flight to insure the affected system or component is operating properly.

Suspected Unapproved Parts

In the 1990s, the FAA began tracking a number of fatal aircraft accidents involving the failure of reciprocating engine turbocharger systems. They found that technicians were repairing turbochargers using unapproved parts and procedures. They also found some technicians were installing lower-cost automotive turbochargers on aircraft. Then, in 1995, an engine on a DC-9 aircraft caught fire while the aircraft was on the ground (there were no fatalities.) The engine had been repaired at a foreign repair facility that did not follow the engine manufacturer's published procedures. Because of these incidents, the FAA began a major initiative to curtail the use of unapproved parts.

The FAA lists three categories of aircraft parts:

- **Approved parts.** Approved parts are those produced by the aircraft manufacturer in accordance with his specifications, produced by a sub-contractor for the manufacturer and carrying a manufacturer's part number, manufactured by a third party under a Parts Manufacturing Approval (PMA) or Technical Standard Order (TSO), or fabricated by an air carrier with the authorization to produce the parts to the manufacturer's specifications.

- **Unapproved parts.** Unapproved parts are parts that may be airworthy but lack the proper FAA documentation.
- **Standard parts.** Standard parts are those items that are manufactured to AN (Air Force – Navy), NAS (National Aerospace Standard), or MS (Military Standard) specification. Bolts, nuts, rivets, and other standard hardware items are examples. When ordered, a *Statement of Conformity* should be requested. The statement will indicate that the parts were manufactured according to the published standard and have been given the required inspections. Even then you should only buy from a reputable distributor.

Bogus parts. Bogus parts include parts that have been improperly repaired, were produced for automotive or other non-aviation use, or counterfeit parts that are low in quality but made to look serviceable.

For a number of reasons, aircraft parts are extremely expensive. In order to reduce costs, some people in the aviation industry substitute bogus or unapproved parts for those specified by an aircraft manufacturer. Some of these parts appear identical to the required ones. However, if they are not approved parts their use is a violation of the law.

Federal Aviation Regulations state that the technician installing parts is ultimately responsible for determining their airworthiness. If you install a bogus part on an aircraft and it later fails or is discovered by the FAA, you are subject to civil and criminal penalties including fines and imprisonment. Check the part's paperwork before you install it. Inspect the part for obvious damage or irregularities.

> **CAUTION:** Do not use parts that lack documentation. If you install bogus parts and get caught, you will pay the fine, not your employer.

Everything you install must have documentation that allows the part, material or component to be tracked to its source. The 8130-3 form should accompany all rotable airworthy components. Figure 9-9-2 illustrates an FAA form 8130-3, *Airworthiness Approval Tag*.

OMB Control No. 2120-0018
09/30/2007

1. Approving National Aviation Authority/Country:	2. **AUTHORIZED RELEASE CERTIFICATE** FAA Form 8130–3, AIRWORTHINESS APPROVAL TAG	3. Form Tracking Number:
4. Organization Name and Address:		5. Work Order/Contract/Invoice Number:

6. Item:	7. Description:	8. Part Number:	9. Eligibility: *	10. Quantity:	11. Serial/Batch Number:	12. Status/Work:

13. Remarks:

14. Certifies the items identified above were manufactured in conformity to: ☐ Approved design data and are in a condition for safe operation. ☐ Non-approved design data specified in Block 13.		19. ☐ 14 CFR 43.9 Return to Service ☐ Other regulation specified in Block 13. Certifies that unless otherwise specified in Block 13, the work identified in Block 12 and described in Block 13 was accomplished in accordance with Title 14, Code of Federal Regulations, part 43 and in respect to that work, the items are approved for return to service.	
15. Authorized Signature:	16. Approval/Authorization No.:	20. Authorized Signature:	21. Approval/Certificate No.:
17. Name (Typed or Printed):	18. Date (m/d/y):	22. Name (Typed or Printed):	23. Date (m/d/y):

User/Installer Responsibilities

It is important to understand that the existence of this document alone does not automatically constitute authority to install the part/component/assembly.

Where the user/installer performs work in accordance with the national regulations of an airworthiness authority different than the airworthiness authority of the country specified in Block 1, it is essential that the user/installer ensures that his/her airworthiness authority accepts parts/components/assemblies from the airworthiness authority of the country specified in Block 1.

Statements in Blocks 14 and 19 do not constitute installation certification. In all cases, aircraft maintenance records must contain an installation certification issued in accordance with the national regulations by the user/installer before the aircraft may be flown.

FAA Form 8130–3 (6–01) *Installer must cross-check eligibility with applicable technical data. NSN: 0052-00-012-9005

Paperwork Reduction Act Statement:
An agency may not conduct or sponsor, and a person is not required to respond to, a collection of information unless it displays a currently valid OMB control number associated with this collection of information is 2120-0018. Comments concnerning the accuracy of this burden and suggestions for reducing the burden should be directed to the FAA at: 800 Independence Ave. SW, Washington, DC 20591, Attn: Information Collection Clearance OFficer, ABA-20.

Figure 9-9-2. All airworthy parts should have this form, which should not be separated from the part.

10

Tools and Techniques

Section 1

Tool Procedures and Practices

The aircraft technician has a large variety of tools at his disposal. There are basic hand tools, measuring tools, power tools, special tools for aircraft, and torque tools.

The efficiency of a technician and the tools he or she uses is determined to a great extent by the condition in which the tools are kept. Tools should be wiped clean and dry before being placed in a tool box. If their use is not anticipated in the near future, they should be lubricated to prevent rust. This is especially true if tools are stored under conditions of extremely humid or salty air.

Proper cleaning is of prime importance in the care of aircraft maintenance tools. Listed below are a few simple procedures which are the basis for their care.

Tool care. Wash grease and dirt from tools with Stoddard solvent, and wipe them dry with a clean, dry cloth. Clean serrated jaw faces of pliers, vises, etc., with a wire brush. Remove filings from between teeth of files with a file card.

When using air pressure, be extremely careful. Do not blow a stream of air toward yourself or any other person. Wear safety glasses, goggles, or a face shield. Ear protection may be required. Use an OSHA-approved blow gun so pressure will not exceed 30 p.s.i.g. Do not horseplay with compressed air. Many permanent injuries have resulted from seemingly harmless fun.

Learning Objectives

REVIEW
- General tool care and use practices

DESCRIBE
- Types and functions of:
  - Measuring tools
  - Maintenance tools
  - Pneumatic tools
  - Torque tools
  - Tools specific to aircraft

EXPLAIN
- Toque principles and procedures

Left. The proper handling of tools requires that the mechanic exercise a reasonable amount of skill.

Wipe excess lubricating oil or residue from taps and dies. Lightly coat non-working surfaces with a film of oil.

Tools should always be kept in their appropriate storage place when not in use. A tool box not only keeps the tool protected from dirt, it also ensures that the tool can be found, as long as it is returned to its place after use. The tool box should be locked and stored in a designated area, and an inventory list maintained for that box. Many shops have a tool control program to prevent items from being left in places that can cause damage to equipment. Following such a program is a proven way to prevent foreign object damage (FOD).

Tool selection. The selection of the proper tool or size of tool to fit the job is of prime importance. Using a tool not suited for the job or of incorrect size can result in damage to the tool, damage to equipment being maintained, or injury to yourself or other workers. Proper choice of tools enables the technician to perform his work quickly, accurately, and safely.

Tool use. Keep each tool in its proper storage place. Use each tool only for the purpose for which it was designed. For example, do not use a screwdriver as a chisel or pliers as a wrench. The tool and/or the aircraft component may be damaged beyond repair.

Keep tools within easy reach where they cannot fall on the floor or on machinery. Avoid placing tools above machinery or electrical apparatus. Serious damage will result if the tool falls into the machinery after the equipment is turned on or running.

Damaged tools. Never use damaged tools. A faulty screwdriver may slip and damage the screw slot or cause injury to the user. A gauge stretched out of shape will result in inaccurate measurements.

Shop housekeeping. Housekeeping is the yardstick by which all shops are judged. A clean, well-arranged shop is safe and reflects credit on all personnel concerned with its operation. The following shop practices should be observed:

- Oil pans or drip pans should be used where leaking oil, grease, and similar materials may cause hazardous accumulations on equipment or floors. All spills should be cleaned up immediately. Approved sweeping compound may be used to remove these materials from the floor.
- Floors should not be cleaned with volatile or flammable liquids. A flammable film may remain and cause a fire hazard.
- Floors should be maintained smooth and clean, free of all obstructions and slippery substances. Holes and irregularities in floors must be repaired to maintain a level surface, free from tripping hazards.
- All unnecessary materials on walls should be removed and projections kept to a minimum. Aisles should be clearly defined and kept free of hazardous obstructions. Where possible, aisles should be suitably marked by painting or striping.
- All machines, work benches, aisles, etc., should be adequately illuminated.
- Machines should be located to provide operators with sufficient space to handle materials and perform job operations without interference.
- All machinery that can move or "walk" due to vibration (drill press, bench grinder, etc.) shall be bolted down.
- Shop machinery should be operated only by qualified personnel. If you have not used a specific piece of machinery before, get checked out first.
- Safety devices, such as guards, interlocks, automatic releases, and stops, should always be kept in operating condition. Suitable mechanical guards, such as enclosures or barricades, should be permanently installed on all machinery not already equipped with such to eliminate danger of injury from moving parts.
- Machinery should not be adjusted, repaired, oiled, or cleaned while machine is in operation or power is on.
- Personnel operating machinery should wear protective clothing as prescribed. A protective face shield or goggles should be worn when operating a grinder, regardless of whether the grinder is equipped with attached shields.
- Jewelry should not be worn while performing any maintenance.

Fire safety. A constant vigilance must be maintained to seek out fire hazards. Fire hazards are constantly present in the shop where sparks, friction, or careless handling can cause an explosion that may destroy equipment or buildings and injure people.

Most shops do not allow smoking on the premises.

Oily waste, rags, and similar combustible materials shall be discarded in self-closing metal containers, which should be emptied daily.

Flammable materials should not be stored in the shop. They should be stored in an OSHA-approved area.

Use only approved cleaning solvents. Never freelance when choosing cleaning materials.

Tool boxes. Tool boxes come in a wide variety of sizes and styles. They are usually made of steel, and not only provide storage and security, but are an important part of *tool control*. Tool control means that all tools are where they belong at all times. None are left in or on the airplane in such a manner as to turn into FOD. A stray wrench or pair of pliers can destroy a turbine engine in short order. Portable tool boxes are used for carrying and storing a variety of hand tools. Tool bags are usually made of canvas. Like the boxes, they are available in a variety of sizes and serve similar functions. Typical tool boxes are shown in Figure 10-1-1.

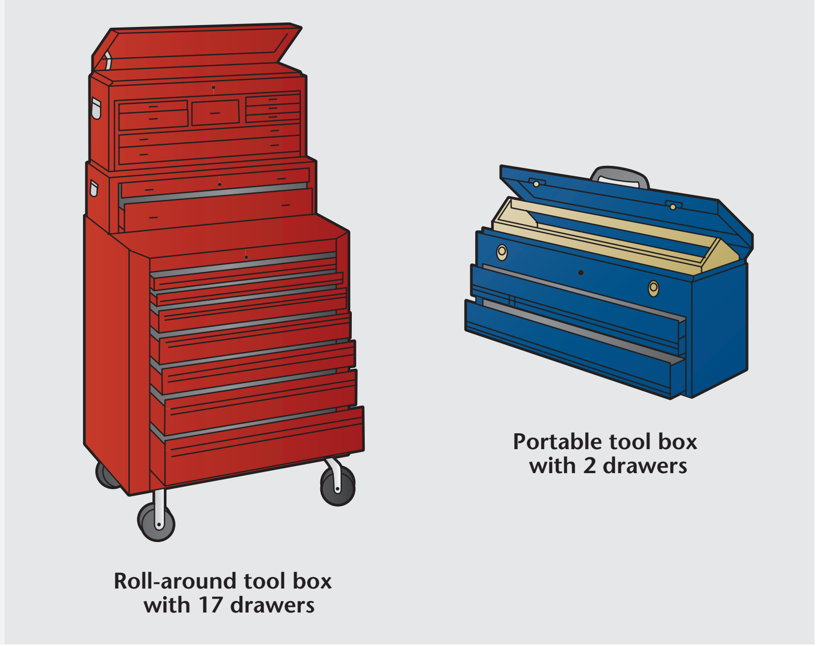


Figure 10-1-1. Typical tool boxes.

Tool storage inside tool boxes should be neat and orderly. This allows for instant recognition if a tool is missing. Many different types of racks and drawer organizers are available from tool suppliers and auto parts houses. A typical drawer organizer is shown in Figure 10-1-2.

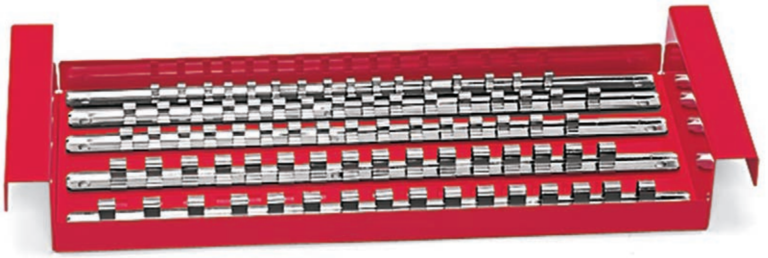


Figure 10-1-2. Racks for tools are widely available and make orderly storage simple. *Photo courtesy of Snap-on Tools*

Section 2

Measuring Tools

In the maintenance of aircraft, the fabrication of many parts may be required. During this process, accurate measurements must be made before and during the fabrication. A partly finished or a finished part must also be checked for accuracy. This inspection includes comparing the dimensions of the part with the required dimensions shown on a drawing or sketch. These measurements are made using a variety of measuring tools. The accuracy of the measurements will depend upon the types of tools used and the ability of the aircraft technician to use them correctly.

Levels

Levels are tools designed to prove whether a plane or surface is in the true vertical or true horizontal. All levels consist of a liquid-filled glass tube or tubes, supported in a frame. There are many types of levels used in aircraft maintenance.

Use. To use a level, simply place it on the surface to be checked. Inspect the vial which is nearest to the horizontal. If the surface is level, the bubble will be situated between the two etched lines on the vial. A level condition is shown in Figure 10-2-1.

Do not drop or handle a level roughly. To prevent damage, store it in a rack or other suitable place when not in use. Testing the accuracy of a level is a fairly simple process. Simply place the level on a flat surface and observe the reading. Pick the level up and rotate it end for end. Place it down in the exact same position as before and observe the reading again. If the level is accurate, it will be the same as the first reading. Generally speaking, repair of damaged levels is not cost-effective. They are usually replaced.

Figure 10-2-1. Level condition is read with the center vial.

Plumb Bobs

A plumb bob is an ancient instrument. It is used to establish a true vertical transfer and line up a reference point. Plumb bobs are usually made of brass or solid steel, as shown in Figure 10-2-2. They are most useful in establishing measurement during weight and balance checks, as well as checking the alignment of fuselages, wings, etc.

Figure 10-2-2. Plumb bobs.

Figure 10-2-3. Machinist's scriber.

Figure 10-2-4. Typical tapes.

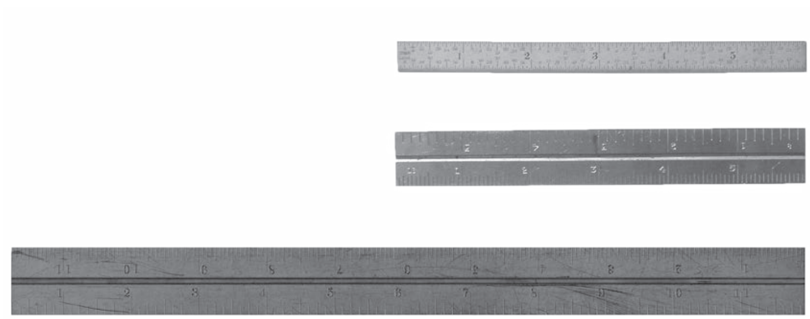


Figure 10-2-5. Rules come in various dimensions, from pocket sizes up to several feet in length.

Scribers

A scriber is a sharp, hard steel pick. It is used when laying out work on metal, as a pencil is used when drawing on paper. A scriber should not be used on Alclad aluminum or aluminum alloy where the scribed line will not later be removed during shearing or cutting. A scribed line left on the material will both create a place for corrosion to start and create a *stress riser* for development of a future crack. The two basic types of scribers are the machinist's and the tungsten carbide scribers.

Machinist's scriber. The machinist's scriber is used to mark or score on steel, glass, aluminum, copper, or similar surfaces. There are two basic types of machinist's scribers; single-point pocket scribers and bent-point/straight-point scribers. The bent-point scriber, as shown in Figure 10-2-3, is the most popular.

Tungsten carbide. Tungsten carbide tips have extremely hard points and are used on hardened steel or glass.

Using a scriber. Place a steel rule or straight edge on the work beside the line to be scribed. Use the fingertips of one hand to hold the straight edge securely. Hold the scriber in your hand as you would a pencil. Scribe the line by drawing the scriber along the straight edge at a 45° angle, tipped in the direction it is being moved.

Tapes and Rules

Tapes and rules are the measuring instruments most often used for all general measurements. They are graduated into fractions of an inch; 1/8, 1/16, 1/32, and 1/64.

Tapes. There are several kinds and lengths of tapes, but the one most often used is 6 to 12 feet long and made of flexible steel. It is coiled in a circular case and may or may not have one end fastened permanently to the case. It is graduated on one side only in 1/16-inch and 1/32-inch divisions. A small lip on the end prevents the tape from sliding completely inside the case and also easily lines up the end of the tape with the end of a piece of stock. Examples of typical tapes are shown in Figure 10-2-4. Tapes are generally accurate, but some shops have established a specific brand and model of tape to be used, thus ensuring consistent measurement between individual technicians.

Rules. Rules are usually made of flexible or rigid steel and are 4, 6, or 12 inches long. They are graduated in 1/8ths, 1/16ths, 1/32nds, and 1/64ths. There are special aircraft reading rules available that are graduated in 1/16-inch and

1/64-inch readings on one side and 1/50-inch and 1/100-inch readings on the other. When the total length of a measurement is not too great, the rule should be used. It is more accurate and easier to read than the tape. Typical rules are shown in Figure 10-2-5.

Squares

Squares are primarily used for testing and checking trueness of an angle or for laying out lines on materials. Most squares have a rule marked on the edge, so they may also be used for measuring. The common types of squares include the carpenter's, try, combination, sliding T-bevel, and the bevel protractor squares.

Carpenter's square. The carpenter's square, shown in Figure 10-2-6, is made up of two parts: the blade (long side) and the tongue (short side). It has inches divided into 1/8ths, 1/10ths, 1/12ths, and 1/16ths. If dropped on a corner, the square can be knocked out of square by the impact. To check for accuracy, lay the square on a flat surface and draw a line down both the blade and tongue. Raise the blade and rotate the square 180°, leaving the tongue on the surface. Draw lines as before. If the lines match, the square is accurate. If not, it is bent and should be replaced.

Combination square. A combination square is made of the components shown in Figure 10-2-7. It has a square head, a center head, and an adjustable protractor with a built-in level. The protractor head can be used to check control-surface travel, as well as check or mark angled lines. A smaller 6-inch unit without the protractor head is also available.

Rule. The combination square has a slotted 12-inch steel rule which is graduated in 1/8ths, 1/16ths, 1/32nds, and 1/64ths of an inch. It can be used as a measuring scale by itself or with any one of its components:

Center head. The center head, when attached to the rule, bisects a 90° angle. It is used for determining the center of cylindrical work.

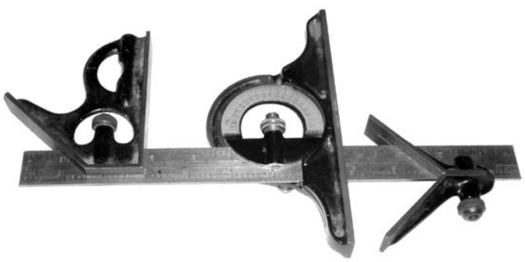


Figure 10-2-7. A combination square has all of the components shown: a ruler, a square head, a protractor, and a center head.

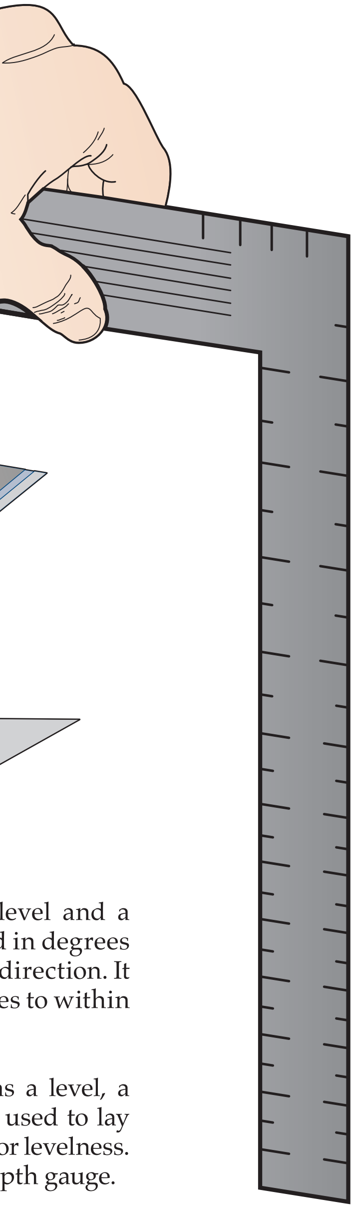


Figure 10-2-6. Carpenter's square.

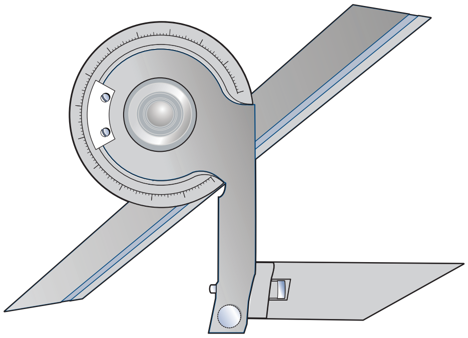


Figure 10-2-8. Bevel protractor.

Protractor. The protractor has a level and a revolving turret which is graduated in degrees from 0° to 180° or 0° to 90° in either direction. It is used to lay out and measure angles to within one degree.

Square head. The square head has a level, a scribe, and 45° and 90° angles. It is used to lay out 45° and 90° angles and to check for levelness. It may also be used as a height or depth gauge.

Bevel protractor square. The bevel protractor is made up of an adjustable blade and a graduated dial which contains a scale. The bevel protractor is used to establish an angle and determine its relationship to other surfaces. The acute angle attachment is used for measuring acute angles accurately. This type of square is shown in Figure 10-2-8.

Uses of Squares

The various types of squares are used in the following manner:

Carpenter's square. In layout of sheet metal or other flat material, the carpenter's square is used to mark a square line. To mark a square line, proceed as follows:

Place the blade or tongue of the square against the side of the material, with the square tilted

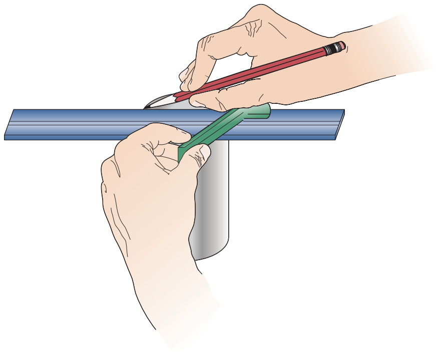


Figure 10-2-9. Setting the center head.

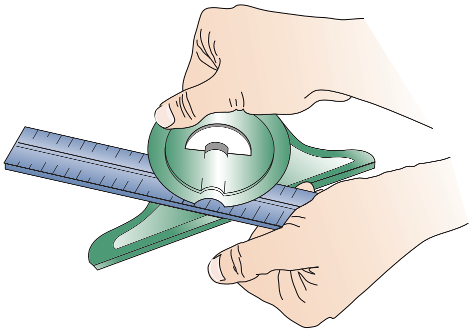


Figure 10-2-10. Installing protractor head on rule.

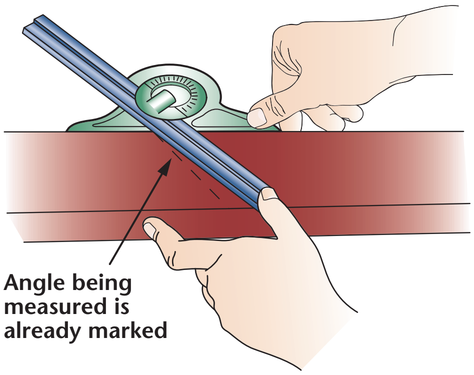


Figure 10-2-11. Checking angle.

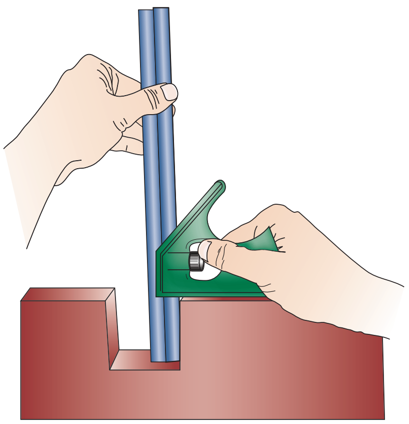


Figure 10-2-12. Determining depth with the square head.

slightly so the blade or tongue of the square extends across the work.

> **NOTE:** Do not mark on any metal surface with a graphite pencil. Graphite is cathodic and will establish the basis for galvanic corrosion.

Mark a line across the work using a marking pencil.

Center head. The center head can be used to locate and mark the diameter of a cylinder, as shown in Figure 10-2-9.

Protractor head. The protractor head can be used to determine the angle of a previously marked line. Slide the protractor head on the rule, as shown in Figure 10-2-10, and tighten the setscrew. Loosen the protractor adjustment screws so the protractor may be pivoted about the rule, as shown in Figure 10-2-11.

Place the rule on the angle being measured, and pivot the protractor head against the edge. Tighten adjustment screws. Read the measured angle on the protractor (Figure 10-2-11).

Square head. The square head can be used to determine depth in the following manner:

1. Slide the square head on the rule.
2. Set the flat surface of the square head above the edge and adjust the rule until it hits the bottom, as shown in Figure 10-2-12.
3. Tighten the setscrew.
4. Remove the square and read the depth indicated on the rule.

Bevel protractor. The bevel protractor is used much the same as the protractor head of the combination square.

Dividers

Dividers are tapered steel picks, hinged together on the blunt end. They are used to scribe arcs and circles and to transfer measurements when laying out work. They are also used to transfer or compare measurements directly from a rule. The most common types of dividers are the spring divider and the wing divider.

Spring divider. A spring divider, as shown in Figure 10-2-13, consists of two sharp points at the end of straight legs, held apart by a spring and adjusted by means of a screw and nut. The spring divider is available in sizes from 3 to 10 inches in length and is the most common model.

Figure 10-2-13. Spring divider.

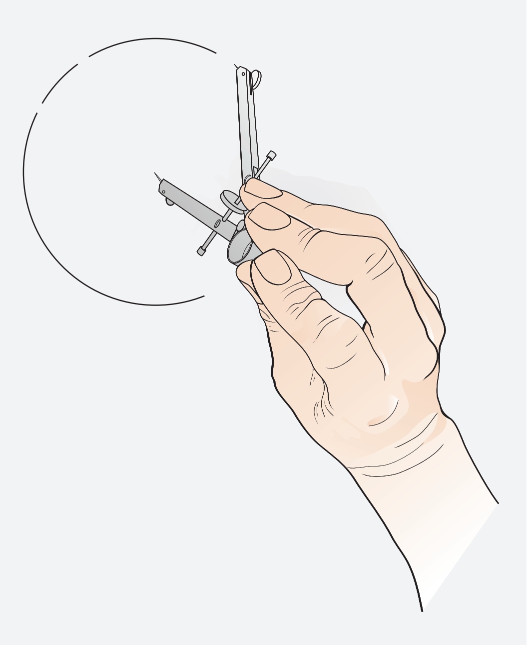


Figure 10-2-14. Scribing a circle with dividers.

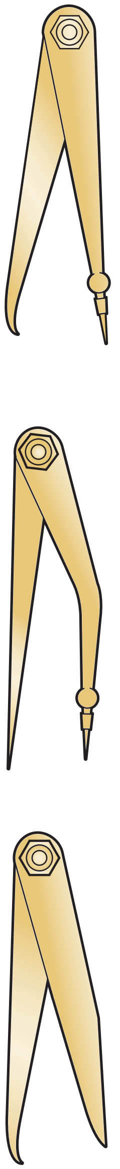


Figure 10-2-16. Hermaphrodite calipers.

Use of Dividers

Dividers can be used to scribe a circle by using the following procedures (Figure 10-2-14):

1. Set the desired radius on the dividers using the appropriate graduations on a rule.
2. Place the point of one of the divider legs on the point to be used as the center.
3. Lean the dividers in the direction of movement and scribe the circle by revolving the dividers.
4. Scribe the circumference only if the line is to be removed by cutting. Otherwise use a compass with a small felt tip marker.
5. If the circle is to be saved rather than cut out, tape a small piece of sheet metal at the pivot point. Put a prick punch mark at the center point. This avoids marking the finished part.

Calipers

Calipers are used to measure diameters. Outside calipers measure outside diameters. Inside calipers measure inside diameters. Simple calipers are used along with a scale to find the measurement. Slide calipers and vernier calipers have their own scales. They are more accurate than a ruler and, when used properly with a micrometer, they can be used to take measurements to within 0.0001 inch

Types of calipers. There are a variety of caliper styles available to the aircraft technician:

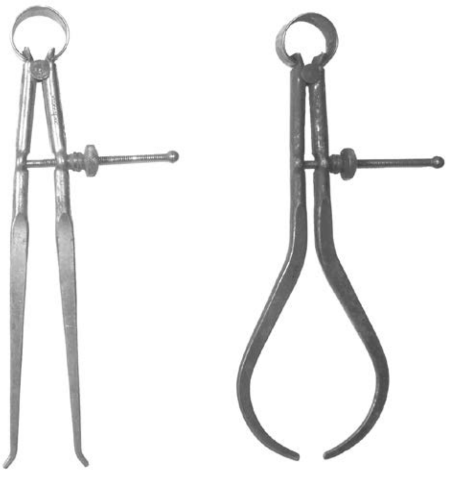


Figure 10-2-15. Spring-joint calipers.

Spring-joint calipers. The spring-joint calipers have the same type of legs, but are joined by a strong spring hinge, screw, and adjustment nut. They are shown in Figure 10-2-15.

Hermaphrodite calipers. The hermaphrodite calipers have one straight leg ending in a sharp point, as shown in Figure 10-2-16. On some models, one point is removable. The opposite leg is usually bowlegged. The hermaphrodite caliper is used for finding shaft centers or locating shoulders.

Slide calipers. Slide pocket calipers have a fixed jaw fastened to the end of a bar and a movable jaw fastened to a frame which slides on this bar. The bar has a scale on it, and the frame has two index marks labeled IN and

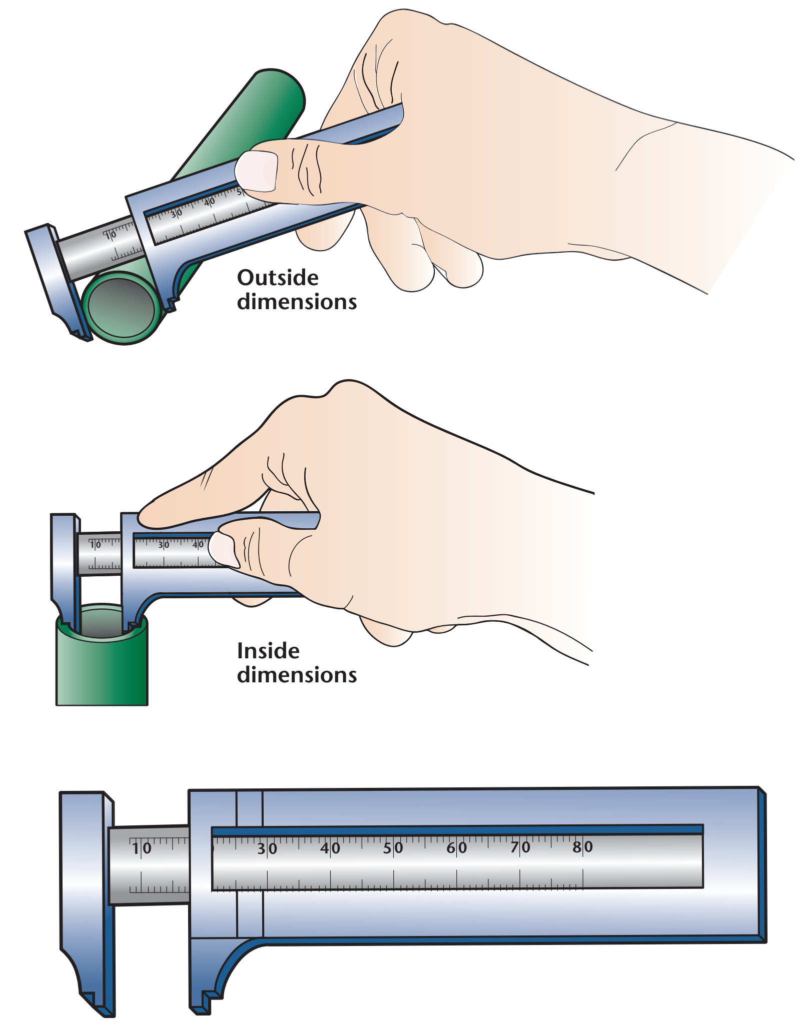


Figure 10-2-17. Slide caliper.

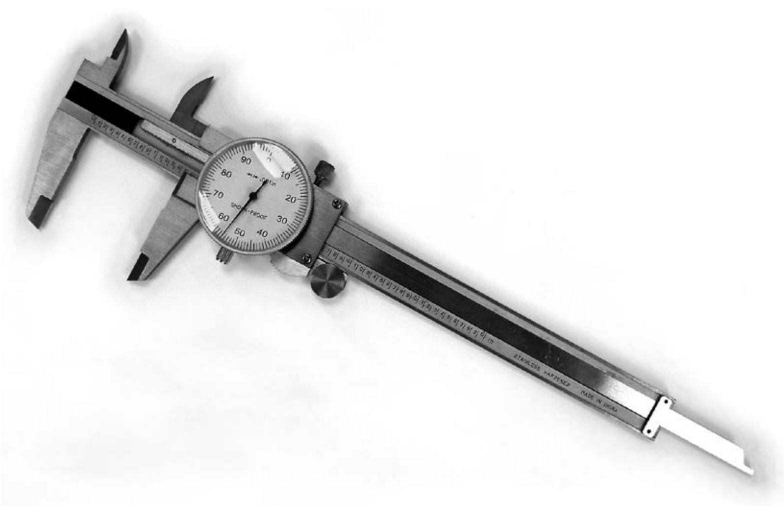


Figure 10-2-18. Vernier dial caliper.

OUT (Figure 10-2-17). To measure the outside diameter of a round bar or the thickness of a flat bar, the jaws of the caliper are opened and placed over the stock. The movable jaw is then

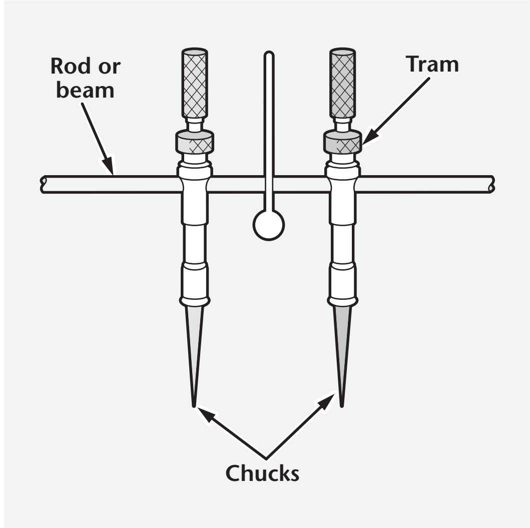


Figure 10-2-19. A trammel.

slid forward until the jaws just touch the stock. The calipers may then be removed, and the dimension opposite the OUT index mark can be read. To take an inside measurement, the jaws are placed inside and spread apart until they just touch the stock. The dimension may then be read using the IN index mark.

Vernier calipers. Vernier calipers work much like slide calipers. Shown in Figure 10-2-18, vernier dial calipers can make very accurate, easy-to-read outside or inside measurements.

Trammels. The trammel, shown in Figure 10-2-19, measures distances beyond the range of calipers. The trammel consists of a rod or beam to which trams are clamped. It can also be used as a divider by changing the points.

Use of calipers. The operation of most calipers is relatively straightforward. Vernier calipers, however, can be finely adjusted to provide a very accurate reading (Figure 10-2-20) for the procedures used to make accurate measurements with vernier calipers.

Reading a Vernier Caliper

To read a vernier caliper, the steel rule, and the scales, Figure 10-2-21, needs to be understood.

Steel rule. The steel rule is graduated in 0.025-inch segments. Every fourth division (representing 1/10 inch) is numbered.

Vernier scale. The vernier scale is divided into 25 parts and numbered 0, 5, 10, 15, 20, and 25. These 25 parts are equal to 24 parts on the steel rule. The difference between the width of one of the 25 spaces on the vernier scale and one of the 24 spaces on the steel rule is 1/1000 inch.

Reading the measurement. Read the measurement as outlined below: Read the number of whole inches on the top scale to the left of the vernier zero index and record 1.000 inch.

- Read the number of tenths to the left of the vernier zero index and record 0.400 inch.
- Read the number of twenty-fifths between the tenths mark and the vernier zero index and record 3 × 0.025 = 0.075 inch.
- Read the highest line on the vernier scale that lines up with the lines on the top scale and record. (Remember that 1/25 = 0.001 inch) 11/25 = 0.011 inch.
- Total all preceding measurements:

1.000
0.400
0.075
<u>0.011</u>
1.486 inches

The measurement, therefore, is 1.486 inch.

Conversion for inside measurement. Most vernier calipers read outside on one side and inside on the other side. If a scale is not marked and an inside measurement must be taken, read

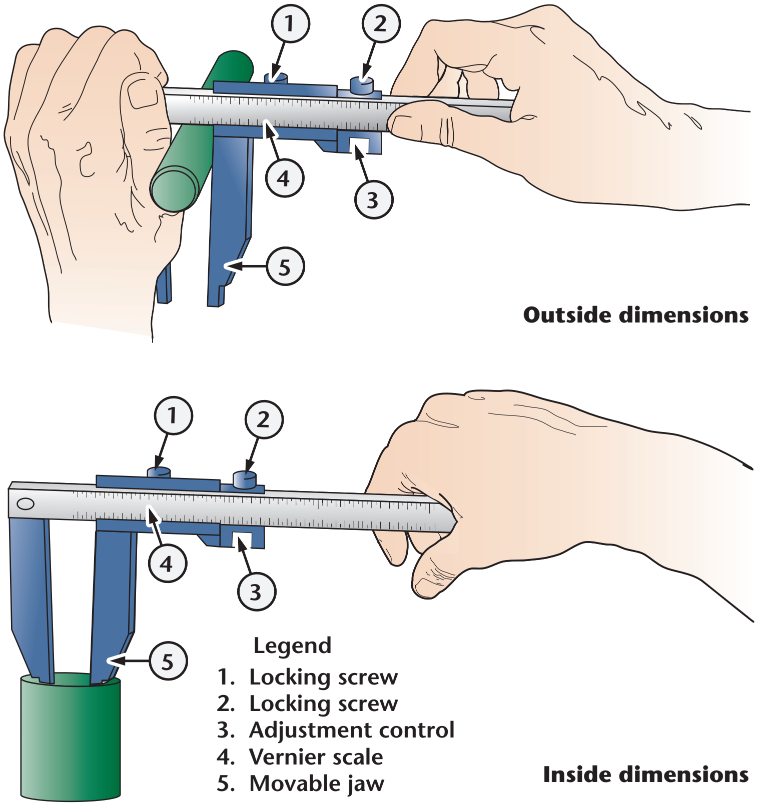


Figure 10-2-20. Operation of vernier calipers.

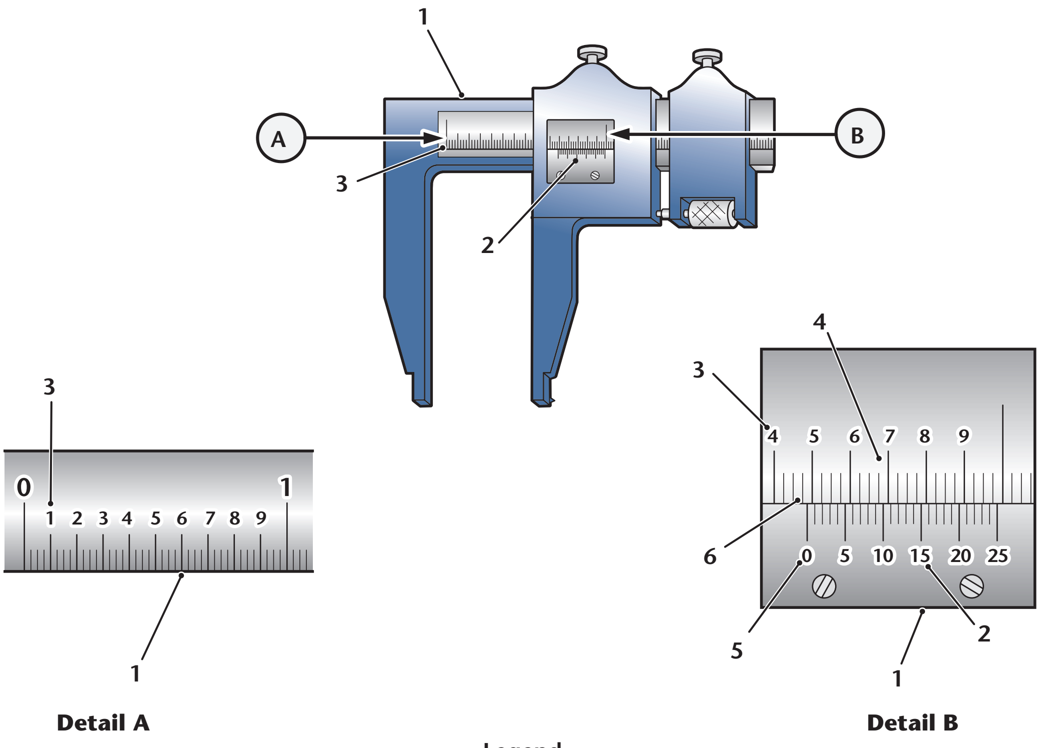


Figure 10-2-21. Reading a measurement on a vernier caliper.

Figure 10-2-22. Direct-reading digital calipers take all the guesswork out of interpreting a measurement reading.

Figure 10-2-23. Outside micrometer.

Figure 10-2-24. Inside micrometer with extensions.

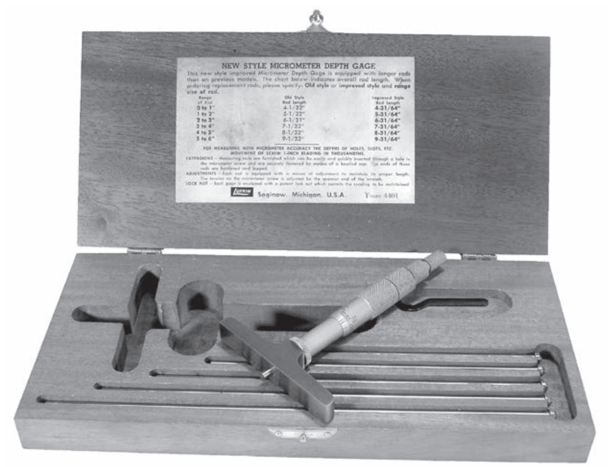


Figure 10-2-25. Depth micrometer, with additional rod extensions.

the scale as for an outside measurement. Then add the measuring point allowance by referring to the instructions of the manufacturer.

Digital Calipers

Digital calipers have made all the complexity of reading vernier calipers academic. Direct-reading digital calipers do just as the name implies; the measurement can be read directly from the digital electronic readout. While feel is still an important part of obtaining an accurate measurement, figuring out how to read the result just got simpler. Additionally, digital instruments are self-zeroing. The accuracy is self-adjusted each time you turn them on.

Digital calipers (Figure 10-2-22) come in all sizes for almost any application. The revolution in digital measurement has been applied to most all other forms of measurement for several years now. Digital instruments have reached the price level where it only makes sense to purchase them whenever possible.

Micrometers

The micrometer is the most accurate of the adjustable measuring instruments. The internal parts of a micrometer are not cut on a lathe, but are ground to size on a machine grinder.

There are three types of micrometers which are most commonly used: the outside micrometer, the inside micrometer, and the depth micrometer.

Outside micrometer. An outside micrometer, shown in Figure 10-2-23, is used more often than any other type of micrometer. It is used to

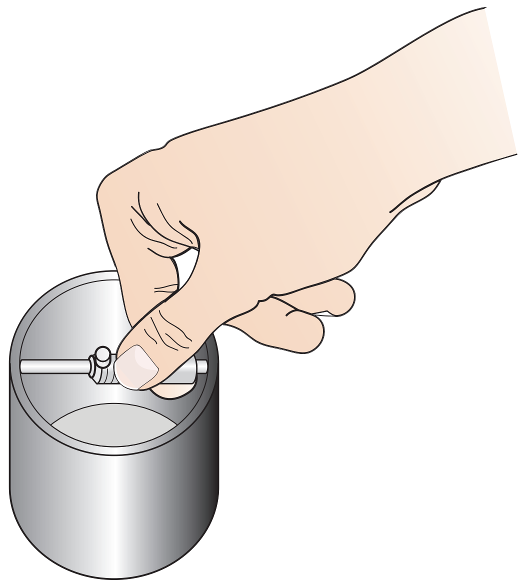


Figure 10-2-26. Using an inside micrometer.

measure the outside diameter of shafts, thickness of stock, and to make other, similar measurements. It is also used to set inside calipers to a given dimension.

Inside micrometer. An inside micrometer is used to measure the inside diameters of cylinders, the width of recesses, and similar work. Some typical inside micrometers are shown in Figure 10-2-24.

Depth micrometer. A depth micrometer, shown in Figure 10-2-25, is used to measure the depth of recesses or holes.

The types of micrometers commonly used are made so that the longest movement possible between the spindle and the anvil is 1 inch. This movement is called the range. The size of a micrometer indicates the size of the largest work it will measure. Therefore, a 2-inch micrometer has a range of 1 to 2 inches and will measure only work between 1 and 2 inches thick. A 6-inch micrometer has a range of 5 to 6 inches and will measure only work between 5 and 6 inches thick.

It is necessary, therefore, that the technician first find the approximate size of the work to the nearest inch, and then select a micrometer that will fit it. With inside and depth micrometers, rods of suitable lengths are fitted into the tool to get the approximate dimension within an inch, after which the exact dimension is obtained by turning the thimble, as shown in Figure 10-2-26.

Using an outside micrometer. As shown in Figure 10-2-27, the micrometer is held in one hand and the stock in the other. The thimble is turned until the anvil and spindle just touch the stock. The micrometer is then read for an accurate measurement.

Using an inside micrometer. The normal procedure when using an inside micrometer is to set it across a diameter or between the inside surfaces, remove it, and then read the dimension. For this reason, the thimble on an inside micrometer is much stiffer than on a micrometer caliper so that it holds the dimension well. It is good practice to verify the reading of an inside micrometer by measuring it with a micrometer caliper.

Figure 10-2-28 shows an inside micrometer with extension rod being used to check the diameter of a bored hole. Note the arrows that indicate the direction the operator is feeling for the largest dimension horizontally and the smallest dimension vertically. Inside micrometers have spherical contact points, which require more practice to feel the full measurement of the diameter. One contact point is generally held in a fixed position and the other rocked in different directions to be sure the tool is spanning the true diameter of a hole or the correct width of a slot.

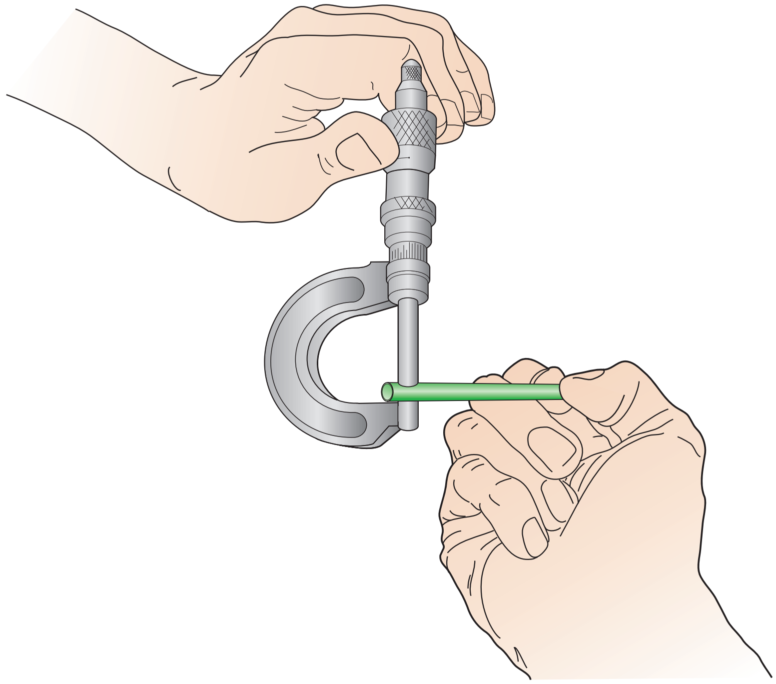


Figure 10-2-27. Using an outside micrometer.

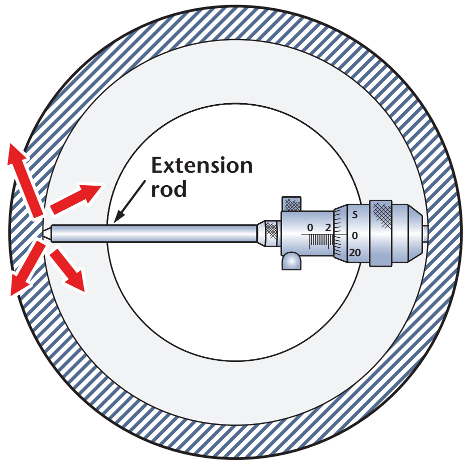


Figure 10-2-28. Using an inside micrometer with extension rod.

Handle attachment. For probing a deep hole or a restricted place, a handle attachment may be used. The handle clamps onto the body of the micrometer.

Reading a Standard Micrometer

Reading a standard micrometer is a matter of reading the micrometer scale or counting the revolutions of the thimble (Figure 10-2-29) and adding to this any fraction of a revolution.

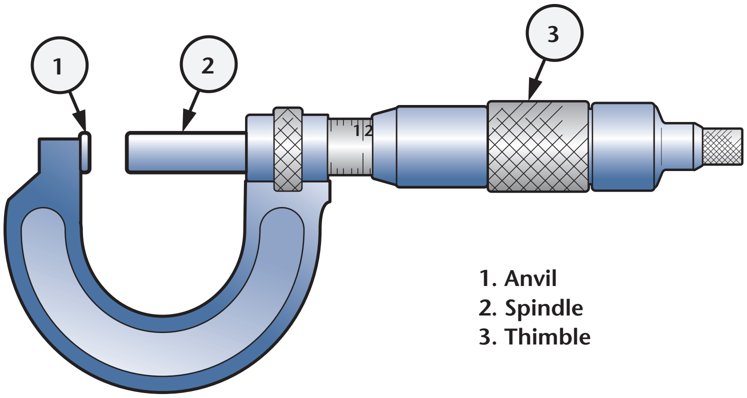
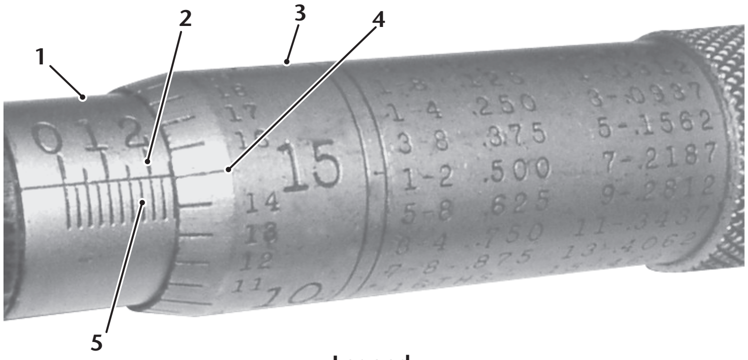


Figure 10-2-29. Parts of a micrometer.



Legend

1. Barrel
2. 0.1 inch divisions
3. Thimble
4. 0.001 inch divisions
5. 0.025 inch divisions

Figure 10-2-30. Reading a measurement on a micrometer.

Spindle movement. The micrometer screw has 40 threads per inch. This means that one complete and exact revolution of the thimble moves the spindle toward or away from the anvil exactly 1/40 or 0.025 inch.

Barrel measurements. The following paragraphs describe the markings that are inscribed on the micrometer barrel and thimble (Figure 10-2-30).

Barrel lines. The lines on the barrel conform to the pitch of the micrometer screw under the thimble. Each line represents 0.025 inch, and each fourth line is numbered, representing tenths of an inch.

Thimble lines. The beveled edge of the thimble is graduated into 25 parts, each line representing 0.001 inch. One complete and exact revolution of the thimble will indicate 0.025 inch. Every fifth line is numbered to assist in reading these marks.

Reading a measurement. A measurement can be read as follows:

1. Read the highest whole number visible on the barrel and record 2 = 0.200 inch.
2. Count the number of lines visible between the 2 and the thimble edge and record 1 = 0.025 inch.
3. Locate the line on the thimble that coincides with or has passed the horizontal line in the barrel. Record 16 = 0.016 inch.
4. Total all measurements: 0.241 inch.

The measurement, therefore, is 0.241 inch.

Reading a Vernier Micrometer

Reading the vernier micrometer is the same as reading the standard micrometer. A vernier micrometer is shown in Figure 10-2-31. An additional step must be taken to add the vernier reading to the dimensions. This allows for precise measurements that are accurate to 1/10,000 (0.0001) of an inch. This scale furnishes the fine readings between the lines on the thimble rather than making an estimate as you would on a standard micrometer.

Vernier scale. The ten spaces on the vernier scale are equivalent to 9 spaces on the thimble. Therefore, each unit on the vernier scale is equal to 0.0009 inch and the difference between the sizes of the units on each scale is 0.0001 inch.

Reading the measurement. A measurement can be read as follows:

1. Read the highest whole number visible on the barrel (6) and record 2 = 0.200 inch.
2. Count the number of lines visible between the 2 on the barrel and the thimble edge and record 3 = 0.075 inch.
3. Locate the line on the thimble that coincides with or has passed the horizontal line in the barrel and record 11 = 0.011 inch.
4. Locate the line on the vernier scale that coincides with a division line on the thimble and record 2 = 0.0003 inch.
5. Total all preceding measurements.

0.200
0.075
0.011
<u>0.0003</u>
0.2863 inch

The measurement, therefore, is 0.2863 inch.

Transferring inside and outside measurements. When it becomes necessary to transfer a measurement from the inside of a caliper or micrometer to the outside of a caliper or micrometer, do the following:

After setting the inside caliper or inside micrometer to the work, hold the micrometer caliper in one hand and the inside tool in the other hand.

Turn the thimble of the micrometer caliper with the thumb and forefinger until the inside tool legs lightly contact the anvil and spindle of the micrometer caliper.

Hold the tips of the inside tool legs parallel to the axis of the micrometer caliper spindle. The micrometer caliper will be accurately set when the inside tool will just pass between the anvil and spindle by its own weight.

Micrometer testing. At times it may become necessary to adjust and/or test the accuracy of a micrometer. A micrometer is tested for accuracy as follows:

Measure the length of the micrometer test gauge, or *gauge block*, of the same length as the minimum capacity of the micrometer. The micrometer should read the exact measurement. For the 1-inch. micrometer, screw the thimble down until the spindle contacts the anvil. The reading should be 0.000 inch.

Measure the length of the micrometer test gauge of the same length as the maximum capacity of the micrometer. The micrometer should read its exact maximum capacity.

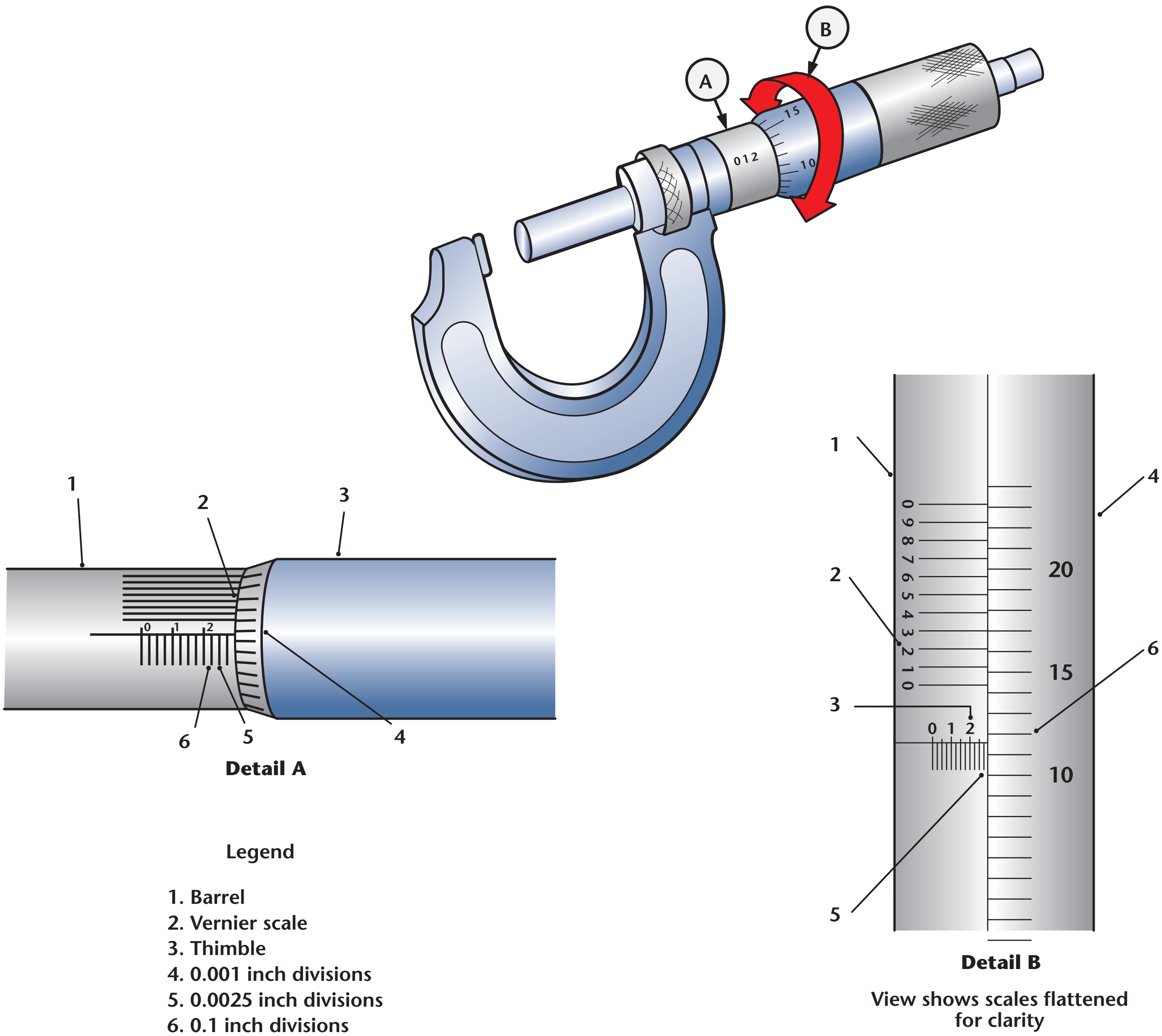


Figure 10-2-31. Reading a vernier micrometer.

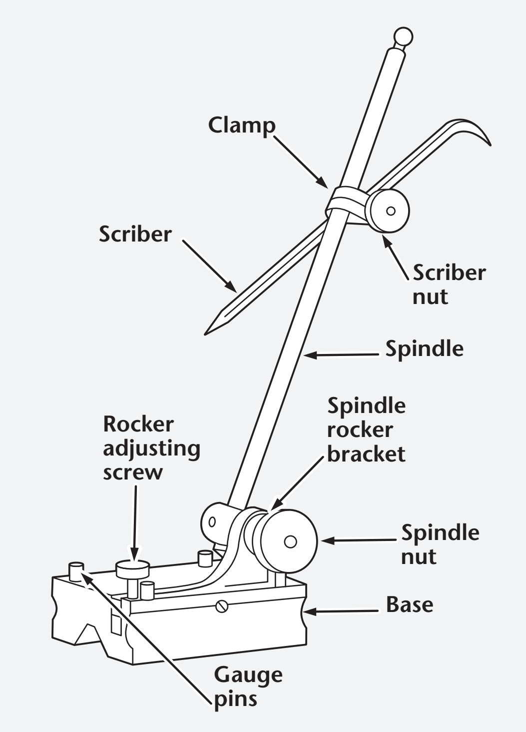


Figure 10-2-32. Surface gauge.

The gauge block is made of hardened, polished steel, which is precision-ground to a dimensional accuracy within millionths of an inch.

All precision measuring tools that are used on aircraft must be calibrated periodically to ensure accuracy. Most maintenance shops will have a calibration program for these tools. Calibration and repair of precision tools should only be performed by personnel who have the qualification and equipment.

Surface Gauge

A surface gauge is a measuring tool used to transfer measurements to work by scribing a line. It also indicates the accuracy or parallelism of surfaces.

As shown in Figure 10-2-32, the surface gauge consists of a base with an adjustable spindle to which may be clamped a scriber or an indicator. Surface gauges are made in several sizes and are classified by the spindle length. The smallest spindle is 4 inches long, the average is 9 to 12 inches, and the largest is 18 inches. The bottom and the front end of the base of the surface gauge have deep V-grooves, which allow the gauge to measure from a cylindrical surface. The base has two gauge pins, used to prevent slippage.

Setting height on a surface gauge. To set a surface gauge for height, proceed as follows:

Wipe off the top of a layout table or surface plate and the bottom of the surface gauge. Place the squaring head of a combination square on a flat surface, as shown in Figure 10-2-33. If a combination square is not available, use a rule with a rule holder. A rule alone cannot be held securely without wobbling; consequently, an error in setting generally results.

Secure the rule in the squaring head so that the end of the rule is in contact with the surface. Move the surface gauge into position, and set the scriber to the approximate height required, using the adjusting clamp that holds the scriber onto the spindle. Make the final adjustment for the exact height required with the adjusting screw on the base of the gauge.

Depth Gauges

Depth gauges are used to measure the distance from a surface to a recessed point. The three common types of depth gauges are the *rule depth gauge*, the *micrometer depth gauge*, and the *vernier depth gauge*.

Rule depth gauge. The rule depth gauge, shown in Figure 10-2-34, is a graduated rule with a sliding head designed to bridge a hole or slot and hold the rule perpendicular to the measured surface. The type shown has a measuring range of 0 to 5 inches. The sliding head has

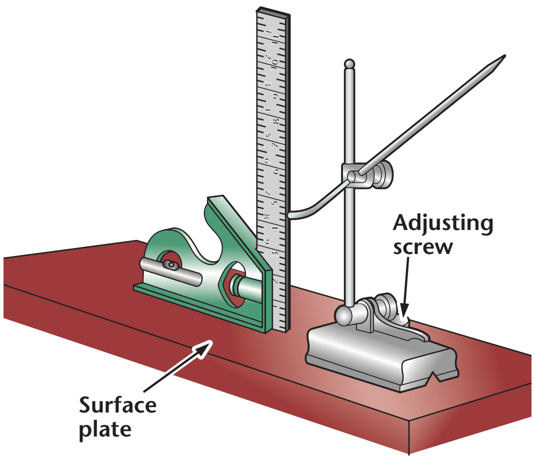


Figure 10-2-33. Setting height on a surface gauge.

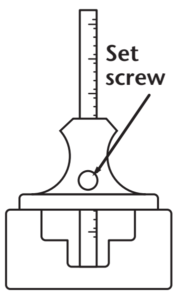


Figure 10-2-34. Rule depth gauge.

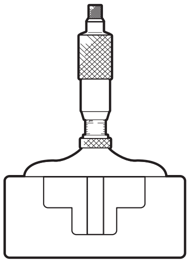


Figure 10-2-35. Micrometer depth gauge.

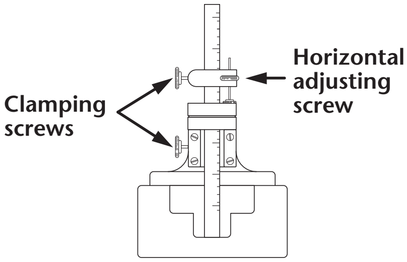


Figure 10-2-36. Vernier depth gauge.

a clamping screw so that may be fixed in any position. It is flat and perpendicular to the axis of the rule and ranges in size from 2 to 2-5/8 inch wide and from 1/8 to 1/4 inch thick.

Micrometer depth gauge. The micrometer depth gauge, shown in Figure 10-2-35, consists of a flat base attached to the barrel of a micrometer head. These gauges have a range of 0 to 9 inches, depending on the length of extension rod used. The hollow micrometer screw itself has a range of either 1/2 or 1 inch. Some are provided with a ratchet stop. The flat base ranges in size from 2 to 6 inches. Several extension rods are normally supplied with this type of gauge.

Vernier depth gauge. The vernier depth gauge, shown in Figure 10-2-36, consists of a graduated scale, either 6 or 12 inches long, and a sliding head similar to the one on the vernier caliper. The sliding head is specifically designed to bridge holes and slots. The vernier depth gauge has the range of the rule depth gauge and not quite the accuracy of a micrometer depth gauge. It cannot enter holes less than 1/4 inch in diameter, whereas a micrometer depth gauge will enter a 3/32-inch hole. However, it will enter a 1/32-inch slot, whereas a micrometer depth gauge will not. The vernier scale may be adjusted to compensate for wear.

Height Gauges

Height gauges are used to measure the vertical distance of a point from a surface, as shown in Figure 10-2-37. Height gauges usually have vernier scales and are operated similarly to depth

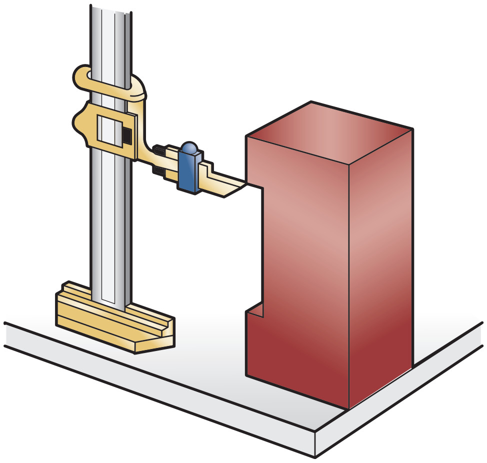


Figure 10-2-37. Typical height gauge.

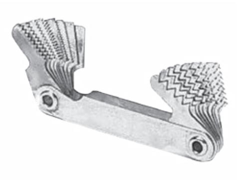


Figure 10-2-38. Thread gauge.

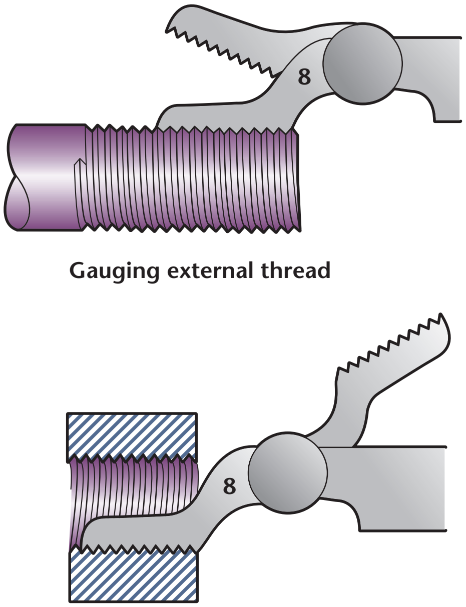


Figure 10-2-39. Using thread gauges.

gauges. Using special arbors and parallel bars, they can be used to check connecting rod twist.

Thread Gauges

Thread gauges are used to determine the pitch and number of threads per inch on threaded fasteners. They consist of leaves whose edges are toothed to correspond to standard threads. A typical thread gauge is shown in Figure 10-2-38.

To measure the unknown pitch of a thread, compare it with the standard of the thread gauge. Various leaves are held to the threads until an exact fit is found, as shown in Figure 10-2-39. The number of threads per inch is indicated

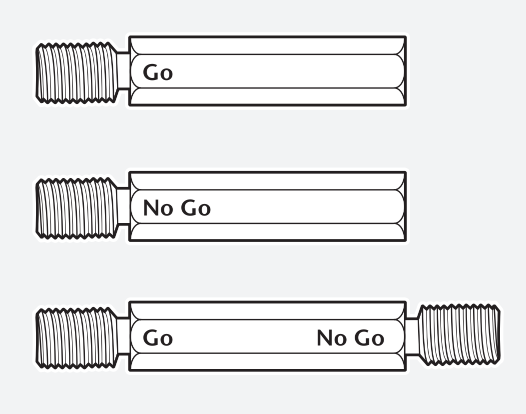


Figure 10-2-40. Plug gauges.

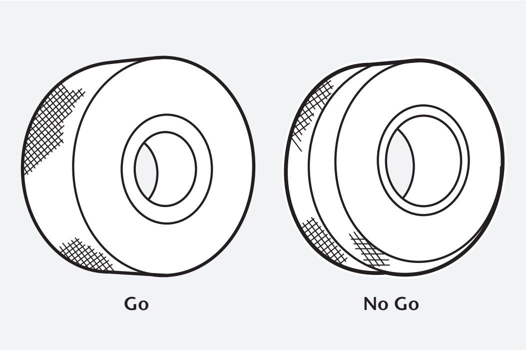


Figure 10-2-41. Ring gauge types.

on the leaf which is found to exactly match the threads being measured. Using this value as a basis, correct sizes of nuts, bolts, screws, taps, and dies are selected for use.

Plug Gauges

Though thread gauges provide a fast and reliable method of determining whether internal and external threads match, one disadvantage of their use is that part of the thread tolerance must be built into the thread gauge. For more precise measurement of thread pitch, plug gauges are used.

GO and NO GO plug gauges are used to inspect internal threads. They are available as separate tools or with both ends combined in one tool, as shown in Figure 10-2-40. Threads are inspected as follows:

GO plug gauge. For an internal thread to be accepted, the GO plug gauge must pass through the entire length of the thread.

NO GO plug gauge. An internal thread within limits must not accept the NO GO gauge past 1 and 1/2 turns.

GO and NO GO plug gauges are typically used in major engine repair or overhaul.

Ring Gauges

Ring gauges are used as standards to determine whether or not one or more dimensions of a manufactured post are within specified limits. They are nonadjustable and therefore called fixed gauges. The ring gauge is an external gauge of circular form. There are two types of ring gauges; the GO and the NO GO gauges (Figure 10-2-41).

GO ring gauges. GO ring gauges are larger than NO GO gauges. The outer surface of the ring is knurled.

NO GO ring gauges. The NO GO gauges are slightly smaller than GO gauges, and are *distinguished by an annular groove* cut in the knurled outer surface of the ring.

Tolerances. Depending on the use, ring gauges are manufactured to different tolerances. The following classes of gauges and their limits of accuracy are standard for all makes:

- Class X—Precision lapped to close tolerances for many types of masters and the highest quality working and inspection gauges.
- Class Y—Good lapped finish to slightly increased tolerances.
- Class Z—Commercial finish (ground and polished, but not fully lapped) with fairly wide tolerances.
- Class ZZ—Ground only to meet the demand for an inexpensive gauge, with liberal tolerances.

Ring gauges are used more often in the inspection of finished parts than parts in process.

> **NOTE:** The GO ring gauge controls the maximum dimension of a part, and the NO GO plug gauges control the minimum dimension of a hole. Therefore, GO gauges measure the tightness of fit of mating parts, while NO GO gauges measure the looseness of fit.

Thickness Gauge (Feeler Gauge)

The thickness gauge (commonly called a feeler gauge) consists of thin leaves ground to definite thicknesses, which are marked on the leaves. It is called a feeler gauge because *clearance is determined by feel*. The leaves are usually in sets, with one end of each leaf fastened in a case. Figure 10-2-42 shows a typical feeler gauge.

The feeler gauge is used to measure the clearance between two surfaces, such as checking

Figure 10-2-42. Thickness (feeler) gauge.

piston ring gap and side clearance. Another typical use is shown in Figure 10-2-43.

If a leaf of the proper thickness is not available, two leaves may be used, the dimensions of which add up to the required clearance.

Feeler gauges are also available in GO/NO GO sets, which are primarily used to check valve clearance.

Sheet Metal and Wire Gauge

The sheet metal and wire gauge, shown in Figure 10-2-44, is used for measuring the diameters of wires or the thickness of sheet metal.

Types. The type of sheet metal and wire gauge to be used depends on the type of material being measured. They are available as follows:

- English Standard Iron wire, hot-and cold rolled sheet steel
- American Standard Non-ferrous sheet metal and wire
- US Standard Sheet and plate iron and steel
- Steel wire gauge

Find the slot that refuses to pass the wire without forcing. Try the next larger slots until one is found that passes the wire. This is the correct size. Measurements are taken at the slot portion rather than the cutout portion of the gauge. The decimal equivalent of the gauge number is shown on the opposite side of the gauge.

Fillet and Radius Gauges

Fillet and radius gauges are used to check the inside or outside corners (or fillets) of a machined part. The blades of fillet and radius gauges are made of hard-rolled steel. The double-ended blades of the gauge have a lock that holds the blades in position. The inside and outside radii are on one blade of one of the gauges shown in Figure 10-2-45. The other gauge has separate blades for inside and outside measurements. Each blade of each gauge is marked in 1/64-inch increments. Each gauge has 16 blades.

Fillet or radius gauges are used to check the inside or outside corners of a machined part, as shown in Figure 10-2-46. These gauges can

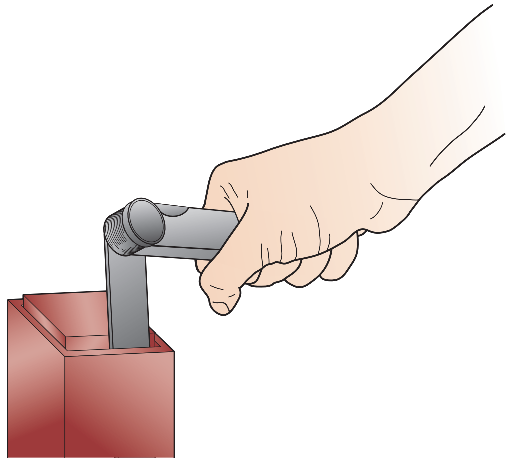


Figure 10-2-43. Using a thickness (feeler) gauge.

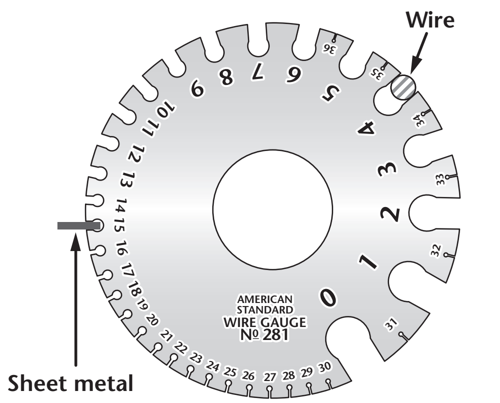


Figure 10-2-44. Measuring sheet metal and wire.

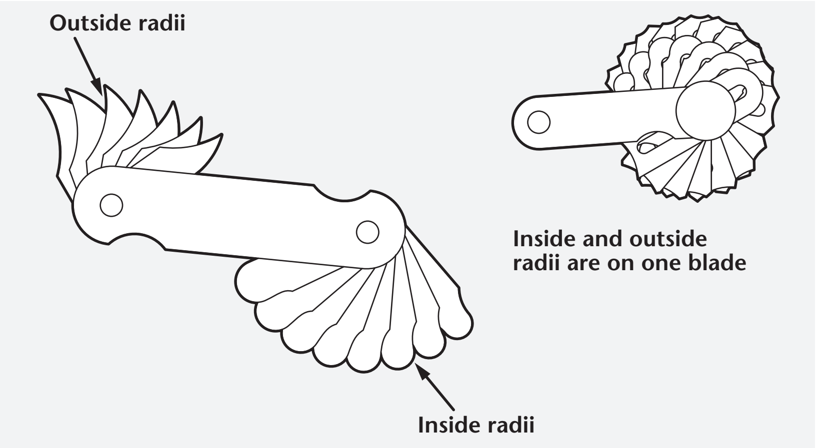


Figure 10-2-45. Radius gauges.

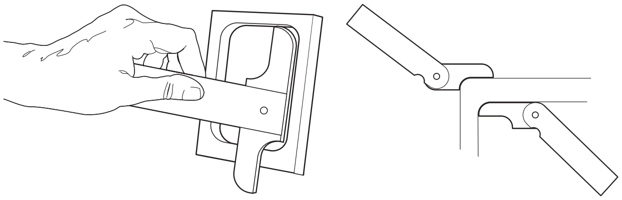


Figure 10-2-46. Using fillet and radius gauges.

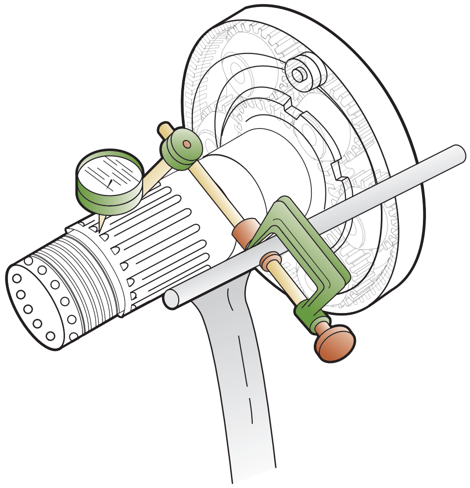


Figure 10-2-48. Checking propeller shaft run out.

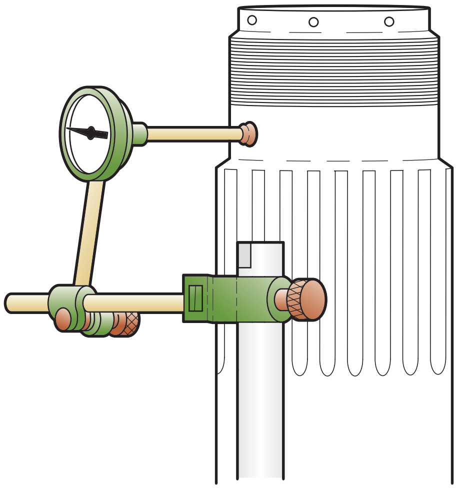


Figure 10-2-47. Universal dial indicator.

be used in any position and at any angle for both inside and outside radii.

Dial Indicators

A dial indicator is a precision measuring tool designed for checking items such as bearing radial and axial play, propeller shaft run out, bushing and flight control system components for excessive play and runout of a disk. The dial indicator plays an important part in deciding if a part is worn beyond an allowable tolerance.

The dial indicator consists of a dial with reading needle and a graduated scale. The dial indicator has a measuring range from 0.001 to 0.200 of an inch. The dial is adjustable and has the reading pointer located on the back of the dial. The indicator can be mounted in various positions using a special clamp and tool post holder which is provided in the dial indicator kit. This assembly is shown in Figure 10-2-47.

Generally speaking, the dial indicator measures variations from a perfectly circular condition. Proceed with installation and use as follows:

NOTE: The following general procedures are used for checking propeller shaft run-out. Refer to the applicable aircraft maintenance manual (MM) for specific procedures to be used when use of a dial indicator is required.

- Remove the propeller.
- Remove one of the nuts securing the thrust bearing cap to the reduction gear assembly, and install a reversible-type dial indicator on the long stud from which the nut was removed (Figure 10-2-48).
- Adjust the dial indicator so that the arm

Figure 10-2-49. Telescoping gauges.

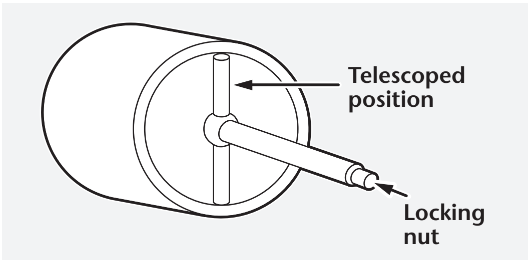


Figure 10-2-50. Measuring a hole using a telescoping gauge.

point is on propeller shaft at the front cone location.

- Rotate the propeller shaft and note the total indicator movement. The maximum allowable run-out at the front cone location is found in the applicable aircraft MM.
- Adjust the dial indicator so that the arm point is on the propeller shaft, at the rear cone location.
- Rotate the propeller shaft and note the total indicator movement. The maximum allowable run-out at the rear cone location is found in the applicable aircraft MM.

Telescoping Gauges

Telescoping gauges, shown in Figure 10-2-49, are used for measuring the inside size of slots or holes up to 6 inches in width or diameter. They are T-shaped tools in which the shaft of the T is used as a handle, and the crossarm is used for measuring. The crossarms telescope into each other and are held out by a light spring.

These tools are commonly furnished in sets, the smallest gauge for measuring the distances from 5/16 to 1/2 inch and the largest for distances from 3-1/2 to 6 inches.

To use the gauge, the arms are compressed, placed in the hole to be measured, and allowed to expand, as shown in Figure 10-2-50. A twist of the locknut on top of the handle locks the arms. The tool may then be withdrawn and the distance across the arms measured usually with a micrometer.

Small-Hole Gauges

For measuring smaller slots or holes than the telescoping gauges will measure, small-hole gauges can be used. These gauges come in sets of four or more and will measure distances of approximately 1/8 to 1/2 inch. They are shown in Figure 10-2-51.

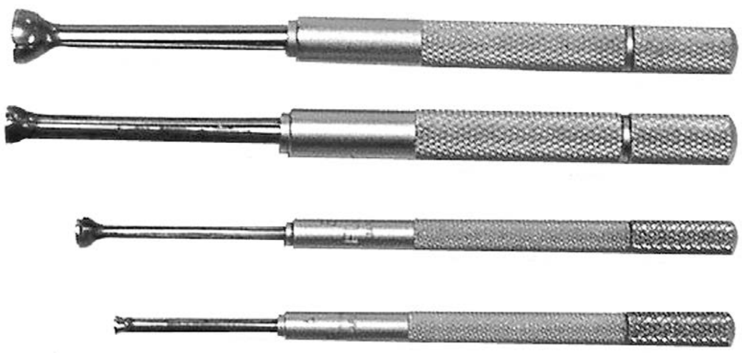


Figure 10-2-51. Small-hole gauges.

Section 3

Maintenance Tools

Regardless of the type of work to be done, a technician must select and use the correct tools in order to do his work quickly, accurately, and safely. Without the correct tools and the knowledge to use them, the AMT will waste time, reduce efficiency, and can even injure himself. This section explains the purposes, correct use, and proper care of the more common tools. Special tools are described in the individual sections to which they pertain.

Hammers

Hammers are striking tools which are composed of a head made of metal, plastic, leather, or wood mounted on a handle. The handle is usually made of wood, although some modern hammers and mallets have handles made of fiberglass. The more common types of hammers are described in the following paragraphs.

Ball peen hammer. The ball peen hammer is the type most often used by mechanics (Figure 10-3-1).. It has a steel head and is usually available in 4, 6, 8, and 12 ounce sizes as well as 1, 1-1/2 and 2 pounds. As Figure 10-3-1 shows, this hammer is identified by the ball-shaped peen at the opposite end of the face.

Figure 10-3-1. Ball peen hammers. *Photo courtesy of Snap-on Tools*

Figure 10-3-2. Body hammers are specialty tools used in the auto body trade. They are used principally for finishing hand-formed parts.

Figure 10-3-3. Lead or copper hammer. *Photo courtesy of Snap-on Tools*

Figure 10-3-4. Soft-faced hammer. *Photo courtesy of Snap-on Tools*

Body hammer. A body hammer, shown in Figure 10-3-2, is used to straighten and form metal. The three most common types are shrinking, stretching, and planishing.

Lead or copper hammers. These are used when it is necessary to avoid creating marks or sparks. The heads are generally one piece (Figure 10-3-3). They produce a heavy blow, but the head is malleable so any damage is relegated to the hammer, not the work.

Soft-faced hammer. The soft-faced hammer, shown in Figure 10-3-4, is capable of delivering heavy blows to machined, highly polished, or soft surfaces without damage to those surfaces. On some of these hammers, the faces can be removed and replaced when damaged or when a different hardness or toughness is required.

Mallets

Mallets are generally made of softer substances for working items which would be damaged by metal hammers. The following paragraphs describe some of the more common types.

Rawhide mallet. The rawhide mallet (Figure 10-3-5) has a cylindrical head which is made by tightly wrapping and staking a sheet of leather. It is used for forming and shaping sheet metal.

Rubber mallet. A rubber mallet has a cylindrical rubber head. It is used for forming sheet metal and driving dowels.

Hammer and Mallet Safety

The following precautions must be kept in mind when using hammers:

- Do not use a hammer handle for bumping parts in an assembly. Never use it as a pry bar. Such abuses will cause the handle to split, which can result in bad cuts or pinches to the hand. When a handle splits or cracks, do not try to repair it by binding with string or wire. Replace it.
- Ensure that the head fits tightly on the handle. If it is loose, it can fly off during use and cause serious injury to personnel.
- Do not strike a hardened steel surface with a steel hammer. Small pieces of steel may break off and injure someone in the eye or damage the work.
- When using metal hammers, always wear eye protection to prevent metal particles from entering the eyes.
- When using a hammer or mallet, ensure that the material will not be damaged by the tool. The hammer should be gripped near the end of the handle and should strike the surface evenly.
- Broken or chipped faces may be replaced. Remove damaged faces by turning in a counterclockwise direction. Use a pair of pliers or a rag on broken faces to prevent injury to the hands.

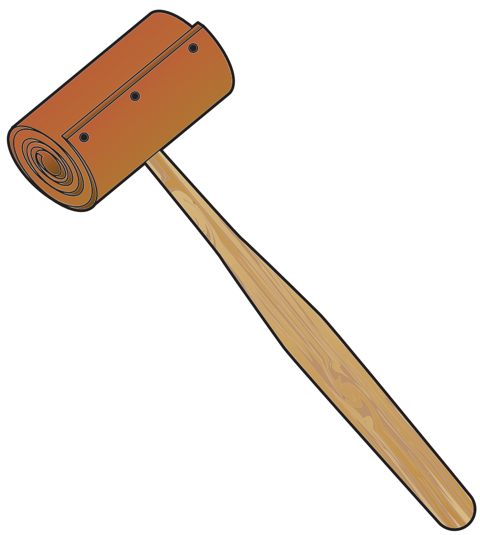


Figure 10-3-5. Rawhide mallets are used principally in sheet metal forming. They are not generally used for finishing.

Screwdrivers

Screwdrivers are tools used for driving or removing screws. Generally, they consist of a steel blade and shank set in a handle of wood or plastic. They also come in various other shapes, some adapted for a particular usage. It is generally better to start out with a full set of screwdrivers. They can be obtained in sets stored in bolsters (tool rolls). These serve both as storage and as an inventory method for tool control.

Common screwdrivers. The common, or standard, screwdriver, shown in Figure 10-3-6, is suitable for driving or removing slotted screws. The blade must have sharp corners and fit the screw slot closely. The size is designated by the length of the shank and blade.

Cross-point screwdrivers. The most common cross point screwdrivers are *Reed & Prince* and *Phillips*. The Phillips screwdriver has a blunt cross tip. The tip is ground to a 30° angle, as shown in Figure 10-3-7. Phillips points come in four sizes: No. 1 through No. 4. The most common is No. 2. A Reed & Prince screwdriver is one of the early points designed for power drivers. It has a sharp point.

> **NOTE:** The Phillips screwdriver is not interchangeable with the Reed & Prince screwdriver. The use of the wrong type screwdriver results in mutilation of the screwdriver and the screw head.

Offset screwdrivers. The offset screwdriver shown in Figure 10-3-8 is composed of a shank with a blade on each end. The blades are bent at right angles to the shank. One is parallel to the shank, the other is set at 90°. This screwdriver is especially usefully in performing close work. Some offset screwdrivers are available as ratchet types, which allow the screw to be driven without having to remove the tip from the screw head (Figure 10-3-9).

Ratchet screwdrivers. The ratchet screwdriver shown in Figure 10-3-10 is fast acting in that it turns the screw without having to remove the tip from the screw head for repositioning after rotation. It can be set to turn the screw clockwise or counterclockwise, or it can be locked in position and used as a standard screwdriver. Many have extra tips stored in the handle. The ratchet screwdriver is not a heavy-duty tool and should be used only for light work.

> **NOTE:** When using a ratchet screwdriver, extreme care must be used to maintain constant pressure and prevent the blade from slipping out from the slot in the screw head. If this occurs, the surrounding structure is subject to damage.

Figure 10-3-6. Common screwdrivers. *Photo courtesy of Snap-on Tools*

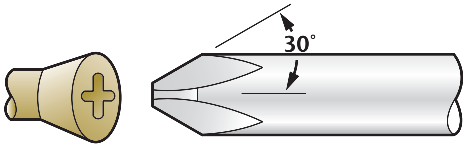


Figure 10-3-7. Phillips screwdriver with blunt point.

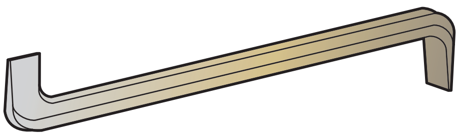


Figure 10-3-8. Offset screwdriver.

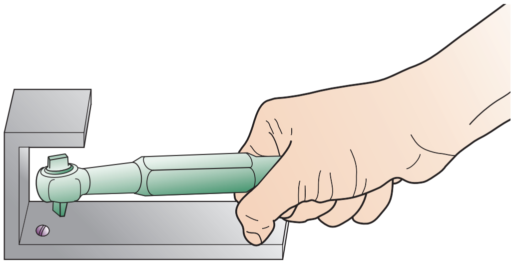


Figure 10-3-9. Using an offset ratchet screwdriver.

Figure 10-3-10. Ratchet screwdriver.

Nonmagnetic screwdrivers. The nonmagnetic screwdriver is shaped like a common screwdriver, but the blade is made of brass so as to have no magnetic effect. It is used for compensating compasses.

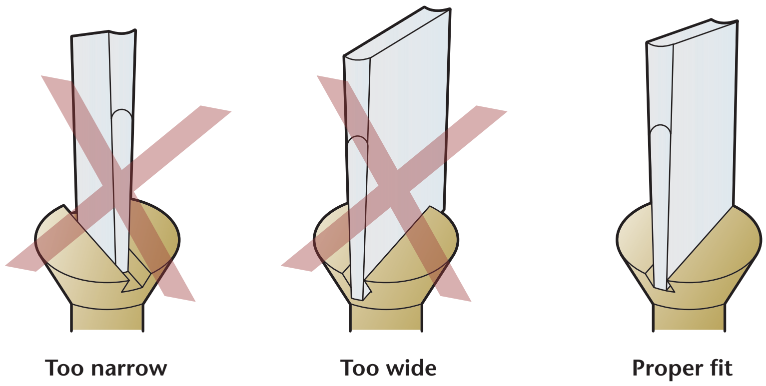


Figure 10-3-11. Proper fit of screwdrivers.

Electric screwdrivers. There is an extremely large variety of electric and battery operated screwdrivers on the market. Most are good. Because of the large number of screws involved in servicing aircraft, they can be a real time saver when removing access panels. However, they can also do a large amount of damage if used incorrectly, especially during reassembly. If the wrong size screw (either diameter or length) is driven with an electric screwdriver, damage can be done before you recognize it. *Do not use electric screwdrivers around fuel tank access plates. They can present an explosion hazard.*

Screwdriver Safety

The following precautions may keep you from injuring yourself with a screwdriver:

- Ensure that the handle is clean.
- Do not use a screwdriver for prying, punching, chiseling, scoring, or scraping.
- Do not use a screwdriver to check an electric circuit, since an electric arc will burn the tip and make it useless. In some cases, an electric arc may fuse the blade to the unit being checked.
- When using a screwdriver on a small part, always hold the part in a vise or rest it on a workbench. Do not hold the part in your hand, because the screwdriver may slip and cause serious personal injury.

Figure 10-3-12. Screwdriver tip grinding.

Proper fit. Select a screwdriver large enough so the blade fits closely in the screw slot. A loose-fitting blade can slip and cause burring of the screw slot and damage to the blade. Proper and improper fits are shown in Figure 10-3-11. It is important that the screwdriver be held firmly against the screw to prevent it from slipping and possibly injuring the mechanic or scarring the work.

Screwdriver Repair

Battered or nicked blades may be repaired by grinding to the original shape.

Common screwdrivers. When grinding common screwdrivers, the tip should be squared and the sides parallel, as shown in Figure 10-3-12.

Cross-point screwdrivers. Phillips screwdrivers require special holding fixtures for grinding but can be shaped in an emergency by filing, as long as the original angles and bevels are maintained.

Removing Stubborn Screws

Special screwdrivers. There are special screwdrivers available that have a hexagonal section on the shank next to the handle. This allows a wrench to be used for additional leverage. Others are available that have a square drive fitting in the handle, for using a breaker bar or ratchet.

Hand-impact wrenches, designed to be struck with a hammer while under twisting pressure, sometimes work well when used with square-drive screwdriver bits. Sometimes light-duty impact wrenches can also be used to loosen (never to tighten) a stubborn screw. Aircraft tool suppliers also make drivers that use screwdriver bits and fit rivet guns. These work well because the air hammer blows while the screw is under rotational pressure.

Unfortunately, even with all these special tools, sometimes nothing works, and the errant screw must be drilled out. Refer to the sheet metal section and read the part on rivet removal first.

Wrenches

Wrenches are used for tightening or removing nuts, bolts, or cap screws and also for gripping round objects such as pipe. They are made of a relatively hard substance, such as chromemolybdenum steel, which enables them to withstand the rigors of normal use.

Figure 10-3-13. Open-end wrench.

Types of wrenches. Wrenches used in aircraft maintenance can be generally categorized as open-end, box-end, combination, adjustable, socket, hexagonal, and spanner wrenches.

Open-end wrenches. Open-end wrenches have two parallel jaws at each end of a bar, as shown in Figure 10-3-13. The jaws of an open-end wrench are usually machined 15° from parallel to the centerline of the wrench. The two ends of each wrench fit consecutively-sized nuts such as 3/8- and 7/16-inch, 1/2- and 9/16-inch, and so on.

Box-end wrenches. Box-end wrenches have a head on each end of a bar, as shown in Figure 10-3-14. The head completely surrounds the nut or bolt, which decreases the chances that the wrench will slip off the work. Box-end wrenches are available with 6-point and 12-point openings. These openings are offset from the shank at a 15° angle to allow clearance. A box-end wrench should be used whenever possible because it provides the best protection to both the user and the equipment. These wrenches are sized the same as open-end wrenches.

Figure 10-3-15. Combination wrench set in a molded plastic holder.
Photo courtesy of Snap-on Tools

Figure 10-3-14. A set of five box-end wrenches offers 10 nut sizes. *Photo courtesy of Snap-on Tools*

Combination wrenches. The combination wrench shown in Figure 10-3-15 combines the best features of the open-end and box wrench into a single wrench. The size opening on the wrench is the same on both ends, but one end has a box head and the other end has an open-end head. The length of the wrench varies with the size of the head. The box-end opening is offset from the shank by 15°.

Adjustable wrench. Adjustable wrenches in-clude Crescent®, automobile, and pipe wrenches, shown in Figure 10-3-16. These wrenches are generally intended for use on odd-sized nuts and bolts, and are adjusted by a knurled worm gear, which moves the movable jaw to fit the part. Adjustable wrenches are available in sizes ranging from 4 to 24 inches in length. The jaw capacity is proportional to the handle length.

Figure 10-3-16. Adjustable wrenches.

Figure 10-3-17. Sockets come in many sizes and lengths. *Photo courtesy of Snap-on Tools*

Figure 10-3-18. Straight-head ratchet handle. *Photo courtesy of Snap-on Tools*

Figure 10-3-19. Sliding T-bar handle.

Figure 10-3-20. Hinged handle.

Figure 10-3-21. Speed handle.

Socket Wrenches

Sockets. Sockets are round metal sleeves with a square opening in one end for insertion of a handle and a six-point or 12-point wrench opening in the other, as shown in Figure 10-3-17. They are available in common (short) and deep (long) lengths. The drive end can vary from 1/4 to 1 inch. Sockets are driven by a wide variety of handles.

Figure 10-3-22. Hexagonal setscrew wrench (Allen wrench) set. *Photo courtesy of Snap-on Tools*

Figure 10-3-23. Crowfoot wrench. *Photo courtesy of Snap-on Tools*

Socket Wrench Handles

There are many types of handles used to drive sockets. The following paragraphs describe the more common types in use.

Ratchet handle. Ratchet handles may have either a straight head or a flex head. The flex head is used to go around objects. Both types have a selection lever on the top of the head to determine the direction of drive. A straight head type is shown in Figure 10-3-18.

Sliding T-bar handle. The sliding T-bar handle shown in Figure 10-3-19, has a single head which may be adjusted along a bar handle. It has two spring loaded balls, one for keeping the bar in the head and the other for keeping the socket on the head. The sliding T-bar is used for increased leverage or for working around other objects.

Hinged handle. A hinged handle has a hinged adapter on one end which may be rotated in 90° steps, used when additional leverage or torque is needed to loosen nuts or bolts. This type of handle is shown in Figure 10-3-20.

Speed handle. The speed handle, shown in Figure 10-3-21, has a brace-type shaft with a revolving grip on the top. It is used for rapid removal and installation of nuts or bolts, which are out in the open and have little or no torque.

Hexagonal Wrenches

Hexagonal setscrew wrenches (Allen wrenches) are L-shaped, headless, hexagonal bars that range in size from 3/64 to 1/2 inch.

A typical Allen wrench set is shown in Figure 10-3-22. They are used to tighten or remove screws that have hexagonal recesses.

Allen wrenches are also available to fit square-drive handles. They are frequently easier and faster to operate. They also have the advantage of fitting a torque wrench.

Crowfoot Wrench

Figure 10-3-23 shows a typical crowfoot wrench, to be used where a bolt is installed in a location where an obstruction does not allow the use of a socket or a wrench. The wrench is attached to an extension.

Ensure that the wrench being used is of the right size. Use of a wrench larger than the head of the bolt or nut will result in rounding of the faces.

Uses of Wrenches

When using any type wrench, special attention should be given to choosing the one best suited for the job. Selecting a wrench larger than the nut or bolt head often results in rounded corners and additional maintenance time. Arrange work so a wrench is pulled, not pushed. Never use pipe or other extensions to increase leverage. The following paragraphs describe the various procedures involved with operating the previously described wrenches.

Use of open-end wrenches. The 15° offset of the jaws from the centerline of the wrench makes the open-end wrench appropriate for use in some applications where there is room to make only part of a complete turn of a nut or bolt. A typical procedure for this application is described below and illustrated step by step in Figure 10-3-24.

> **NOTE:** Where conditions prohibit use of a socket or box-end, an open-end wrench may be used. The open-end wrench has fewer contact points than either a socket or box-end and is more likely to round off the corners of the nut.

1. The wrench is positioned with the opening sloping to the left, about to be placed on the nut.
2. Position the wrench on the nut. Note that space for swinging the wrench is limited.
3. Move the wrench counterclockwise to loosen the nut. The wrench will strike the casting which prevents further movement.
4. Remove the wrench from the nut and turn counterclockwise to place it on the next set of flats on the nut.

   NOTE: The corner of the casting may prevent the wrench from fitting the nut.

5. If this occurs, flip the wrench over so that the opening will slope to the right.
6. Position the wrench on the next two flats on the nut.
7. Turn the wrench counterclockwise to further loosen the nut.
8. Continue flipping the wrench as required until the nut is completely loose.

Use of box-end wrenches. Box-end wrenches are very good for final tightening of nuts. The following procedures describe the typical use of box-end wrenches:

1. Select the size of wrench that fits the nut or bolt.
2. Place the wrench on the nut or bolt and turn as required to loosen or tighten.
3. If there is insufficient room to swing the wrench in a full circle, as shown in Figure 10-3-25, lift it completely off the nut when it

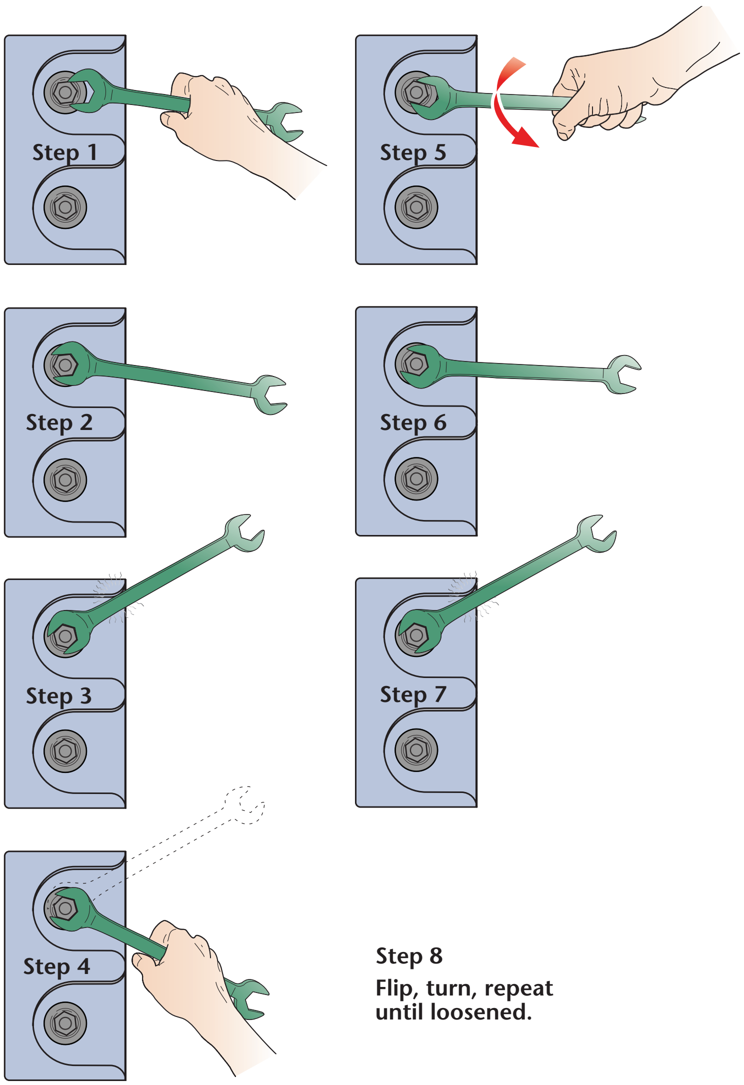


Figure 10-3-24. Use of open-end wrench.

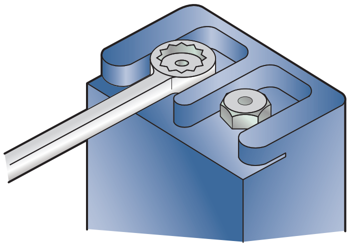


Figure 10-3-25. Use of box-end wrench.

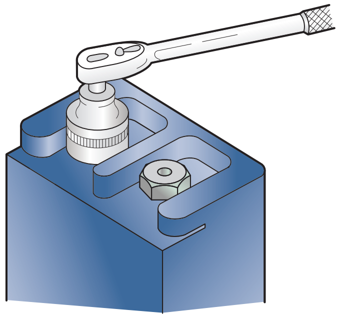


Figure 10-3-26. Use of socket wrench.

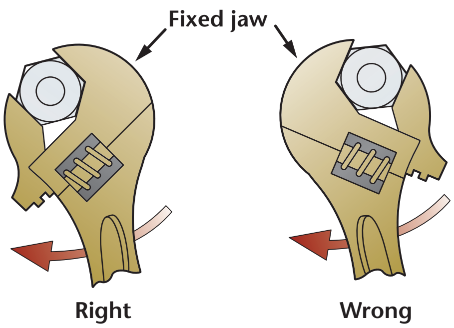


Figure 10-3-27. Adjustable wrench procedure.

comes to the limit of the swing and place it in a new position, permitting another swing. A swing through a 15° arc is usually sufficient to continuously loosen or tighten a nut or bolt.

Use of socket wrenches. Where practical, a socket wrench is best for loosening or tightening nuts and bolts. Speed can be attained through the use of ratchets and speed handles. Length of the handle used is very important, as very little pressure is required to strip threads or twist off a small bolt using a long handle. Extension bars and universal joints enable a mechanic to get at nuts or bolts that would otherwise be out of reach or at a difficult angle. Figure 10-3-26 shows the typical use of a ratchet wrench. The procedure is outlined as follows:

1. Select the size of the socket that fits the nut or bolt to be turned. Push it onto the handle which is best suited for the job.

2. Turn the socket with the handle to tighten or loosen the nut or bolt.

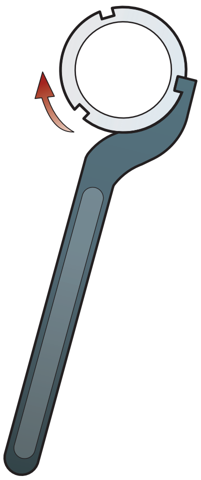


Figure 10-3-28. Hook spanner wrench.

Adjustable Wrenches

Use of adjustable wrenches. Adjustable wrenches should be used only when wrenches of the correct size are unavailable. They should be properly adjusted and pulled so the handle moves in the direction of the adjustable jaw, as shown in Figure 10-3-27. Place the wrench on the nut so that the force used to turn it is applied to the stationary jaw side of the wrench.

Spanner Wrenches

Many special nuts used in propeller systems are made with notches or holes cut into the outer edge (face) of the nut. These nuts are designed to be driven with spanner wrenches.

Spanner wrenches. Spanner wrenches can generally be classified as one of two types: solid and adjustable.

Solid spanner wrenches. The following paragraphs describe the various types of solid spanner wrenches.

Nuts with notches cut into the outer edge are driven with the *hook spanner*, as shown in Figure 10-3-28. This wrench has a curved arm with a lug or hook in the end. This lug fits into one of the notches of the nut, and the handle is pulled to tighten or loosen the nut.

The *pin spanner*, shown in Figure 10-3-29, has a pin in place of the hook. This pin fits into a hole on the outer edge of the nut.

Face pin spanners are designed so that the pins fit into holes in the face of the nut, as shown in Figure 10-3-30.

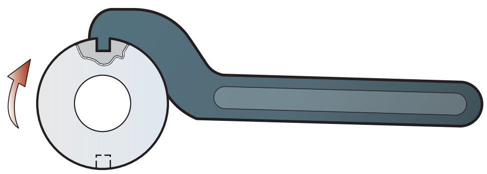


Figure 10-3-29. Pin spanner wrench.

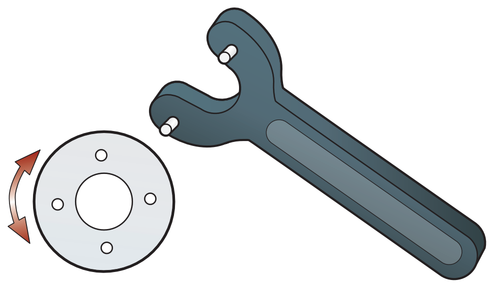


Figure 10-3-30. Face pin spanner wrench.

Adjustable spanner wrench. Solid spanner wrenches are sized for specific sizes of nuts. The adjustable spanner wrench, shown in Figure 10-3-31, has a pivoting end which allows the wrench to fit several nut sizes. The wrench shown is a hook spanner, used the same way as the solid hook spanner.

Pliers

Pliers are so constructed that a force or pressure applied to the handles is intensified through the pivot point to the jaws. This leverage enables the mechanic to hold materials which the hand alone is not strong enough to hold.

Types of pliers. Pliers are made in various types for various uses. The more common types are listed in the following paragraphs.

Retaining ring pliers. Retaining ring (snap ring) pliers (Figure 10-3-32) are used to remove internal and external retaining rings.

Slip-joint pliers. The slip-joint combination pliers, shown in Figure 10-3-33, have serrated (grooved) jaws, with a rod-gripping section, a cutting edge, and a pivot. The serrated jaws and rod-gripping section are used to hold objects. The cutting edge permits the cutting of soft wire and nails. However, cutting hard materials or large gauge wire will spring the jaws, rendering the pliers useless. The pivot is used to adjust the jaw opening to handle large or small objects.

Diagonal-cutting pliers. The diagonal-cutting pliers, shown in Figure 10-3-34, have a fixed pivot. The jaws are offset by about 15° and are shaped to give enough knuckle clearance while making flush cuts. These pliers are used for cutting objects such as wire, cotter pins, and similar items. These pliers are not to be used to hold or grip objects.

Long-nose pliers. Long-nose pliers (Figure 10-3-35) are used to reach places inaccessible to the fingers and perform tasks such as inserting cotter pins in close places. They are also used to bend small pieces of metal.

Flat-nose pliers. The flat-nose pliers (duckbills), shown in Figure 10-3-36, have flat serrated jaws, a fixed pivot, and curved handles, which may have insulated sleeves. These pliers are used to bend light sheet metal and wire and install safety wire.

Water pump pliers. Water pump pliers, sometimes referred to as *Channel Lock*® *pliers* (Figure 10-3-37), are used for their powerful grip and ability to adjust to several different sizes. There are two adjustment methods used with this type of pliers. Water pump pliers should not be used to loosen/tighten cannon plugs and other electrical plugs. They will damage the connector.

Vise-grip® pliers. *Vise-grip* pliers have a clamping action which allows them to be

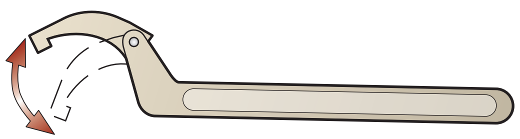


Figure 10-3-31. Adjustable hook spanner wrench.

Figure 10-3-32. Retaining ring pliers.
Photo courtesy of Snap-on Tools

Figure 10-3-33. Slip-joint combination pliers.

Figure 10-3-34. Diagonal cutting pliers.
Photo courtesy of Snap-on Tools

Figure 10-3-35. Long-nose pliers.

Figure 10-3-36. Flat-nose pliers.

Figure 10-3-37. Water pump pliers.

Figure 10-3-38. Locking pliers. *Photo courtesy of Snap-on Tools*

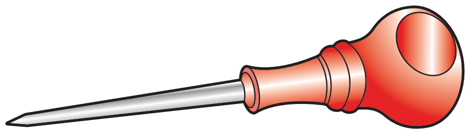


Figure 10-3-39. Awl.

clamped onto an object. They will stay there and free the other hand for other work. These pliers, shown in Figure 10-3-38, are sometimes made with a clamp-type jaw which allows them to be used for clamping sheet metal. The pliers can be adjusted by turning the knurled adjustment screw until the desired jaw dimension is reached. They are made in many different sizes and shapes.

> **NOTE:** Vise-grip pliers should be used with care since the teeth in the jaws tend to damage the object on which they are clamped. Do not use them on nuts, bolts, tube fittings, or other objects which must be reused.

Use of pliers. Pliers come in various sizes and should be selected according to the job being performed. They should never be used as a substitute for a wrench, because this practice batters nut and jaw serrations unnecessarily. Although there are several uses for pliers, they are not all-purpose tools and should not be used as pry bars or for hammering.

Awls

Awls are used in aircraft maintenance to align holes, as in the installation of a deicer boot, and to place scribe marks on metal and plastic surfaces. A typical awl is shown in Figure 10-3-39.

Knives

Most knives are used to cut, pare, and trim wood, leather, rubber, and other soft materials. The types that the aircraft technician will probably encounter are the shop knife, pocket knife, and the putty knife.

Utility knife. The utility knife (Figure 10-3-40) can be used to cut cardboard and paper. It has an aluminum handle and is furnished with interchangeable blades which are stored in the handle. Different types of blades are available.

Putty knife. A putty knife (Figure 10-3-41) is used for applying putty compound and sealant, as well as for scraping gasket material. The blade has a wide, square point and is available in different lengths and widths. The square edge can be restored by filing when worn or rounded.

Vises

Vises and clamps are used to hold objects being worked to a definite size and shape. The objects must be held firmly while the work is being performed. The bench vise and the carriage clamp are the clamping devices most widely used in aircraft maintenance.

Bench vise. The bench vise, shown in Figure 10-3-42, is a large steel vise with rough jaws that prevent the work from slipping. Most vises of this type have a swivel base so that the upper portion can be rotated. The bench vise

Figure 10-3-40. Utility knife.

Figure 10-3-41. Putty knife.

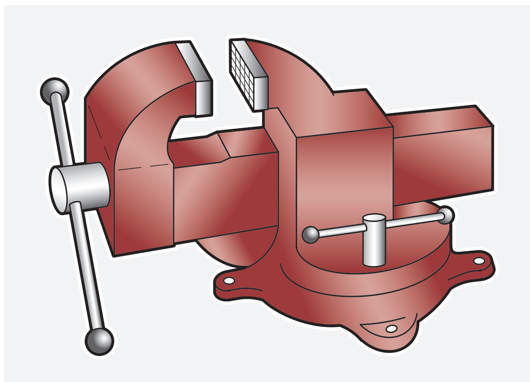


Figure 10-3-42. Bench vise.

Figure 10-3-43. Using a bench vise.

Figure 10-3-44. Adjustable bar clamps with rubber jaw pads.

is usually bolt-mounted onto a bench. Some woodworking vises have large wooden jaws and will not mark sheet metal.

Jaw pads. Install brass or copper caps on the vise jaws, Figure 10-3-43, to prevent scratching and denting of soft substances when clamping. Highly polished surfaces may be protected by pieces of rawhide or leather.

Clamps

A look at any tool catalog will reveal a bewildering selection of bar clamps. Some work well for aircraft repair, some do not. The choice should be based on application to the job with no damage to the work by making marks, dents, creases, etc.

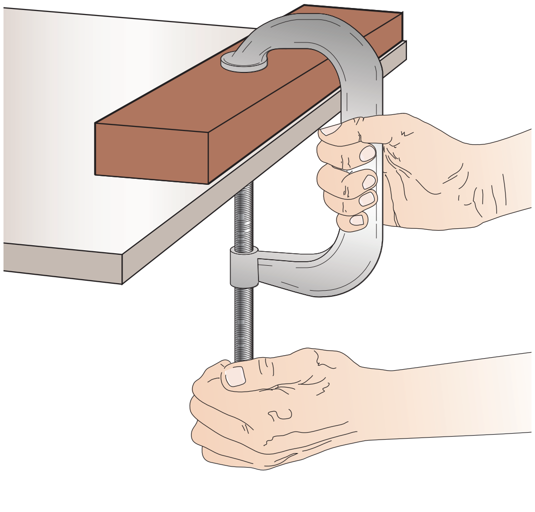


Figure 10-3-45. Carriage clamp (C-clamp).

Adjustable bar clamps. Designed to be closed with one hand, these general-purpose clamps (Figure 10-3-44) are good for clamping complex assemblies. Rubber pads are available for the jaws to prevent marring and slippage. They work very well for clamping doubler plates to spars during repairs. Available in several sizes, adjustable bar clamps are an excellent all-around choice.

Carriage clamps. The carriage clamp, commonly called a *C-clamp,* is constructed in the shape of a large C, as shown in Figure 10-3-45. It is tightened by use of a screw threaded through one of the bars and has a swivel plate to prevent the end of the screw from turning against the item being clamped. C-clamps are used to hold work which cannot be held in a vise or which has to be held for an extended period of time. They are available in a wide variety of sizes.

CAUTION: Some items, such as glass and highly polished objects, must be protected to prevent localized stress and damage. Use brass shims or wooden blocks to provide this protection.

Do not use wrenches or bars to tighten clamps. Excessive pressure will result in damage to the item being clamped.

Cold Chisels

A chisel is a tool that has a cutting edge at the end of a metal blade, used in dressing, shaping, and working metal. The cold chisel derives its name from the fact that it can be used to cut metal that has not first been softened by heating. It is usually made of carbon steel with a tempered cutting edge.

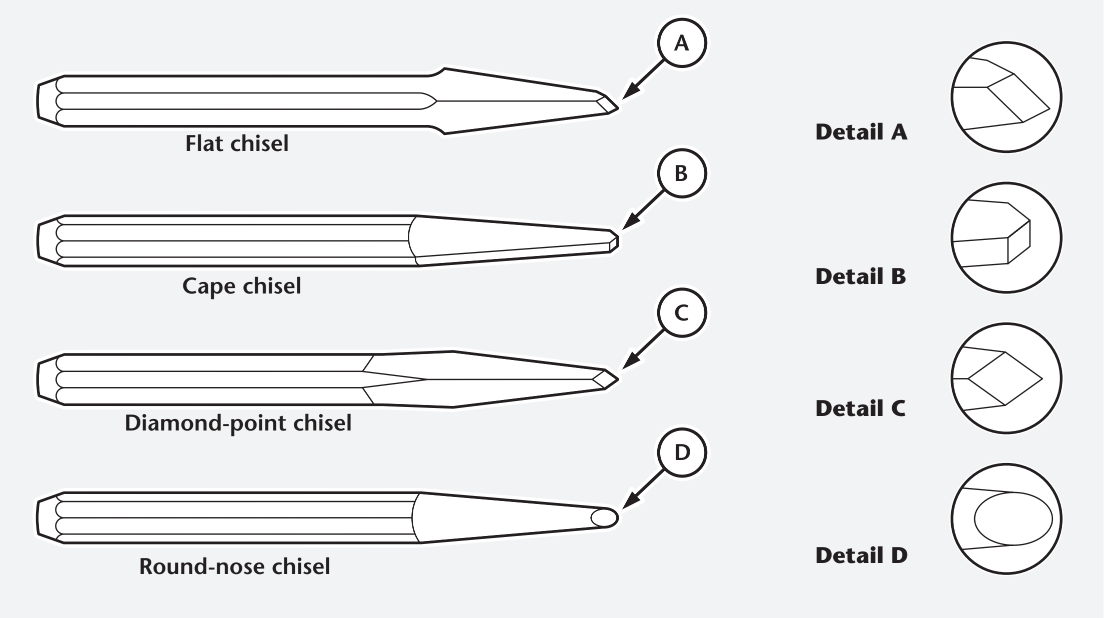


Figure 10-3-46. Chisels.

Types of cold chisels. The most common types of cold chisel are the *flat*, *cape*, *diamond-point,* and *round-nose* types, as shown in Figure 10-3-46.

Flat chisel. The flat chisel is used to split nuts, chip castings, and to cut rivets and thin metal sheets.

Cape chisel. The cape chisel is used for special jobs like cutting keyways, narrow grooves, and square corners.

Diamond-point chisel. The diamond-point chisel is used to cut V-grooves and sharp corners.

Round-nose chisel. Round-nose chisels make circular grooves and chip inside corners with a fillet.

Repairing a chisel edge. Nicked or battered chisels may be repaired by grinding. If necessary, temper can also be restored. Chisels are usually ground to a 70° angle, but that may be as high as 90° for harder substances. When grinding, set the rest on the grinding wheel to adjust for the desired bevel and set the space between the rest and the wheel.

Move the chisel from side to side while grinding so that the cutting edge will be slightly curved. Ensure that the bevels are kept centered or the cutting edge will not be centered.

Preserve temper by dipping frequently in water. If the edge turns blue, you have destroyed the temper and the chisel will not hold an edge.

NOTE: Wear eye protection when grinding chisels to avoid serious injury.

Punches

Punches usually are made of carbon steel tempered on both ends. They generally are classified as either solid punches or hollow punches, and are designed according to their intended use. Hollow punches vary in size. Solid punches vary both in size and in point design.

Solid Punches

Solid punches are named according to their shape and are designed for various purposes. The following paragraphs describe the common types of punches used in aircraft maintenance.

Prick punch. A prick punch, shown in Figure 10-3-47, is used to place reference marks in metal. It is also often used to transfer dimensions from a paper pattern directly onto the metal. It is relatively slender and is tapered to a point of about 30°. The following precautions should be taken when using a prick punch:

- Never strike a prick punch heavily with the hammer because it could bend the punch or cause excessive damage to the item being worked.

Figure 10-3-47. Prick punch.

- Do not use a prick punch to remove objects from holes, because the point of the punch will spread the object and cause it to bind even tighter.
- A prick punch does not make a good center punch. The mark is not the correct angle.

Center punch. A center punch, shown in Figure 10-3-48, is used to make large indentations in metal of the kind needed to start a twist drill. This punch has a heavier body than the prick punch, and its point is ground to an angle of about 60°.

Never strike the center punch with enough force to excessively dimple the material around the indentation. The 60° angle causes a large amount of metal to displace (stretch). The stretch will cause a small buckle at each punch mark. When the hole is drilled, all of the stretched metal will not be removed and the sheet will not lay flat.

Automatic center punch. The automatic center punch, shown in Figure 10-3-49, is used only to indent metal to make starting points for twist drills. It contains a mechanism that automatically strikes a blow of the required force when the user puts the punch in place and presses on it with his hand. This punch has an adjustable cap for regulating the stroke; the point can be removed for regrinding or replacement. Never strike an automatic center punch with a hammer.

> **NOTE:** If you have trouble with a drill "walking" after using a center punch, the trouble more than likely is not the center punch mark. Most likely the drill point is worn or uneven. Replace the drill.

Drive punch. The drive punch, shown in Figure 10-3-50, is often called a *taper punch*. It is used to drive out damaged rivets, pins, and bolts, which sometimes bind in holes. Therefore, the drive punch is made with a flat face instead of a point. The size of the punch is determined by the width of the face, usually 1/8 to 1/4 inch.

Pin punch. A pin punch, shown in Figure 10-3-51, is also often called a *drift punch*. It is similar to a drive punch and is used for the same purpose. The difference between the two is that the shank of a drive punch is tapered all the way to the face, while the pin punch has a straight shank. Pin punch points are sized in 1/32-inch increments and range from 1/16 to 3/8 inch in diameter. The usual method for driving out a pin or bolt is to start working it out with a drive punch, which is used until the shank of the punch is touching the sides of the

Figure 10-3-48. Center punch.

Figure 10-3-49. Automatic center punch. *Photo courtesy of Snap-on Tools*

Figure 10-3-50. Drive punch. *Photo courtesy of Snap-on Tools*

Figure 10-3-51. Pin punch. *Photo courtesy of Snap-on Tools*

hole. A pin punch is then used to drive the pin or bolt the rest of the way out of the hole.

Pins and bolts or rivets that are hard to dislodge, may be started by placing a thin piece of scrap copper, brass, or aluminum directly against the pin and then striking it with a heavy hammer until it begins to move. A *backup bar* may be necessary to keep from bending thin sheet.

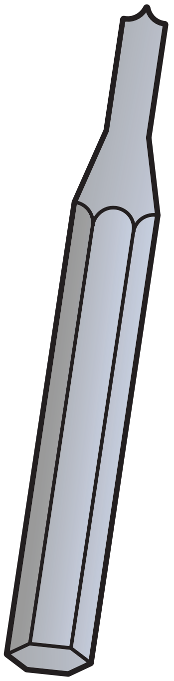


Figure 10-3-52. Transfer punch.

Transfer punch. The transfer punch, like the one shown in Figure 10-3-52, is used to transfer the holes through the template or patterns to the item beneath. This punch is usually about 4 inches long. Its point is tapered at the back and then turns straight for a short distance to fit the drill-locating hole in a template. The tip ends in a point similar to that of a prick punch.

Repairing the end of a punch. To a point, punches can be repaired by grinding. Pin, drive, or other blunt end punches must be ground so that the end is perfectly flat and at right angles to the centerline of the punch. Center punches and prick punches are ground to conical points of 60° and 30°, respectively.

Hollow Punches

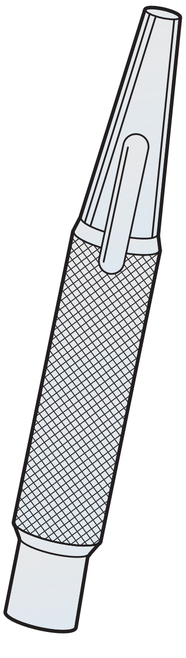


Figure 10-3-53. Hollow punch.

Hollow punches, frequently called *gasket punches*, are used to cut holes in thin, soft metal or other items such as rubber, cork, leather, or paper. Figure 10-3-53 shows a typical hollow punch. The edge of hollow punches should be protected by using a backup under the material being punched out. Plywood or masonite make good backup material.

Files

Files are hardened steel tools used for cutting, removing, smoothing, or polishing metal. The cutting edges, or *teeth*, are made by diagonal rows of chisel cuts. The parts of a file are named and illustrated in Figure 10-3-54. Files can be classified by grade and shape, and they are graded according to whether they have single-cut or double-cut teeth and by their degree of fineness.

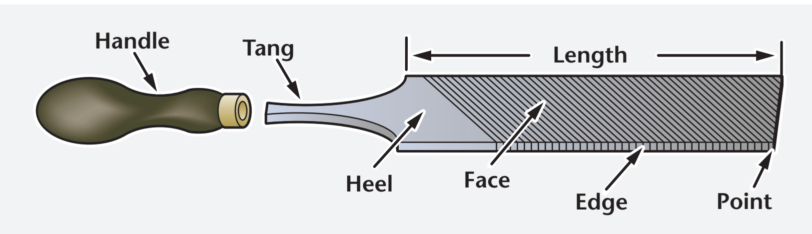


Figure 10-3-54. A typical file and its nomenclature.

Figure 10-3-55. Single- and double-cut file teeth.

Single- and Double-Cut Teeth

The difference between single- and double-cut teeth is apparent in Figure 10-3-55.

Single-cut. Single-cut files have rows of teeth cut parallel to each other. These teeth are set at an angle of about 65° from the centerline. These files are used for sharpening tools, finish filing, and draw filing. They are also the best tools for smoothing the edges of sheet metal.

Double-cut. Double-cut files have crossed rows of teeth. The double-cut forms teeth that are diamond-shaped and fast cutting. These files are more abrasive than single-cut files, and they are used for quick removal of metal and for rough work.

Degree of fineness. Files are also graded according to the spacing and size of their teeth, or by their coarseness and fineness. Shown in Figure 10-3-56, the usual grades of fineness are called *coarse*, *bastard*, *second-cut*, and *smooth*. The fineness or coarseness is influenced by the length of the file. Most round and half-round files are bastard cut and remove material quickly.

Shapes of Files

Files come in different shapes. When selecting a file for a job, the shape of the finished work must be considered. Common file shapes are described in the following paragraphs.

Triangular files. Triangular files are tapered toward the point on all three sides. They are used to file acute internal angles and to clear out square corners. Certain triangular files are used to file saw teeth.

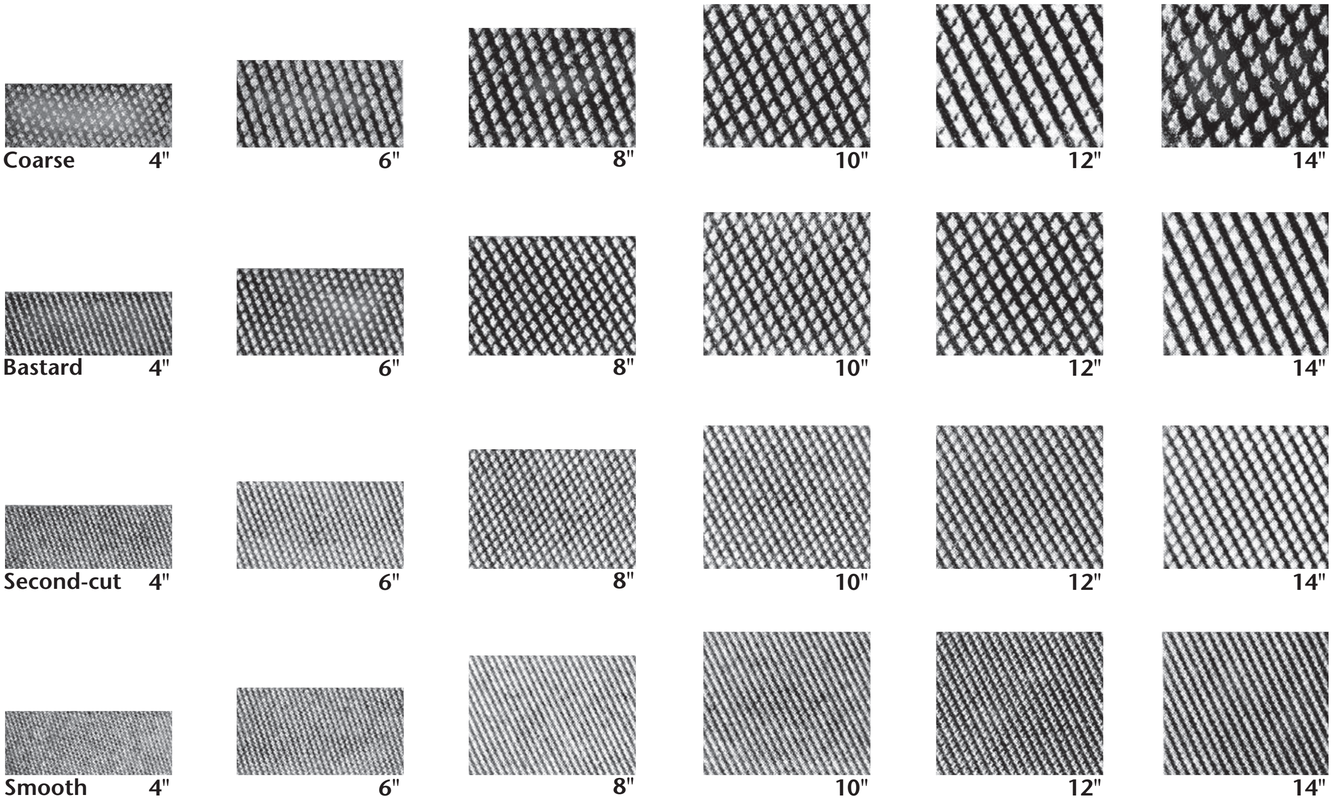


Figure 10-3-56. File teeth spacing and fineness.

Mill files. Mill files are tapered in both width and thickness. One edge has no teeth and is known as a safe edge. Mill files are used for smoothing lathe work, draw filing, and other precision work. They are always single-cut. Mill files, Figure 10-3-57, are the most common files you will use.

Flat files. Flat files are general-purpose and may be either single or double-cut. They are tapered in width and thickness. Double-cut flat files are usually used for rough work, while single-cut, smooth files are used for finish work.

Square files. Square files are tapered on all four sides and are used to enlarge rectangular holes and slots.

Round files. Round files serve to enlarge or smooth round openings. Small round files are often called *rattail files*.

Half-round files. The half-round file is a general-purpose tool. The rounded side is used on curved surfaces, and the flat side is used on flat surfaces. When filing an inside curve, use a file whose curve most nearly matches the curve of the work.

Curved-tooth files. Curved-tooth files (also called *Vixen files* or *auto body files*) are generally used on aluminum and sheet steel, on both flat and curved surfaces. They are also used for smooth, rapid work on bronze, lead, babbitt, zinc, and plastic. An example of this type of file is shown in Figure 10-3-58.

Figure 10-3-57. Mill file.

File Selection for the Job

Certain file grades are most effective and produce very specific finishes on certain metals. The following are some of the suggested grades of files to be used on the applicable metals.

- For heavy, rough cutting, use a large, coarse, double-cut file.
- For finishing cuts, use a second-cut or smooth-cut single-cut file.

Cast iron. When working on cast iron, start with a bastard-cut file and finish with a second-cut file. A second-cut file is one grade finer than a bastard cut.

Soft metal. When filing soft metal, start with a second-cut file and finish with a smooth-cut file.

Figure 10-3-58. Vixen curved-tooth file.

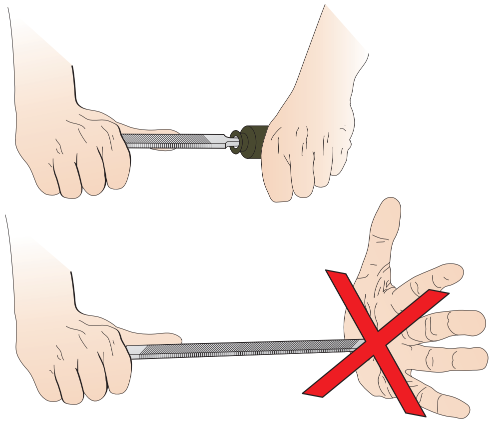


Figure 10-3-59. Correct use of file handle.

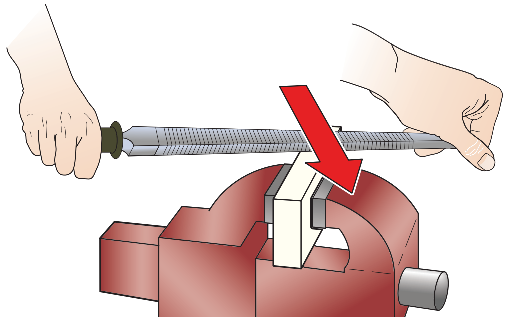


Figure 10-3-60. Crossfiling.

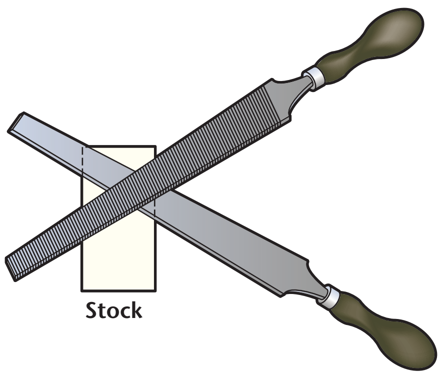


Figure 10-3-61. Filing for a flat surface.

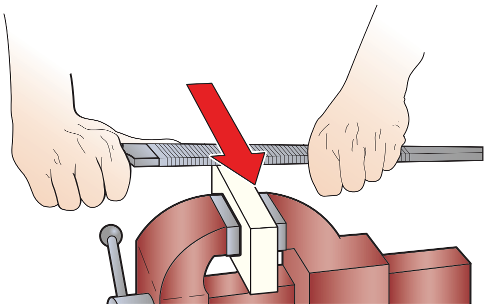


Figure 10-3-62. Drawfiling.

Hard steel. When filing hard steel, start with a smooth-cut file and finish with a dead-smooth file.

Brass or bronze. When filing brass or bronze, start with a bastard-cut file and finish with a second- or smooth-cut file.

Aluminum, lead, or babbitt. When filing aluminum, lead, or babbitt metal, use a standard-cut curved tooth file.

Using a File Safely and Correctly

Using a file is an operation that is nearly indispensable when working with metal. Most filing operations can be classified as crossfiling and drawfiling. There are several basic precautions, however, that must be taken when using and maintaining a file.

- If the file is designed to be used with a handle, do not attempt to use it without the handle. *Holding the tang of the file in your hand while filing may result in serious injury* (Figure 10-3-59).
- Do not use a file for prying. The tang end is soft and bends easily, while the body of the file is hard and brittle and will snap under a very light bending force.
- Do not hammer on a file. This may cause the file to shatter.
- The strokes with the file should be long and smooth and there should not be more than 40 strokes per minute to prevent overheating of the teeth.
- There should be no pressure on the file as it is being drawn back. The teeth slant forward and back stroke pressure will cause them to break more readily than on the forward stroke. However, when filing very soft metal such as aluminum, a slight back stroke pressure will aid in cleaning the teeth.
- For small work, use a short file. For medium- sized work, use an 8-inch file. For large work, use the file size that is most convenient.

Crossfiling. Crossfiling means that the file is moved across the surface of the work in an approximate crosswise direction, as shown in Figure 10-3-60. When an exceptionally flat surface is required, hold the file at an angle and file across the entire length of the stock. Then, turn the file, as shown in Figure 10-3-61, and file across the entire length of the stock again. Because the teeth of the file pass over the stock in two directions, the high and low spots will be readily visible after filing in both positions.

Drawfiling. Drawfiling produces a finer surface finish and, usually, a flatter surface than crossfiling. Refer to Figure 10-3-62 and proceed as follows:

- Hold the file as shown. The cutting stroke is away from the body when the file handle is held in the right hand. If the handle is held in the left hand, the cutting stroke will be toward the body.
- Hold the file at right angles to the direction of the stroke, and keep hands relatively close together to prevent bending the file.
- Keep the pressure light. The pressure can remain the same for both the cutting stroke and the return stroke. The speed of filing is not important.
- When drawfiling no longer improves the surface texture, wrap a piece of abrasive cloth around the file and stroke in the same manner.

Cleaning a file. Keeping a file clean will make for smooth cuts. If metal filings are allowed to build up to the point that they stick together, they can end up marking the teeth, especially on a mill file. This will leave marks on the filed surface and may result in having to replace the file.

The brush used to clean a file is called a *file card* (Figure 10-3-63). File cards generally come with a small metal pick attached. Its purpose is to pick out any metal filings that will not brush out with the card's metal bristles. A clean file cuts better and lasts longer.

Hand Drills

A hand drill is used when electric or pneumatic power is not available. These drills provide a much slower drilling speed because they are hand-powered. The most common is the so-called *egg beater.*

Hand drill. The hand drill, shown in Figure 10-3-64, has a handle to provide pressure by hand. This drill is used to drill holes in wood and sheet metal, and is generally the most common.

Drills

A drill is a pointed tool that is rotated to cut holes in material. It is made of carbon steel or harder alloy steels, depending upon the type of work required. A typical drill bit and its parts are shown in Figure 10-3-65. Some of these parts are explained in the following paragraphs.

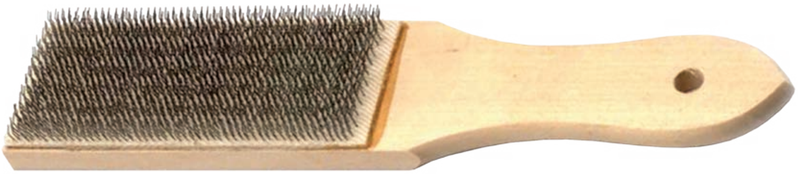


Figure 10-3-63. File card.

Figure 10-3-64. Hand drill.

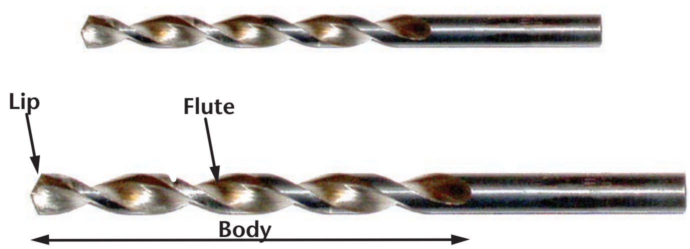


Figure 10-3-65. Typical drill bits.

Lips. The lips are the parts which actually do the cutting.

Flutes. The flutes allow the chips to escape, give the correct rake to the lips or cutting edges and, when it is necessary to use a lubricant, they allow the lubricant to reach the cutting edges.

Body. The body of the drill is ground away slightly, except at the margin, to reduce the friction of the drill as it rotates.

Drill Sizes

The number, letter, fractional, and decimal sizes of drill bits are shown in Table 10-3-1.

Laying out work. When laying out work to be drilled, mark the hole locations in the following manner:

- Do not hit the center punch too hard, because it will dent the surrounding

Drill	Decimal	Drill	Decimal	Drill	Decimal	Drill	Decimal
80	0.0135	49	0.073	20	0.161	I	0.272
79	0.0145	48	0.076	19	0.166	J	0.277
78	0.016	5/64	0.078125	18	0.1695	K	0.281
1/64	0.0156	47	0.0785	11/64	0.171875	9/32	0.28125
77	0.018	46	0.081	17	0.173	L	0.29
76	0.02	45	0.082	16	0.177	M	0.295
75	0.021	44	0.086	15	0.18	19/64	0.296875
74	0.0225	43	0.089	14	0.182	N	0.302
73	0.024	42	0.0935	13	0.185	5/16	0.3125
72	0.025	3/32	0.09375	3/16	0.1875	O	0.316
71	0.026	41	0.096	12	0.189	P	0.323
70	0.028	40	0.098	11	0.191	21/64	0.328125
69	0.0292	39	0.0995	10	0.1935	Q	0.332
68	0.031	38	0.1015	9	0.196	R	0.339
1/32	0.03125	37	0.104	8	0.199	11/32	0.34375
67	0.032	36	0.1055	7	0.201	S	0.348
66	0.033	7/64	0.109375	13/64	0.203125	T	0.358
65	0.035	35	0.11	6	0.204	23/64	0.359375
64	0.036	34	0.111	5	0.2055	U	0.368
63	0.037	33	0.113	4	0.209	3/8	0.375
62	0.038	32	0.116	3	0.213	V	0.377
61	0.039	31	0.12	7/32	0.21875	W	0.386
60	0.04	1/8	0.125	2	0.221	25/64	0.390625
59	0.041	30	0.1285	1	0.228	X	0.397
58	0.042	29	0.136	A	0.234	Y	0.404
57	0.043	28	0.1405	15/64	0.234375	13/32	0.40625
56	0.0465	9/64	0.140625	B	0.238	Z	0.413
3/64	0.046875	27	0.144	C	0.242	27/64	0.421875
55	0.052	26	0.147	D	0.246	7/16	0.4375
54	0.055	25	0.1495	E	0.25	29/64	0.453125
53	0.0595	24	0.152	1/4	0.25	15/32	0.46875
1/16	0.0625	23	0.154	F	0.257	31/64	0.484375
52	0.0635	5/32	0.15625	G	0.261	1/2	0.5
51	0.067	22	0.157	17/64	0.265625		
50	0.07	21	0.159	H	0.266		

Table 10-3-1. Drill sizes.

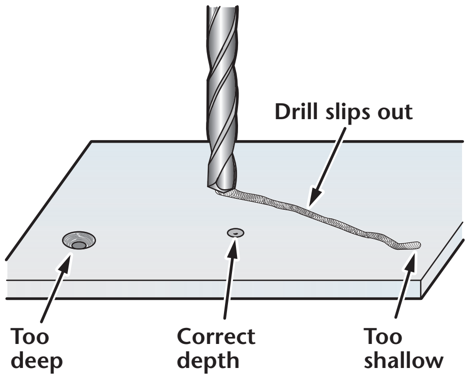


Figure 10-3-66. Correct depth of center punch for drilling.

metal. Place a bucking bar behind the metal to prevent denting.

- Because it is hard to see around the 60° point of a center punch, locate the exact center of the hole to be drilled and mark the spot with a prick punch.
- Enlarge the prick punch mark with a center punch so that the point of the drill can seat properly. This is shown in Figure 10-3-66.

Drilling holes. To drill the material, proceed as follows:

- Use eye protection when drilling.
- Place the drill in the center-punched mark. When using a power drill manually, rotate the chuck a few turns before starting the motor.
- Hold the drill at a 90° angle to the work and apply pressure while drilling.

NOTE: The amount of pressure to be applied while drilling depends on the size of the drill and the hardness of the metal being drilled. Stainless steel requires more pressure than steel, which requires more pressure than aluminum.

- When the center punch mark has been cut away, lift the drill and examine the cut to ensure that it is in the required location. If it is not, the drill can be made to lead in the desired direction by cutting a groove in the side of the drilled portion with a cold chisel. The drill cannot be made to lead after the entire point has entered the item.
- As the drill begins to emerge from the stock, release pressure on the drill so that it does not catch on the chips in the hole. If it catches when drilling thin sheet metal, the drill will enlarge the hole.

Sharpening Drills

When drills are worn or need to be modified for certain metals, they can be reground. They can be reground by machine or by hand.

Machine grinding. The most accurate way to grind a drill is to use a machine designed specifically for this purpose. One is shown in Figure 10-3-67. There are many other types, some much better than others. A good drill grinding fixture must allow for heel clearance. It should also allow for 135° split-point drills.

Hand grinding. Drills may be ground by hand, but only if a drill-grinding machine is not available. It takes a lot of practice to learn to grind a drill by hand; not many people can do a good job. Drill sharpening is a skill that is best taught by someone that has the capability to do it correctly.

Holes are generally not drilled perfectly smooth, exactly straight, and square. When an item needs a hole of an exact size, it must be reamed.

Reamers

A reamer is a cutting tool with one or more cutting surfaces used for enlarging or to size and contour a previously formed hole. A reamer functions by removing a small amount of stock from the walls of a hole. To ream effectively, the diameter of a reamer must be a greater diameter than the hole to be reamed.

NOTE: Do not use the reamer to remove more than 0.002 to 0.003 inches of metal. If the hole is too small, enlarge it with a drill before reaming it.

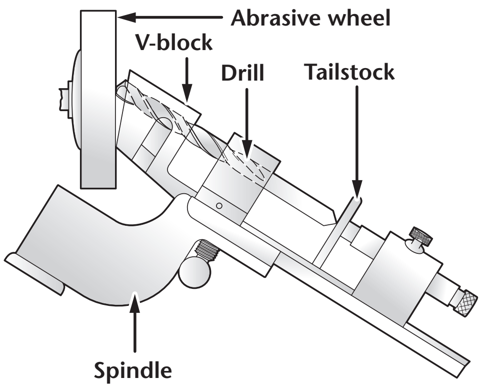


Figure 10-3-67. Machine grinding a drill.

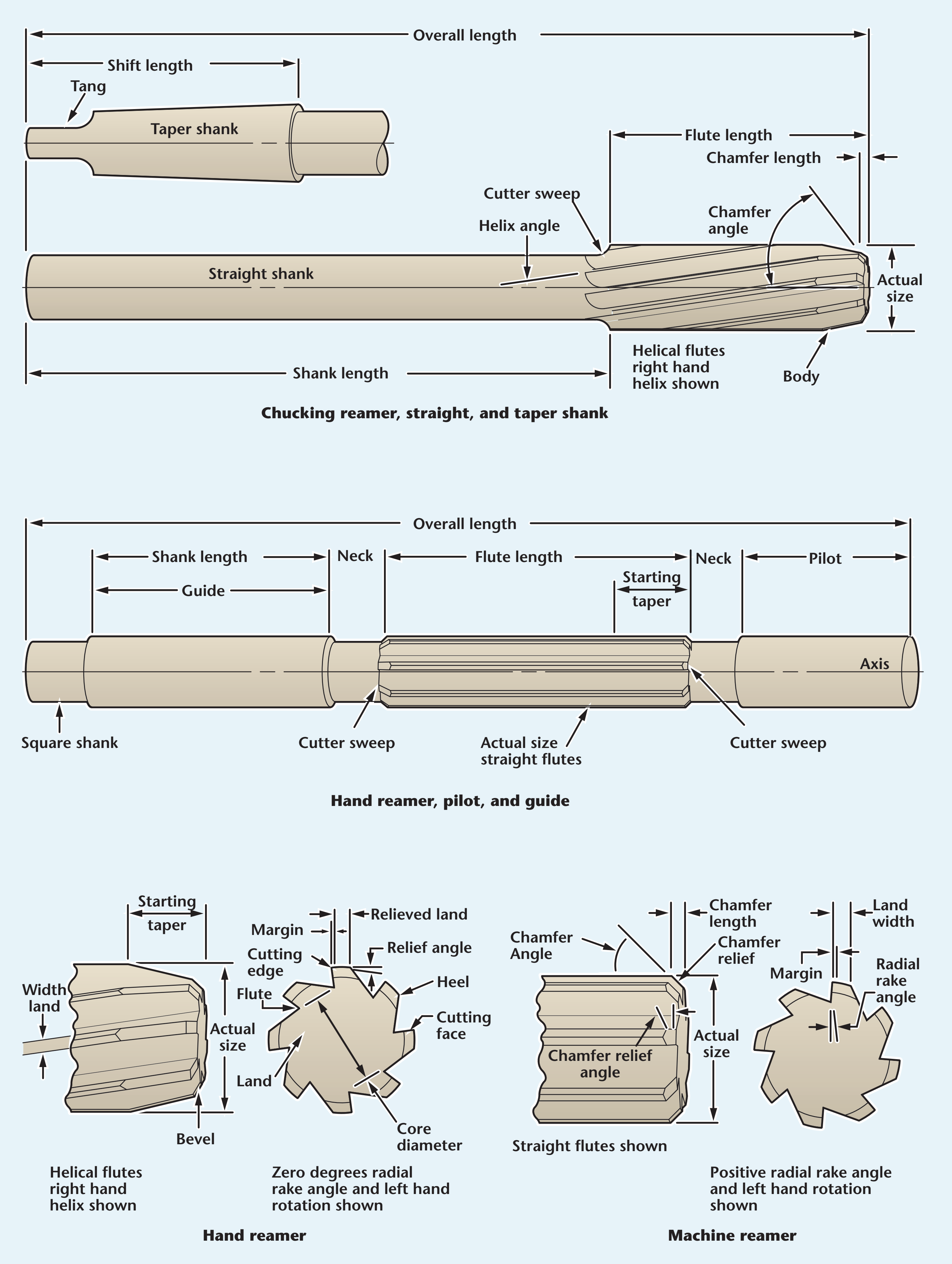


Figure 10-3-68. Identification of parts of reamers.

Figure 10-3-68 shows the parts of several types of reamers. The cutting face is the leading edge in the direction of rotation. Longitudinal channels (flutes) in the body of the reamer are used for the passage of lubricating fluid and chips.

Types of reamers. Reamers conform to types, classes, and styles as specified by industry standards. Reamers are classified according to construction and/or method of holding and driving.

Adjustable, inserted blade, straight fluted (hand). These reamers are fitted with removable cutting blades, which are adjustable for reaming holes of any size within the range for which the reamer was designed. These reamers have straight, round shanks with square ends, and they contain slots for holding the blades. The reamer assembly is capable of reaming round, straight, and smooth holes. This reamer is shown in Figure 10-3-69.

Jobber's (machine) reamer. These reamers are of grade-A, high-speed steel and have straight flutes and right-hand cut, as shown in Figure 10-3-70. The cutting section of these reamers is capable of cutting straight, round holes of specific diameters.

Brown and Sharpe taper socket (hand). These reamers have a fluted-type section and straight, round shank with squared ends. The cutting section of these reamers is tapered for reaming Brown and Sharpe (B&S) 1/2-inch-per-foot standard sockets. The B&S taper is used for tools with B&S taper shanks. It is also used for threaded taper pins. This type is shown in Figure 10-3-71.

Repairman's T-handle. These reamers have straight flutes and a solid handle. The cutting section tapers 1-1/4 inches per foot, as shown in Figure 10-3-72.

Selecting and Using Reamers

- The diameter of a reamer should be greater than the diameter of the hole to be reamed. All reamers, except for adjustable reamers, are marked with their nominal size.
- A reamer should enter a hole at right angles to the work surfaces to permit all teeth to simultaneously engage. On a curving surface, the rotating axis of the reamer is presumed to be at right angles to a plane tangent at the point of entrance.
- Where possible, provisions should be made for the reamer to pass through the workpiece. Line reaming is required for concentricity and alignment of holes.
- Work aids, which incorporate bushings to guide the reamers, are needed to produce holes that are in parallel alignment at exact distances from location points. For long holes, it is preferable to guide the reamers at both ends. Work aids are locally fabricated.
- Reamers are operated at slower speeds and higher feed rates than drills of the corresponding diameter. Reamer feed rates will depend upon the type of metal and the size or strength of the reamer.

Figure 10-3-69. Adjustable (hand) reamer.

Figure 10-3-70. Jobber's (machine) reamer.

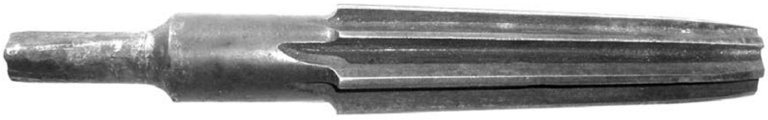


Figure 10-3-71. Brown and Sharpe tapered (hand) socket reamer.

Figure 10-3-72. Repairman's T-handle (hand) reamer.

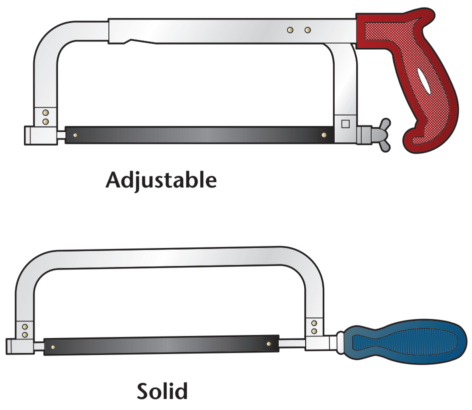


Figure 10-3-73. Hacksaws.

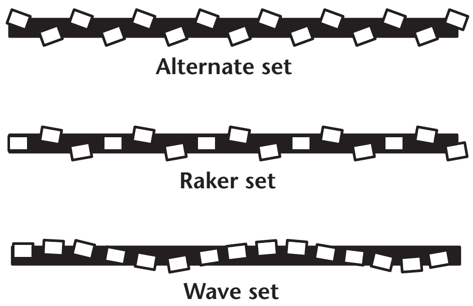


Figure 10-3-74. Hacksaw blade set.

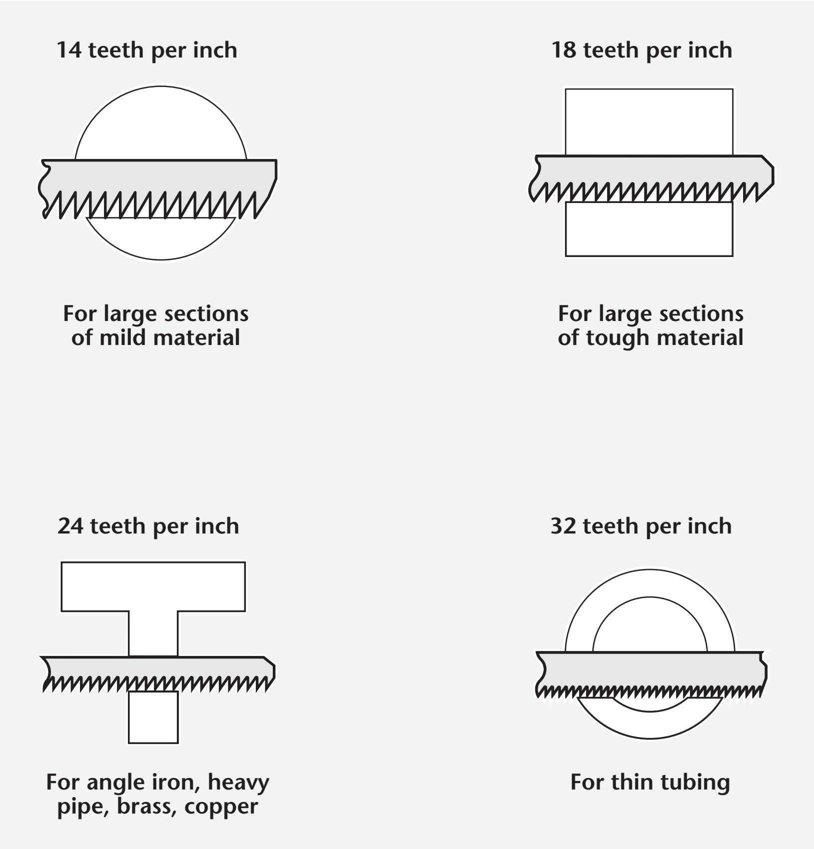


Figure 10-3-75. Application of blade pitch for certain materials.

- Install the reamer shank into a tap wrench and tighten the handle to clamp the reamer in place.
- Turn the reamer in the cutting direction (direction of the cutting edges) only. *Do not ever turn reamer backwards. To do so will result in rapid wear, chipping, and dulling of the cutting edges.*
- Turn the reamer very slowly in the cutting direction (clockwise) until the reamer is in the center of the hole.
- When reaming steel, use cutting oil or machine oil to lubricate the tool.
- Do not turn the reamer too quickly or too slowly because this will cause the reamer to chatter, producing an out-of-round hole.
- Turn the wrench in the cutting direction with steady, firm pressure until the reamer has been turned in the hole.
- Remove the reamer from the hole by continuing to turn the reamer in the cutting direction and raising the reamer at the same time.

Hacksaws

Hacksaws are used to cut metal that is too heavy for snips or bolt cutters. The two parts of the hacksaw are the frame and the blade.

Frame. The frame may be solid or adjustable, as shown in Figure 10-3-73. Adjustable frames can be made to hold blades from 8 to 16 inches long, while those with solid frames take only the length blade for which they are made. This length is the distance between the two pins that hold the blade in place. The blade is installed in the frame with the teeth pointing forward and is tightened by turning the handle or a wing nut.

Blades. Hacksaw blades are made of high-grade tool steel. They are about 1/2 inch wide, from 8 to 16 inches long, and have a pitch (number of teeth per inch) of 14, 18, 24, or 32.

Temper. Hacksaw blades come in two types: all-hard and flexible. The all-hard blades are hardened throughout, whereas only the teeth of the flexible blades are hardened.

Set. The set in a saw refers to how frequently the alternating teeth are set in opposite directions from the sides of the blade. The three different kinds of set are alternate set, raker set, and wave set, as shown in Figure 10-3-74.

Stock thickness. Heavy stock is usually cut with the all-hard blade because it has less tendency to wander. The flexible blade is less likely to break and is used for thin stock.

Figure 10-3-76. Proper way to hold a hacksaw.

Stock hardness. Generally speaking, the pitch of the blade depends on the hardness of the stock. Figure 10-3-75 shows the typical applications for the different saw blade pitches.

> **NOTE:** When cutting, there should always be at least two teeth working on the stock. Therefore, for thin-walled stock, a finer blade than is ordinarily used may be necessary.

Using a Hacksaw Correctly

Install the blade in the hacksaw frame with the teeth pointing away from the handle. Tighten the wing nut so that the blade is taut.

Place the stock to be cut in a vise. Maintain a minimum of overhang to reduce vibration, give a better cut and lengthen the life of the blade. Ensure that the layout line on the stock is outside of the vise jaw and visible during sawing.

Hold the hacksaw as shown in Figure 10-3-76.

When cutting, apply pressure on the forward stroke, which is the cutting stroke. Do not apply pressure on the return stroke. Use long, smooth strokes.

Taps and Dies

Taps and dies are made of hard, tempered steel and are used to cut threads in metal, fiber, or plastic. Four types of threads may be cut with standard taps and dies. These are *national coarse, national fine*, *national extra fine,* and *national pipe*.

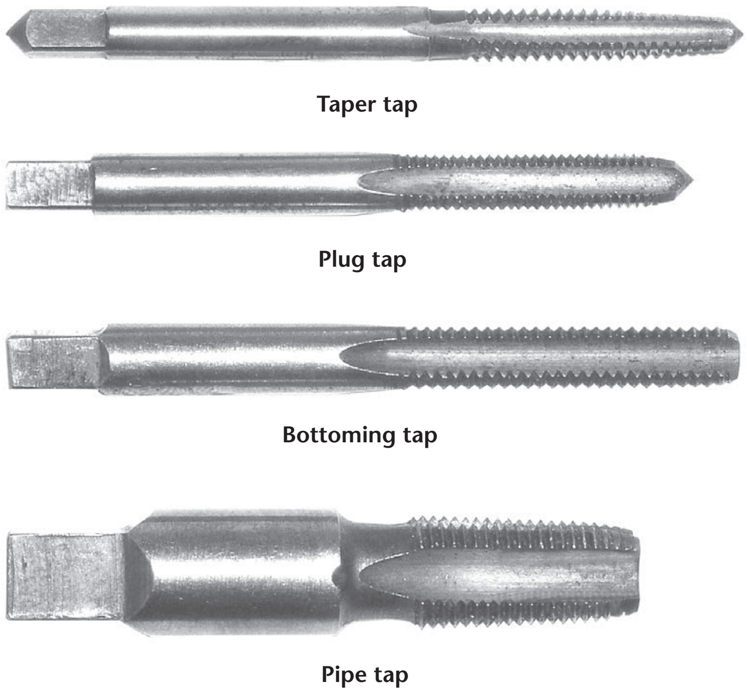


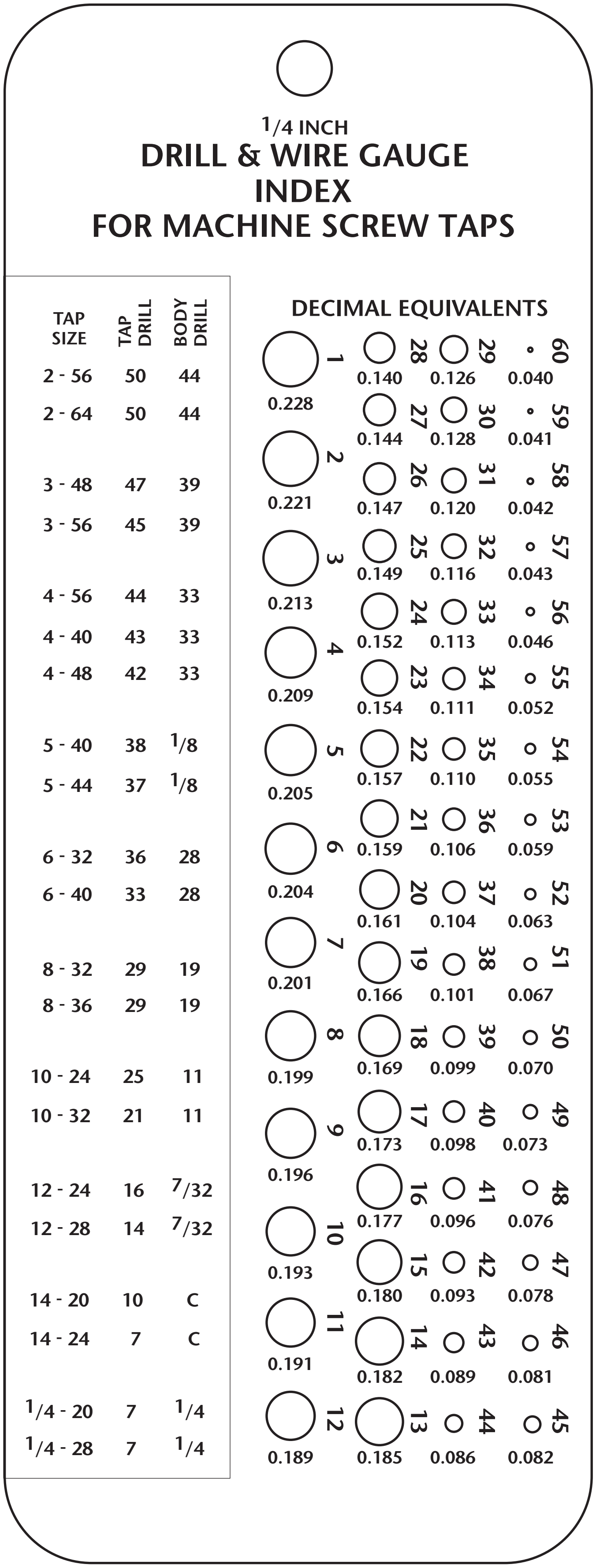
Figure 10-3-77. Taps.

Taps

Taps are used for cutting inside, or female, threads.

Types of taps. The four types of taps are the *taper*, *plug*, *bottoming*, and *pipe taps*, as shown in Figure 10-3-77.

Taper tap. The taper tap has a chamfer length of 8 to 10 threads. This tap is used to start all



TAP SIZE	TAP DRILL	BODY DRILL
2 - 56	50	44
2 - 64	50	44
3 - 48	47	39
3 - 56	45	39
4 - 56	44	33
4 - 40	43	33
4 - 48	42	33
5 - 40	38	1/8
5 - 44	37	1/8
6 - 32	36	28
6 - 40	33	28
8 - 32	29	19
8 - 36	29	19
10 - 24	25	11
10 - 32	21	11
12 - 24	16	7/32
12 - 28	14	7/32
14 - 20	10	C
14 - 24	7	C
1/4 - 20	7	1/4
1/4 - 28	7	1/4

Figure 10-3-78. Correct drill sizes for tapping.

threads and to tap through holes. Taper taps are used for all normal thread cutting.

Plug tap. Plug taps have a chamfer length of 3 to 5 threads. They are used when one end of the hole is closed but a full thread is not required all the way to the bottom of the hole.

Bottoming tap. The bottoming tap is used for cutting a full thread to the bottom of a closed hole.

Pipe tap. Tapered pipe threads are used for pipe fittings, grease fittings, and other places where an extremely tight fit is necessary. The tap diameter tapers at the rate of 3/4 inch per foot.

Tapping Internal Threads

A hole to be tapped must be of the correct size. Figure 10-3-78 shows a drill and wire gauge index, which gives the correct drill sizes for specific sizes and threads of taps.

> **NOTE:** Plug taps or bottoming taps should never be used to start a thread. First use a taper tap, then change to a plug or bottom tap to finish the hole.

The wrench should be held in the center when starting the tap, and light pressure should be applied for the first two or three turns.

Apply a cutting oil or lubricant corresponding to the type of metal being tapped (Table 10-3-2). Never use a sulphur-based cutting oil on aluminum, as the sulphur can be absorbed into the pores of the aluminum and cause corrosion.

Turn the tap backwards about 1/3 turn for every full revolution forward to break off the chip and make cutting easier. It also allows the chip to collect in the grooves of the tap.

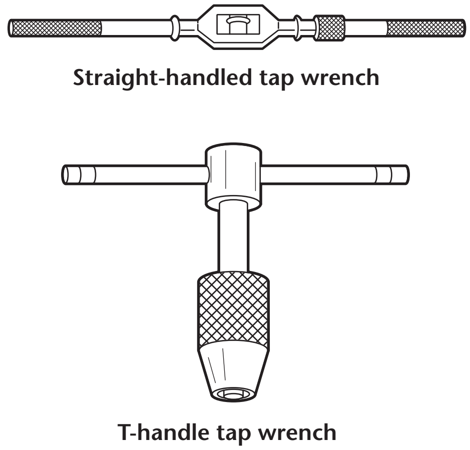


Figure 10-3-79. Tap wrenches.

Material	Tapping	Drilling	Reaming	Turning
Tool steel	Oil	Oil	Lard oil	Oil
Soft steel	Oil	Oil	Lard oil	Oil
Cast iron	Oil	Dry	Dry	Dry
Brass	Oil	Dry	Dry	Dry
Copper	Oil	Oil	Oil	Dry
Aluminum	Kerosene	Safety solvent	Kerosene	Soluble oil

Table 10-3-2. Lubricants for tapping and die-cutting threads.

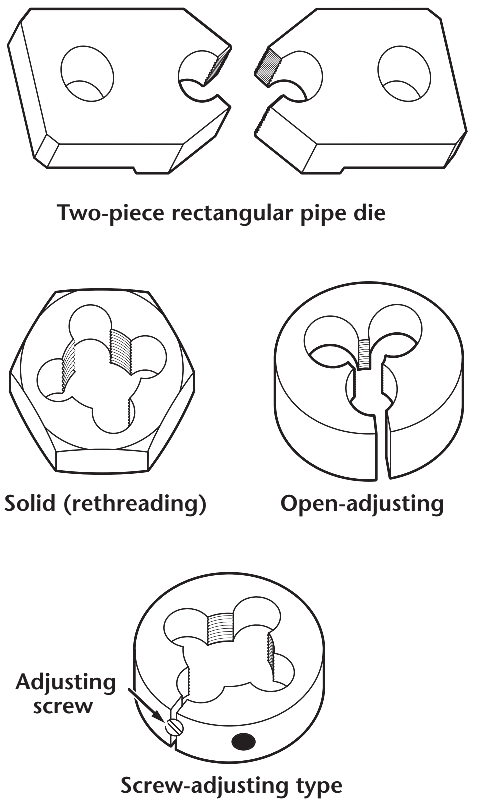


Figure 10-3-80. Dies.

After the tap is started, the threads will draw it into the work.

Removing broken tap. Even when used with care, taps will sometimes break. A broken tap may be removed with a pipe wrench when enough of the tap protrudes to allow a grip. When the broken tap does not protrude, it should be completely removed with a tap extractor.

Tap Wrenches

The two types of tap wrenches commonly used are the straight-handled and the T-handle tap wrench. These are shown in Figure 10-3-79.

Dies

Dies are used for cutting outside, or male, threads on a rod, bolt, or pipe.

Types of Dies

The three types of dies commonly used in aircraft maintenance are the *solid, adjustable-split,* and *pipe* dies, as shown in Figure 10-3-80.

Solid dies. Solid dies, also called *re-threading* dies, are used mainly for restoring damaged or rusty threads on screws or bolts. They are available in a variety of sizes for re-threading *American Standard Coarse* and *Fine threads.* These dies are usually hexagonal in shape and can be turned with a diestock, socket, box-end, open-end, or any other wrench that will fit.

Adjustable-split dies. Adjustable-split dies can be used in either diestocks or machine holders. These dies are either the *screw-adjusting* type or the *open-adjusting* type.

Screw-adjusting type. The adjustment in the screw-adjusting type of die is made by a fine-pitch screw, which forces the sides of the die apart or allows them to spring together. Adjustment is achieved by turning the adjusting screw clockwise to increase thread diameter, counterclockwise to decrease the thread diameter.

Open-adjusting type. The adjustment in the open-adjusting type is made by means of three screws in the diestock: one for expanding and two for compressing the die.

Pipe dies. Two-piece rectangular pipe dies are used to cut *American Standard Pipe threads.* They are held either in ordinary or ratchet diestocks. The jaws of these dies are adjusted by setscrews. An adjustable guide serves to keep the pipe in alignment with the dies.

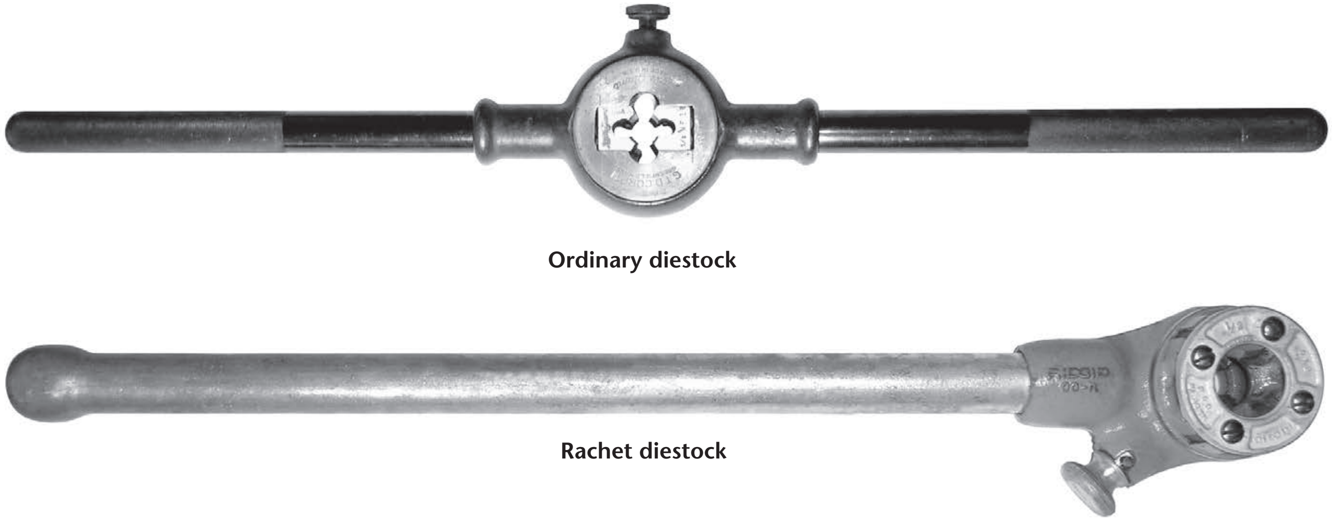


Figure 10-3-81. Diestocks.

Figure 10-3-82. Straight screw extractor.

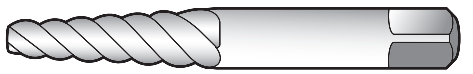


Figure 10-3-83. Spiral tapered extractor.

Figure 10-3-84. Tap extractor.

Cutting External Threads

Male threads are cut on a piece of stock by the following procedures:

1. Secure the work firmly in a vise.
2. Assemble the die to the diestock and tighten the setscrew.
3. Use an appropriate cutting oil (Table 10-3-2) for the type of metal being threaded.
4. Rotate the diestock slowly but firmly, until the die takes hold.
5. Turn the die backwards about 1/4 turn for every full turn forward in order to break off the chip and make cutting easier.
6. When the desired length of thread has been cut, slowly back the diestock off the threaded work.

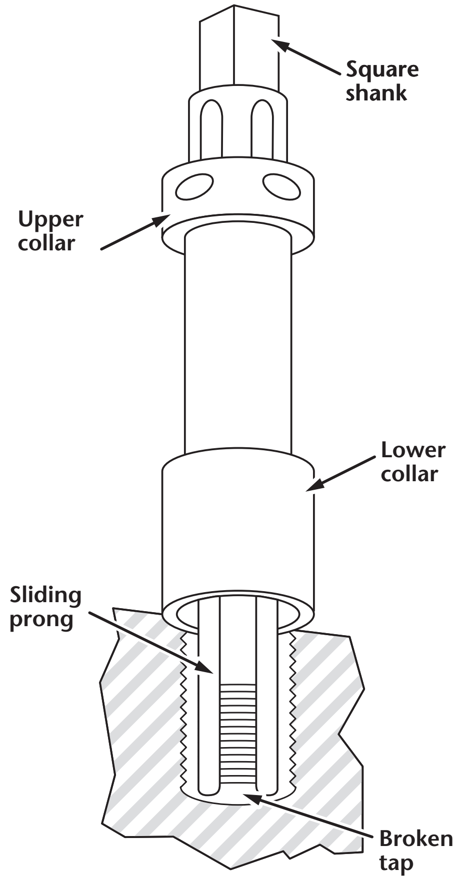


Figure 10-3-85. Using a tap extractor.

Diestocks for Pipe Threads

Figure 10-3-81 shows the ordinary and ratchet-type diestocks normally used with dies. The ratchet-type diestocks are usually used with rectangular pipe dies.

Screw and Tap Extractors

Screw and tap extractors are made of hardened steel and are used to remove broken screws and taps without damaging the surrounding metal or the threaded hole.

Screw extractors. Some screw extractors, as shown in Figure 10-3-82, are straight. They have flutes from end to end. These extractors are available in sizes to remove broken screws having 1/4-inch to 1/2-inch outside diameters. Spiral tapered extractors, shown in Figure 10-3-83, are sized to remove screws and bolts from 3/16-inch to 2-1/8-inch outside diameter.

Tap extractors. Tap extractors, shown in Figure 10-3-84, are sized to remove taps with an outside diameter of 3/16 to 2-1/8 inches.

Using a spiral extractor. To remove a broken screw or tap with a spiral extractor, proceed as follows:

- Center punch and drill a hole of the proper size in the screw or tap. Use a drill size guide, if available. If one is not available, drill the hole slightly smaller than the diameter of the extractor.
- Insert the extractor into the drilled hole. Place a tap wrench or an open-end wrench on the extractor.
- Remove the broken screw by turning the extractor counterclockwise.

Using a tap extractor. If a tap has broken off at or slightly below the surface of the work, proceed as follows:

- Apply a liberal amount of penetrating oil to the broken tap.
- Place the tap extractor over the broken tap and lower the upper collar to insert the four sliding prongs down into the four flutes of the tap, as shown in Figure 10-3-85.
- Slide the bottom collar down to the surface of the work so that it will hold the prongs tightly against the body of the extractor.
- Apply a tap wrench to the square shank and tighten.
- Loosen the tap by carefully working the extractor back and forth.

NOTE: It may be necessary to remove the extractor and strike a few sharp blows with a small hammer and a pin punch to jar the tap loose. Then reinsert the extractor and carefully try to back the tap out of the hole.

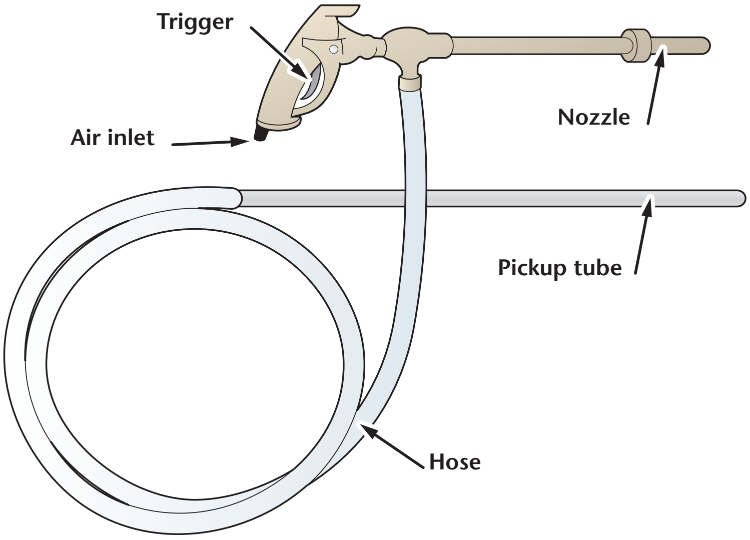


Figure 10-4-1. Cleaning solvent gun.

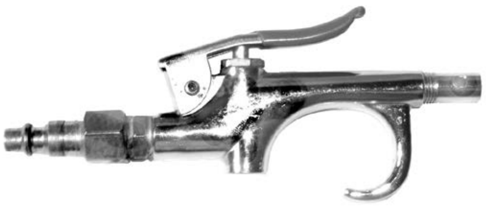


Figure 10-4-2. Most blow guns have nozzles that limit discharge pressure to 30 p.s.i.

Section 4

Pneumatic Tools

Pneumatic tools look much the same as electric tools, but they are driven by compressed air. These tools can be used for a vast variety of jobs that otherwise would be impossible to do.

Safety precautions. Air-driven tools do require additional safety precautions to prevent injury.

- Inspect the air hose for cracks or other defects.
- Before connecting an air hose to an air outlet, open the shutoff valve momentarily to expel any condensation.
- Stop the flow of air to a pneumatic tool by closing the shutoff valve before connecting, disconnecting, adjusting, or repairing the tool.
- Always wear eye protection when using pneumatic tools.
- Always drain condensate drains daily. More often if the system is heavily used.

Figure 10-4-3. Pneumatic drills operate at higher r.p.m. than most electric models. *Photo courtesy of Snap-on Tools*

Cleaning Guns

Cleaning guns are used for applying air, a mixture of air and cleaning solution, or solvent spray under pressure to parts which must be cleaned. There are two main types of cleaning guns: the *solvent cleaning gun* and the *air blow gun*.

Solvent cleaning gun. A solvent cleaning gun, shown in Figure 10-4-1, is used for applying a spray of solvent to engines and other structures that are cleaned with solvent. Before using any chemical in a solvent gun, make sure it is approved for the project.

Air blow cleaning gun. The air blow cleaning gun, shown in Figure 10-4-2, is used for applying a direct blast of air to clear away dirt, dust, and metal shavings, or to air dry parts cleaned with solvent. All blow guns should be of the pressure limiting OSHA-approved type.

Figure 10-4-4. Pneumatic die grinders are lightweight and powerful. *Photo courtesy of Snap-on Tools*

Blow gun safety. Remember to never aim a blow gun at anyone. Debris flying from the hose could cause serious injury. Never horseplay with a blow gun. Air pressure can pierce the skin and inject air into a person's body, causing death or serious injury.

Vacuum Cleaner

The shop vacuum cleaner is used to clean up metal shavings which result from drilling and filing jobs on aircraft and in shops. The attachments give the vacuum cleaner versatility. These attachments include a round brush, a crevice tool, a fan-shaped end, and tube extensions of varying lengths, which allow use in restricted areas. Smaller hoses can be attached to reducer fittings and threaded into very tight spaces. These attachments are available from hardware stores or home centers and come blister-packed.

Pneumatic Drill Motors

Pneumatic drill motors are used where sparks from an electric drill might pose a fire hazard. They also are somewhat more lightweight than electric drill motors. When working with aluminum, air drill motors tend to run at higher speeds (r.p.m.) closer to the desired speed and feed rates of the material.

Types. Pneumatic drills that are available are straight or set at 90°, like the drill shown in Figure 10-4-3. These different types allow a part to be drilled in just about any location.

Using Air Drill Motors

- Do not apply further pressure with pliers or wrenches after the chuck is hand-tightened with the chuck key.
- Always remove the key immediately after it is used. Otherwise, the key will fly loose when the drill motor is started and may cause serious injury to personnel.
- A drill bit that wobbles or is slightly bent should not be used because it will cause enlarged holes.
- Test the drill bit for trueness and vibration by running the drill freely.
- Wear eye protection when drilling. Failure to comply may result in serious injury to personnel.
- Always hold the drill at right angles to the work regardless of the position or curvatures. Tilting the drill at any time may cause elongation of the hole.

Pneumatic Grinders

A typical pneumatic grinder is shown in Figure 10-4-4. The grinders are rated by no-load speeds, which typically result in terms of light-, medium-, and heavy-duty loads being used to describe the grinder. The grinding stones come in numerous shapes and give versatility to the grinder.

When changing stones, always make sure the replacement stone is of the correct rated speed. If the speed is too low for the machine, it will disintegrate, causing possible injury.

- A grinding stone that wobbles or has a bent shaft should not he used.
- Test the grinding stone for trueness and vibration by running the grinder freely. Grinding stones that are glazed, out-of-true, or out-of-round may be reshaped with a dressing stick.
- Wear eye protection when grinding. Failure to comply may result in serious injury to personnel.
- Perform grinding operations by holding the grinder so that the proper edge of the grinding stone is against the work.
- Always protect surrounding parts and assemblies from grinding dust. Clean the area when completed.

Many additional air-powered tools are used in aircraft work, particularly in sheet metal and structural repair. They are discussed in the appropriate sections.

Air Ratchets & Impact Drivers

Normally, air-powered wrenches of any kind are not used in aircraft maintenance. The part of the impact wrench that actually does the impacting (hammering) on the drive square causes torque to spike with each hammer hit. The design makes it virtually impossible to control torque within the design limits specified by the manufacturer. Because of this difficulty in controlling the application of torque, they do not work well in a maintenance function.

Saws

Panel saws. The Keets saw panel saw (Figure 10-4-5) is an air-powered tool that has been a standard aircraft tool for many years. In essence, it is a drill-type air motor with a right-angle drive. On the shaft extension, there is a tool steel saw blade mounted with an appropriate guard. The blade is depth-adjustable and is used for cutting sheet metal either in place or before fabrication. It works well for material that would be difficult to cut with snips or a saber saw.

Figure 10-4-5. A Ketts panel saw.

Figure 10-4-6. Air-powered sabre saws are lightweight and reduce the fire/explosion hazard. *Photo courtesy of Snap-on Tools*

Sabre saw. An air-powered reciprocating sabre saw, Figure 10-4-6, is excellent for cutting heavier aluminum sheet or plate. They are lightweight, powerful, and can cut curves easily. By drilling holes in each corner and then cutting to the holes, any opening can be sawed quickly. Because of marks left by the saw teeth, any sawn edges must be filed smooth. They need to be supported during filing so the sheet will not bend.

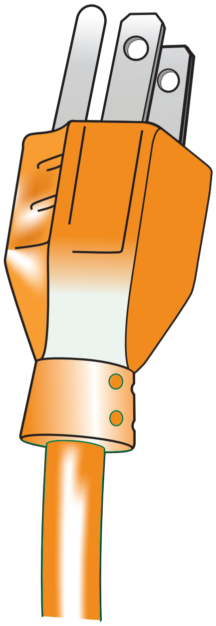


Figure 10-5-1. Three-prong grounded plugs are used on most commercial electrical tools.

Section 5

Electrical Power Tools

The power tools described within this section are some of the more common types used. These tools are usually used in a shop environment, although they can be used in the field with an adequate power supply.

Safety

The following safety precautions should always be followed when operating electric power tools:

- Never operate power tools unless they are completely understood. If in doubt, consult the operator's manual.
- Inspect all power tools before use to ensure their serviceable condition.
- Prior to connecting the tool to its power source, ensure that the power switch is in the OFF position.
- Keep all safety guards in position, and wear safety shields or goggles when necessary.
- Fasten all loose clothing and aprons. Watch out for neckties, chains, scarves, or any other item that might be loose.
- Never try to clear jammed machinery before disconnecting the tool from its power source.
- Before plugging a tool into a power source, ensure that the power source provides the correct voltage required by the tool.
- If the power cord has a ground pin, as shown in Figure 10-5-1, do not attempt to use it with an adapter. The ground pin decreases the possibility of electric shock.
- Do not use sparking electric tools in places where flammable gases or liquids are present. Use pneumatic tools in these areas.
- Replace cords when they are damaged.
- Ensure that the power cord is of sufficient length so that it will not be pulled taut to reach the work location.
- Position power cords so that they will not be tripping hazards.

Figure 10-5-2. Electric drills.

Electric Drill Motors

The electric drill motor is a hand tool driven by a small, high-speed electric motor. The motor is geared to the chuck through reduction gears. The components of the drill are enclosed in a metal or plastic pistol grip case to permit ease of handling. Although it is specially designed for drilling holes, it can be adapted for different jobs by the addition of various accessories. It can be used for sanding, buffing, polishing, wire brushing, and paint mixing. Typical electric drills are shown in Figure 10-5-2.

Sizes. The sizes of electric drills are classified by the largest straight shank drills that they will hold. Therefore, a 1/4-inch drill will hold straight-shank drills up to and including 1/4 inch, and a 3/8-inch drill will hold bits up to and including 3/8 inch.

Speed. The drill is made to run at speeds which will prevent the motor from burning out. For this reason, large drills run at slower speeds than smaller drills. This is because larger drills are designed to turn larger cutting tools or to drill heavy stock, both of which require a slower speed. Therefore, to drill in a metal such as steel, a 3/8-inch or 1/2-inch drill should be used; whereas for drilling holes in wood or sheet metal, a 1/4-inch drill will be sufficient.

Using an electric drill. The operation of an electric drill motor involves simply installing the drill bit, plugging in the cord, and operating the drill.

Installing the drill bit. The drill bit is installed in the chuck on the drill. Nearly all electric drills are equipped with a three-jaw chuck, which is tightened and loosened by means of a chuck key, as shown in Figure 10-5-3.

Do not apply further pressure with pliers or wrenches after the chuck is hand tightened with the chuck key. Always remove the key immediately after it is used, or the key could fly loose when the drill motor is started and cause serious injury to personnel.

Electric Grinders

To keep hand tools in the best condition, cutting edges must be sharpened frequently, and certain other tools must be trued or shaped for special purposes. Chisels, punches, drills, snips, screwdrivers, and other hand tools are shaped or sharpened on a grinder. There are two basic types of grinders: a *bench-type* grinder and a *pedestal-type* grinder. These grinders, shown in Figure 10-5-4, consist of an electric motor with a grinding wheel attached to each end of the motor shaft. One wheel is *coarse*, for rough work, while the other is *fine* and is used for sharpening purposes.

Grinding safety. The grinding wheel is a fragile cutting tool which operates at high speeds. Great emphasis must be given, therefore, to the safe operation of bench and pedestal grinders. The following procedures are mandatory safety precautions for the safety of the operator and of personnel in the vicinity:

- Secure all loose clothing, and remove rings and other jewelry.
- Inspect the grinding wheel, wheel guards, tool rest, and other safety devices to ensure that they are properly installed and in serviceable condition.

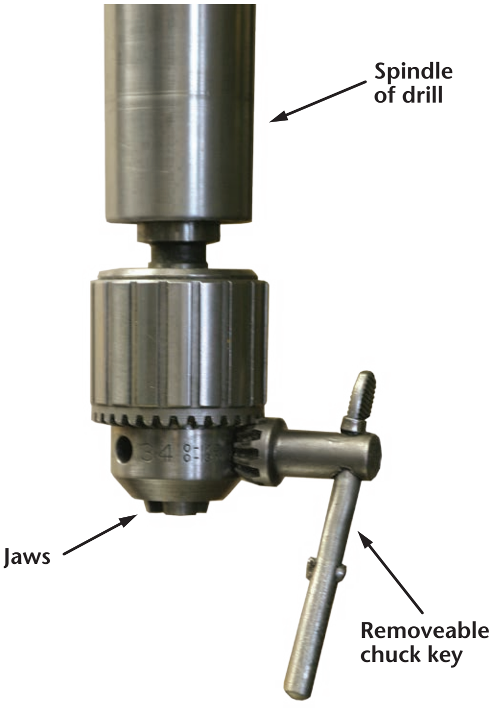


Figure 10-5-3. Three-jaw chuck and chuck key. Never leave the key in the chuck.

- Always wear eye protection when using a grinder.
- Stand aside when starting the grinder motor until operating speed is reached. This prevents injury if the wheel explodes from a defect that has not been noticed.

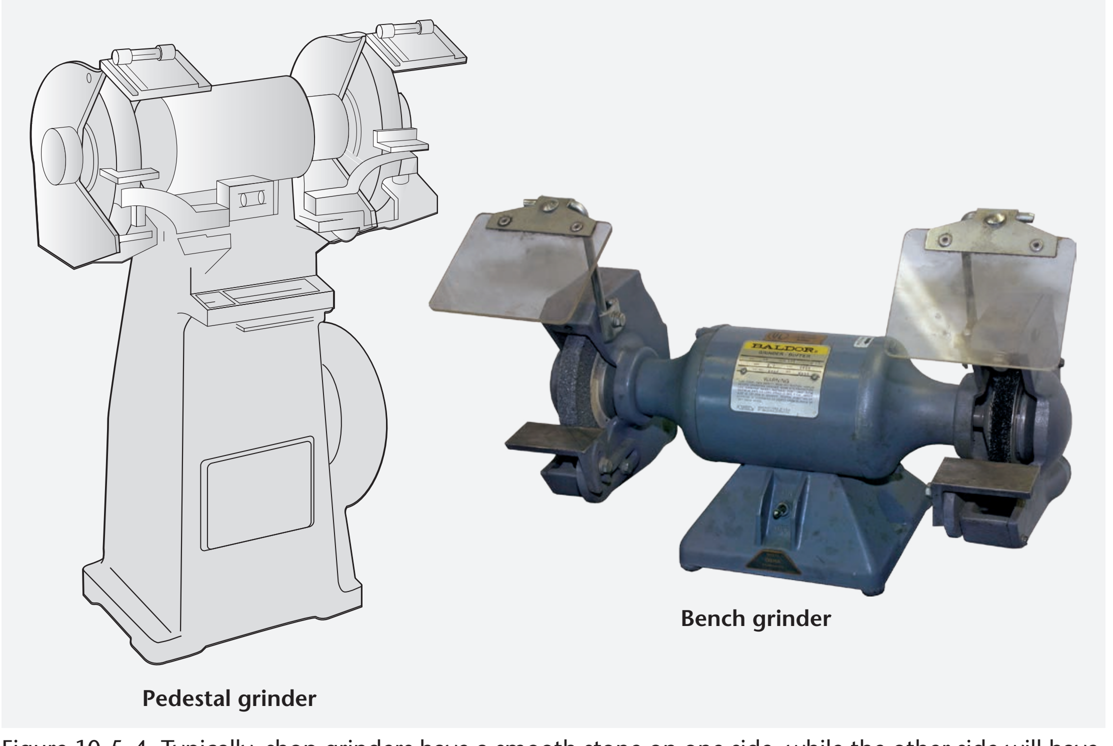


Figure 10-5-4. Typically, shop grinders have a smooth stone on one side, while the other side will have a coarse stone.

- Use light pressure when starting a grind; too much pressure on a cold wheel may cause failure.
- Grind only on the face or outer circumference of a grinding wheel unless the wheel is specifically designed for side grinding.
- Use a coolant (typically water) to prevent overheating the work.
- Hold the work so that fingers or knuckles will not inadvertently come into contact with the grinding wheel.

Description of Grinding Wheels

A grinding wheel is composed of abrasive grains and a bonding agent and is graded for coarseness and hardness.

Abrasives

The two types of abrasives are natural and manufactured abrasives.

Natural abrasives. Natural abrasives, such as emery, corundum (natural aluminum oxide), and diamond, are used only in honing stones and in special types of grinding wheels.

Manufactured abrasives. The common manufactured abrasives are aluminum oxide and silicon carbide. They have superior qualities and are more economical than natural abrasives.

Coarseness. Generally speaking, fine-grain wheels are preferred for grinding hard metals, as they have more cutting edges and will cut faster than coarse-grain wheels. Coarse-grain wheels are generally preferred for rapid metal removal on softer metals, though coarse-grain stones wear faster.

Hardness. Hardness of a grinding wheel is a measurement of the ability of the bond to retain the abrasive grains in the wheel. Grinding wheels are said to have a soft-to-hard grade, which indicates whether the wheel has a large amount of bond (hard) or a small amount of bond (soft).

Types of Grinding Wheels

The selection of grinding wheels for precision grinding can be discussed generally in terms of such factors as the physical properties of the stock to be ground, the amount of stock to be removed (depth of cut), the wheel speed and work speed, and the finish required. Selection of a grinding wheel is determined by considering one or more of these factors. The following paragraphs describe the types of wheels which can be used to grind metals with certain general qualities.

Wheel abrasive type. An aluminum oxide abrasive is most suitable for grinding carbon and alloy steel, high-speed steel, cast alloys, and malleable iron. A silicon carbide abrasive is most suitable for grinding nonferrous metals, nonmetallic substances, and cemented carbides.

Wheel coarseness. Generally, the softer and more ductile the substance being ground, the coarser the wheel grain selected should be. Also, if a large amount is to be removed, a coarse grain wheel is recommended (except on very hard objects). If a good finish is required, a fine grain wheel should be used.

Wheel hardness. For soft metals, small depth of cut, or high work speed, use a soft-grade wheel. If the machine you are using is worn, a harder grade may be necessary to help offset the effects of wear on the machine. Using a coolant also permits the use of a harder grade of wheel.

Wheel installation. The wheel of a grinder must be properly installed. If it is not, the wheel may operate improperly, and an accident may occur. Install a grinder wheel as follows (Figure 10-5-5).

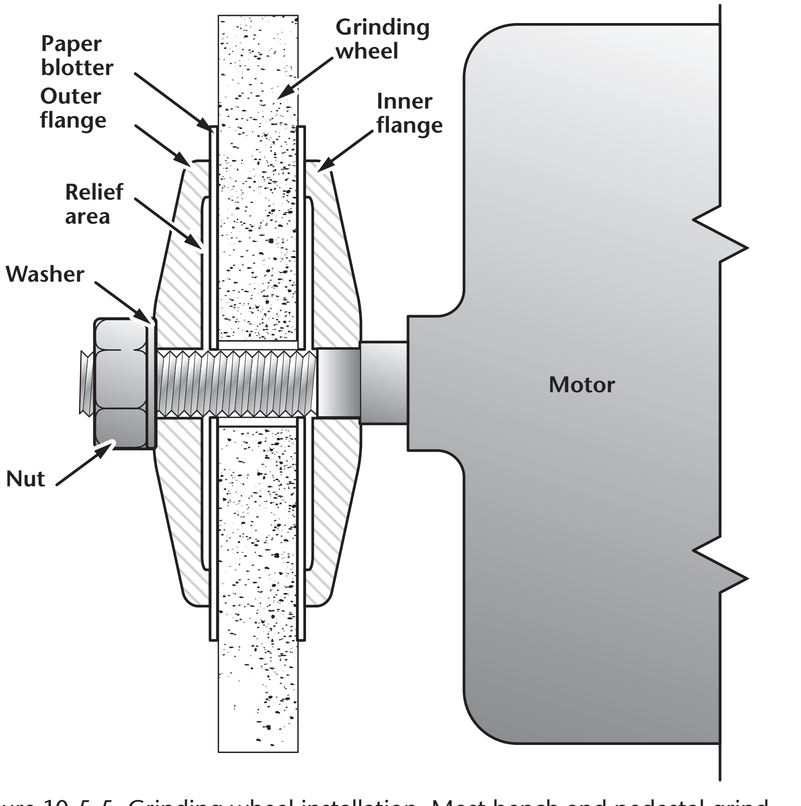


Figure 10-5-5. Grinding wheel installation. Most bench and pedestal grinders have both right- and left-hand threads on the spindle.

- Test the wheel for soundness by tapping it lightly with a piece of hard wood. (Do not tap with a piece of metal.) A good wheel gives out a clear, ringing sound when tapped. If the wheel is cracked, a dull thud will be heard.
- Ensure that the shaft and flanges are clean and free of grit and old blotter. Install the inner flange on the shaft. The blotter thickness for paper must be no thicker than 0.025 inch. A leather or rubber blotter must be no thicker than 0.125 inch.
- Place a blotter on the shaft and up against the flange to ensure even pressure on the wheel and to dampen the vibration between the wheel and the shaft.
- Never force the wheel on the shaft. This may cause the wheel to crack or go out of alignment.
- A 0.002- to 0.005-inch clearance should be provided.
- Mount the wheel on the shaft, and ensure that it fits without play.
- Install another blotter and then the outer flange.
- Install the washer and the nut. Do not overtighten the spindle nut; you may crack the grinding wheel.
- Operate the grinder for a minute or two in order to test for breakage.

WARNING: Always wear safety goggles when using a grinder. Failure to comply may result in serious bodily injury.

Tool Rests

Ensure that tool rests are firmly in place. A loose tool rest could cause the tool or piece of work to be grabbed by the wheel, and the operator's hand could accidentally contact the wheel. Serious bodily injury *will* result.

Operation of Electric Grinders

The grinder can be used to dress points on chisels, screwdrivers, and drills. It can be used for removing excess metal from work and smoothing metal surfaces.

Use of other types of wheels. The grinding wheels are removable. The grinders are usually designed so that wire brushes, polishing wheels, or buffing wheels can be substituted for the abrasive wheels.

Dressing. Grinding wheels, like other cutting tools, require frequent reconditioning to perform efficiently. *Dressing* is the term used to describe the process of cleaning the periphery of grinding wheels. This cleaning breaks away dull abrasive grains and smooths the surface so that there are no grooves.

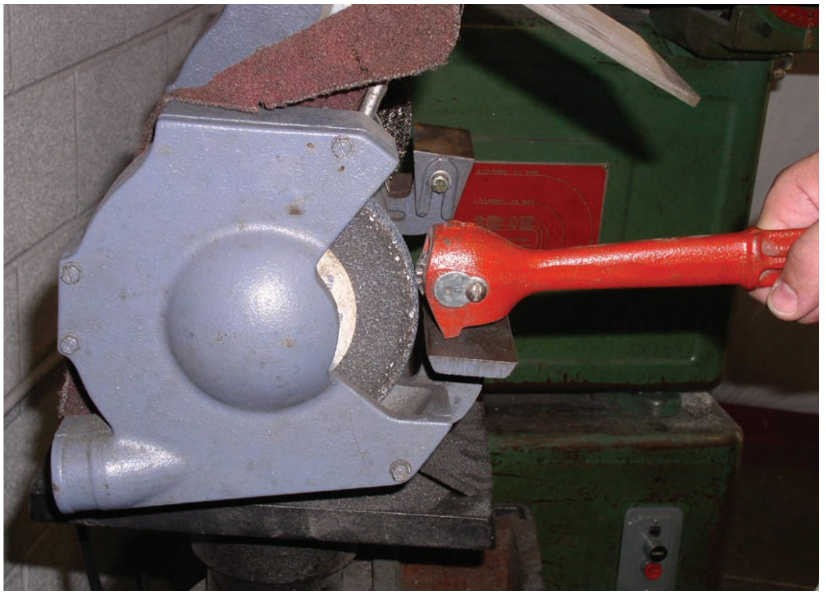


Figure 10-5-6. Dressing a grinding wheel using a wheel type dressing tool.

To dress a wheel, set the wheel dresser on the tool rest, as shown in Figure 10-5-6, and bring it into firm contact with the wheel.

Trueing. *Trueing* is the term used to describe the removal of abrasive from the cutting face of the wheel so that the resultant surface runs absolutely true to some other surface, such as the grinding wheel shaft.

Move the wheel dresser back and forth across the face of the wheel until the surface is clean and approximately square with the sides of the wheel.

Wheel rebalancing. If a grinding wheel gets out of balance because of out-of-roundness, dressing the wheel will usually remedy the condition. A grinding wheel can get out of balance by being left sitting with part of the wheel immersed in the coolant. If this happens, the wheel should be removed and dried out by baking. If a wheel gets out of balance axially, it probably will not affect its efficiency. This unbalance may be remedied simply by removing the wheel and cleaning the shaft spindle and spindle hole in the wheel and the flanges.

Safety Precautions

Do not attempt to make any adjustment to the tool rest until the grinder is shut down and the power disconnected. Failure to comply *will* result in serious injury to the operator.

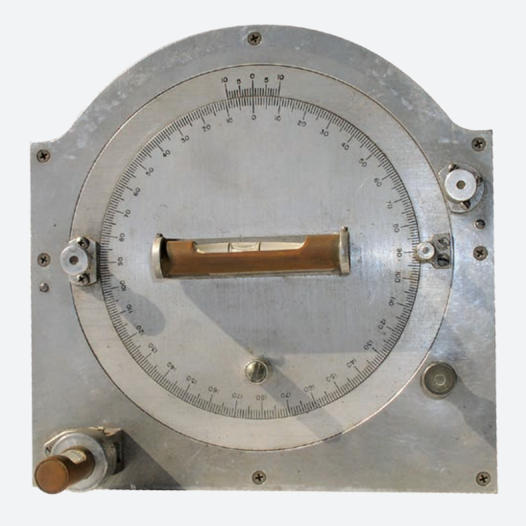


Figure 10-6-1. The standard propeller protractor has been in use for many years.

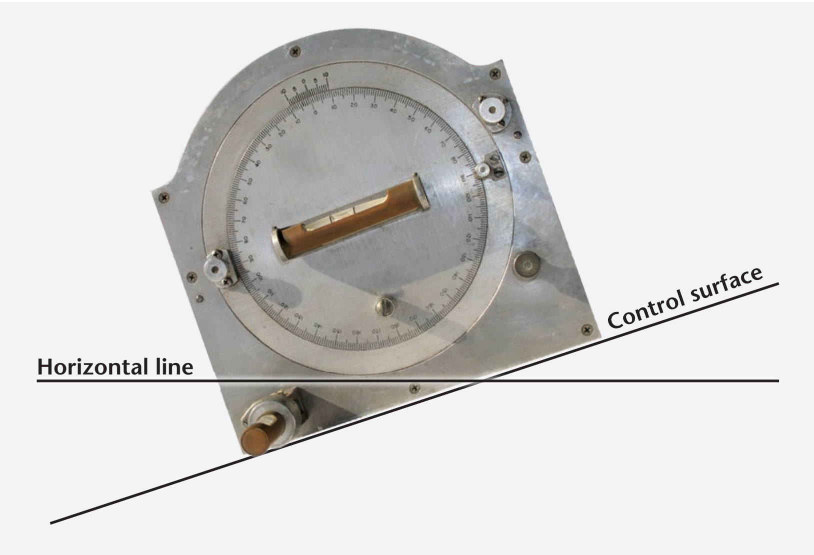


Figure 10-6-2. Protractor with flight control surface in neutral position.

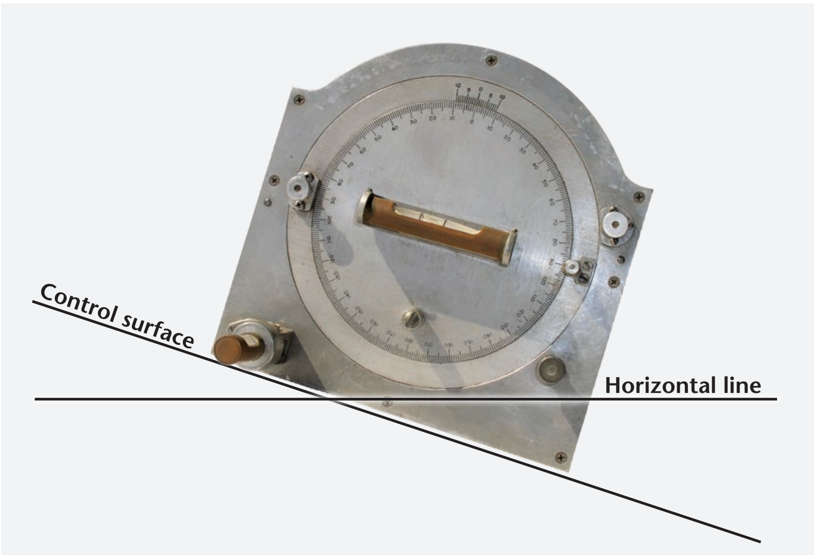


Figure 10-6-3. Measuring the control surface angle at full throw.

Resetting the tool rest. Each time that a wheel is dressed, check the clearance between the tool rest and the wheel. Reestablish the clearance at 1/16 inch, as required.

Use of side of wheel. As a rule, it is not good practice to grind work on the side of an abrasive wheel. When an abrasive wheel becomes worn, its cutting efficiency is reduced because of a decrease in surface speed. When a wheel becomes worn on the side, it loses strength and should be discarded and a new one should be installed.

Grinding soft materials. Do not grind soft substances such as aluminum or brass, as these materials will clog the pores of the grinding wheel and stop its cutting action. A clogged wheel will have a tendency to grab the work and try to pull it into the guard. A clogged or glazed wheel should be dressed to obtain proper cutting action.

Section 6

Special Aircraft Tools

Some tools are used in specific applications. Some of these tools, such as inspection mirrors, make basic tasks simpler. Some, like the propeller protractor, make inspection simpler, while others, like the cable tensiometer, are used for critical maintenance tasks.

Propeller Protractor

The protractor (actually *propeller protractor*) assembly may be used to measure propeller-blade angle, control-surface movement, or any other angle.

The protractor, shown in Figure 10-6-1, consists of an aluminum frame in which a steel ring and a disk are mounted. Spirit levels are mounted on both the frame and disk. Locks are provided for locking the ring to the frame or the disk. Scales are marked on the disk and the ring. Zeros on the scales provide reference marks between which the angle may be read. Hand-adjusting screws are provided so that the ring and the disk may be rotated in relation to the housing and to each other. Functioning parts of the protractor are described in the following paragraphs.

Indicating surface. The indicating surface of the protractor is the bottom edge opposite the upper curved edge.

Primary level. The level at the lower left corner of the protractor is the primary level and is parallel with the indicating surface. This level

Figure 10-6-4. This type of aircraft cable tensiometer works for most general aircraft control systems.

has two positions: against the face and at a right angle to the face.

Secondary level. The level at the center of the protractor is a secondary level functioning with the inner and vernier dials.

Lock assembly. The lock assembly releases and engages the inner protractor dial with the vernier scale at zero alignment only.

Ring-to-frame lock. The knob locks, by tension, the other vernier scale at any rotary position in relation to the indicating surface of the protractor.

Ring adjuster. The knob at the upper right side is used for fine rotation adjustment of the vernier scale.

Disk adjuster. The knob at 90° left of the zero on the vernier dial is used for fine rotation of the inner protractor dial.

Measuring Control Surface Travel

The following steps outline the procedures for measuring the angle of a control surface in an extreme position:

1. Align the control surface in the neutral position.
2. Lock the ring to the disk at zero by dropping the lockpin in the deepest slot.
3. Place the protractor in the approximate middle of the control surface next to a rib.
4. Using the ring adjusting screw, turn the ring to center the bubble in the level.
5. Lock the ring to the frame with the ring-to-frame lock.
6. Move the control surface to an extreme limit of movement, as shown in Figure 10-6-2.
7. Unlock the disk from the ring.
8. Turn the disk adjusting screw until the bubble is centered in the level and read the degrees of travel in that direction.
9. Repeat the process with the control surface moved in the opposite direction. Center the bubble and read the control surface throw in degrees, as shown in Figure 10-6-3.

The angle is read by reading the degrees on the inner dial that correspond to the zero on the vernier scale. The vernier scale indicates tenths of a degree.

Cable Tensiometer

Control surface movements must be synchronized with the movements of the cockpit controls. To accomplish this, the flight controls must be rigged. To properly rig control surfaces, a protractor must be used to check the throw of the surfaces, and a cable tensiometer is used to check the tension of the flight control cables.

Several manufacturers make a variety of tensiometer. Each type is designed for different kinds of cable, cable sizes, and cable tensions. A typical tensiometer is shown in Figure 10-6-4. Cable tension is determined by measuring the amount of force needed to make an offset in the cable between two hardened steel blocks, called anvils. A riser or plunger is pressed against the cable to form the offset.

Measuring cable tension with a tensiometer (Figure 10-6-5) is a fairly simple process:

- With the trigger lowered, place the cable to be tested under the two anvils.

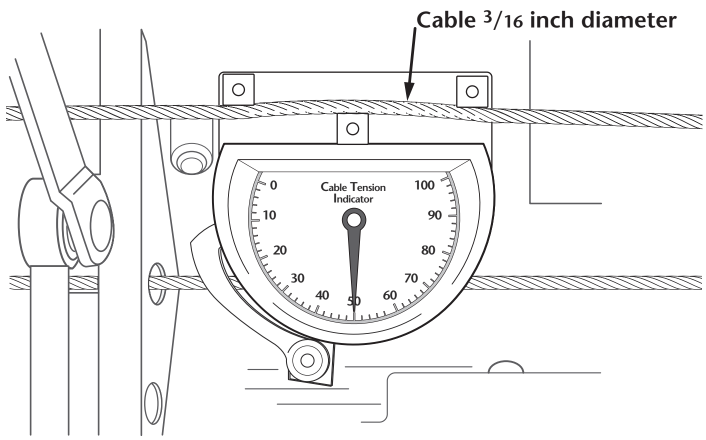


Figure 10-6-5. A cable tensiometer can be used on installed control systems to check cable tension.

Tension	Riser no. 1			Riser no. 2		Riser no. 3	
Tension (pounds)	Diameter			Diameter		Diameter	
	1/16	3/32	1/8	5/32	3/16	7/32	1/4
30	14	17	21	18	26		
40	20	24	28	24	32		
50	25	30	35	29	38		
60	30	35	42	34	43		
70	35	40	48	39	48		
80	39	45	54	43	53		
90	44	50	60	47	58		
100	48	55	65	51	62		

Table 10-6-1. Conversion of tensiometer reading in pounds.

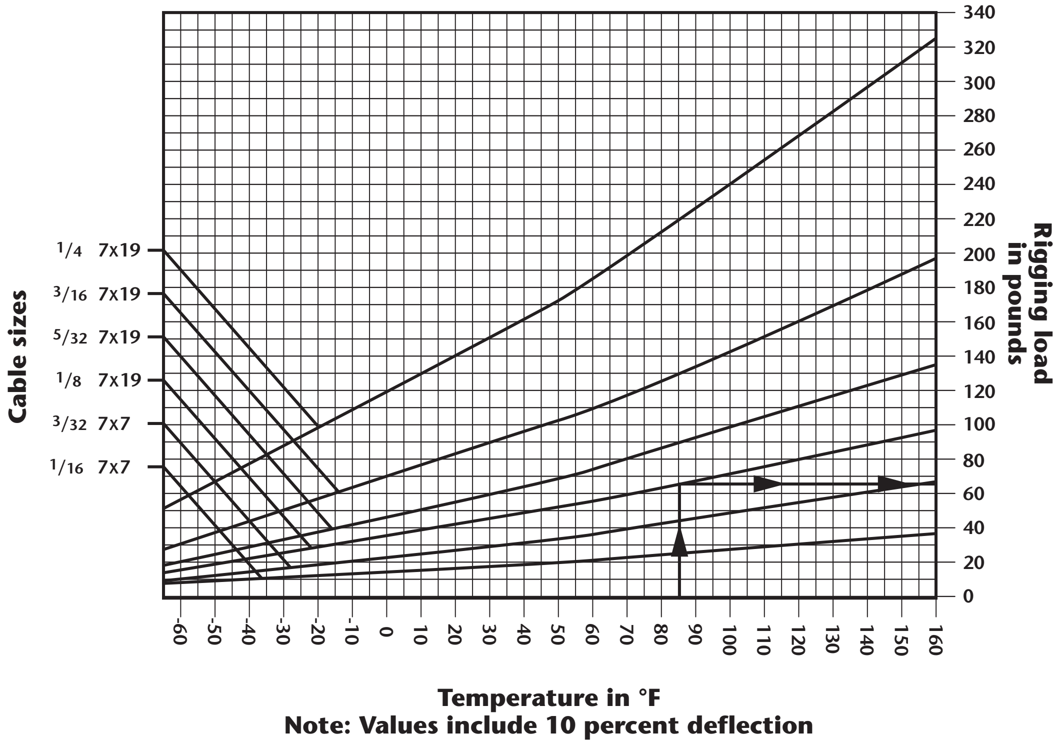


Table 10-6-2. Typical cable rigging tension chart.

- Close the trigger. Movement of the trigger pushes up the riser, which pushes the cable at right angles to the clamping points under the anvils.
- Note the scale reading on the face of the dial.

When taking a reading, it may be difficult to see the dial. The tensiometer has a *pointer lock* to make the job easier. Push it in to lock the pointer. Then remove the tensiometer from the cable and observe the reading. After observing the reading, pull the lock out and the pointer will return to zero.

Different risers are used with different sizes of cable. Each riser has an identifying number and is identified in the tensiometer kit. Risers are easily inserted into the tensiometer.

Conversion of tensiometer reading to pounds. Each tensiometer comes with a conversion table which is used to convert the dial reading to pounds. The conversion table is very similar to that shown in Table 10-6-1.

> **NOTE:** The conversion table in Table 10-6-1 is only an example to illustrate the process of conversion. Consult the table included with the tensiometer in use for the correct tension values. Note that the risers are specified for use with specific cable diameters.

Since this particular tensiometer is not designed for use in measuring 7/32- or 1/4-inch cable, no

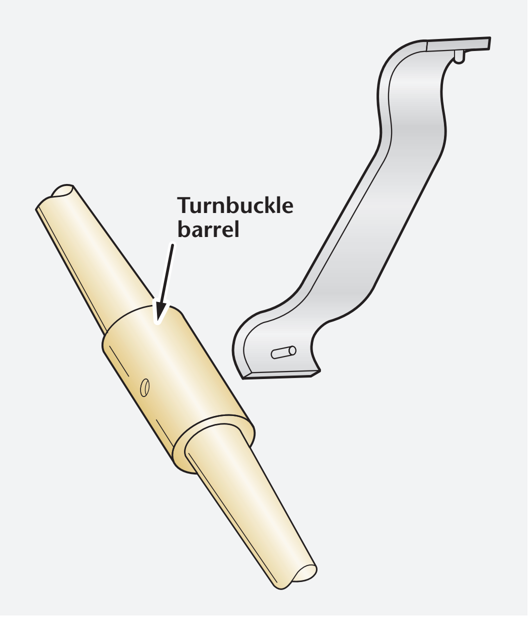


Figure 10-6-6. Turnbuckle wrench.

values are shown in the column for the No. 3 riser.

Using a No. 2 riser to measure the tension of a 3/16-inch cable, a reading of 48 is obtained.

As shown in Table 10-6-1, read across to the tension column for a reading of 70 lbs. Therefore, the actual tension of the cable is 70 lbs.

Cable rigging tension charts. Cable rigging tension charts are graphic tools used to compensate for temperature variations. They are used when establishing cable tensions in flight control systems, landing gear systems, or any other cable-operated systems. A typical chart is shown in Table 10-6-2. To use the chart, proceed as follows:

- Determine the size of the cable to be tested and the ambient air temperature. For this example, assume that the cable is 1/8 inch in diameter, that it is a 7 × 19 cable and the ambient air temperature is 85°F (29°C).
- Follow the 85°F (29°C) line upward until it intersects the curve for the 1/8-inch cable.
- Extend a horizontal line from this point of intersection to the right edge of the chart. The value at this point indicates the required tension to be established on the cable. The required tension in this example is 70 lbs.

Turnbuckle Wrench

The turnbuckle wrench, shown in Figure 10-6-6, is used for ease in adjusting a turnbuckle. It is a short bar curved on each end to fit the body of a turnbuckle. Each curved surface has a short steel peg, which fits into the hole in the center of the turnbuckle.

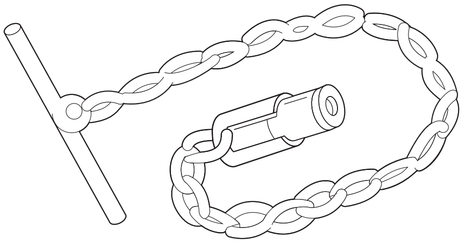


Figure 10-6-7. Valve stem fishing tool.

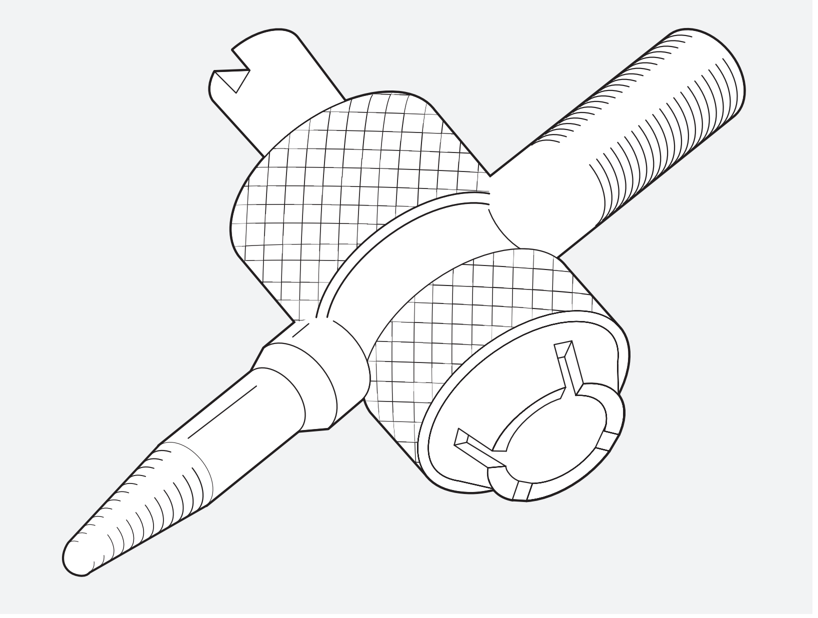


Figure 10-6-8. Valve repair tool.

Valve Stem Fishing Tool

The valve stem fishing tool, shown in Figure 10-6-7, consists of a chain with a cap fastened to one end and a small T-handle fastened to the other end. The cap is threaded to fit a valve stem. When replacing tires on wheels this tool is used in order to prevent the valve stem from slipping inside the tire. They are a standard automotive tool.

Valve Repair Tool

The valve repair tool shown in Figure 10-6-8 used for reconditioning air valves. The tap is used on the inside threads, and the die is used on the outside threads. The end opposite the tap is designed for removing and installing the valve core. This tool is also a standard automotive tool.

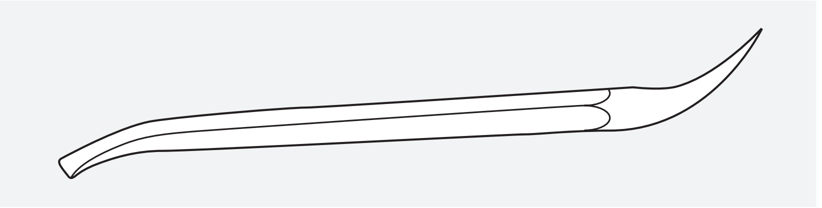


Figure 10-6-9. Cotter pin extractor.

Figure 10-6-10. Mechanical fingers.

Cotter Pin Extractor

The cotter pin extractor, shown in Figure 10-6-9, is a steel bar with a curved taper on one end and a curved wedge on the other.

A cotter pin can be removed by inserting the point of the taper into the eye of the cotter pinch. With the outside of the curved portion bearing on a supporting structure, the cotter pin is removed by prying. The curved wedge end may be used to bend or straighten the ends of the cotter pinch.

If damaged, the wedge or the taper can be repaired by grinding. Observe all safety precautions when performing this repair.

Mechanical Fingers

Mechanical fingers are used to retrieve small articles which have fallen into places where they cannot be reached by hand. They are also used to start nuts or bolts in difficult areas.

The mechanical fingers tool, as shown in Figure 10-6-10, is a flexible or fixed cable/tube with long, flat springs running through it. Applying or releasing pressure on the plate operates the mechanical fingers for retrieving hard-to-reach objects.

Mechanical fingers should not be used as a substitute for wrenches or pliers. The fingers are made of thin sheet metal or spring wire and can be easily damaged by overloading.

Figure 10-6-12. Flare nut wrench.

Figure 10-6-11. Telescoping magnet.

Figure 10-6-13. Lockwire pliers.

Telescoping Magnet

The telescoping magnet, shown in Figure 10-6-11, is used to retrieve magnetic objects which have fallen into locations not accessible by hand. It is similar in principle to the mechanical fingers, but instead of the fingers, it has a magnet at the end of a telescoping tube. The tube is simply extended to reach the object, and the object is held by the magnet as it is pulled out.

CAUTION: The warning concerning the use of a telescoping magnet also applies to magnetic-tipped screwdrivers: Keep them away from solid-state electrical components. A magnet can destroy an electronic chip.

Flare-Nut Wrench

Flare-nut wrenches are used to tighten *B nuts*, which secure tubing. The handle-type nut wrench is shown in Figure 10-6-12. A set of four flare-nut wrenches will cover almost all aircraft mechanics' usage. When the handle-type wrench is not available, one may be fabricated by removing a section of a box-end wrench, allowing it to slip over the tubing.

In an emergency, an open-end wrench may be used on brass or steel nuts, but it is likely to distort the shape of an aluminum nut, rendering it useless for future purposes.

Lockwire (Safety Wire) Pliers

Lockwire pliers, shown in Figure 10-6-13, are pliers that hold, twist, and cut lockwire. They are designed to reduce the time used in twisting lockwire. Safety wire pliers are available from several different sources, including the better automotive tool suppliers.

During the twisting operation, keep the wire tight without overstressing it or allowing it to become nicked or otherwise mutilated. This is the basic sequence:

- Grasp the wire between the jaws, and apply the locking sleeve with the thumb.
- Pull the knob to twirl the pliers which make uniform twists in the wire.
- If further twisting is required, push the knob back into the pliers and pull the knob again.
- When the wire is satisfactorily twisted, squeeze the handles together to unlock the jaws and release the wire.
- Cut the wire to the desired length with the side cutter.

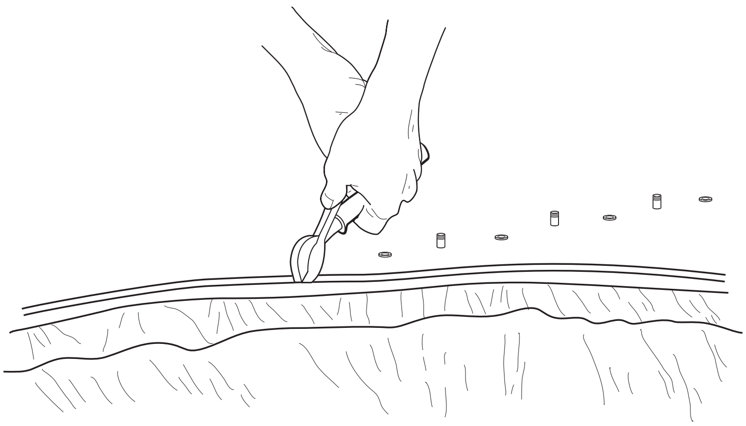


Figure 10-6-14. Using deicer boot pliers.

Figure 10-6-15. A leather punch has a range of hole sizes it can punch.

- Fold the pigtail inward so as not to leave a sharp end out. It could cut an arm badly.

Deicer Boot Pliers

When an old-style deicer boot is installed on an aircraft, it usually is pulled on over rivnut studs to hold it in place while the rivnut screws are started. To provide a larger gripping surface, which prevents tearing of the deicer boot, deicer boot pliers are used. These pliers have two rods, each about an inch long, welded perpendicularly to the jaws and wrapped with tape. They are often locally fabricated. Figure 10-6-14 shows deicer boot pliers being used.

Leather Punch

The leather punch is used to cut holes in the old-style deicer boot for rivnut screws, as shown in Figure 10-6-15. The leather punch is shaped like a pair of pliers, but has a selection of sharp-edged tubes (for different sized holes) mounted on one jaw and a plate on the other. To properly locate holes, hold deicer boot and fairing strip together. Punch holes directly through the holes in fairing strip.

Figure 10-6-16. A deicer boot roller.

Deicer Boot Roller

The deicer boot roller (Figure 10-6-16) is used to roll the flaps of the boot down when cementing them to the aircraft wing. This is one of those tools a mechanic might think he'll never need, but if he works with boots, he almost certainly will. Maintenance of this tool is minimal. Occasionally lubricate the axle to facilitate smooth rolling and keep nicks smoothed out.

Section 7

Torque Tools and Torque Principles and Procedures

Torque measuring tools are used in the maintenance and manufacture of most equipment and machinery. Each threaded fastener is designed to operate at a specific torque. If installed either too tightly or too loosely, both the fastener and the part may suffer damage and will certainly lose dependability. By specifying the torque for a fastener, a designer can predict the strength and dependability of an assembly. If torque is left to happenstance, there is no method of knowing if, or when, a fastener or assembly may fail. As a result, proper torque procedures are extremely important to the maintenance process. Torque values should be listed in MMMs or standard values may be found in AC 43.13-1B.

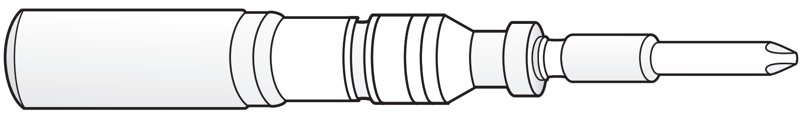


Figure 10-7-1. Preset torque screwdriver.

Fine thread		
Size and thread	Plain and castellated steel hex nuts	Thin plain and castellated steel hex nuts
	Average	Average
8-36	12-15	7-9
10-32	20-25	12-15
1/4-28	50-700	30-40
5/16-24	100-140	60-85
3/8-24	160-190	95-110
7/16-20	450-500	270-300
1/2-20	480-690	290-410
9/16-18	800-1,000	480-600
5/8-18	1,100-1,300	600-780
3/4-16	2,300-2,500	1,300-1,500
7/8-14	2,500-3,000	1,500-1,800
1-14	3,700-5,500	2,200-3,300
1 1/8-12	5,000-7,000	3,000-4,200
1 1/4-12	9,000-11,000	5,400-6,000
Coarse thread		
8-32	12-15	7-9
10-24	20-25	12-15
1/4-20	40-50	25-30
5/16-18	80-90	48-55
3/8-16	160-185	95-100
7/16-14	235-255	140-155
1/2-13	400-480	240-290
9/16-12	500-700	300-420
5/8-11	700-900	420-540
3/4-10	1,150-1,600	700-950
7/8-9	2,200-3,000	1,300-1,800

Table 10-7-1. This is a standard table of torque values in inch pounds.

Manual Torque Tools

Torque screwdriver. The preset screwdriver, shown in Figure 10-7-1, is a manual torque tool which can be preset. A device in the tool limits the applied torque to the preset measure by allowing the handle to turn free of the driven bit when the preset torque limit is reached.

Torque Wrenches

Torque wrenches are divided into three types: deflecting-beam, rigid-frame, and audible-indicating.

Deflecting-beam torque wrench. On the deflecting-beam torque wrench shown in

Figure 10-7-2. Deflecting-beam torque wrench.

Figure 10-7-2, the deflecting element is the beam itself. When a load is applied, the beam bends (deflects). A pointer attached to the socket end remains straight and indicates the applied load as torque on a graduated plate attached to the handle end. Other wrenches of this type may have a graduated dial instead of the indicator plate. Audible sensory indicators are sometimes provided in addition to the indicator plate or dial. On the deflecting-beam wrench, the location of the grip on the handle determines the length of the lever and the accuracy of the torque reading. For this reason, some flexible-beam wrenches are provided with a pivoted grip to ensure that the point of load application is maintained at the proper distance from the socket drive.

Audible-indicating torque wrench. The audible-indicating torque wrench, shown in Figure 10-7-3, has a micrometer-type barrel for presetting the desired torque.

The deflecting element is a compression spring that applies pressure to a lever in a detent or release. When the preset torque is reached, the lever slips out of the detent with an audible click, which can also be felt in the handle.

Torque Wrench Selection

The appropriate torque wrench can be selected for a specific job based on the type desired, the range of the tool and the appropriate torque units.

In aircraft maintenance applications, the rigid frame with the indicating dial and the audible-indicating torque wrenches are used in preference to the deflecting-beam-type wrench. The audible-indicating torque wrench is preferred because of its ability to be used in places of limited accessibility where it would be difficult to read a dial or scale while performing the tightening operation.

Torque range. When selecting a torque for a particular application, the range of the wrench must be considered. When practical, the required torque value should be between the 30- and 80-percent points of the torque wrench range. The accuracy of most torque wrenches tends to decrease at the extremes of the torque range. The best accuracy is obtained in the mid-range. The graduated increments on the torque wrench should not be greater than 10 percent of the torque value being measured.

Appropriate torque units. The torque wrench should be calibrated using the same torque units (inch-pounds, foot-pounds, newton-meters, etc.) as are used to specify the torque for the fastener.

Determining correct torque value. There is a correct torque value for tightening every fastener. In some instances, the torque value will be given in the MM with the detailed instructions for the assembly or the installation of the components. In most instances, the torque value will be obtained from a table, similar to Table 10-7-1, in the general instructions section of the aircraft MM. Table 10-7-1 is a standard table of recommended torque values for tightening different types of standard nuts. This table, or its equivalent, should be consulted for the correct torque value for any fastener that does not have a torque value specified in the assembly instructions. Values are for clean, dry threads.

Figure 10-7-3. Audible-indicating torque wrench makes a click when the proper torque is reached. *Photo courtesy of Snap-on Tools*

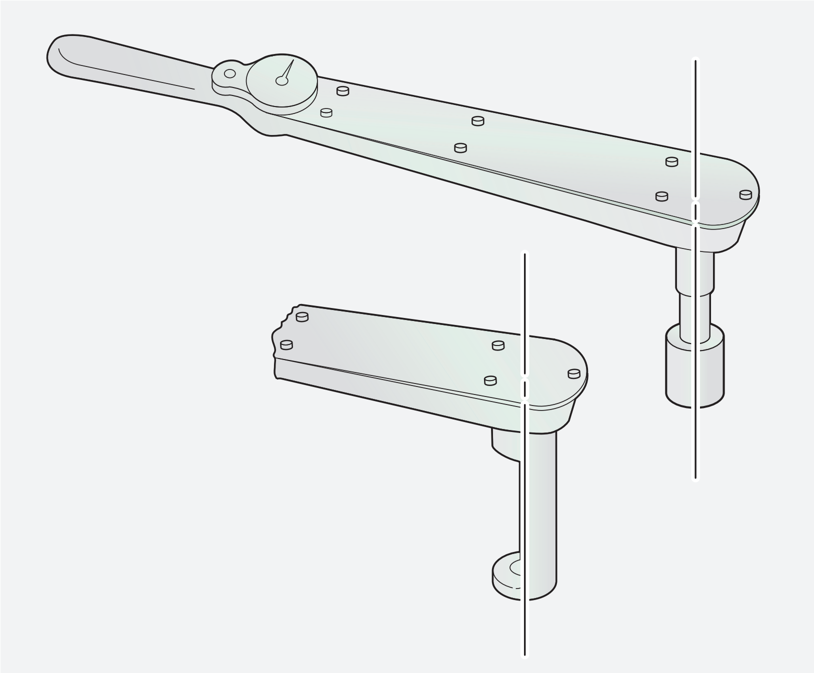
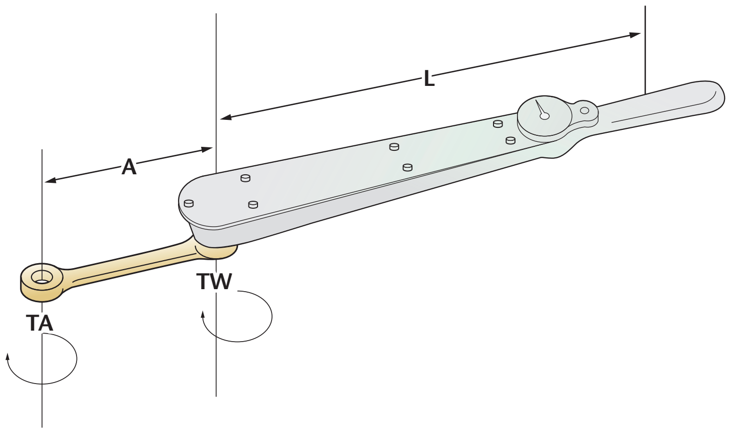


Figure 10-7-4. Concentric attachments.



TW = Indicated torque value on torque wrench

TA = Actual torque value applied to fastener

L = Lever length

A = Attachment length

$$TW = \frac{TA \times L}{L + A}$$

Figure 10-7-5. Nonconcentric attachments to torque wrench.

Torque Wrench Operation and Use

To properly use a torque wrench, a smooth, steady force must be applied to obtain accurate torque values. Rapid or jerky force can result in considerable error in the torque applied.

Reading the torque value. With the indicating dial-type wrench, the torque value is read on the dial as the force is applied. With the audible-indicating torque wrench, the torque value is preset on the wrench by releasing the lock in the end of the handle and rotating the grip to the desired torque setting. When the preset torque value is reached during the tightening operation, the handle will automatically release or break, producing approximately 15° to 20° of free travel. This release is distinct, easily detected by the mechanic and indicates completed torquing action on the fastener.

Use of attachments and extensions. Many torque wrench applications will require the use of attachments such as adapters and extensions to reach fasteners in places of limited accessibility or to position the torque wrench so that the dial is more easily read. In some cases, the use of such attachments may greatly affect the actual torque applied to the fastener.

Concentric attachments. The use of an attachment which operates in line with the drive square of the wrench presents no particular problem, since the effective length of the wrench is not lengthened or shortened. The torque applied to the fastener will therefore be the torque value indicated on the dial. Figure 10-7-4 illustrates typical attachments of this type. These attachments may also be used on the audible indicating torque wrenches without affecting the torque setting.

Non-concentric attachments. For some tightening applications, an attachment that does not operate concentrically with the drive square can be used on the torque wrench. An attachment of this type has the effect of lengthening or shortening the lever, and the torque value shown on the dial is not the torque that is applied to the fastener. When using these attachments, it is necessary to calculate the effect of the lever length to determine the correct torque reading.

Extending lever length. Figure 10-7-5 shows an attachment that adds to the lever length with the applicable formula for obtaining the correct torque reading. The formula is as follows:

$$TW = \frac{TA \times L}{L + A}$$

where:

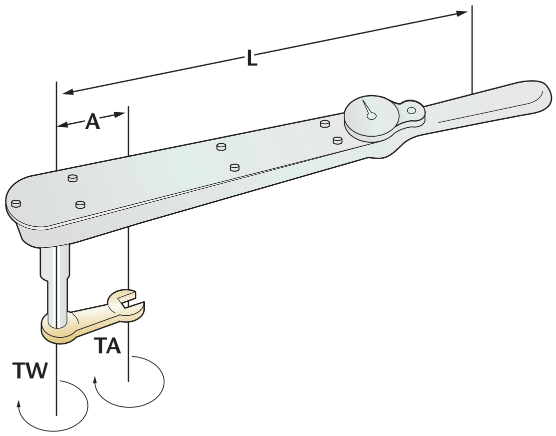
TA = Actual torque applied to fastener

TW = Indicated torque value on torque wrench

L = Lever length

A = Attachment length

For example, if the length of the torque wrench is 10 inches, the length of the attachment is 4



TW = Indicated torque value on torque wrench

TA = Actual torque value applied to fastener

L = Lever length

A = Attachment length

$$TW = \frac{TA \times L}{L - A}$$

Example

TA = Required torque = 200 in. lbs.

L = 12 in.

A = 2 in.

$$TW = \frac{200 \times 12}{12 - 2} = \frac{2400}{10} = 240 \text{ in. lbs.}$$

Figure 10-7-6. Torque wrench attachment offset reverse extension.

inches, and the desired torque to be applied is 300 inch-lbs., the formula would be completed as follows:

$$TW = \frac{TA \times L}{L + A}$$

$$TW = \frac{300 \times 10}{10 + 4}$$

$$TW = \frac{3{,}000}{14}$$

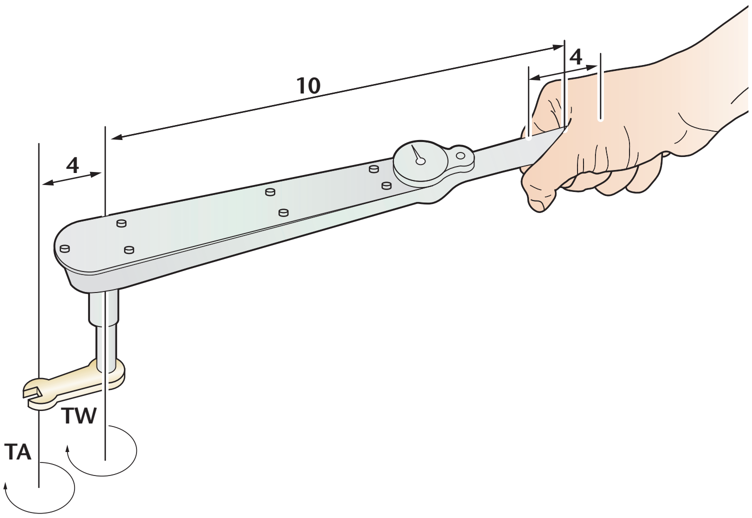
TW = 214 in. lbs.

Therefore, the torque wrench must indicate 214 inch-lbs. in order for the desired torque of 300 inch-lbs. to be obtained on the fastener.

Shortening lever length. In the previous case of added lever length, the indicated torque value is smaller than the actual torque value. Attachments, when used as shown in Figure 10-7-6, shorten the effective lever length. In these instances, the attachment length (A) is subtracted in the formula and the indicated torque value is greater than the actual torque value.

Importance of proper technique. When using these formulas, the lever length L is a critical factor. On a flexible beam-type wrench with a pivoted grip, this dimension is fixed, and the pivot point of the grip determines the point of force application and, therefore, the length of the lever. On the rigid frame and audible indicating torque wrenches, the point of force application must be in the center of the grip as shown in Figure 10-7-7.

In Figure 10-7-8 using the 10-inch lever length, 107 inch-lbs. of torque, as read on the torque wrench, results in 150-lbs. of torque on the fastener when the force is applied correctly to the center of the grip. If the force were applied to



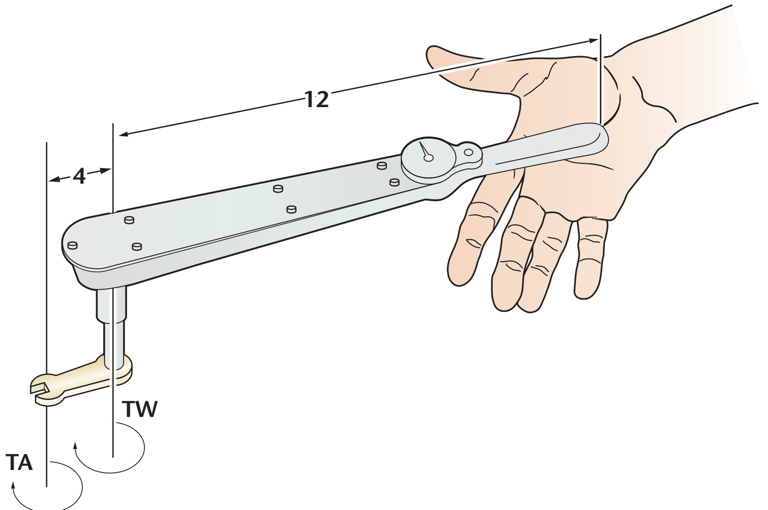
TA = Required torque = 150 in. lbs.

$$TW = \frac{TA \times 10}{10 + 4} = \frac{150 \times 10}{10 + 4} = \frac{1{,}500}{14} = 107 \text{ in. lbs.}$$

Figure 10-7-7. Proper application of force when using an extension.

the torque wrench at the tip end or the root of the grip, as shown in Figure 10-7-8, at the same 107 inch-lbs. reading, the torque applied to the fastener would be 142.6 inch-lbs. and 160.5 inch lbs., respectively.

Angle attachments. Attachments will not always extend straight from the end of the torque wrench. In instances where the centerline of the adapter is not in line with the centerline of the torque wrench, as shown in Figure 10-7-9, the length of the adapter is not used. The effective length used to calculate the torque reading is the distance (A) in Figure 10-7-9.

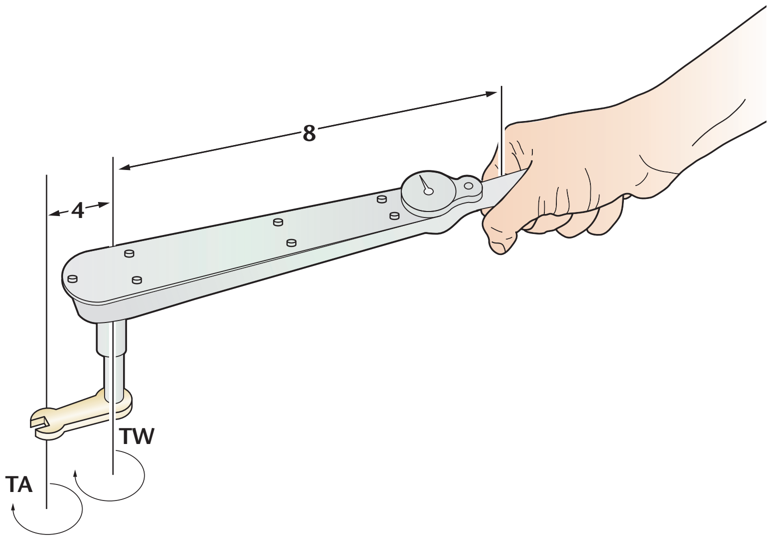


TW = Torque wrench reading = 107 in. lbs.

$$TA = \frac{TA \times (L + A)}{L}$$

$$TA = \frac{107 \times (12 + 4)}{12}$$

$$TA = \frac{107 \times (16)}{12} \quad TA = 142.6 \text{ in. lbs.}$$



TW = Torque wrench reading = 107 in. lbs.

$$TA = \frac{TA \times (L + A)}{L}$$

$$TA = \frac{107 \times (8 + 4)}{8}$$

$$TA = \frac{107 \times (12)}{8} \quad TA = 160.5 \text{ in. lbs.}$$

Figure 10-7-8. Improper application of force when using an extension.

Care of torque tools. A torque tool is a precision measuring tool and, when handled and used with reasonable care, will remain accurate and serviceable for a considerable period of time. Observe the following practices for the care and upkeep of torque tools:

- Never toss a torque tool carelessly among other tools. Store it in a clean, dry place where it will not be subjected to shock or damage.
- On audible-indicating torque wrenches, return the micrometer-type barrel to its lowest setting after each use and before returning to storage.
- Never drop a torque tool on the floor. If this does happen, the wrench should be checked for accuracy before its next use.
- Do not file, mark, or etch the beam of a flexible beam wrench. This structure is the measuring element of the wrench. Any alteration will seriously affect the accuracy of the wrench.
- Do not load a tool in excess of its capacity. Overloading a torque tool can result in permanently deforming the torque-sensing element and damaging the tool.
- Before use, check all non-adjusting torque wrenches for minimum torque indication. If they do not indicate minimum torque, tag them for calibration.

Testing of Torque Wrenches

A torque wrench is subject to wear and many other factors that can be detrimental to the accuracy of the tool. Periodic testing in accordance with FAA regulations is essential to ensure continued accuracy. Most shops and all certified repair stations keep records on calibration tests. Several different types of torque wrench testers are manufactured and, to ensure their proper use, some understanding of their operating principles is necessary.

A torque wrench tester consists of a force-resisting element to absorb the load applied by the tool and a dial or scale to indicate the magnitude of the applied load in torque units. A maximum-reading pointer is provided that remains at the point of maximum applied torque and holds the reading when the load is released until reset to zero by the operator. Other types of testers use optical magnification or electronic amplifiers.

Torque Multipliers

The direct application of torque to a fastener is limited by the force that can be applied by the technician and by the length of the wrench. The force varies to some extent but is approximately 100 lbs. With a wrench 30 inches long, the torque that can be applied is 100 × 30 or 3,000 inch-lbs. (250 foot-lbs.). Higher torque values are possible with longer wrenches; however, there is a limit to the size of a wrench that can be used effectively by one person. Torque multipliers are used for the high torque values, such as those specified for engine thrust nuts, propeller nuts and helicopter rotor hub nuts. Figure 10-7-10 shows a typical torque multiplier.

Torque multipliers are available in ratios ranging from 3:1 to 11.1:1. Multipliers must be anchored or secured to a structure relative to the fastener being tightened, or they must be fitted with a reaction bar to prevent the multiplier from turning. For this reason, their use is usually restricted to special applications.

Determining torque. When using a torque multiplier, the torque to be applied with the torque wrench is determined by dividing the specified torque for the fastener by the multiplier ratio. For example: If the torque specified for the fastener is 3,000 foot-lbs. and a torque multiplier with an 11.1 to 1 ratio is going to be used, then 11.1 or 270-lbs. is the torque applied by the torque wrench. In this case, a 350 foot-lbs. capacity torque wrench or a wrench up to a 900 foot-lbs. capacity would be used to apply 270 foot-lbs. of torque to the input of the torque multiplier. In this range of torque wrenches, the applied torque is between the desired 30- to 80-percent range.

Power Torque Tools

The three common types of powered torque tools are the *nutrunner*, the *screwdriver,* and the *impact wrench*. These tools operate on compressed air at a pressure of 90 (+10) p.s.i. In general, power torquing devices are not used in aircraft maintenance. They do not deliver a consistent torque.

The torque that the tool will apply to a fastener at a given torsion bar setting is dependent, to some extent, on the bolt diameter and length, the type of nut, and the compression characteristics of the metal in the joint. The shutoff torque of the tool must be checked and the torsion bar adjusted as required when there is any change in any of these conditions, even though the required torque remains the same.

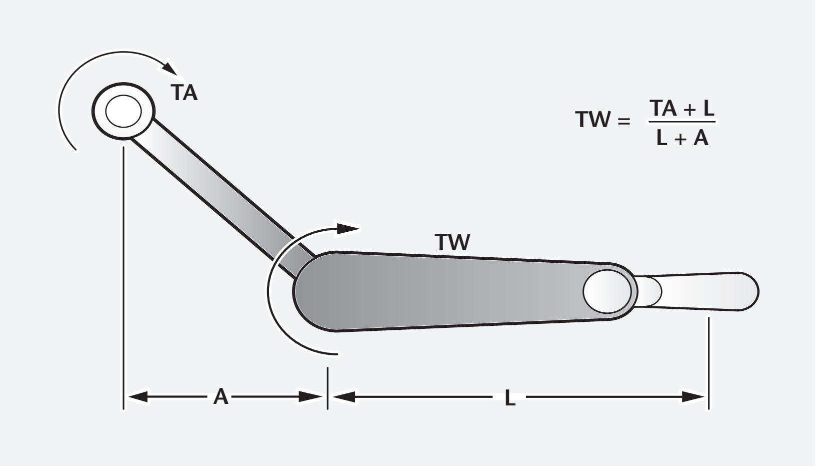


Figure 10-7-9. An illustration of angle extension torque wrench adjustment.

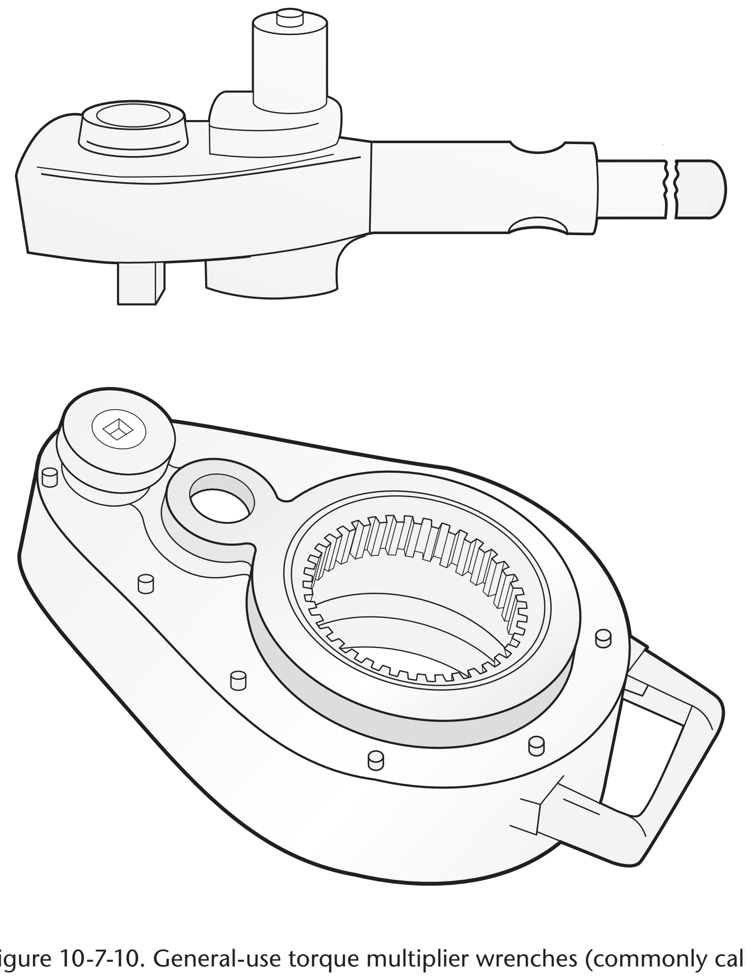
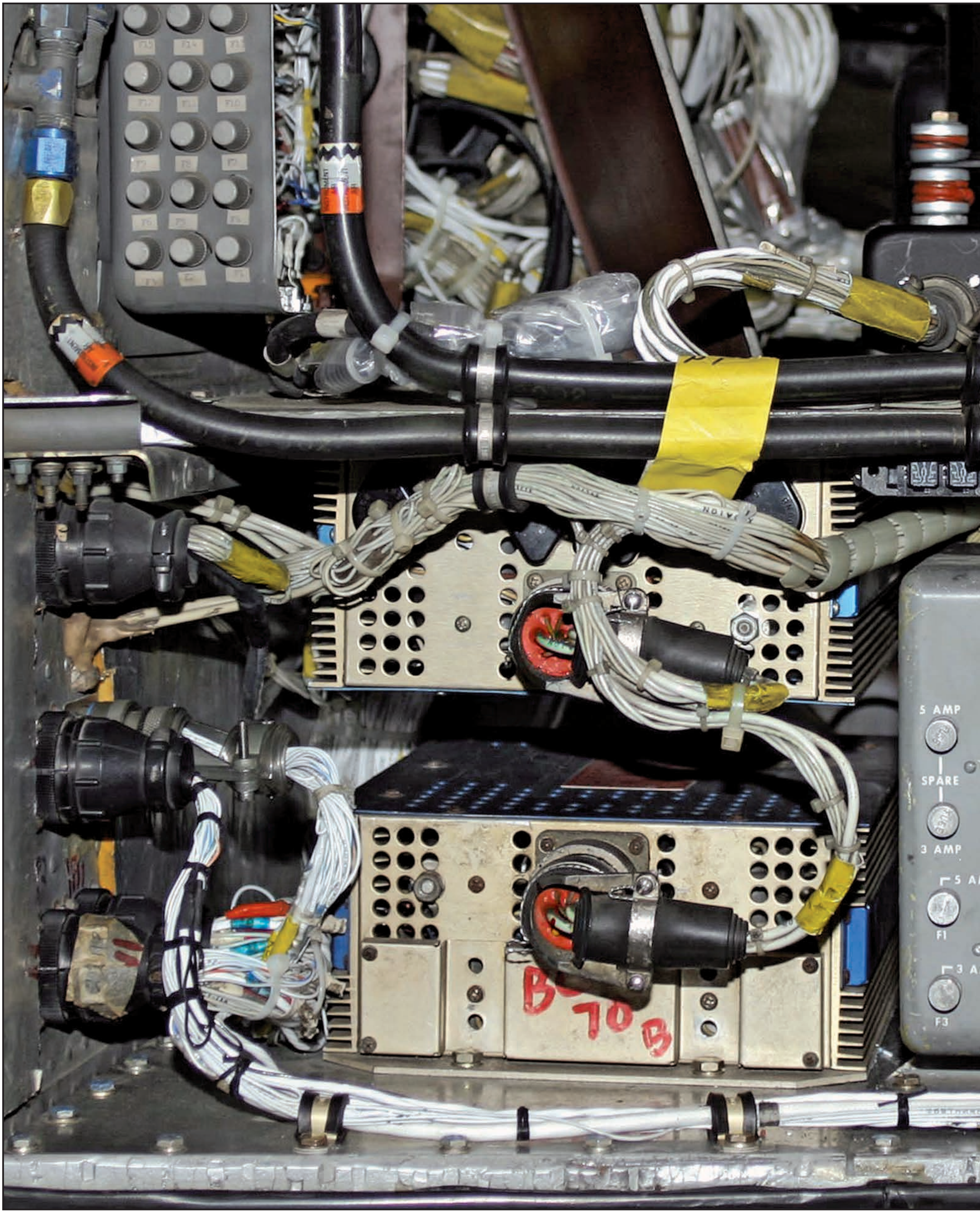


Figure 10-7-10. General-use torque multiplier wrenches (commonly called Sweeney wrenches).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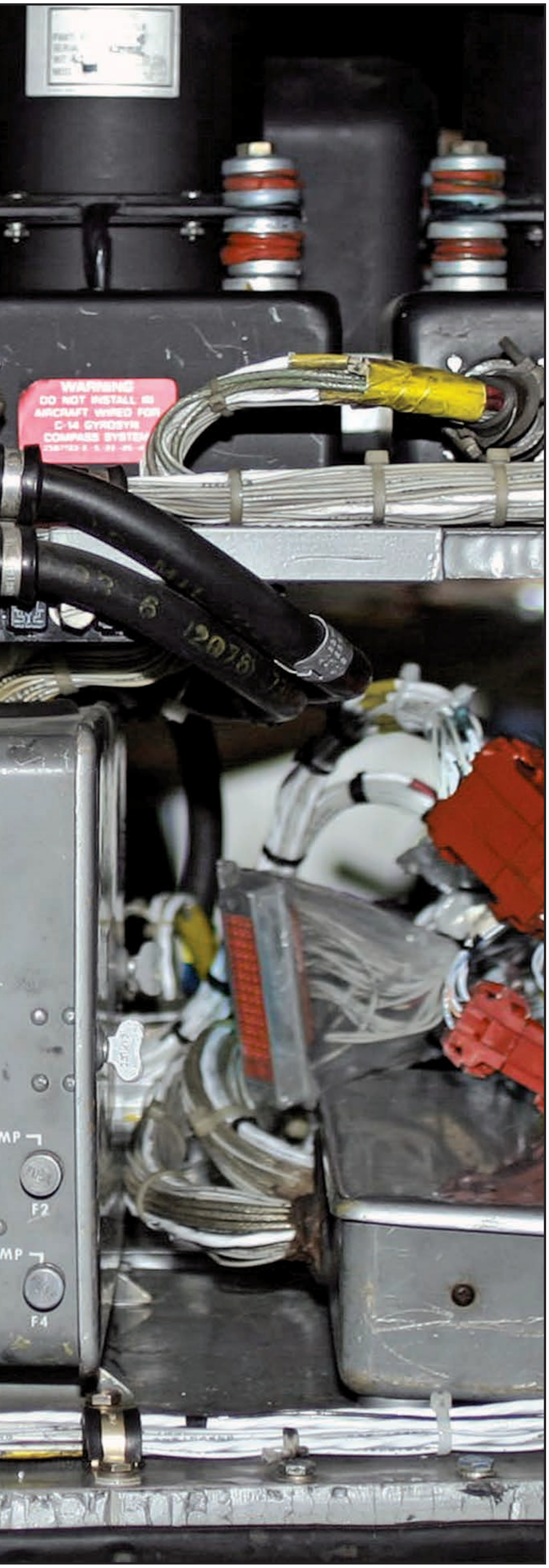


11

Basic Electricity

Section 1

Discovery of Electricity

The effects of electricity have fascinated observers for centuries. The early Greeks noted that when certain materials were rubbed, light objects would be attracted to them. It was later discovered that electrical charges were the cause of these strange phenomena.

Both the 1700s and 1800s brought a number of discoveries and developments that led to the electrical and electronic industries that we know today. In the later 1700s, the static electricity theory was developed. In 1820, Danish physicist Hans Christian Oersted (1777-1851) demonstrated that an electric current produces magnetic effects. Later, British physicist Michael Faraday (1791-1867) discovered that a magnet in motion can generate electricity, and Scottish physicist James Clerk Maxwell (1831-1879) predicted electromagnetic waves, which were later demonstrated by Heinrich Rudolf Hertz (1857-1894), a German physicist. Croatian-born American electrical engineer Nikola Tesla (1857-1943) demonstrated that the awesome powers of electricity could be harnessed and developed, leading to the alternating-current (AC) power grid that is still in use today. In the early 1900s, the invention of the vacuum tube led to the growth of radio. The invention of the transistor in 1948 by American scientists John Bardeen, Walter Brattain, and William Schokley in the Bell labs and the development of the integrated circuit by Jack Kilby and Robert Noyce in the 1960s opened the door to the electronics revolution and the future.

The electrical/electronics industry has come a long way since Benjamin Franklin's experiments with kites, and his subsequent develop-

Learning Objectives

REVIEW
- Fundamentals of electricity
- Battery types, uses and service
- Electrical measuring instrument types

DESCRIBE
- Categories and arrangements of circuit elements
- Circuit analysis principles and procedures
- Types, construction and operation of electric motors

EXPLAIN
- Factors affecting capacitance
- Function of electron control devices
- Static electricity
- Magnetisim
- Alternating current generation and circuits

Left. In all of aviation, nothing has advanced as rapidly as electrical systems. A thorough knowledge of basic electricity is necessary to understand modern aircraft electrical systems.

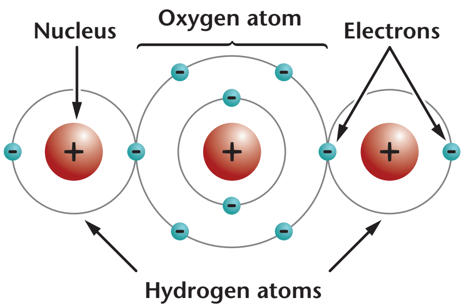


Figure 11-1-1. A water molecule.

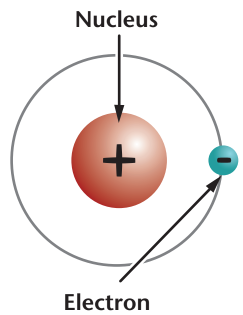


Figure 11-1-2. Hydrogen atom.

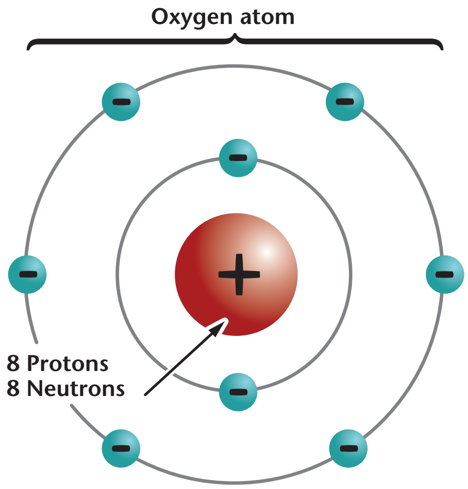


Figure 11-1-3. Complex atom of oxygen.

ment of the theory that electricity was a fluid that flows from high energy levels (positive) to lower energy levels (negative). The utilization of electronic equipment aboard aircraft has grown from the first radio (telegraphy) message transmitted from an airplane in 1911 to the *glass cockpits* and computerized flight control systems of the latest generation aircraft flying today.

Electron Theory

Composition of matter. Matter can be defined as anything that has mass (weight) and occupies space. Thus, matter is everything that exists. It may exist in the form of solids, liquids, or gases. The smallest particle of matter in any state or form that still possesses its identity is called an atom.

Substances composed of only one type of atom are called elements. However, most substances occur in nature as combinations of two or more types of atoms and are referred to as compounds. The smallest unit that a compound can be divided into, while retaining its chemical properties, is the molecule.

A molecule of water is composed of two atoms of hydrogen and one atom of oxygen. A water molecule is illustrated in Figure 11-1-1. It would no longer retain the characteristics of water if it were compounded of any other combination of hydrogen and oxygen atoms.

The atom is considered the basic building block of all matter. As previously described, it is the smallest possible particle that an element can be divided into and still retain its chemical properties. In its simplest form, it consists of one or more electrons orbiting at a high rate of speed around a center, or nucleus, made up of one or more protons and, in most atoms, one or more neutrons. Since an atom is so small that as many as 200,000 could be placed side by side in a line 1 inch long, it cannot be seen. Nevertheless, a great deal is known about its behavior from various tests and experiments.

The simplest atom is that of hydrogen, which is one electron orbiting around one proton as shown in Figure 11-1-2. A more complex atom is that of oxygen (Figure 11-1-3) which consists of eight electrons rotating in two different orbits around a nucleus made up of eight protons and eight neutrons.

An electron is the basic negative charge of electricity and cannot be divided further. Some electrons are more tightly bound to the nucleus of their atom than others and rotate in an imaginary shell or sphere closer to the nucleus. Other electrons, on the other hand, are more loosely bound and orbit at a greater distance from the nucleus. These latter electrons are called free electrons because they can be freed easily from the positive attraction of the protons in the nucleus to make up the flow of electrons in a practical electrical circuit.

The neutrons in a nucleus have no electrical charge. They are neither positive nor negative but are equal in size and weight to the proton. Since a proton weighs approximately 1,845 times as much as an electron, the overall weight of an atom is determined by the number of protons and neutrons in its nucleus. The weight of an electron is not considered in determining the weight of an atom. Indeed, the nature of electricity cannot be defined clearly because it is not certain whether the electron is a negative charge with no mass (weight) or a particle of matter with a negative charge.

Ions are electron deficiencies or excesses in atoms. Electricity is best understood in terms of its behavior, which is based in part on the charge an atom carries. When the total positive charge of the protons in the nucleus equals the total negative charge of the electrons in orbit around the nucleus, the atom is said to have a neutral charge. If an atom has a shortage of electrons, it is positively charged and is called a positive ion. If it possesses an excess of electrons, it is said to be negatively charged and is called a negative ion.

Electron flow. Effects of electron flow can be seen. Due to their small size, electrons cannot be observed as they move through conductors. However, their movement can be observed through the effects they produce, such as heat, light and electromagnetism.

Direction of flow of electrons is always from a negative point to a positive point. The movement of electrons in an electrical circuit is from a point of excess electrons (negative) to a point with a deficiency of electrons (positive). Hence electron flow in a circuit is from negative to positive. This flow is called electrical current.

Units of Electrical Measurement

The quantity or number of electrons flowing in a circuit in a given time is important, since an electric current may consist of varying numbers of electrons.

Electrons can be counted by measuring the basic electrical charge on each electron. Since this charge is very small, a practical unit, the coulomb, is used to measure quantity of electrical charge. The accumulated charge of 6.28 billion billion electrons is called one *coulomb*. When this quantity of electrons flows past a given point in 1 second in an electrical circuit, 1 ampere of current is said to be flowing in the circuit.

Current flow is measured in amperes, or parts of amperes, by an electrical instrument called an ammeter. The symbol used to indicate current in formulas and on schematics is the capital letter *I*, which stands for the intensity of current flow.

Current flow. Electrons in motion make up an electric current. This electric current is usually referred to as *current* or *current flow*, no matter how many electrons are moving. When the current flow is in one direction only, it is called direct current (DC). Later in the study of electrical fundamentals, current that reverses itself periodically, called alternating current, will be discussed. For a basic understanding of electrical principles, all references are to DC unless otherwise stated.

The drift of free electrons must not be confused with the concept of current flow that approaches the speed of light. When a voltage is applied to a circuit, the free electrons travel but a short distance before colliding with atoms. These collisions usually knock other electrons free from their atoms, and these electrons travel on toward the positive terminal of the wire, colliding with other atoms as they drift at a comparatively slow rate of speed. To understand the almost instantaneous speed of the effect of electric current, it is helpful to visualize a long tube filled with steel balls, as shown in Figure 11-1-4.

It can be seen that a ball (representing an electron) introduced into one end of the tube (which represents a conductor) will immediately cause a ball to be emitted at the opposite end of the tube. Even if the tube were long enough to reach across the country, this effect could still be visualized as being instantaneous. Thus, electric current flow can be viewed as occurring instantaneously, even though it is a result of a comparatively slow drift of electrons.

Pressure. The flow of electrons, or electric current, can be compared to the flow of water between two interconnected water tanks, where a difference of pressure exists between the two tanks. Figure 11-1-5 shows the level of water in tank A to be at a higher level than the water level in tank B. If the valve in the interconnecting line between the tanks is opened, water will flow from tank A into tank B until the level of water is the same in both tanks. It is important to note that it was not the pressure in tank A that caused the water to flow. Rather, it was the difference in pressure between tank A and tank B that caused the flow. When the water in the two tanks is at the same level, the flow of water ceases because there is no longer a difference of pressure.

This comparison illustrates the principle that causes the electrons to move, when a proper path is available, from a point of excess electrons to one deficient in electrons. The force that causes this movement is the potential difference in electrical energy between the two points. This force is called the *electrical pressure* or *potential difference* or *electromotive force* (electron-moving force), which can all be considered the same thing. Electromotive force, abbreviated emf, causes current (electrons) to move in an electrical path or circuit. The practical

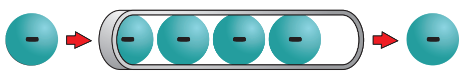


Figure 11-1-4. Electron movement.

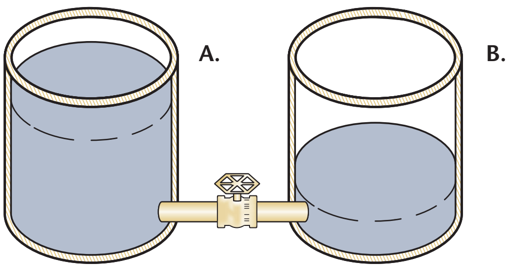


Figure 11-1-5. Difference of pressure.

unit of measurement of emf (symbolized *E*), or potential difference, is the volt.

Some publications may use the letter *V* to represent electromotive or potential difference, rather than the letter *E*. Either usage may be considered to be correct, but should be consistent.

If the water pressure in tank A of Figure 11-1-5 is 10.0 p.s.i. and the pressure in tank B is 2 p.s.i., there is a difference in pressure of 8 p.s.i. Similarly, it can be said that an emf of 8 volts exists between two electrical points. Since potential difference is measured in volts, the word *voltage* can also be used to describe amounts of potential difference. Thus, it is correct to say that the voltage of a certain aircraft battery is 24 volts, another means of indicating that a potential difference of 24 volts exists between two battery terminals connected by a conductor to electrical loads.

Opposition. The property of a conductor of electricity that opposes the flow of current is called resistance. Electromotive force is required to overcome this resistance and cause current to flow in a conductor.

The materials from which electrical conductors are manufactured, usually in the form of extruded wire, are materials that offer very little resistance to current flow.

While wire of any size or resistance value may be used, the word *conductor* usually refers to materials which offer low resistance to current flow.

The word *insulator* describes materials that offer high resistance to current. However, under certain conditions, all types of materials will conduct some current.

Another class of conductive materials, referred to as *semiconductors*, will conduct electric current under proper conditions and is used in electronic components such as diodes and transistors. These devices will be discussed in greater detail later in this text.

The best conductors are metals that possess a large number of free electrons. Conversely, insulators are materials having few free electrons. The best conductors are silver, copper, gold, and aluminum; but some non-metals, like carbon and water, can be used as conductors. Materials such as rubber, glass, ceramics, and plastics are such poor conductors that they are usually used as insulators. The current flow in these materials is usually considered zero.

The unit used to measure resistance is called the ohm. The symbol for the ohm is the Greek letter omega (Ω). In mathematical formulas, the capital letter *R* is used to refer to resistance. The resistance of a conductor or electrical load and the voltage applied to it determine the number of amperes of current flowing through the conductor. Thus, 1 ohm of resistance will limit the current flow to 1 ampere in a conductor to which a voltage of 1 volt is applied.

Power. In addition to the volt, ampere, and ohm, the unit of power is one other unit frequently used in electrical circuit calculations.

Power is defined as the rate of doing work and is equal to the product of the voltage and current. The unit used to measure power in DC electrical circuits is the watt.

When current is multiplied by emf and the result is power, this indicates that the electrical power delivered to a circuit varies directly with the applied voltage and current flow.

Metric Prefixes and Powers of Ten

Prefixes. In any system of measurements, a single set of units is usually not sufficient for all the computations involved in electrical repair and maintenance. Small distances, for example, can usually be measured in inches, but larger distances are more meaningfully expressed in feet, yards, or miles.

Because electrical values often vary from numbers that are a millionth part of a basic unit of measurement to very large values, it is often necessary to use a wide range of numbers to represent the values of such units as volts, amperes, or ohms. A series of prefixes that appear with the name of the unit have been devised for the various multiples or submultiples of the basic units. There are 12 of these prefixes, which are also known as conversion factors. Six of the most commonly used prefixes with a short definition of each are as follows:

Mega — one million (1,000,000)

Kilo — one thousand (1,000)

Centi — one-hundredth (1/100)

Milli — one-thousandth (1/1,000)

Micro — one-millionth (1/1,000,000)

Pico — one-millionth-millionth (1/1,000,000,000,000)

One of the most extensively used conversion factors, kilo, can be used to explain the use of prefixes with basic units of measurement.

Conversion table		
1 ampere	=	1,000,000 microamperes
1 ampere	=	1,000 milliamperes
1 farad	=	1,000,000,000,000 picofarads
1 farad	=	1,000,000 microfarads
1 farad	=	1,000 millifarads
1 Henry	=	1,000,000 microhenrys
1 Henry	=	1,000 millihenrys
1 kilovolt	=	1,000 volts
1 kilowatt	=	1,000 watts
1 megohm	=	1,000,000 ohms
1 microampere	=	0.000001 ampere
1 microfarad	=	0.000001 farad
1 microhm	=	0.000001 ohm
1 microvolt	=	0.000001 volt
1 microwatt	=	0.000001 watt
1 picofarad	=	0.000000000001 farad
1 milliampere	=	0.001 ampere
1 millihenry	=	0.001 henry
1 millisiemens	=	0.001 siemens
1 milliohm	=	0.001 ohm
1 millivolt	=	0.001 volt
1 milliwatt	=	0.001 watt
1 volt	=	1,000,000 microvolts
1 volt	=	1,000 millivolts
1 watt	=	1,000 milliwatts
1 watt	=	0.001 kilowatt

Table 11-1-1. Conversion table.

Number	Prefix	Symbol
1,000,000,000,000	tera	T
1,000,000,000	giga	G
1,000,000	mega	M
1,000	kilo	k
100	hecto	h
10	deka	da
0.1	deci	d
0.01	centi	c
0.001	milli	m
0.000001	micro	μ
0.000000001	nano	n
0.000000000001	pico	p

Table 11-1-2 . Prefixes and symbols for multiples of basic quantities.

Kilo means 1,000, and when used with volts is expressed as kilovolt, meaning 1,000 volts. The symbol for kilo is the letter *k*. Thus, 1,000 volts is one kilovolt or 1 kV. Conversely, 1 volt would equal one-thousandth of a kV, or 1/1000 kV. This could also be written 0.001 kV.

Similarly, the word *milli* means one-thousandth; thus, 1 millivolt equals one-thousandth (1/1,000) of a volt.

These prefixes may be used with all electrical units. They provide a convenient method for writing extremely large or small values. Most electrical formulas require the use of values expressed in basic units. Therefore, all values must usually be converted before computation can be made.

Table 11-1-1 contains a conversion table, which lists a number of the most commonly used electrical values.

Table 11-1-2 contains a complete list of the multiples used to express electrical quantities, together with the prefixes and symbols used to represent each number.

Powers of ten. When dealing with extremely large or extremely small numbers, it is often helpful to use a method called the powers of ten. When using this method, the first step is to convert the number into a number between one and ten by moving the decimal point in the appropriate direction.

As an example, 3,000 can be converted to 3.0 by moving the decimal point three places to the left. Since the original number is larger than one, the converted number will need to be multiplied by a power of ten to equal the original number. The converted number, 3.0, will need to be multiplied by 10^3 to equal 3,000. This expression would be written as 3.0×10^3.

Numbers smaller than one are converted in basically the same way. The only difference is in the sign of the power of ten. For example, to convert 0.0005 to a power of ten would require that the number five first be converted to 5.0 by moving the decimal point four places to the right. Next, the converted number will need to be multiplied by a negative power of ten since the original number was less than one. This expression would be written as 5.0×10^{-4}.

Numbers expressed as powers of ten may be multiplied or divided by first performing the required math, then adding the powers of ten to multiply, or subtracting to divide.

The following examples demonstrate mathematical functions using the powers of ten:

$$0.12 \times 10^0 = (1.2 \times 10^{-1}) \times (1.0 \times 10^2) = 1.2 \times 10^1 = 12$$

$$0.00038 \times 0.006 = (3.8 \times 10^{-4}) \times (6 \times 10^{-3}) = 2.28 \times 10^{-6} = 0.00000228$$

$$4{,}000 \times 1{,}500 = (4 \times 10^3) \div (1.5 \times 10^3) = 6 \times 10^6 = 6{,}000{,}000$$

$7{,}000 \div 300 = (7 \times 10^3) \div (3 \times 10^2) =$
$2.33 \times 10^1 = 23.3$

$0.015 \div 2{,}500 = (1.5 \times 10^{-2}) \div (2.5 \times 10^3) =$
$6 \times 10^{-6} = 0.000006$

$0.002 \div 0.12 = (2 \times 10^{-3}) \div (1.2 \times 10^{-1}) =$
$1.67 \times 10^{-2} = 0.0167$

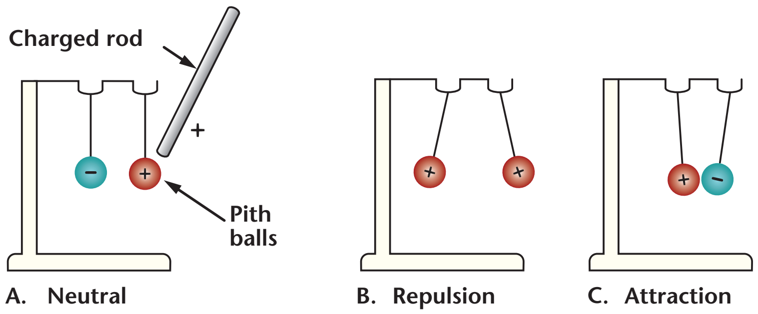


Figure 11-2-1. Reaction of like and unlike charges.

Section 2

Static Electricity

Although useless in the performance of work, static electricity can be produced by contact, friction, or induction.

Using friction to produce static electricity, when two materials are rubbed together, some electron orbits of atoms in one material may cross the orbits or shells of the other, and one material may give up electrons to the other. The transferred electrons are those in the outer orbits, called free electrons. Some materials that build up static electricity easily are flannel, silk, rayon, amber, hard rubber, and glass.

When a glass rod is rubbed with silk, the glass rod gives up electrons and becomes positively charged. The silk becomes negatively charged since it now has excess electrons. The source of these electric charges is friction.

This charged glass rod may be used to charge other substances. For example, if two pith balls are suspended, as shown in Figure 11-2-1A, and each ball is touched with the charged glass rod, some of the charge is transferred to the balls. The balls now have similar charges and, consequently, repel each other as shown in Figure 11-2-1B.

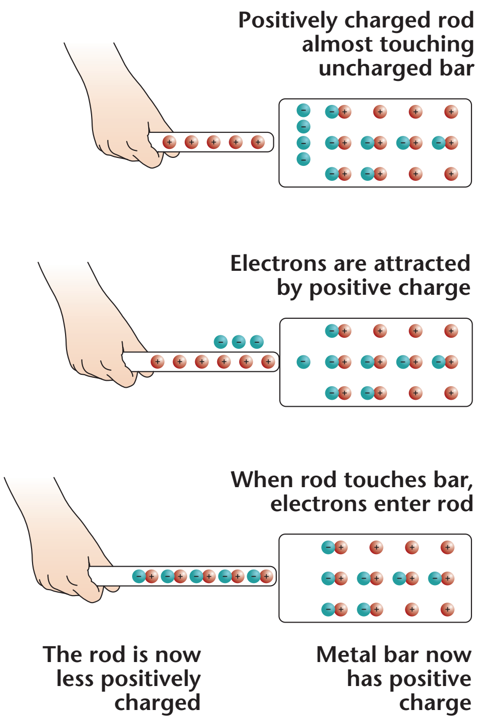


Figure 11-2-2. Charging by contact.

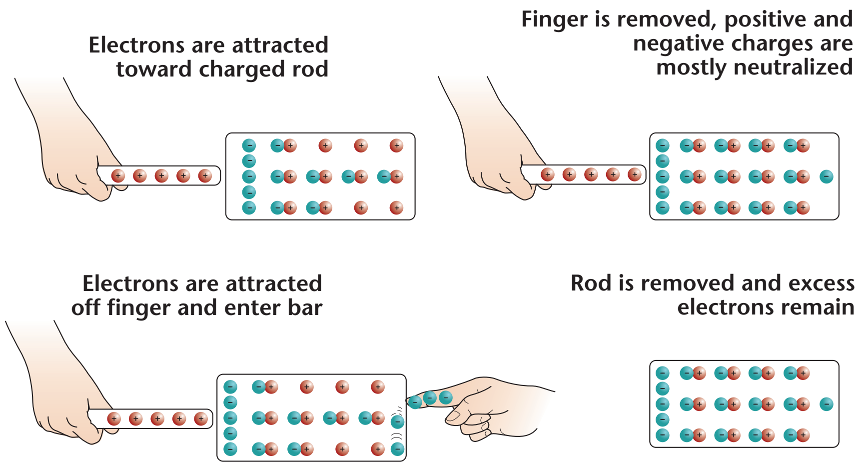


Figure 11-2-3. Charging a bar by induction.

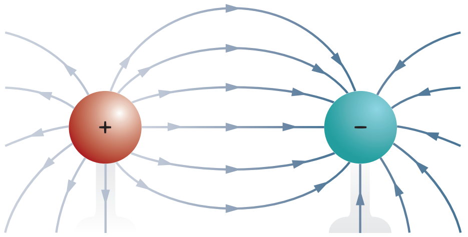


Figure 11-2-4. Direction of electric field around positive and negative charges.

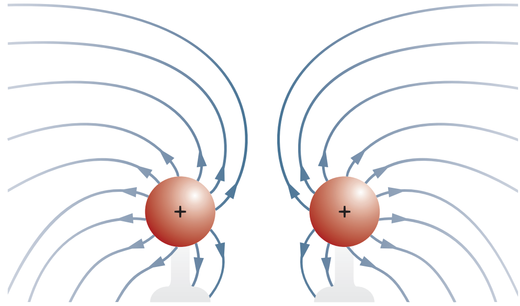


Figure 11-2-5. Field around two positively charged bodies.

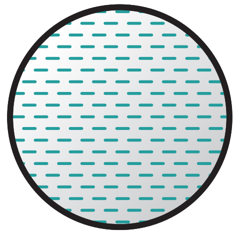


Figure 11-2-6. Even distribution of charge on metal disk.

If a plastic rod is rubbed with fur, it becomes negatively charged and the fur is positively charged. By touching each ball with these differently charged sources, the balls obtain opposite charges and attract each other as shown in Figure 11-2-1C.

Static charge produced by contact is illustrated in Figure 11-2-2. Although most objects become charged with static electricity by means of friction, a charged substance can also influence objects near it by contact. If a positively charged rod touches an uncharged metal bar, it will draw electrons from the uncharged bar to the point of contact. Some electrons will enter the rod, leaving the metal bar with a deficiency of electrons (positively charged) and making the rod less positive than it was, or perhaps even neutralizing its charge completely.

Static charge produced by induction is demonstrated in Figure 11-2-3. A positively charged rod is brought near, but does not touch, an uncharged metal bar. Electrons in the metal bar are attracted to the end of the bar nearest the positively charged rod, leaving a deficiency of electrons at the opposite end of the bar. If this positively charged end is touched by a neutral object, electrons will flow into the metal bar and neutralize the charge. The metal bar is left with an overall excess of electrons.

Electrostatic Fields

A field of force exists around a charged body. This field is an electrostatic field (sometimes called a dielectric field) and is represented by lines extending in all directions from the charged body and terminating where there is an equal and opposite charge.

To aid in understanding the action of an electrostatic field, lines are used to represent the direction and intensity of the electric field of force. As illustrated in Figure 11-2-4, the intensity of the field is indicated by the number of lines per unit area, and the direction is shown by arrowheads on the lines pointing in the direction in which a small test charge would tend to move if acted upon by the field of force.

Distribution of electrical charges. Either positive or negative test charges may be used, but it has been arbitrarily agreed by scientists that a small positive charge will always be used in determining the direction of the field. Thus, the direction of the field around a positive charge is always defined as being away from the charge, as shown in Figure 11-2-4, because a positive test charge would be repelled. On the other hand, the direction of the lines about a negative charge is toward the charge, since a positive test charge is attracted toward it.

The field around bodies having like charges is illustrated in Figure 11-2-5. Positive charges are shown, but regardless of the type of charge, the lines of force would repel each other if the charges were alike. The lines terminate on material objects and always extend from a positive charge to a negative charge. These lines are imaginary lines used to show the direction a real force takes.

It is important to know how a charge is distributed on an object. Figure 11-2-6 shows a small metal disk on which a concentrated negative charge has been placed. By using an electrostatic detector, it can be shown that the charge is spread evenly over the entire surface of the disk. Since the metal disk provides uniform resistance everywhere on its surface, the mutual repulsion of electrons will result in an even distribution over the entire surface.

The charge on a hollow sphere, another example of charge distribution, is shown in Figure 11-2-7. Although the sphere is made of a conducting material, the charge is evenly distributed over the outside surface. The inner surface is completely neutral. This phenomenon is used to safeguard operating personnel of the large Van de Graaff static generators used for atom smashing. The safest area for the operators is inside the large sphere, where millions of volts are being generated.

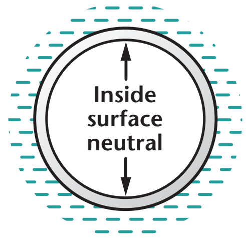


Figure 11-2-7. Charge on a hollow sphere.

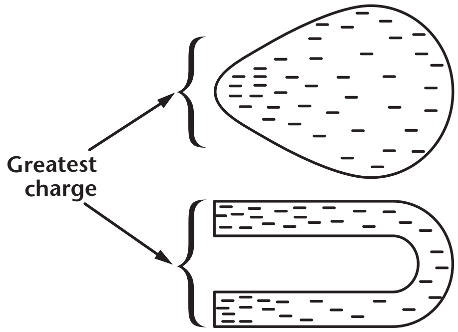


Figure 11-2-8. Charge on irregularly shaped objects.

The distribution of the charge on an irregularly shaped object differs from that on a regularly shaped object. Figure 11-2-8 shows that the charge on such objects is not evenly distributed. The greatest charge is at the points, or areas of sharpest curvature, of the objects.

The effects of static electricity must be considered in the operation and maintenance of aircraft.

Static interference in the aircraft avionics systems and the static charge created by the aircraft's movement through the air are examples of problems created by static electricity. Parts of the aircraft must be *bonded* or joined together to provide a low-resistance path for static discharge, and avionics equipment must be shielded.

Static charges must be considered in refueling of the aircraft to prevent possible igniting of the fuel. Provision must be made to ground the aircraft structure, either by static-conducting tires or by a grounding wire, prior to refueling.

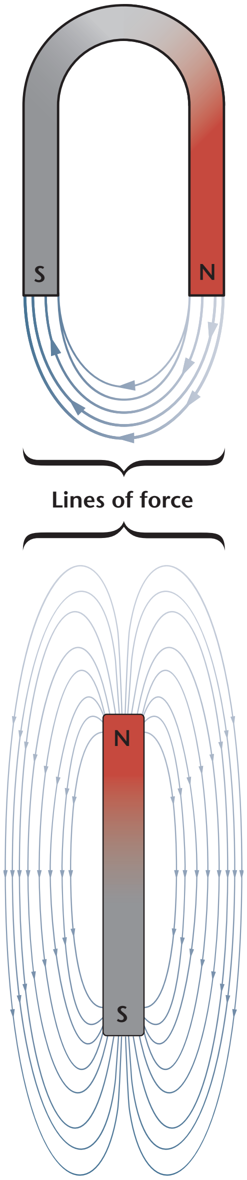


Figure 11-3-2. Magnetic field around magnet.

Section 3

Magnetism

Magnetism is so closely allied with electricity in the modern industrial world, it can be safely stated that without magnetism the electrical world would not be possible. Knowledge of magnetism has existed for many centuries, but it was not until the eighteenth century that this stream of knowledge was joined with that of electricity by the discoveries of science.

The earliest known magnet was the lodestone, a natural mineral found in Asia Minor. Today this substance is called magnetite or magnetic oxide of iron. When a piece of this ore is suspended horizontally by a thread or floated on wood in undisturbed water, it will align itself in a north-south direction. This characteristic led to its use as a compass and the name lodestone, meaning leading stone. Other than the earth itself, the lodestone is the only natural magnet. All other magnets are produced artificially.

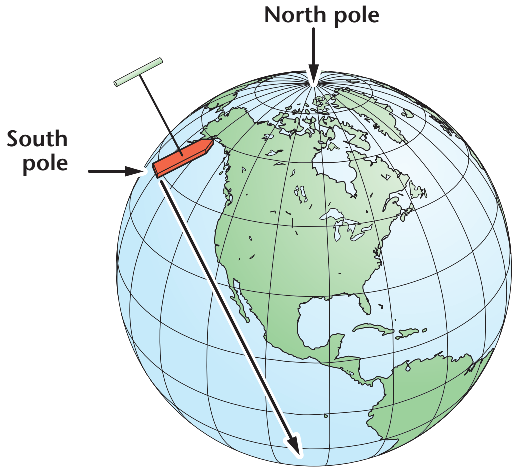


Figure 11-3-1. One end of magnetized strip points to the North Pole.

From the earliest times, a great deal was known about the elementary behavior of magnets. For example, it was known that the property of magnetism could be induced in an iron bar by stroking it with a lodestone. In addition, it was known that if the north-seeking end of a suspended magnet was brought near the north-seeking end of another, the magnets would repel each other. On the other hand, they found that a north-seeking and a south-seeking end would attract each other.

Magnetism defined. Magnetism is defined as the property of an object to attract certain metallic substances. In general, these substances are ferrous materials; that is, materials composed of iron or iron alloys, such as soft iron or steel.

Magnetism is an invisible force, the ultimate nature of which has not been fully determined. It can best be described by the effects it produces. Examination of a simple bar magnet similar to that illustrated in Figure 11-3-1 discloses some basic characteristics of all magnets.

If the magnet is suspended to swing freely, it will align itself with the Earth's magnetic poles. One end is labeled *N*, meaning the north-seeking end or pole of the magnet. If the *N* end of a compass or magnet is referred to as north-seeking rather than north, there will be no conflict in referring to the pole it seeks, which is the north magnetic pole.

The opposite end of the magnet, marked *S*, is the south-seeking end and points to the south magnetic pole. Since the earth is a giant magnet, its poles attract the ends of the magnet.

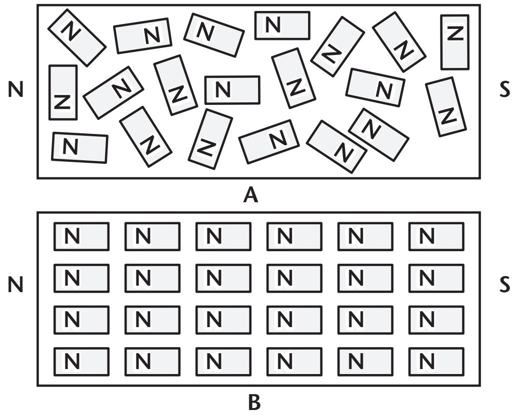


Figure 11-3-3. Arrangements of molecules in a piece of magnetic material.

These poles are not located at the geographic poles.

This somewhat mysterious and completely invisible force of a magnet depends on a magnetic field that surrounds the magnet as illustrated in Figure 11-3-2. This field always exists between the poles of a magnet and will arrange itself to conform to the shape of any magnet.

Magnetic theory. The theory that explains the action of a magnet holds that each molecule making up the iron bar is itself a tiny magnet, with both north and south poles as demonstrated in Figure 11-3-3A. These molecular magnets each possess a magnetic field, but in an unmagnetized state the molecules are arranged at random throughout the iron bar.

If a magnetizing force, such as stroking with a lodestone, is applied to the unmagnetized bar, the molecular magnets rearrange themselves in line with the magnetic field of the lodestone, with all north ends of the magnets pointing in one direction and all south ends in the opposite direction.

In a configuration such as the one shown in Figure 11-3-3, illustration B, the magnetic fields of the magnets are combined to produce the total field of the magnetized bar.

Characteristics of Magnets and Magnetism

The presence of the magnetic force, or field, around a magnet can best be demonstrated by the experiment illustrated in Figure 11-3-4.

A sheet of transparent material, such as glass or Lucite, is placed over a bar magnet and iron filings are sprinkled slowly on this transparent shield. If the glass or Lucite is tapped lightly, the iron filings will arrange themselves in a definite pattern around the bar, forming a series of lines from the north to south end of the bar to indicate the pattern of the magnetic field.

The field of a magnet, as shown, is made up of many individual forces that appear as lines in the iron-filing demonstration. Although they are not *lines* in the ordinary sense, this word is used to describe the individual nature of the separate forces making up the entire magnetic field.

These lines of force are also referred to as magnetic flux. They are separate and individual forces, since one line will never cross another; indeed, they actually repel one another. They remain parallel to one another and resemble stretched rubber bands, since they are held in place around the bar by the internal magnetizing force of the magnet.

This demonstration with iron filings further shows that the magnetic field of a magnet is concentrated at the ends of the magnet. These areas of concentrated flux are called the north and south poles of the magnet. There is a limit to the number of lines of force that can be crowded into a magnet of a given size. When a magnetizing force is applied to a piece of magnetic material, a point is reached where no more lines of force can be induced or introduced. The material is then said to be saturated.

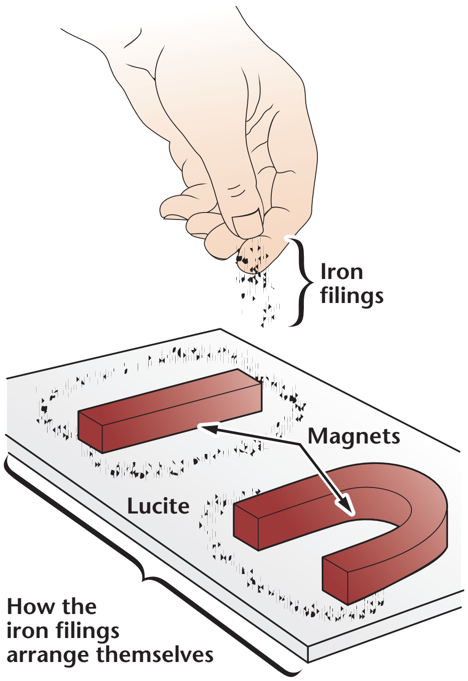


Figure 11-3-4. Tracing out a magnetic field with iron filings.

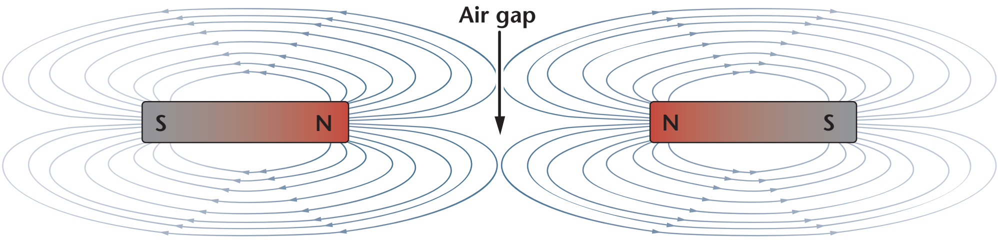


Figure 11-3-5. Like poles repel.

The characteristics of the magnetic flux can be further demonstrated by tracing the flux patterns of two bar magnets with like poles together, as shown in Figure 11-3-5.

The two like poles repel one another because the lines of force will not cross each other. As the arrows on the individual lines indicate, the lines turn aside as the two like poles are brought near each other and travel in a path parallel to each other. Lines moving in this manner repel each other, causing the magnets as a whole to repel each other.

By reversing the position of one of the magnets, the attraction of unlike poles can be demonstrated, as shown in Figure 11-3-6.

As the unlike poles are brought near each other, the lines of force rearrange their paths and most of the flux leaving the north pole of one magnet enters the south pole of the other. The tendency of lines of force to repel each other is indicated by the bulging of the flux in the air gap between the two magnets.

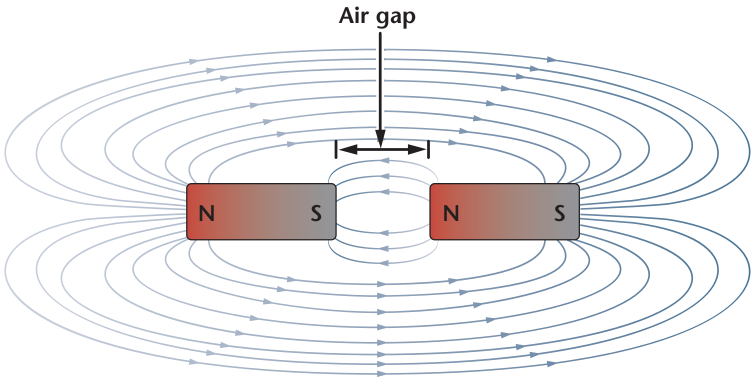


Figure 11-3-6. Unlike poles attract.

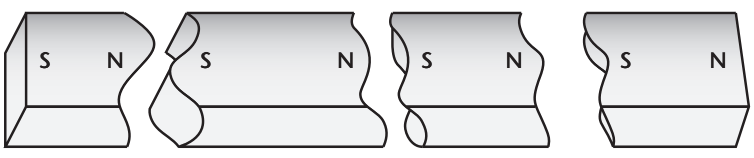


Figure 11-3-7. Magnetic poles in a broken magnet.

Another characteristic of magnets is illustrated in Figure 11-3-7. If the bar magnet is cut or broken into pieces, each piece immediately becomes a magnet itself with a north and south pole. This feature supports the theory that each molecule is a magnet, since each successive division of the magnet produces still more magnets.

Since the magnetic lines of force form a continuous loop, they form a magnetic circuit. It is impossible to say where in the magnet they originate or start. Arbitrarily, it is assumed that all lines of force leave the north pole of any magnet and enter at the south pole.

Resistance to magnetism. There is no known insulator for magnetic flux, or lines of force, since they will pass through all materials. However, it has been found that they will pass through some materials more easily than others.

Thus, it is possible to shield certain areas, such as instruments, from the effects of the flux by surrounding them with a material that offers an easier path for the lines of force.

An instrument surrounded by a path of soft iron, such as the one shown in Figure 11-3-8, offers very little opposition to magnetic flux. The lines of force take the easier path—referred to as the path of greater permeability—and are guided away from the instrument.

Materials, such as soft iron and other ferrous metals, are said to have a high permeability, the measure of the ease with which magnetic flux can penetrate a material. The permeability scale is based on a perfect vacuum with a rating of one.

Air and other nonmagnetic materials are so close to this that they are also considered to have a rating of one.

The nonferrous metals having a permeability greater than one, such as nickel and cobalt, are called *paramagnetic*, while the term *ferromagnetic* is applied to iron and its alloys, which have, by far, the greatest permeability. Any substance having a permeability of less than one, such as bismuth, is considered *diamagnetic*.

Reluctance, the measure of opposition to the lines of force through a material, can be compared to the resistance of an electrical circuit. The reluctance of soft iron, for instance, is much lower than that of air. Figure 11-3-9 demonstrates that a piece of soft iron placed near the field of a magnet can distort the lines of force, which follow the path of lowest reluctance through the soft iron.

Types of magnets. Magnets are either natural or artificial. Since naturally occurring magnets, or lodestones, have no practical use, all magnets considered in this study are artificial, or man-made.

Artificial magnets can be further classified as permanent magnets, which retain their magnetism long after the magnetizing force has been removed, and temporary magnets, which quickly lose most of their magnetism when the external magnetizing force is removed.

Hard steel has long been used to make permanent magnets, but magnets of even better quality are now available from various alloys. Alnico, an alloy of iron, aluminum, nickel, and cobalt, is considered one of the very best. Others with excellent magnetic qualities are alloys such as Remalloy and Permendur.

The old method of producing a magnet by stroking a piece of steel or iron with a natural magnet has been replaced by other means. A piece of metal placed in contact with, or even near, a magnet will become magnetized by induction, and the process can be accelerated by heating the metal and then placing it in a magnetic field to cool. Magnets can also be produced by placing the metal to be magnetized in a strong magnetic field and striking it several times with a hammer. This process can be used to produce permanent magnets from metals such as hard steel. The ability of a magnet to hold its magnetism varies greatly with the type of metal and is known as retentivity.

Magnets made of soft iron are very easily magnetized but quickly lose most of their magnetism when the external magnetizing force is removed.

The small amount of magnetism remaining, called residual magnetism, is of great importance in such electrical applications as generator operation.

Magnets can be made in many different shapes, such as balls, cylinders, or disks. One special type of magnet is the ring magnet, or Gramme ring, often used in instruments. This is a closed-loop magnet, similar to the type

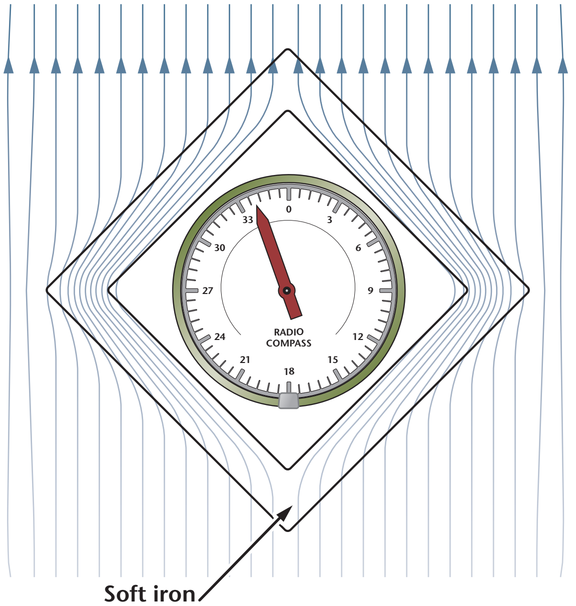


Figure 11-3-8. Magnetic shield around an instrument.

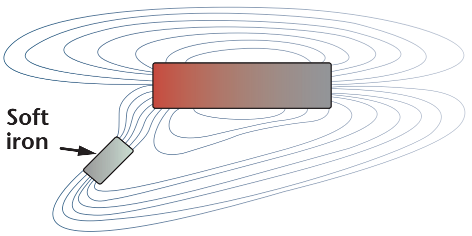


Figure 11-3-9. Effect of a magnetic substance in a magnetic field.

used in transformer cores and is the only type that has no poles.

Some special applications require that the field of force lie through the thickness rather than the length of a piece of metal. Such magnets are called flat magnets and are used as pole pieces in generators and motors.

Electromagnetism

In 1819, the Danish physicist Hans Christian Oersted discovered that the needle of a compass brought near a current-carrying conductor would be deflected. When the current flow stopped, the compass needle returned to its original position. This important discovery demonstrated a relationship between electricity and magnetism that led to the electromagnet and to many of the inventions on which modern industry is based.

Terms relating to magnetism and electromagnetism. The magnetic circuit can be compared in many respects to an electrical circuit. The magnetomotive force (mmf), causing lines of force in the magnetic circuit, can be compared to the emf or electrical pressure of an electrical circuit.

The mmf is measured in *gilberts*, symbolized by the letters *Gb*. The symbol for the intensity of the lines of force, or *flux*, is the Greek letter phi (φ), (and the unit of field intensity is the gauss. An individual line of force, called a *maxwell*, in an area of 1 square centimeter produces a field intensity of 1 gauss.

Using reluctance rather than permeability, the law for magnetic circuits can be stated: A magnetomotive force of 1 gilbert will cause 1 maxwell, or line of force, to be set up in a material when the reluctance of the material is one.

Section 4

Electrical Energy (Electromotive Force, emf)

An emf may be produced in a number of ways. Some methods of producing an emf are more practical than others and therefore have a wider application. The following list identifies six methods of producing an emf:

Friction. An emf can be produced by rubbing materials together. This will produce static electricity, which was discussed earlier.

Magnetism. An emf may be produced by moving a conductor through a magnetic field. This is one of the most widely employed methods of producing voltage and will be discussed in detail in a later section of this chapter.

Ohm's law
$\text{Current} = \frac{\text{Electromotive force}}{\text{Resistance}}$ $I = \frac{E}{R}$ $\quad$ $\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$
$\text{Resistance} = \frac{\text{Electromotive force}}{\text{Current}}$ $R = \frac{E}{I}$ $\quad$ $\text{Ohms} = \frac{\text{Volts}}{\text{Amperes}}$
Electromotive force = Current × Resistance   E = I R $\quad$ Volts = Amperes × Ohms

Table 11-4-1 Ohm's law.

Chemical action. A voltage may be produced chemically when certain substances are placed in a chemical solution. Production of emf by this method takes place in a battery.

Heat. An emf may be produced by heating the junction where two dissimilar metals join, as in a thermocouple. Heating the thermocouple junction causes electron movement in the junction and through an external circuit connected to the junction.

Pressure. An emf produced by pressure is referred to as piezoelectric effect and is caused by applying pressure to crystals of certain substances. Some of the common devices that use piezoelectricity are accelerometers, phonograph cartridges, and microphones.

Light. Voltage produced by light is known as photovoltaic electricity, or photoelectricity. Light striking the surface of certain substances dislodges electrons from their orbits. These electrons can be made to flow in a circuit and perform useful work.

Current Electricity and Ohm's Law

Ohm's law. One of the most fundamental laws applicable to the study of electricity is Ohm's law. This law, which outlines the relationship between voltage, current, and resistance in an electrical circuit, was first stated by German physicist George Simon Ohm (1787-1854).

This law applies to all direct-current circuits. In a modified form, it may be applied to the alternating circuits to be studied later in this text.

Ohm's experiments showed that current flow in an electrical circuit is directly proportional to the amount of voltage applied to the circuit. Stated in different words, this law says that as the voltage increases, the current increases; and when the voltage decreases, the current flow decreases. It should be added that this relationship is true only if the resistance in the circuit remains constant. For it can be readily seen that if the resistance changes, current also changes.

Ohm's law may be expressed as an equation, as follows:

$$I = \frac{E}{R} \text{ or } R = \frac{E}{I}$$

Where I is current in amperes, E is the potential difference measured in volts, and R is the resistance measured in ohms (designated by the Greek letter omega, Ω). If any two of these circuit quantities are known, the third may be found by simple algebraic transposition.

The basic equations derived from Ohm's law are summarized, together with the units of measurements of circuit quantities, in Table 11-4-1.

The various equations which may be derived by transposing the basic law can be easily obtained by using the triangles in Figure 11-4-1. The triangles containing E, I, and R are divided into two parts, with E above the line and I × R below it. To determine an unknown circuit quantity when the other two are known, cover the unknown quantity with a thumb. The location of the remaining uncovered letters in the triangle will indicate the mathematical operation to be performed.

As an example, to find I, refer to Figure 11-4-1A, and cover I with the thumb. The uncovered letters indicate that E is to be divided by R, or I =E/R. To find R, refer to Figure 11-4-1B, and cover R with the thumb. The result indicates that E is to be divided by I, or E = I × R. To find E refer to Figure 11-4-1C, and cover E with the thumb. The result indicates I is to be multiplied by R, or E = I × R.

Mechanical Power in Electrical Circuits

The watt is named for Scottish engineer James Watt (1736-1819), the inventor of the condensing steam engine. He devised an experiment to measure the power of a horse, to quantify the mechanical power of his steam engine. One horsepower (hp) is required to move 33,000 lbs. one foot in one minute. Since power is the rate of doing work, it is equivalent to the work divided by time. Stated as a formula, this is:

$$\text{Power} = \frac{33{,}000 \text{ ft.} - \text{lb.}}{60 \text{ sec } (1 \text{ min})}$$

$$P = 550 \text{ ft.} - \text{lb./ sec}$$

Electrical power can be rated in a similar manner. For example, an electric motor rated at 1 hp requires 746 watts of electrical energy. But the watt is a relatively small unit of power. The much more common unit is the kilowatt, or 1,000 watts.

In measuring amounts of electrical energy consumed, the kilowatt hour is used. For example, if a 100-watt bulb consumes electrical energy for 20 hours, it has used 2,000 watt hours, or 2 kilowatt hours of electrical energy.

Heat in Electrical Circuits

Electrical power that is lost in the form of heat when current flows through an electrical device is often referred to as power loss. This heat is usually dissipated into the surrounding air and serves no useful purpose except when used for heating.

Since all conductors possess some resistance, circuits are designed to reduce these losses. Referring again to the basic power formula, P = I × E, it is possible to substitute the Ohm's law values for E in the power formula to obtain a power formula that directly reflects the power losses in a resistance.

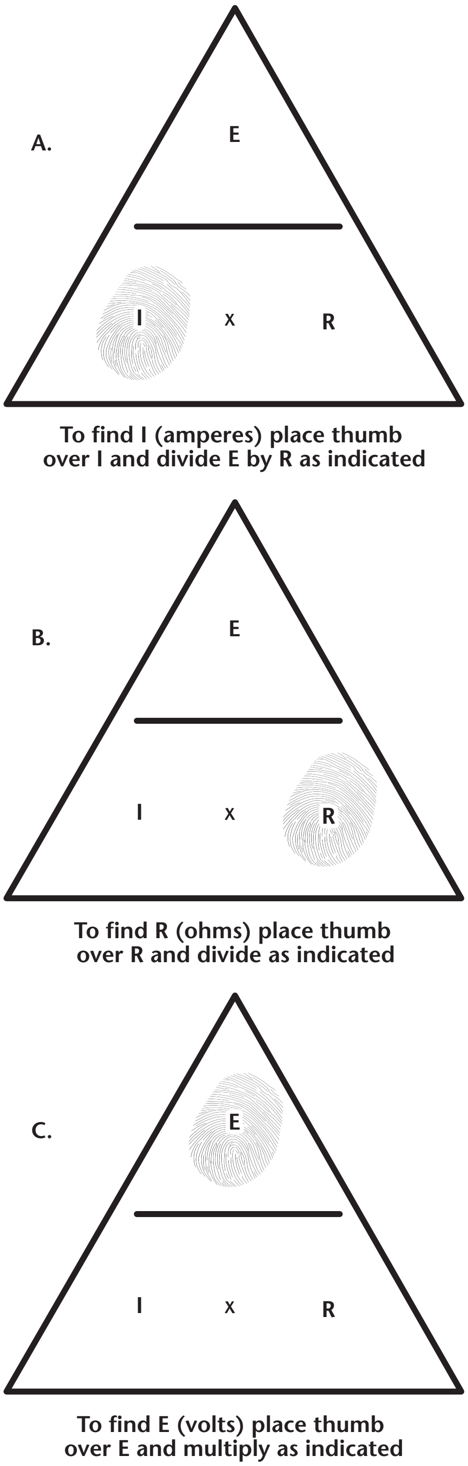


Figure 11-4-1. Ohm's law chart.

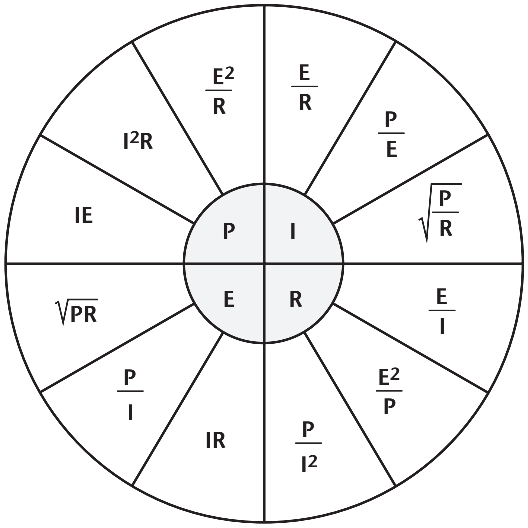


Figure 11-4-2. Summary of basic equations using the volt, ampere, ohm, and watt.

$P = I \times E$
$E = I \times R$

Substituting the Ohm's law value for $E(I \times R)$ in the power formula:

$P = I \times I \times R$

Collecting the terms, this gives:

$P = I^2R$

From this equation, it can be seen that the power in watts in a circuit varies as the square of the circuit current in amperes and varies directly with the circuit resistance in ohms.

Finally, the power delivered to a circuit can be expressed as a function of current and resistance by transposing the power equation $P = I^2R$. Transposing to solve for current gives:

$$I^2 = \frac{P}{R}$$

and by extracting the square root of both sides of the equation:

$$I = \sqrt{\frac{P}{R}}$$

Thus, the current through a 500-watt, 100-ohm load (resistance) is as follows:

$$I = \sqrt{\frac{P}{R}} = \frac{500}{100} = 2.24 \text{ amperes}$$

The electrical equations derived from Ohm's law and the basic power formula do not reveal all about the behavior of circuits. They do indicate the numerical relation between the volt, ampere, ohm, and watt. Figure 11-4-2 provides a summary of all the possible transpositions of these formulas in a 12-segment circle.

Section 5

Circuit Elements

Conductors

Physical characteristics that affect the use of a material as a conductor are resistivity and temperature.

Resistivity is a material's resistance to current flow. As previously mentioned, certain metals are commonly used as conductors because of the large number of free electrons they possess.

Silver is the best conductor, but it is not used due to high cost. Copper is the second best conductor and is considered to be the most practical conductor material.

Copper wire of a given size offers less resistance to current than an aluminum wire of the same size. However, aluminum is much lighter than copper and for this reason, as well as cost considerations, is often used when the weight factor is important.

Temperature is a major factor influencing the resistance of a conductor. Although some conductor materials, such as carbon, show a decrease in resistance as the ambient (surrounding) temperature increases, most materials used as conductors increase in resistance as temperature increases. The resistance of a few alloys, such as constantan and manganin, change very little as the temperature changes.

Initial temp. °C	Increase in resistance per °C	
	Copper	Aluminum
0	0.00427	0.00439
5	0.00418	0.00429
10	0.00409	0.00420
15	0.00401	0.00411
20	0.00393	0.00403
25	0.00385	0.00396
30	0.00378	0.00388
40	0.00364	0.00373
50	0.00352	0.00360

Table 11-5-1. Temperature resistance coefficients.

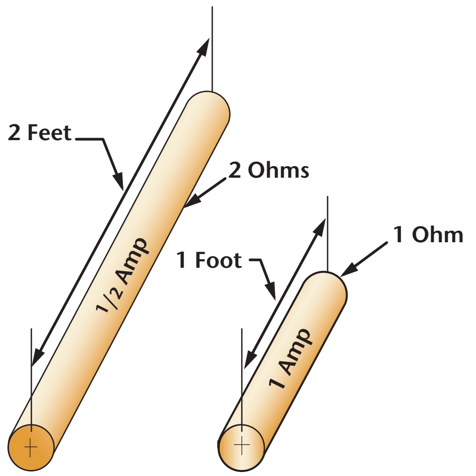


Figure 11-5-1. Resistance varies with length of conductors.

The temperature coefficient of a material is referred to by the designation alpha (Greek letter α). The temperature coefficient for copper, per degree Celsius (°C) is 0.004. This would indicate that for each 1°C temperature rise, a copper wire having a resistance of 50 ohms will increase in resistance 50 × 0.004, or approximately 0.2 ohms. The standard temperature for specific resistance is 25°C.

The temperature coefficient of resistance must be considered where large changes in temperature may occur in a conductor during operation. Table 11-5-1 shows the properties of copper and aluminium.

The dimensions of a conductor affect its resistance to current flow and ability to withstand heat.

The longer a given size of wire, the greater its resistance to current flow. Figure 11-5-1 shows two wire conductors of different lengths. If 1 volt of electrical pressure is applied across the two ends of the conductor that is 1 foot in length, and the resistance to the movement of free electrons is assumed to be 1 ohm, the current flow is limited to 1 ampere. If the same size conductor is doubled in length, the same electrons set in motion by the 1 volt applied now find twice the resistance. Consequently, the current flow will be reduced by one-half.

Cross-sectional area, or the end surface of a conductor, affects the resistance of a conductor. This area may be triangular or even square, but it is usually circular. If the cross-sectional area of a conductor is doubled, the resistance to current flow will be reduced to one-half. This is true because of the increased area in which an electron can move without collision or capture by an atom. Thus, the resistance varies inversely with the cross-sectional area of a conductor.

To compare the resistance of one conductor with that of another having a greater cross-sectional area, a standard unit of conductor size must be established. The standard unit of measurement of wire diameter is the mil (1 mil = 0.001 inch). The standard unit of wire length is the foot. Using these standards, the unit of wire size will be the mil-foot. Thus, a wire with a diameter of 1 mil and a length of 1 foot is referred to as being a mil-foot. The resistance, in ohms, of 1 mil-foot of any wire material is known as the specific resistance of the material.

Since the diameters of round conductors may be only a fraction of an inch, it is convenient to express these diameters in mils to avoid the use of decimals. The circular mil is the standard unit of wire cross-sectional area used in American and English wire tables. Therefore, the diameter of a wire that is 0.025 inch may be more conveniently expressed as 25 mils.

In a circular cross-section having a diameter of 1 mil, the area in circular mils is obtained by squaring the diameter. Thus, a wire with a diameter of 25 mils has an area of 25 squared, or 25 × 25, or 625 circular mils.

Wires are manufactured in sizes numbered according to a table known as the *American Wire Gauge (AWG)*. Wire diameters become smaller as the gauge numbers become larger. This table is available to aviation technicians for reference, not only on wire size, but also resistance and cross-sectional area (Table 11-5-2).

Control Devices

The units in the electrical circuits in an aircraft are not all intended to operate continuously or automatically. Most of them are meant to operate at certain times, under certain conditions, to perform very definite functions. There must be some means of controlling their operation. Either a switch or a relay or both can be included in the circuit for this purpose.

Switches. Switches control the current flow in most aircraft electrical circuits. A *switch* is used to start, to stop, or to change the direction of the current flow in the circuit. The switch in each circuit must be able to carry the normal current of the circuit and must be insulated heavily enough for the voltage of the circuit.

Switches are designated by the number of poles, throws, and positions they have. A *pole* of a switch is its movable blade or contactor. The number of poles is equal to the number of circuits, or paths for current flow, that can be completed through the switch at any one time.

American wire gauge English units. Values at 20°C.									
Gauge	Diameter In Mils	Cross section		Ohms per 1,000 ft.	Feet per ohm	Pounds per 1,000 ft.	Feet per pound	Ohms per pound	Pounds per ohm
		Circular Mils	Square Inch						
0000	460.0	211,600	0.1662	0.04901	20,400	640.5	1.561	0.00007652	13,070
000	409.6	167,800	0.1318	0.06182	16,180	507.8	1.969	0.0001217	8,215
00	364.8	133,100	0.1045	0.07793	12,830	402.8	2.482	0.0001935	5,169
0	324.9	105,600	0.08291	0.09825	10,180	319.5	3.130	0.0003075	3,252
1	289.3	83,690	0.06573	0.1239	8,070	253.3	3.947	0.0004891	2,044
2	257.6	66,360	0.05212	0.1563	6,398	200.9	4.978	0.0007781	1,285
3	229.4	52,620	0.04133	0.1971	5,074	159.3	6.278	0.001237	808.3
4	204.3	41,740	0.03278	0.2485	4,024	126.3	7.915	0.001967	508.5
5	181.9	33,090	0.02599	0.3134	3,190	100.2	9.984	0.003130	319.5
6	162.0	26,240	0.02061	0.3952	2,530	79.44	12.59	0.004975	201.0
7	144.3	20,820	0.01635	0.4981	2,008	63.03	15.87	0.007902	126.5
8	128.5	16,510	0.01297	0.6281	1,592	49.98	20.01	0.01257	79.58
9	114.4	13,090	0.01028	0.7925	1,262	39.62	25.24	0.02000	49.99
10	101.9	10,380	0.008155	0.9988	1,001	31.43	31.82	0.03178	31.47
11	90.7	8,230	0.00646	1.26	793	24.9	40.2	0.0506	19.8
12	80.8	6,530	0.00513	1.59	629	19.8	50.6	0.0804	12.4
13	72.0	5,180	0.00407	2.00	500	15.7	63.7	0.127	7.84
14	64.1	4,110	0.00323	2.52	396	12.4	80.4	0.203	4.93
15	57.1	3,260	0.00256	3.18	314	9.87	101	0.322	3.10
16	50.8	2,580	0.00203	4.02	249	7.81	128	0.514	1.94
17	45.3	2,050	0.00161	5.05	198	6.21	161	0.814	1.23
18	40.3	1,620	0.00128	6.39	157	4.92	203	1.30	0.770
19	35.9	1,200	0.00101	8.05	124	3.90	256	2.06	0.485
20	32.0	1,020	0.000804	10.1	98.7	3.10	323	3.27	0.306
21	28.5	812	0.000638	12.8	78.3	2.46	407	5.19	0.193
22	25.3	640	0.000503	16.2	61.7	1.94	516	8.36	0.120
23	22.6	511	0.000401	20.3	49.2	1.55	647	13.1	0.0761
24	20.1	404	0.000317	25.7	39.0	1.22	818	21.0	0.0476
25	17.9	320	0.000252	32.4	30.9	0.970	1,030	33.4	0.0300
26	15.9	253	0.000199	41.0	24.4	0.7692	1,310	53.6	0.0187
27	14.2	202	0.000158	51.4	19.4	0.610	1,640	84.3	0.0119
28	12.6	159	0.000125	65.3	15.3	0.481	2,080	136	0.00736
29	11.3	128	0.000100	81.2	12.3	0.387	2,590	210	0.00476
30	10.0	100	0.0000785	104	9.64	0.303	3,300	343	0.00292
31	8.9	79.2	0.0000622	131	7.64	0.240	4,170	546	0.00183
32	8.0	64.0	0.0000503	162	6.17	0.194	5,160	836	0.00120
33	7.1	50.4	0.0000396	206	4.86	0.153	6,550	1,350	0.000742
34	6.3	39.7	0.0000312	261	3.83	0.120	8,320	2,170	0.000460
35	5.6	31.4	0.0000246	331	3.02	0.0949	10,500	3,480	0.000287
36	5.0	25.0	0.00000196	415	2.41	0.0757	13,200	5,480	0.000182
37	4.5	20.2	0.00000159	512	1.95	0.0613	16,300	8,360	0.000120
38	4.0	16.0	0.00000126	648	1.54	0.0484	20,600	13,400	0.0000747
39	3.5	12.2	0.00000962	847	1.18	0.0371	27,000	22,800	0.0000438
40	3.1	9.61	0.00000755	1,080	0.927	0.0291	34,400	37,100	0.0000270
41	2.8	7.84	0.00000616	1,320	0.756	0.0237	42,100	55,700	0.0000179
42	2.5	6.25	0.00000491	1,660	0.603	0.0189	52,900	87,700	0.0000114
43	2.2	4.84	0.00000380	2,140	0.467	0.0147	68,300	146,000	0.00000684
44	2.0	4.00	0.00000314	2,590	0.386	0.0121	82,600	214,000	0.00000467
45	1.76	3.10	0.00000243	3,350	0.299	0.00938	107,000	357,000	0.00000280
46	1.57	2.46	0.00000194	4,210	0.238	0.00746	134,000	564,000	0.00000177
47	1.40	1.96	0.00000154	5,290	0.189	0.00593	169,000	892,000	0.00000112
48	1.24	1.54	0.00000121	6,750	0.148	0.00465	215,000	1,450,000	0.000000690
49	1.11	1.23	0.000000968	8,420	0.119	0.00373	268,000	2,260,000	0.000000443
50	0.99	0.980	0.000000770	10,600	0.0945	0.00297	337,000	3,570,000	0.000000280

Note 1: The fundamental resistivity used in calculating the tables is the International Annealed Copper Standard, viz, 0.15328 ohm-g/m² at 20°C. The temperature coefficient, for this particular resistivity, is a_{20}=0.00393 per °C, or a_0=0.00427. However, the temperature coefficient is proportional to the conducitivity, hence the change of resistivity per °C is a constant, 0.0000597 ohm-g/m². The "constant mass" temperature coefficient of any sample is: The density is 8.89 g/cm³ at 20°C.

$$\alpha t = \frac{0.000597 + 0.000005}{\text{resistivity in ohm} - \text{g/m}^2 \text{ at } t \text{ deg. C}}$$

Note 2: The values given in the table are only for annealed copper of the standard resistivity. The user of the table must apply the proper correction for copper of any other resistivity. Hard-drawn copper may be taken as about 2.5 percent higher resistivity than annealed copper.

Table 11-5-2. Wire table for standard annealed copper.

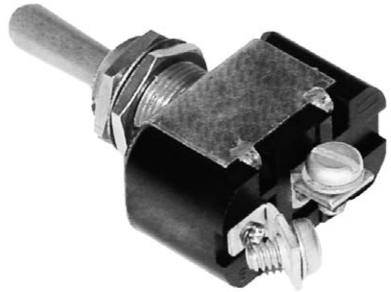


Figure 11-5-2. Single-pole, single-throw switch (SPST).

Figure 11-5-3. Single-pole, double-throw switch (SPDT).

Figure 11-5-4. Double-pole, single-throw switch (DPST).

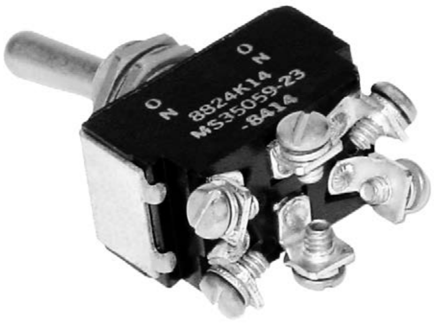


Figure 11-5-5. Double-pole, double-throw switch (DPDT).

The throw of a switch indicates the number of circuits, or paths, for current, that it is possible to complete through the switch in each ON position. The number of ON positions a switch has is the number of places at which the operating device (toggle, plunger, etc.) will come to rest and, at the same time, close one or more circuits.

A single-pole single-throw (SPST) switch, as shown in Figure 11-5-2, makes it possible to complete only one circuit through the switch. A single-pole switch through which two circuits can be completed (not at the same time) is a single-pole double-throw (SPDT) switch (Figure 11-5-3).

A switch with two contactors, or poles, each of which completes only one circuit, is a double-pole single-throw (DPST) switch. A double-pole single-throw toggle-type switch is illustrated in Figure 11-5-4.

A double-pole switch that can complete two circuits, one circuit at a time through each pole, is a double-pole double-throw (DPDT) switch. A toggle-type switch is shown in Figure 11-5-5.

Schematic representations for the most commonly used switches are shown in Figure 11-5-6.

Toggle or rocker switches find extensive use on aircraft. They are available in a number of different styles and configurations. A typical toggle switch is illustrated in Figure 11-5-2. A switch very similar to a toggle switch is the rocker switch. The handle of this switch *rocks* to the ON or OFF position, giving the switch its name.

A toggle switch that is spring-loaded to the OFF position and must be held in the ON position to complete the circuit is a momentary contact two-position switch. One that will come to rest at either of two positions, opening the circuit in one position and closing it in another, is a two-position switch. A toggle switch that will

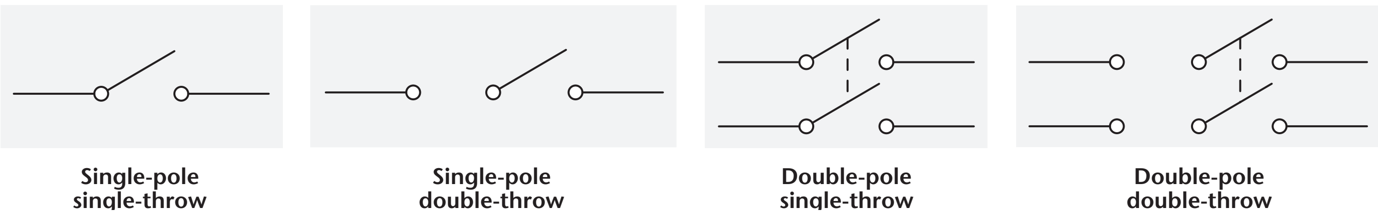


Figure 11-5-6. Schematic representation for typical switches.

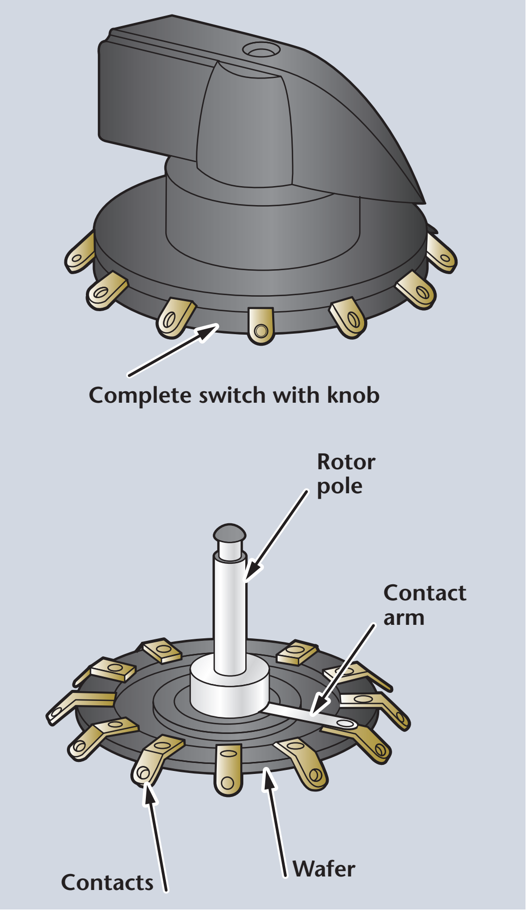


Figure 11-5-7. Rotary switch.

come to rest at any one of three positions is a three-position switch.

A switch that stays open, except when it is held in the closed position, is a normally open switch (usually identified as NO). One that stays closed, except when it is held in the open position, is a normally closed switch (NC). Both kinds are spring-loaded to their normal position and will return to that position as soon as they are released.

A wafer switch, which is a rotary type of switch, may take the place of several switches. A rotary switch may be referred to as a wafer switch since the switch contacts are positioned on a round disk made of insulating material, as shown in Figure 11-5-7.

It may be necessary in some instances to stack the wafers to allow one shaft to control a number of switch contacts. When the knob attached to the shaft is rotated, the switch arm moves to open one circuit and close another. Ignition switches and voltmeter selector switches are examples of wafer switches.

A precision switch, or microswitch, will open or close a circuit with only a very small amount of movement of the switch operating mechanism. The switch arm may need to be moved only a fraction of an inch (i.e., 1/16 inch or less) to open or close the switch contacts. This characteristic gives the switch its name, since only a very small, or micro, and very precise amount of movement activates the switch (Figure 11-5-8).

Microswitches are used for precision control of movable mechanisms requiring very precise stopping locations. They are used primarily as limit switches to provide automatic control of landing gears, actuator motors, and the like.

The diagram in Figure 11-5-9 shows a normally closed microswitch in cross-section and illustrates how these switches operate. When the operating plunger is pressed in, the spring and the movable contact are pushed, opening the contacts and the circuit.

Relays

Relays or relay switches are used for remote control of circuits carrying heavy currents, A relay is often connected in the circuit between the unit controlled and the nearest source of power (or power bus bar) so that the cables carrying heavy current will be as short as possible.

A relay switch consists of a coil and iron core (commonly referred to as a solenoid) and both fixed and movable contacts. A small wire connects one of the coil terminals (which is insulated from the housing) to the source of power through a control switch usually located in the cockpit. The other coil terminal is usually grounded to the housing. When the control switch is closed, an electromagnetic field is set up around the coil.

Relays vary in construction details according to their intended use. When selecting a relay to be installed in a circuit, make sure it is designed for the job it is intended to do.

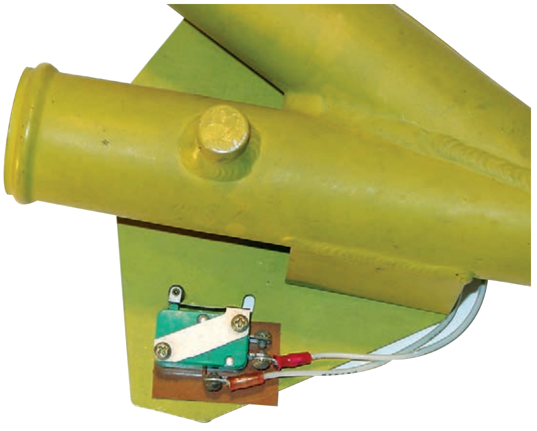


Figure 11-5-8. Microswitch.

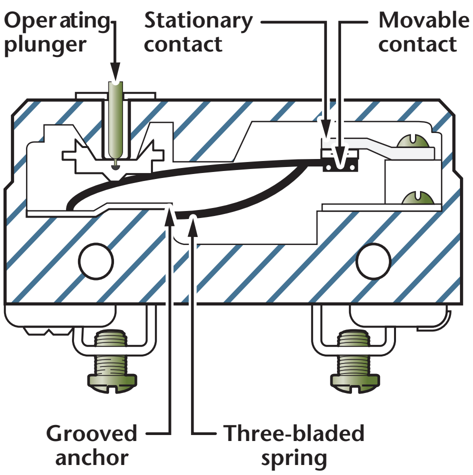


Figure 11-5-9. Cross-section of a microswitch.

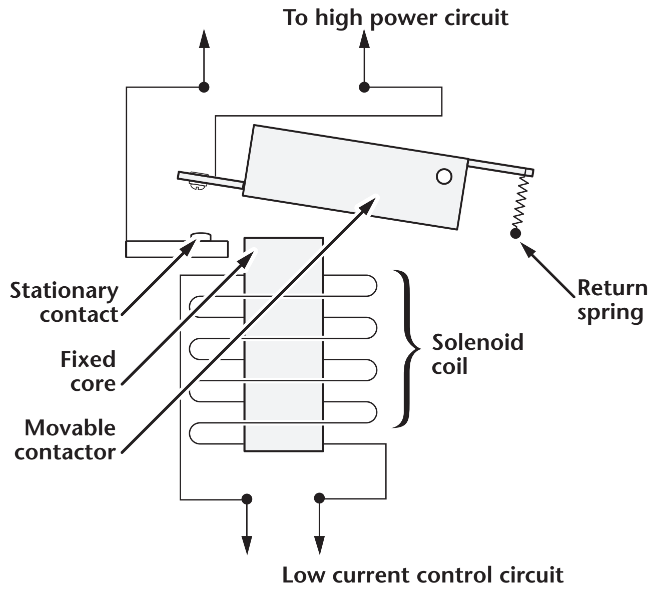


Figure 11-5-10. Fixed-core relay.

In one type of relay switch, the iron core of the solenoid is fixed firmly in place inside the coil. When the control switch is closed, the core is magnetized and pulls a soft iron armature toward it, closing the main contacts. The contacts are spring-loaded to the open position as shown in Figure 11-5-10. When the control switch is turned off, the magnetic field collapses and the spring opens the contacts.

In another type of relay switch, part of the core is movable. A spring holds the movable part a short distance away from the fixed part, as illustrated in Figure 11-5-11. When the coil is energized, the magnetic field tries to pull the movable part of the core into the coil. This pull overcomes the spring tension. As the core moves inward, it brings the movable contacts, which are attached to but insulated from it, down against the stationary contacts. This completes the main circuit. When the control switch is turned off, the magnetic field collapses and the spring returns the movable core to its original position, opening the main contacts.

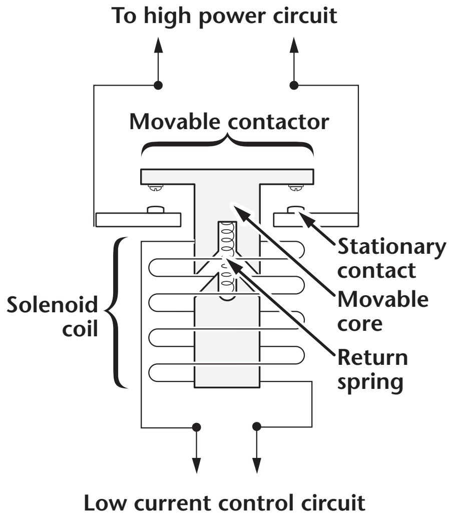


Figure 11-5-11. Movable-core relay.

Some relay switches are made to operate continuously, while others are designed to operate only intermittently (Figure 11-5-12).

Intermittent is generally defined as a duration of two minutes or less. The starter-relay switch is made to operate intermittently and would overheat if used continuously. The battery-relay switch can be operated continuously because its coil has a fairly high resistance, which prevents overheating.

In a circuit carrying a large current, the more quickly the circuit is opened the less it will arc at the relay and the less the switch contacts will be burned. Relays used in circuits with large motors have strong return springs to open the circuit quickly.

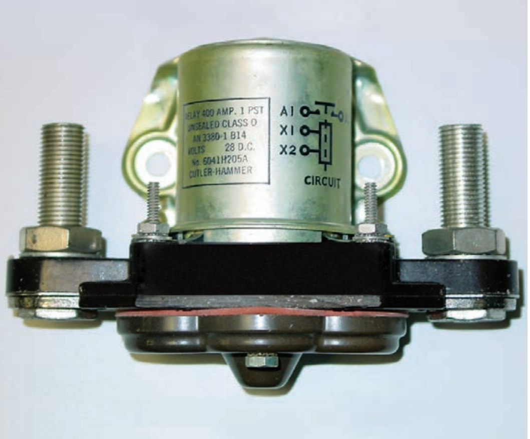


Figure 11-5-12. Starter relay.

Figure 11-5-13. Fuse and plug-in type holder.

Figure 11-5-14. Circuit breaker panel arrangement.

Most relays used in the AC circuitry of an aircraft are energized by DC current. This means that when the coil is energized by DC current, the contacts close allowing AC current to flow in the primary circuit.

Protective Devices

Protective devices are installed to protect aircraft electrical systems from damage and failure caused by excessive current. Fuses, circuit breakers, and thermal protectors are used for this purpose.

Perhaps the most serious trouble in a circuit is a direct short.

The term *direct short* describes a situation in which some point in the circuit, where full system voltage is present, comes in direct contact with the ground or return side of the circuit. This establishes a path for current flow that contains no resistance other than that present in the wires carrying the current, and these wires have very little resistance.

According to Ohm's law, if the resistance in a circuit is small, the current will be great. When a direct short occurs, there will be an extremely heavy current flowing through the wires. Any current flow greatly in excess of normal, such as the case of a direct short, would cause a rapid generation of heat.

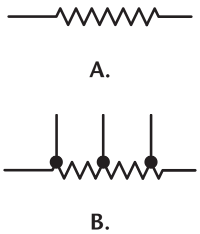


Figure 11-5-15. Symbols for fixed resistors.

If the excessive current flow caused by the short is left unchecked, the heat in the wire will continue to increase until something gives way. Perhaps a portion of the wire will melt, opening the circuit so that nothing is damaged other than the wires involved. The probability exists, however, that much greater damage would result. The heat in the wires could char and burn their insulation and that of other wires bundled with them. This, in turn, could cause more shorts. If a fuel or oil leak is near any of the hot wires, a disastrous fire might be started.

Circuit protective devices, as the name implies, all have a common purpose: to protect the units and the wires in the circuit. Some are designed primarily to protect the wiring and to open the circuit in such a way as to stop the current flow when the current becomes greater than the wires can safely carry. Other devices are designed to protect a unit in the circuit by stopping the current flow to it when the unit becomes excessively warm.

Some circuits have more current flow when first energized than they have on a continuous basis. These circuits require a special type of protective device, referred to as a time-delay or *slow-blow* fuse. This type of fuse will carry higher than its rated current for short durations to permit starting electrical devices such as motors, etc.

Fuses

Fuses are installed in a circuit so that all the current in the circuit passes through them. A fuse is a strip of metal that will melt when current in excess of its carefully determined capacity flows through it. In most fuses the strip of metal is made of an alloy of tin and bismuth. Other fuses are made of copper and are called current limiters; these are used primarily to sectionalize an aircraft circuit.

A fuse melts and breaks the circuit when the current exceeds the rated capacity of the fuse, but a current limiter will stand a considerable overload for a short period of time.

Since the fuse is intended to protect the circuit, it is quite important that its capacity match the needs of the circuit in which it is used. When a fuse is replaced, the applicable manufacturer's instructions should be consulted to be sure a fuse of the correct type and capacity is installed.

Fuses are installed in two types of fuse holders in aircraft. *Plug-in holders* are used for small type and low-capacity fuses. *Clip*-type holders are used for heavy, high-capacity fuses and current limiters (Figure 11-5-13).

Circuit Breakers

Circuit breakers are designed to break the circuit and stop the current flow when the current exceeds a predetermined value. They are commonly used in place of fuses and may sometimes eliminate the need for a switch. A circuit breaker differs from a fuse in that it trips to break the circuit and it may be reset, while a

Figure 11-5-16. Carbon resistor.

fuse melts and must be replaced (Figure 11-5-14).

There are several types of circuit breakers in general use in aircraft systems. One type is the magnetic circuit breaker. When excessive current flows in the circuit, it makes an electromagnet strong enough to move a small armature, which trips the breaker. Another type is the thermal-overload switch or breaker. This consists of a bimetallic strip which, when it becomes overheated from excessive current, bends away from a catch on the switch lever and permits the switch to trip open.

Most circuit breakers must be reset by hand. When the circuit breaker is reset, if the overload condition still exists, the circuit breaker will trip again to prevent damage to the circuit.

Circuit breakers used on aircraft must be designed to open regardless of the position of their operating control. Circuit breakers of this type are referred to as *trip-free*.

Aircraft circuit breakers must (by regulation) be reset manually. Automatic reset circuit breakers are not approved for use on aircraft. When the circuit breaker is reset, if the overload condition still exists, the circuit breaker will trip again to prevent damage to the circuit.

Resistors

Resistance in a practical circuit may take the form of any electrical device, such as a motor or a lamp, that uses electrical power and produces some useful function. On the other hand, the resistance of a circuit may be in the form of resistors inserted in the circuit to limit current flow. A wide variety of resistors are available. Some have a fixed ohmic value and others are variable.

Fixed resistors. Fixed resistors are manufactured from special resistance wire, graphite (carbon) or metal film. Wire-wound resistors control large currents, while composition (carbon) resistors control relatively small currents. The schematic symbols for fixed resistors are shown in Figure 11-5-15.

Composition-type fixed resistors are available in either of two types: carbon or film.

Carbon resistors are manufactured from a rod of compressed graphite and a binding material with wire leads, called *pigtails*, attached to each end of the resistor (Figure 11-5-16).

Two types of film resistors are available. One type is referred to as a carbon-film resistor. It has a thin coating of carbon around an insulator. Another type utilizes a metal film that is wrapped around a ceramic core. The advantage of film resistors is more precise values of resistance. Film resistors typically control low values of current flow.

Wire-wound resistors are constructed by winding resistance wire on a porcelain base, attaching the wire ends to metal terminals, and coating the wire for protection and heat conduction (Figure 11-5-17).

Wire-wound resistors are available with fixed taps, which can be used to change the resistance value in increments or steps. They may also be provided with sliders, which can be adjusted to change the resistance to any fraction of the total resistance (Figure 11-5-18).

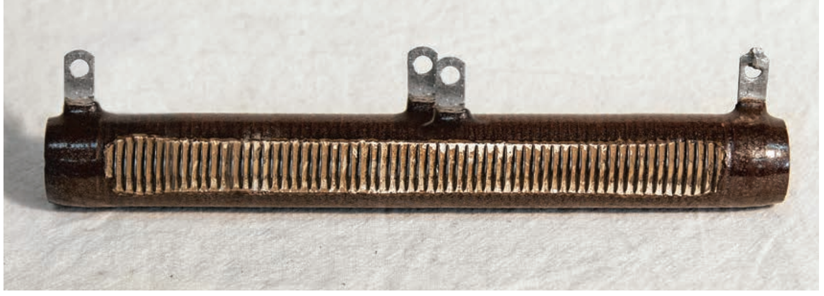


Figure 11-5-17. Fixed wire-wound resistor.

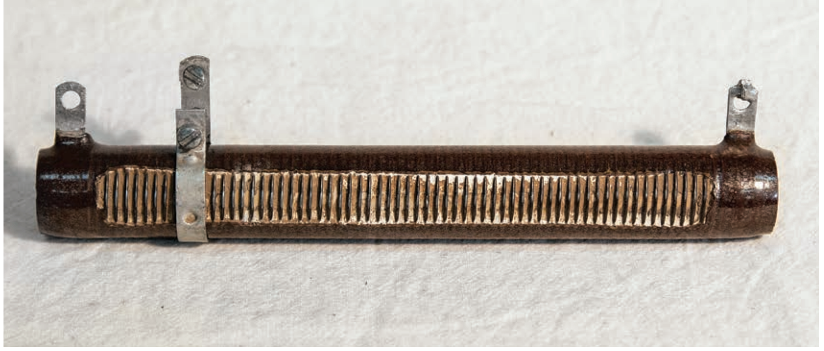


Figure 11-5-18. Wire-wound resistor with fixed and adjustable taps.

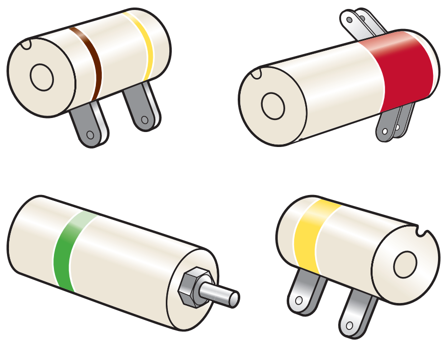


Figure 11-5-19. Precision wire-wound resistors.

Another type of wire-wound resistor is the precision wire-wound resistor (Figure 11-5-19) made of manganin wire. They are used where the resistance value must be very accurate.

Variable resistors are used in circuits where variations in current flow are necessary. The intensity of panel lights, volume of radios, and heated windshields are all examples of circuits that use variable resistors.

Variable resistors. Variable resistors are used to vary the resistance while the equipment is in operation. Wire-wound variable resistors control large currents, and carbon variable resistors control small currents. The two symbols used on a schematic or circuit diagram to represent variable resistors are shown in Figure 11-5-20.

Two types of variable resistors are rheostats and potentiometers. Rheostats and potentiometers are constructed of a circular resistance material over which a sliding contact moves.

The resistance may be distributed in many ways, and the method used determines the classification as either linear or tapered. The linear type provides a resistance evenly distributed over its entire length, while the tapered has more resistance per unit length at one end than at the other.

As an example of the difference between linear and tapered distribution, one-half turn of a linear rheostat places one half of the total resistance between either end and the slider, while one-half turn of a tapered rheostat places one-tenth (or any desired fraction) of the total resistance between one end and the slider.

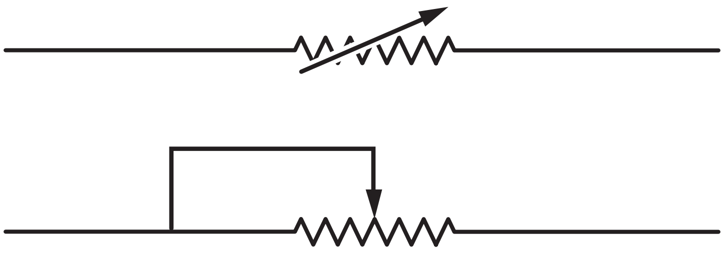


Figure 11-5-20. Symbols for variable resistors.

A *rheostat* is a variable resistor used to vary the amount of current flowing in a circuit. The rheostat is a two-terminal device and is represented schematically as a two-terminal resistance with a sliding arm contact. A rheostat connected in series with an ordinary resistance in a series circuit is shown in Figure 11-5-21.

As the slider arm moves from point A to B, the amount of rheostat resistance (AB) is increased. Since the rheostat resistance and the fixed resistance are in series, the total resistance in the circuit also increases, and the current in the circuit decreases.

If the slider arm is moved toward point A, the total resistance decreases and the current in the circuit increases.

The potentiometer is a variable resistor that has three terminals. Two ends and a slider arm are connected in a circuit. A potentiometer is used to vary the amount of voltage in a circuit and is one of the most common controls used in electrical and electronic equipment.

Resistor color code. The resistance value of any resistor can be measured by using an ohmmeter, but this is seldom necessary.

Most wire-wound resistors have their resistance value in ohms printed on the body of the resistor. Many carbon and film resistors are similarly marked, but are often mounted in such a manner that it is difficult or impossible to read the resistance value. Additionally, heat often discolors the resistor body, making the printed marking illegible. Many carbon and film resistors are so small that a printed marking cannot be used. Thus, a color-code marking is used to identify the resistance value of carbon and film resistors.

There is only one color code for carbon and film resistors, but there are two methods used to apply the colors to the resistor body. The most common is the end-to-center band system and the other is the body-end-dot system. The body-end-dot system is no longer in use in modern electrical and electronic equipment.

In the color-code system, three colors are used to indicate the resistance value in ohms, and a fourth color is sometimes used to indicate the tolerance of the resistor. By reading the colors in the correct order and by substituting numbers from the color code, the resistance value of a resistor can be determined.

It is very difficult to manufacture a resistor to an exact standard of ohmic values. Fortunately, most circuit requirements are not extremely critical. For many uses the actual resistance in ohms can be 20 percent higher or lower than the value marked on the resistor without causing difficulty.

The percentage variation between the marked value and the actual value of a resistor is known as the *tolerance* of a resistor. A resistor coded for a 5 percent tolerance will not be more than 5 percent higher or lower than the value indicated by the color code.

The resistor color code (Table 11-5-3) is made up of a group of colors, numbers, and tolerance values. Each color is represented by a number and in most cases by a tolerance value.

When the color code is used with the end-to-center band marking system, the resistor is normally marked with bands of color at one end of the resistor. The body or base color of the resistor has nothing to do with the color code and in no way indicates a resistance value. To prevent confusion, this body will never be the same color as any of the bands indicating resistance value.

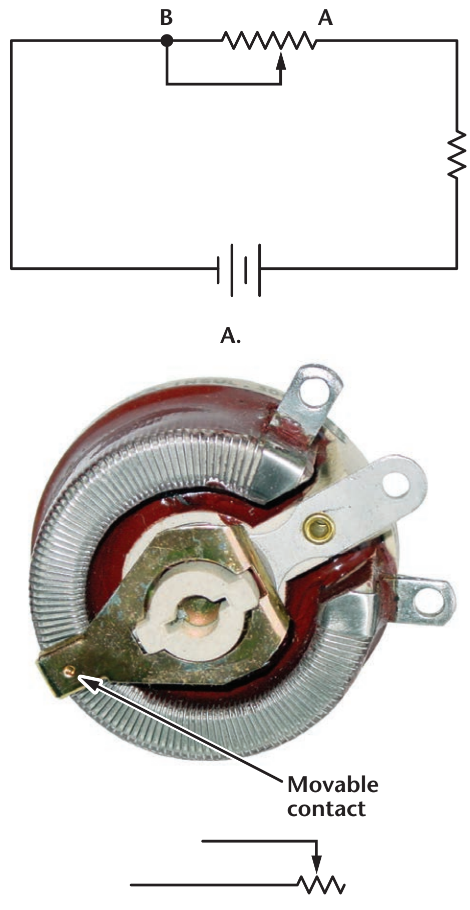


Figure 11-5-21 Rheostat in series with ordinary resistance.

Table color code		
Color tolerance	**Number**	**Tolerance**
Black	0	....
Brown	1	1%
Red	2	2%
Orange	3	3%
Yellow	4	4%
Green	5	5%
Blue	6	6%
Violet	7	7%
Grey	8	8%
White	9	9%
Gold	....	5%
Silver	....	10%

Table 11-5-3. Resistor color code.

When the end-to-center band marking system is used, the resistor will be marked by either three or four bands.

The first color band (nearest the end of the resistor) will indicate the first digit in the numerical resistance value. This band will never be gold or silver in color.

The second color band (Figure 11-5-22) will always indicate the second digit of ohmic value. It will never be gold or silver in color. The third color band indicates the number of zeros to be added to the two digits derived from the first and second bands, except in the following two cases:

If the third band is gold, the first two digits must be multiplied by 10 percent (0.1).

If the third band is silver, the first two digits must be multiplied by 1 percent (0.01).

If there is a fourth color band, it is used as a multiplier for percentage of tolerance, as indicated

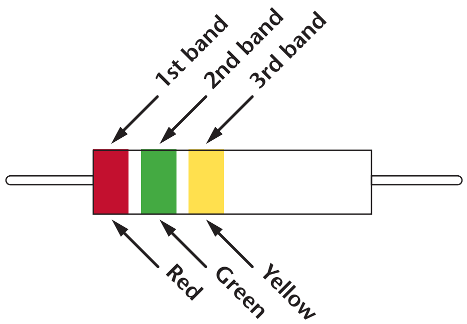


Figure 11-5-22. End-to-center band marking.

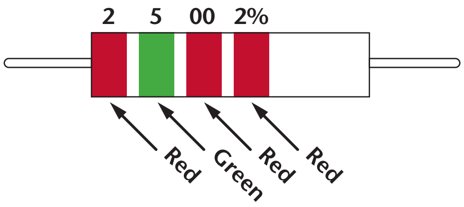


Figure 11-5-23. Resistor with 2 percent tolerance.

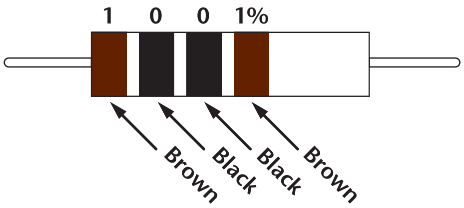


Figure 11-5-24. Resistor with a black third-color band.

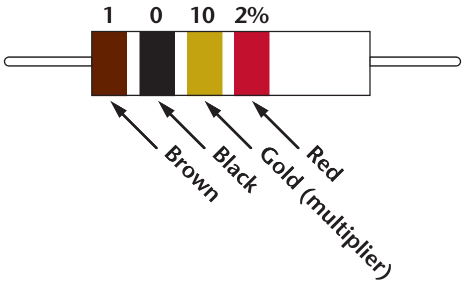


Figure 11-5-25. Resistor with a gold third-color band.

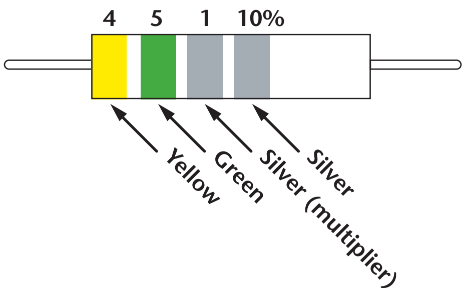


Figure 11-5-26. Resistor with a silver third-color band.

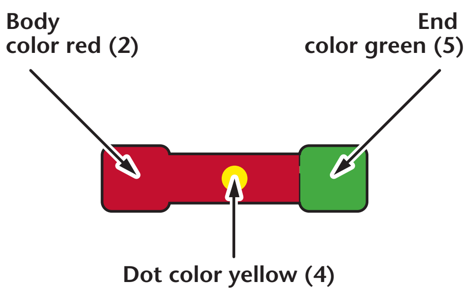


Figure 11-5-27. Resistor coded with body-end-dot system.

in the color code chart in Table 11-5-3. If there is no fourth band, the tolerance is understood to be 20 percent.

If there is a fifth color band, it is used as a product reliability percentage per 1,000 resistors produced.

Sometimes circuit considerations dictate that the tolerance must be smaller than 20 percent. Figure 11-5-23 shows an example of a resistor with a 2-percent tolerance. The resistance value of this resistor is 2,500 ± 2 percent ohms. The maximum resistance is 2,550 ohms, and the minimum resistance is 2,450 ohms.

Figure 11-5-24 contains an example of a resistor with a black third color band. The color code value of black is zero, and the third band indicates the number of zeros to be added to the first two digits.

In this case, a zero number of zeros must be added to the first two digits; therefore, no zeros are added.

The result is that the resistance value is 10 ± 1 percent ohms. The maximum resistance is 10.1 ohms, and the minimum resistance is 9.9 ohms.

There are two exceptions to the rule stating that the third color band indicates the number of zeros. The first of these exceptions is illustrated in Figure 11-5-25. When the third band is gold in color, it indicates that the first two digits must be multiplied by 10 percent. The value of this resistor is

$$10 \times 0.10 \pm 2\% = 1 \pm 0.02 \text{ ohms}$$

The second exception is that when the third band is silver, as is the case in Figure 11-5-26, the first two digits must be multiplied by 1 percent. The value of the resistor is 0.45 ± 10 percent ohms.

Body-end-dot system. The body-end-dot system of marking is rarely used today. A few examples will explain it. The location of the colors has the following significance:

Body color—1^{st} digit of ohmic value

End color—2^{nd} digit of ohmic value

Dot color—Number of zeros to be added

If only one end of the resistor is painted, it indicates the second figure of the resistor value, and the tolerance will be 20 percent. The other two tolerance values are gold (5 percent) and silver (10 percent). The opposite end of the resistor will be painted to indicate a tolerance other than 20 percent. Figure 11-5-27 shows a resistor coded by the body-end-dot system. The values are as follows:

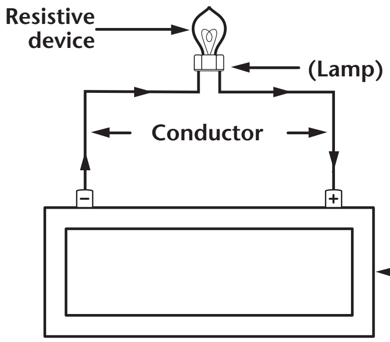


Figure 11-6-1. Simplified circuit.

Body - 1st digit 2

End - 2nd digit 5

Dot - No. of zeros 0000 (4)

The resistor value is 250,000 ± 20 percent ohms. The tolerance is understood to be 20 percent because no second dot is used.

If the same color is used more than once, the body, end, and dot may all be the same color, or any two may be the same, but the color code is used in exactly the same way. For example, a 33,000-ohm resistor will be entirely orange.

Section 6

Basic DC Circuit Arrangement

Circuit considerations. An electrical circuit consists of:

- A source of electrical pressure, or emf
- Resistance, in the form of an energy-consuming electrical device, or load
- Conductors, usually in the form of copper or aluminum wires, to provide a path for electron flow from the negative side of the power source through the resistance and back to the positive side of the power source
- Ground, or earth, is always considered to have zero potential voltage

Figure 11-6-1 is a pictorial representation of a simplified circuit. This illustrated circuit contains a source of emf (storage battery), a conductor to provide a path for the flow of electrons from the negative to the positive terminal of the battery, and a power-dissipating device (lamp) to limit the current flow. Without some resistance in the circuit, the potential difference between the two terminals would be neutralized very quickly or the flow of electrons would become so heavy that the conductor would become overheated and burn.

At the same time that the lamp acts as a current-limiting resistance in the circuit, it is also accomplishing the desired function of creating light. Since the lamp will consume power, it is classified as an electrical *load.*

Types of Circuits

Series circuits. The series circuit is the most basic of electrical circuits. All other types of circuits are elaborations or combinations of series circuits. In a series circuit, current must pass through each of the circuit components in order, one after the other, or *in series.* Due to the nature of a series circuit, if one component were to fail, current flow would cease in the entire circuit.

The circuit shown in Figure 11-6-1 is a series circuit, containing the basic components required for any circuit: a source of power (battery), a load or current-limiting resistance (resistor), and a conductor (wire).

Most practical circuits contain at least two other items: a control device (switch) and a safety device (fuse). With all five components in the circuit, it would appear as shown in Figure 11-6-2, which is a DC series circuit.

To discuss the behavior of electric current in a DC series circuit, Figure 11-6-2 is redrawn in Figure 11-6-3 to include three ammeters and two resistors. Since an ammeter measures the intensity of current flow, three have been located in the circuit to measure the current flowing at various points in the circuit.

Two identifying characteristics of series circuits involve the current and resistance in the circuit.

The first characteristic is that current is the same intensity throughout a series circuit, no matter how many components are included in the circuit. With the switch closed to complete the circuit shown in Figure 11-6-3, all three ammeters will indicate the same amount of current.

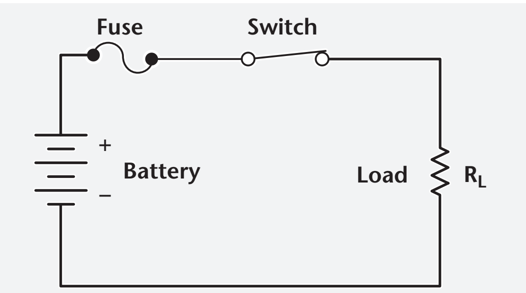


Figure 11-6-2. A DC-series circuit.

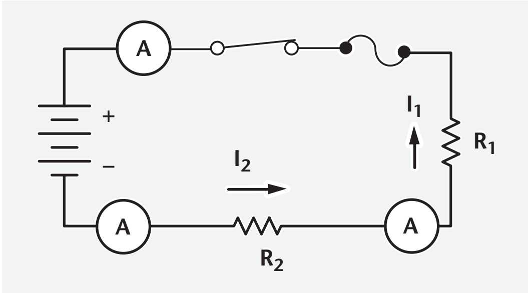


Figure 11-6-3. Current flow in a series circuit.

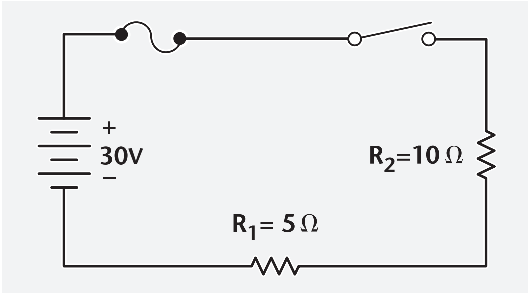


Figure 11-6-4. A series circuit with two resistors.

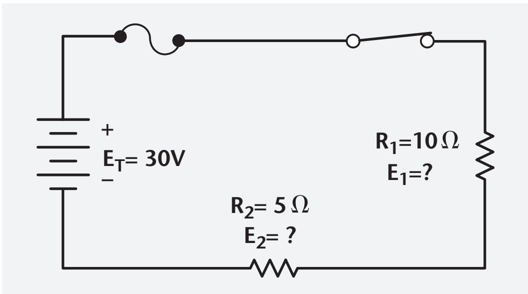


Figure 11-6-5. Voltage drops in a circuit.

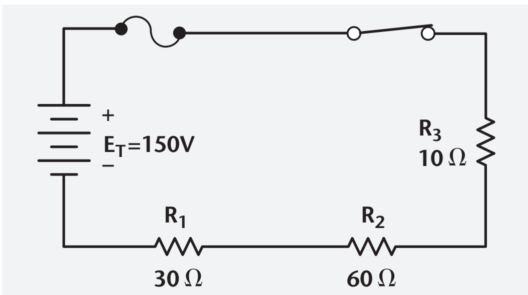


Figure 11-6-6. Applying Ohm's law.

While it is true that an increase in the number of circuit components will increase the resistance to current flow in the circuit, whatever the value of current flowing in the circuit, it will be the same value at all points in the circuit.

In Figure 11-6-3, the current through resistor R_1, is labeled I_1, and the current through resistor R_2 is labeled I_2. If the total current in the circuit is I_T, the formula describing the current flow is:

$$I_T = I_1 = I_2$$

If the number of resistors is increased to five, the formula will be:

$$I_T = I_1 = I_2 = I_3 = I_4 = I_5$$

Without indicating how much current is flowing, it will always be true that the current through any resistor in a series circuit will be the same as that through any other resistor.

The second characteristic of series circuits is that total resistance in a series circuit is the sum of the separate resistances in the circuit. Figure 11-6-4 is a series circuit containing two resistances. In order to determine the amount of current flow in this circuit, it is necessary to know how much resistance or opposition the current flow will encounter. Stated as a formula, this becomes:

$$R_T = R_1 + R_2$$

And in Figure 11-6-4, this is:

$$R_T = R_1(5\ \Omega) + R_2(10\ \Omega) \text{ or } R_T = 5 + 10 = 15\ \Omega$$

The total resistance of the circuit in Figure 11-6-4 is 15 ohms. It is important to remember that, if the circuit were altered to include 10, 20 or even 100 resistors, the total resistance would still be the sum of all the separate resistances.

It is also true that there is a certain negligible resistance in the battery, as well as in the fuse and the switch. These small values of resistance will not be considered in determining the value of current flow in this circuit.

Voltage drop refers to the loss in electrical pressure caused by forcing electrons through a resistance. It is important to distinguish between the terms *voltage* and *voltage drop* in discussing series circuits.

The applied voltage (the battery) in Figure 11-6-5 is 30 volts and is labeled E_T. The subscript T represents *Total* voltage.

Since there are two resistances in the circuit, there will be two separate voltage drops. These two voltage drops will be the loss in electrical pressure used to force electrons through the resistances.

The amount of electrical pressure required to force a given number of electrons through a resistance is proportional to the size of the resistance. Thus, the voltage drop across R_1 will be twice that across R_2 since R_1 has two times the resistance value of R_2. The drop across R_1 is labeled E_1, and the drop across R_2 is E_2. The current, I, is the same throughout the circuit.

Using:

$E = I \times R$ $\qquad$ $E_2 = I \times R_2$

$E_1 = I \times R_1$ $E_2 = 2 \text{ amps} \times 5\ \Omega$
$E_1 = 2 \text{ amps} \times 10\ \Omega$
$E_2 = 10\text{ V}$
$E_1 = 20\text{ V}$

If the voltage drops across the two resistors are added (10 V + 20 V), a value equal to the applied voltage, 30 volts, is obtained. This confirms the basic formula for series circuits:

$E_T = E_1 + E_2$

A series circuit containing three known values of resistance and an applied voltage of 150 volts is shown in Figure 11-6-6. Using these values, the unknown circuit quantities can be determined by applying Ohm's law as follows:

$R_1 = 30\ \Omega$
$R_2 = 60\ \Omega$
$R_3 = 10\ \Omega$
$R_T = 100\ \Omega$
$I_T = 1.5$ amperes
$E_{R_1} = 45\text{V}$
$E_{R_2} = 90\text{V}$
$E_{R_3} = 15\text{V}$

(A) Total resistances:

$$R_T = R_1 + R_2 + R_3 = 30 + 60 + 10 = 100\ \Omega$$

(B) Total current:

$$I_T = \frac{E_T}{R_T} = \frac{150\text{ V}}{100\ \Omega} = 1.5 \text{ amperes}$$

(C) Voltage drops:

$E = I \times R$
$E_{R_1} = I_T \times R_1 = 1.5 \text{ amps} \times 30 = 45\text{ V}$
$E_{R_2} = I_T \times R_2 = 1.5 \text{ amps} \times 60 = 90\text{ V}$
$E_{R_3} = I_T \times R_3 = 1.5 \text{ amps} \times 10 = 15\text{ V}$

Voltage drops versus the applied voltage:

$$E_T = E_{R_1} + E_{R_2} + E_{R_3} = 45\text{ V} + 90\text{ V} + 15\text{ V} = 150\text{ V}$$

The sum of the voltage drops always equals the applied voltage.

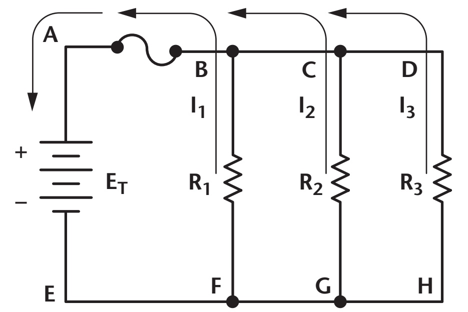


Figure 11-6-7. A parallel circuit.

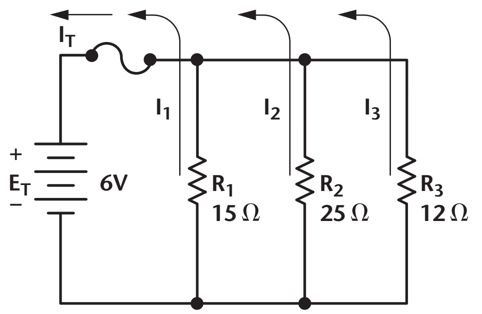


Figure 11-6-8. Current flow in a parallel circuit.

Parallel Circuits

Parallel circuits are circuits in which two or more electrical resistances, or loads, are connected across the same voltage source.

The parallel circuit differs from the series circuit in that more than one path is provided for current flow. An advantage of this is that as more paths are added, there is less opposition to the flow of electrons from the source.

A parallel circuit with three paths for current flow is shown in Figure 11-6-7. Points A, B, C, and D are connected to the same conductor and have the same electrical potential. Similarly, points E, F, G, and H are at the same potential.

Since the applied voltage appears between points A and E, the same voltage is applied between points B and F, points C and G, and between points D and H. When resistors are connected in parallel across a voltage source, each resistor has the same applied voltage, although the currents through the resistors may differ, depending on the values of resistance.

The voltage in a parallel circuit may be expressed as follows:

$E_T = E_1 = E_2 = E_3$

Where E_T is the applied voltage, E_1 is the voltage across R_1, E_2 is the voltage across R_2, and E_3 is the voltage across R_3 (Figure 11-6-7).

The current in a parallel circuit divides among the various branches depending on the resistance of each branch (Figure 11-6-8).

A branch containing a small value of resistance will have a greater current flow than a branch containing a high resistance. Current law, developed by German physicist G.R. Kirchhoff (1824-1887) in an 1874 elaboration on Ohm's law, states that the current flowing toward a point equals the current flowing away from it. Thus, the current flow in a circuit may be expressed mathematically as follows:

$$I_T = I_1 + I_2 + I_3$$

Where I_T is the total current and I_1, I_2, and I_3 are the currents through R_1, R_2, and R_3, respectively. Total current in a parallel circuit may be referred to as *line current.*

Kirchhoff's and Ohm's laws can be applied to find the total current flow in the circuit shown in Figure 11-6-8.

The current flow through the branch containing resistance R_1 is:

$$I_1 = \frac{E}{R_1} = \frac{6}{15} \text{ amps} = 0.4 \text{ amps}$$

The current through R_2 is:

$$I_2 = \frac{E}{R_2} = \frac{6}{25} \text{ amps} = 0.24 \text{ amps}$$

The current through R_3 is:

$$I_3 = \frac{E}{R_3} = \frac{6}{12} \text{ amps} = 0.5 \text{ amps}$$

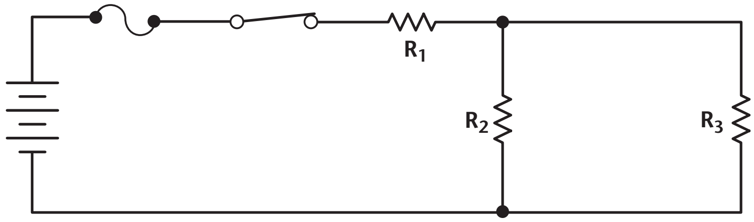


Figure 11-6-9. A series-parallel circuit.

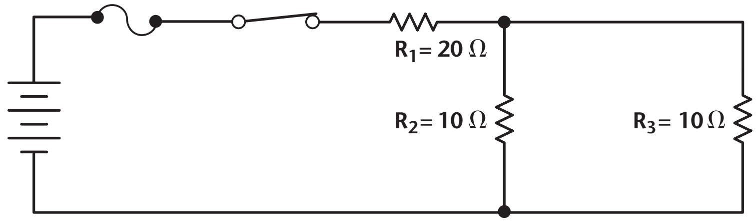


Figure 11-6-10. A series-parallel circuit (redrawn).

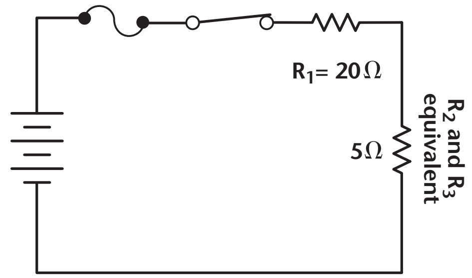


Figure 11-6-11. A redrawn series-parallel circuit.

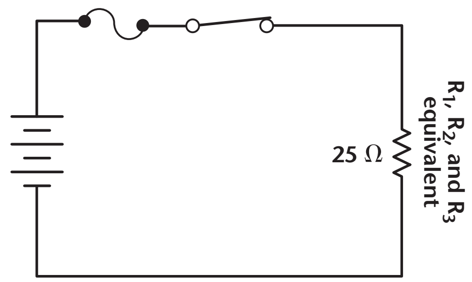


Figure 11-6-12. An equivalent series-parallel circuit.

The total current, I_T, is:

$$I_T = I_1 + I_2 + I_3$$
$$I_T = 0.4 \text{ amps} + 0.24 \text{ amps} + 0.5 \text{ amps}$$
$$I_T = 1.14 \text{ amps}$$

In a parallel circuit, $I_T = I_1 + I_2 + I_3$. By Ohm's law, the following relationships can be obtained:

$$I = \frac{E}{R}$$

Substituting these values in the equation for total current,

$$\frac{E_T}{R_T} = \frac{E_1}{R_1} + \frac{E_2}{R_2} + \frac{E_3}{R_3}$$

In a parallel circuit, $E_T = E_1 = E_2 = E_3$, therefore,

$$\frac{E}{R_T} = \frac{E}{R_1} + \frac{E}{R_2} + \frac{E}{R_3}$$

Dividing through by E gives:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

This equation is the reciprocal formula for finding the total or equivalent resistance of a parallel circuit. Another form of the equation may be derived by solving for R_T.

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

An analysis of the equation for total resistance in a parallel circuit shows that R_T is always less than the smallest resistance in a parallel circuit. Thus, a 10-ohm, a 20-ohm, and a 40-ohm resistor connected in parallel have a total resistance of less than 10 ohms.

If there are only two resistors in a parallel circuit, the reciprocal formula is:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

And simplified, this becomes:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2}$$

This formula can be used when two resistances are in parallel. Another method can be used for any number of resistors in parallel if they are of equal resistance. The resistance value of one resistor is divided by the number of resistors in parallel to determine the total resistance:

$$R_T = \frac{R}{N}$$

Where R_T equals the total resistance, R is the resistance of one resistor, and N is the total number of resistors.

Complex circuits. Most circuits in electrical equipment are not series or parallel circuits. They are usually series-parallel, or *complex,* circuits, which are combinations of series and parallel circuits. A complex circuit consists of groups of parallel resistors connected in a series with other resistors. An illustrated example of a series-parallel circuit is shown in Figure 11-6-9.

While series-parallel circuits may appear extremely complex, the same rules used for series and parallel circuits are applied to solve them.

The easiest method of handling complex circuits is to break them apart and redraw them as equivalent circuits. The circuit in Figure 11-6-10 is an example of a simple complex circuit that can be redrawn to illustrate this procedure.

In this circuit the same voltage is applied to R_2 and R_3; thus, they are in parallel. The equivalent resistance of these two resistors is equal to the value of one resistor divided by the number of resistors in parallel (when they have the same ohmic value). If this rule is applied, the circuit can be redrawn as shown in Figure 11-6-11.

This has converted the original complex circuit into a simple series circuit containing two resistances. To further simplify the circuit, the two series resistances can be added, and the circuit can be redrawn as shown in Figure 11-6-12.

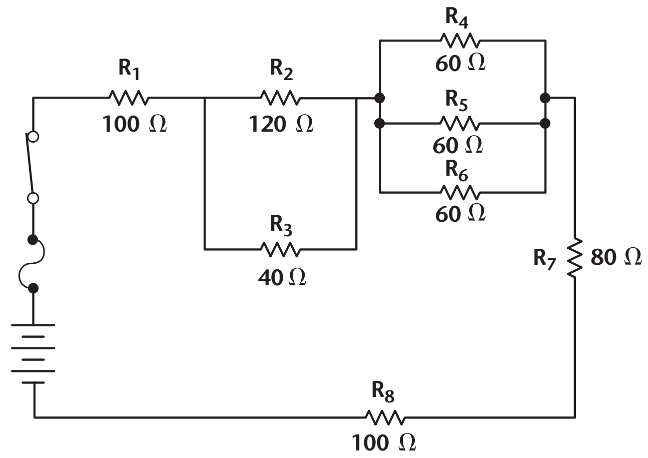


Figure 11-6-13. A more complex series-parallel circuit.

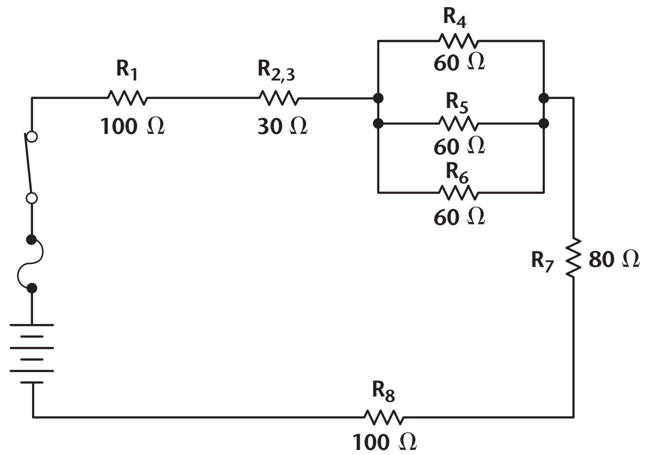


Figure 11-6-14. Series-parallel circuit with one equivalent resistance.

Complex circuits may be simplified by first reducing all parallel resistor groups, referred to as *parallel banks,* to an equivalent series resistance. Following this step, all series resistor groups, referred to as *series strings,* may be treated as basic series circuits.

The first step in simplifying the circuit in Figure 11-6-13 is to reduce each group of parallel resistors, or banks, to a single equivalent resistor.

The first bank is the parallel combination of R_2 and R_3. Since these resistors have unequal values of resistance, the formula for two parallel resistances is used:

$$R_T = \frac{R_2 R_3}{R_2 + R_3} = \frac{120 \times 40}{120 + 40} = \frac{4{,}800}{160} = 30\ \Omega$$

Then the parallel bank of R_2 and R_3 can be replaced with a single 30 Ω resistor, as shown in Figure 11-6-14.

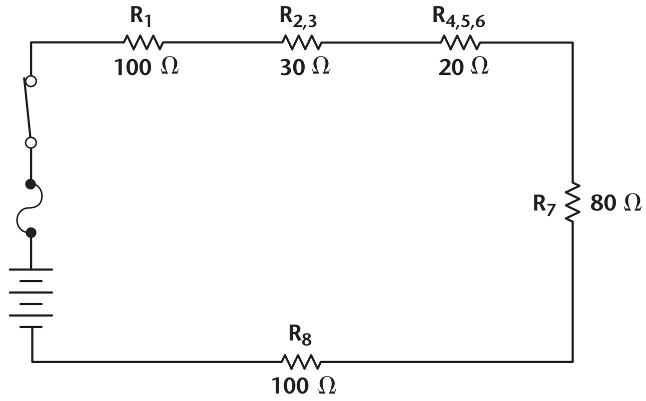


Figure 11-6-15. Series-parallel equivalent circuit.

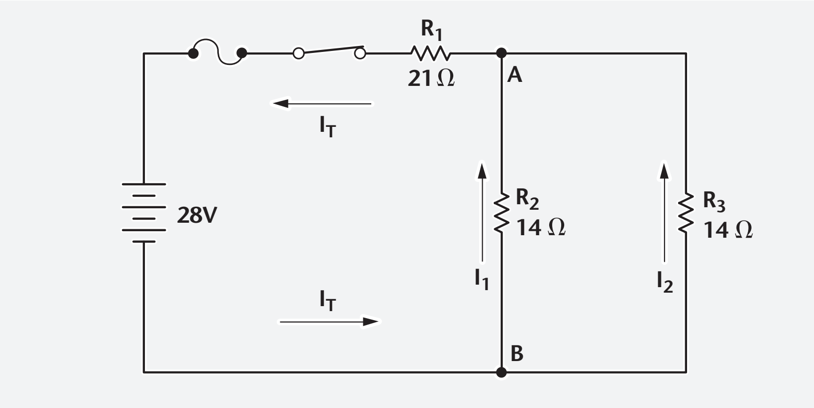


Figure 11-6-16. Current flow in a series-parallel circuit.

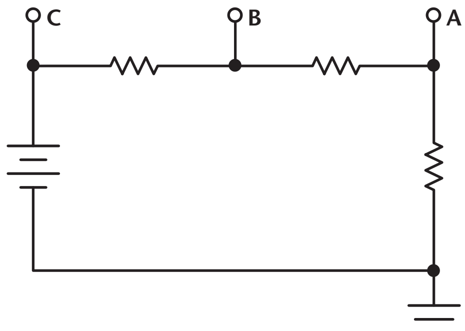


Figure 11-6-17. A voltage divider circuit.

Next, the equivalent resistance of the parallel bank of R_4, R_5, and R_6 can be found with the formula $R_T = R/N$; where $R_{4,5,6}$ is the equivalent resistance of R_4, R_5, and R_6, R is the value of one resistor and N is the number of resistors:

$$R_T = \frac{R}{N} = \frac{60}{3} = 20\ \Omega$$

The parallel bank of R_4, R_5, and R_6 can now be redrawn as a single 20 Ω resistor (Figure 11-6-15).

The original complex circuit has now been replaced with its equivalent series circuit. This circuit could be redrawn again to replace the five resistors in series with one 330-ohm resistor. This can be proved by using the total resistance formula for series circuits:

$$\begin{aligned} R_T &= R_1 + R_a + R_b + R_7 + R_8 \\ &= 100 + 30 + 20 + 80 + 100 \\ &= 330 \text{ ohms} \end{aligned}$$

Current in complex circuits. The first complex circuit used is redrawn to discuss the behavior of current flow (Figure 11-6-16).

Unlike parallel resistance, the branch currents, I_1 and I_2, cannot be established using the applied voltage. Since R_1 is in series with the parallel combination of R_2 and R_3, a portion of the applied voltage is dropped across R_1.

In order to find the branch currents, total resistance and total current must be found first. Since R_2 and R_3 are equal resistance:

$$R_{equiv} = \frac{R}{N} = \frac{14}{2} = 7\ \Omega$$

Total resistance is:

$$\begin{aligned} R_T &= R_1 + R_{equiv} \\ &= 21\ \Omega + 7\ \Omega \\ &= 28\ \Omega \end{aligned}$$

Using Ohm's law, total current is:

$$I_T = \frac{E_T}{R_T} = \frac{28\ V}{28\ \Omega} = 1 \text{ ampere}$$

The total current, 1 ampere, flows through R_1 and divides at point A, with part of the current flowing through R_2, and the other part through R_3. Since R_2 and R_3 are of equal size, it is obvious that half of the total current, or 0.5 amps, will flow through each branch.

Voltage drop in complex circuits are determined by Ohm's law:

$$\begin{aligned} E &= I \times R \\ E_{R_1} &= I_T \times R_1 \\ &= 1 \times 21 \\ &= 21 \text{ Volts} \end{aligned}$$

$$\begin{aligned} E &= I\,R \\ E_{R_2} &= I_T \times R_2 \\ &= 0.5 \times 14 \\ &= 7 \text{ Volts} \end{aligned}$$

$$\begin{aligned} E &= I \times R \\ E_{R_3} &= I_2 \times R_3 \\ &= 0.5 \times 14 \\ &= 7 \text{ Volts} \end{aligned}$$

The voltage drops across parallel resistors are always equal. It should also be remembered that, when the voltage is held constant and

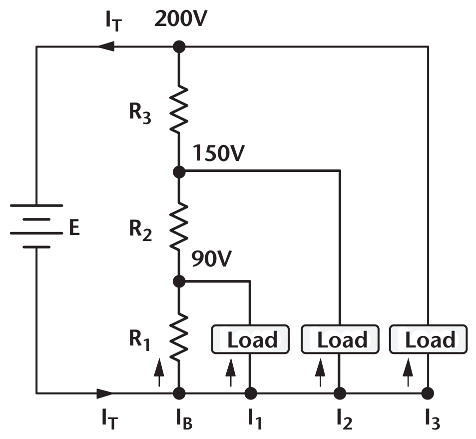


Figure 11-6-18. A typical voltage divider.

the resistance of any resistor in a series-parallel circuit is increased, the total current will decrease.

Do not confuse voltage drop to adding another parallel resistor to a parallel combination, which could reduce total resistance and increase total current flow.

Voltage dividers. A specialized application for a series circuit is a voltage divider. Voltage dividers make it possible to obtain more than one voltage from a single power source. They will always contain some bleeder current. Voltage dividers are useful only when load currents are relatively constant.

Voltage dividers consist of a resistor or resistors connected in series, with fixed or movable contacts and two fixed terminal contacts. As current flows through the resistor, different voltages can be obtained between the contacts.

A typical voltage divider is shown in Figure 11-6-17. This is known as an *unloaded* voltage divider, since no external loads are connected.

A load is any device that draws current. A heavy load means a heavy current drain. In addition to the current drawn by the various loads, there is a certain amount drawn by the voltage divider itself. This is known as bleeder current.

To understand how a loaded voltage divider works, examine the illustration in Figure 11-6-18 carefully and observe the following:

Each load draws a given amount of current: I_1, I_2, I_3. In addition to the load currents, some bleeder current (I_B) flows. The current, I_T, is drawn from the power source and is equal to the sum of all currents.

The voltage at each point is measured with respect to a common point. Note that the common point is the point at which the total current (I_T) divides into separate currents (I_1, I_2, I_3).

Each part of the voltage divider has a different current flowing in it:

- Through R_1—bleeder current (I_B)
- Through R_2—I_B plus I_1
- Through R_3—I_B plus I_1, plus I_2

The voltage across each resistor is:

- 90 volts across R_1
- 60 volts across R_2
- 50 volts across R_3

The voltage divider circuit discussed up to this point has had one side of the power supply (battery) at ground potential. In Figure 11-6-19, the common reference point (chassis ground symbol) has been moved to a different point on the voltage divider. This symbol can be distinguished from the system (airframe) ground symbol used in Figure 11-6-17.

The voltage drop across R_1 is 20 volts; however, since tap A is connected to a point in the circuit that is at the same potential as the negative side of the battery, the voltage between tap A and the reference point is a negative (–) 20 volts. Since resistors R_2 and R_3 are connected to the positive side of the battery, the voltages between the reference point and tap B or C are positive.

A simple method of determining negative and positive voltages follows:

- If current enters a resistance flowing away from the reference point, the voltage drop across that resistance is positive in respect to the reference point.
- If current flows out of a resistance toward the reference point, the voltage drop across that resistance is negative in respect to the reference point. The location of the reference point determines whether a voltage is negative or positive.

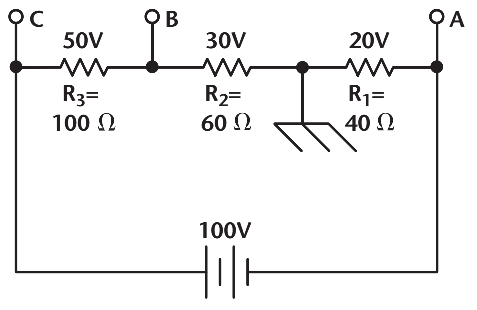


Figure 11-6-19. Positive and negative voltage on a voltage divider.

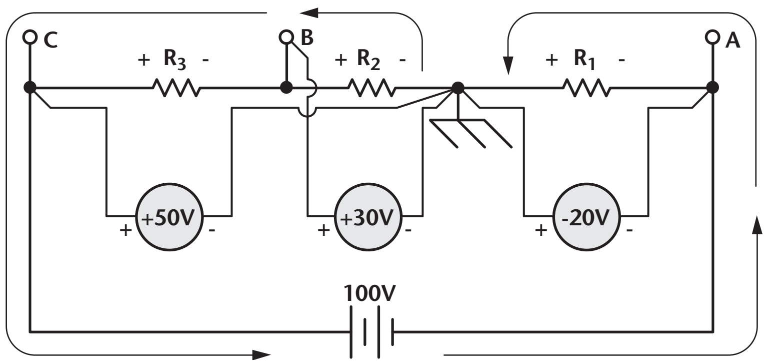


Figure 11-6-20. Current flow through a voltage divider.

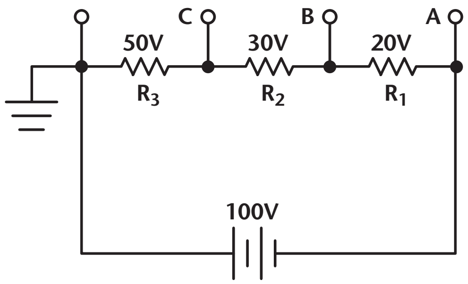


Figure 11-6-21. Voltage divider with changed ground.

- Tracing the current flow provides a means for determining the voltage polarity. Figure 11-6-20 shows the same circuit with the polarities of the voltage drops and the direction of current flow indicated.
- When the current reaches tap B, 30 more volts have been used to move the electrons through R_2. In a similar manner, the remaining 50 volts are used for R_3. Voltages across R_2 and R_3 are positive, since they are above ground potential.
- In the voltage divider used previously (seen in Figure 11-6-21), the voltage drops across the resistances are the same. However, the reference point (airframe ground) has been changed. The voltage between ground and tap A is now a negative 100 volts, or the applied voltage. The voltage between ground and tap B is a negative 80 volts, and the voltage between ground and tap C is a negative 50 volts.

Section 7

Batteries

Batteries are frequently used as DC power sources in aircraft and portable electronics equipment. In some cases, they are used as the only source of power; in others, they may provide reserve or standby power in the event of primary source failure.

Primary Cells

Batteries are made up of smaller power producing units referred to as cells. A cell is a device that converts chemical energy into electrical energy. Primary cells are not rechargeable. Once the energy of a primary cell is consumed, the cell is disposed of. Secondary cells, on the other hand, are rechargeable and therefore reusable. Both primary and secondary cells are used in aircraft and their components.

Carbon-zinc cells. One of the simplest cells is the carbon-zinc cell, shown in Figure 11-7-1.

In laboratory experiments, the carbon-zinc cell consists of a carbon rod and a small strip of zinc suspended in a solution of water (H_20) and sulphuric acid (H_2SO_4), called the electrolyte.

The common flashlight battery, which is a carbon-zinc cell, consists of a carbon rod suspended in an electrolyte paste of ammonium chloride, manganese dioxide, and granulated carbon inside a zinc canister. To prevent leakage as the zinc is consumed, the canister is placed inside a steel jacket and sealed.

Both types of carbon-zinc batteries produce about 1.5 volts, with the amount of current depending on the size of the cell. Voltage is produced in the following manner:

- Current flow in the carbon-zinc cell results from the movement of electrons from the negative electrode of the cell

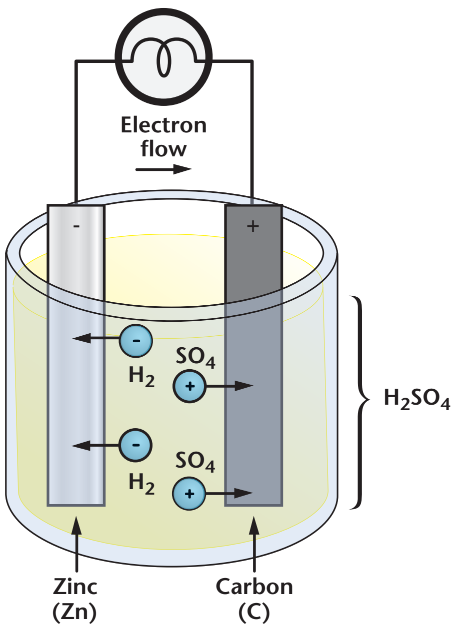


Figure 11-7-1. Simple carbon-zinc cell.

(zinc) to the positive electrode (carbon). This results in fewer electrons in the zinc and an excess of electrons in the carbon.

- The hydrogen ions (H_2) from the sulfuric acid or ammonium chloride will be attracted to the carbon rod (Figure 11-7-1). The hydrogen ions are attracted to the negative charge on the carbon since they are positively charged. The zinc electrode will have a net positive charge since it has lost electrons to the carbon rod.
- This electrolytic action will eat away the zinc electrode. The dissolving zinc will eventually cause the cell to lose its capacity to produce an electric current. Due to the loss of the ability of the cell to produce through degradation of the active cell materials, the cell cannot be recharged.

Alkaline cells. Alkaline cells function essentially the same as carbon-zinc cells. The difference is the electrolyte, which is potassium hydroxide. So the hydrogen ions come from the potassium hydroxide instead of sulfuric acid or ammonium chloride. The result is a battery capable of producing more current with the same (1.5) voltage output.

Mercury cells. Mercury cells use a similar electrolytic action as carbon-zinc and alkaline cells using a mercury pellet instead of the carbon rod. The mercury reacts with zinc through an electrolyte of potassium hydroxide. Although producing the same voltage as the other types of cells, the amount of current produced for its size makes it especially useful in applications where the necessity for small size outweighs its rather high cost.

Secondary Cells

A secondary cell also has its electrodes and electrolyte altered by the chemical action that takes place during cell charge/discharge. Unlike the primary cell, the secondary cell is capable of having the discharge process reversed. That is, the secondary cell may be recharged. Multiple secondary cells are combined in one container to form a storage battery.

Lead-acid batteries. Lead-acid batteries used in aircraft are similar to automobile batteries. Each cell contains positive plates of lead peroxide, negative plates of spongy lead, and electrolyte (sulphuric acid and water). In discharging, the chemical energy stored in the battery is changed to electrical energy; in charging, the electrical energy supplied to the battery is changed to chemical energy and stored. It is possible to charge a storage battery many times before it deteriorates permanently.

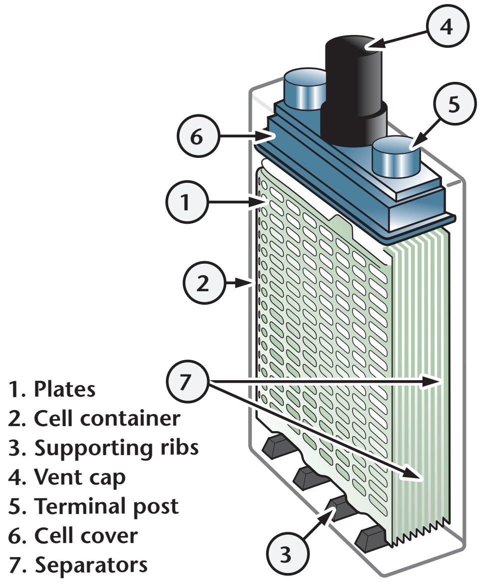


Figure 11-7-2. Lead-acid cell construction.

Construction. The components of a typical lead-acid cell are shown in Figure 11-7-2. Each plate consists of a framework called a grid, made of lead and antimony, to which the active material (spongy lead or lead peroxide) is attached. The positive and negative plates are so assembled that each positive plate is between two negative plates. Thus, the end plate in each cell is negative. Between the plates are porous separators, which keep the positive and negative plates from touching each other and shorting out the cell. The separators have vertical ribs on the side facing the positive plate. This construction permits the electrolyte to circulate freely around the plates. In addition, it provides a path for sediment to settle to the bottom of the cell.

Each cell is sealed in a hard rubber or plastic casing through the top of which are terminal posts and a hole into which is screwed a non-spill vent cap. The hole provides access for testing the strength of the electrolyte and adding water. The vent plug permits gases to escape from the cell with a minimum of leakage of electrolyte, regardless of the position the airplane might assume. In Figure 11-7-3, the construction of the vent plug

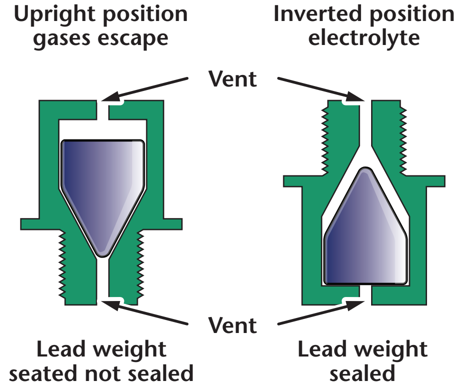


Figure 11-7-3. Nonspill battery vent plug.

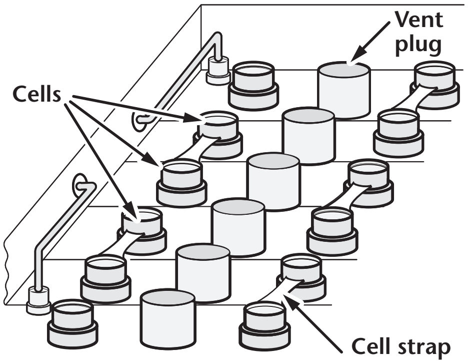


Figure 11-7-4. Connection of storage battery.

is shown. In level flight, the lead weight permits venting of gases through a small hole. In inverted flight, this hole is covered by the lead weight.

The individual cells of the battery are connected in series by means of cell straps, as illustrated in Figure 11-7-4. The complete assembly is enclosed in an acid-resistant metal container (battery box), which serves as electrical shielding and mechanical protection.

Chemical changes during discharge. A lead-acid cell contains positive plates coated with lead peroxide (PbO_2); negative plates made of lead (Pb); and a liquid electrolyte, consisting of sulphuric acid (H_2SO_4) and water (H_2O).

During discharge, lead sulfate ($PbSO_4$) is formed on both the positive and negative plates, the acid content of the electrolyte is decreased and its water content is increased. As discharge continues, the amount of lead sulfate on the plates increases until the sulfate coatings become so thick that the weakened electrolyte cannot effectively reach the active materials (lead and lead peroxide). When this happens, chemical reaction is retarded and the output of the cell is reduced.

In practice, the cell is not permitted to be discharged to this extent because thick coatings of lead sulfate are difficult to remove in charging. Additionally, a cell approaching a state of total discharge is of little use because the high internal resistance (IR) caused by the sulfate coatings on its plates reduces the current to a value too low for practical use.

Chemical changes during charge. When a cell is being charged, lead sulfate is removed from both the positive and negative plates, and sulphuric acid is again formed. In the process, the water content of the electrolyte is decreased and the density of the electrolyte is increased.

Determining the condition of charge. The state of charge of a storage battery depends on the condition of its active materials, primarily

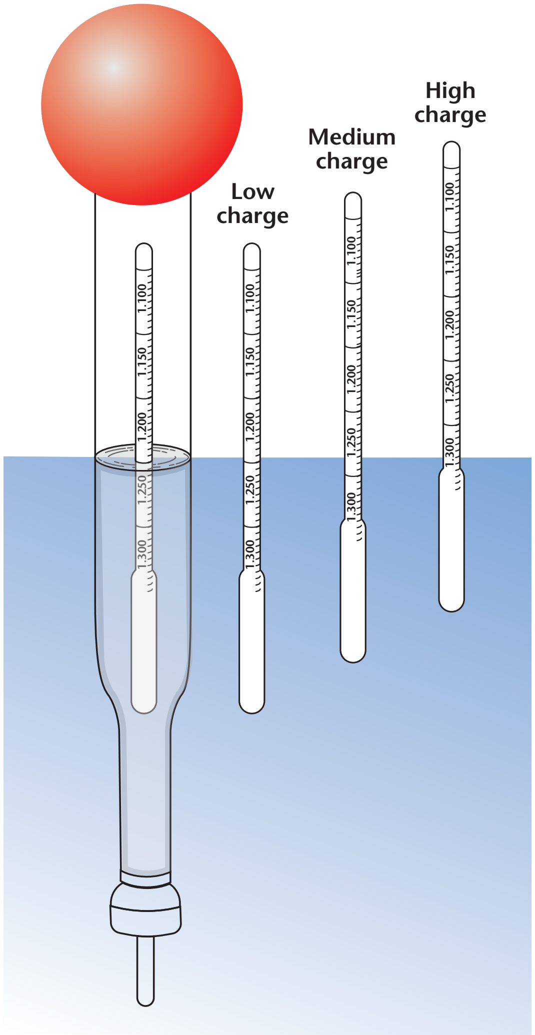


Figure 11-7-5. Hydrometer (specific gravity reading).

the plates. However, the state of charge of a battery is indicated by the density of the electrolyte and is checked by a hydrometer, which is an instrument that measures the specific gravity (weight as compared with water) of liquids.

The hydrometer commonly used consists of a small sealed glass tube weighted at its lower end so it will float upright, as shown in Figure 11-7-5. Within the narrow stem of the tube is a scale with range markings from 1.100 to 1.300.

When the hydrometer is used, a quantity of electrolyte is drawn into the syringe. The quantity of electrolyte must be sufficient to cause the hydrometer tube to float, but not so much that it floats up against the top of the syringe. That is, it must float freely within the tube of the syringe.

The depth to which the hydrometer sinks into the electrolyte is determined by the electrolyte's density, or *specific gravity*. The scale value indicated at the electrolyte level in the syringe tube is its specific gravity. The more dense the electrolyte, the higher the hydrometer will float;

the highest number on the scale (1.300) is at the lower end of the hydrometer tube.

In a new, fully charged aircraft storage battery, the electrolyte is approximately 30 percent acid and 70 percent water (by volume) and is 1.300 times as heavy as pure water.

During discharge, the solution (electrolyte) become less dense and its specific gravity drops below 1.300. A specific gravity reading between 1.300 and 1.275 indicates a high state of charge; between 1.275 and 1.240, a medium state of charge; and between 1.240 and 1.200, a low state of charge.

Aircraft batteries are generally of small capacity, but are subject to heavy loads. The values specified for state of charge are therefore rather high. Hydrometer tests are made periodically on all storage batteries installed in aircraft. An aircraft battery in a low state of charge may have, perhaps, 50 percent charge remaining, but is nevertheless considered low in the face of heavy demands, which would soon exhaust it. A battery in such a state of charge is considered in need of immediate recharging.

When a battery is tested using a hydrometer, the temperature of the electrolyte must be taken into consideration. The specific gravity readings on the hydrometer will vary from the actual specific gravity as the temperature changes.

No correction is necessary when the temperature is between 70°F (21°C) and 90°F (32°C), since the variation is not great enough to be considered. When temperatures are greater than 90°F (32°C) or less than 70°F (21°C), it is necessary to apply a correction factor.

Some hydrometers are equipped with a correction scale inside the tube. With other hydrometers it is necessary to refer to a chart provided by the manufacturer.

In either case, the corrections should be added to, or subtracted from, the reading shown on the hydrometer (Table 11-7-1 on sulfuric acid temperature correction).

Lead-acid battery ratings. The voltage of a battery is determined by the number of cells connected in series to form the battery. A battery rated at 12 volts consists of six lead-acid cells connected in series, and a battery rated at 24 volts is composed of 12 cells. Although the voltage of one lead-acid cell just removed from a charger is approximately 2.2 volts, it is normally rated at only 2 volts; it soon drops to that value because of internal resistance.

The capacity of a storage battery is rated in ampere-hours (amperes furnished by the battery times the amount of time current can be drawn). This rating indicates how long the battery may be used at a given rate before it becomes completely discharged.

Ampere-hour defined. The ampere-hour capacity of a battery depends upon its total effective plate area.

Connecting batteries in parallel increases ampere-hour capacity. Connecting batteries in series increases the total voltage but not the ampere-hour capacity. In multiengine airplanes, where more than one battery is used, the batteries are usually connected in parallel. The voltage is equal to that of one battery, but the ampere-hour capacity is increased. The total capacity is the sum of the ampere-hour ratings for the individual batteries.

In theory, a 100 ampere-hour battery will furnish 100 amperes for 1 hour, 50 amperes for 2 hours, or 20 amperes for 5 hours. Actually, the ampere-hour output of a particular battery depends on the rate at which it is discharged. Heavy discharge current heats the battery and decreases its efficiency and total ampere-hour output.

The standard discharge rate for aircraft batteries is generally accepted as five hours. However, this time of five hours is only a basis for rating and does not necessarily mean the length of time during which the battery is expected to furnish current. Under actual service conditions, the

Electrolyte temperature		Points to be added to or subtracted from specific gravity readings
°C	°F	
60	140	+24
55	130	+20
49	120	+16
43	110	+12
38	100	+8
33	90	+4
27	80	0
23	70	-4
15	60	-8
10	50	-12
5	40	-16
-2	30	-20
-7	20	-24
-13	10	-28
-18	0	-32
-23	-10	-36
-28	-20	-40
-35	-30	-44

Table 11-7-1. Sulfuric acid temperature correction.

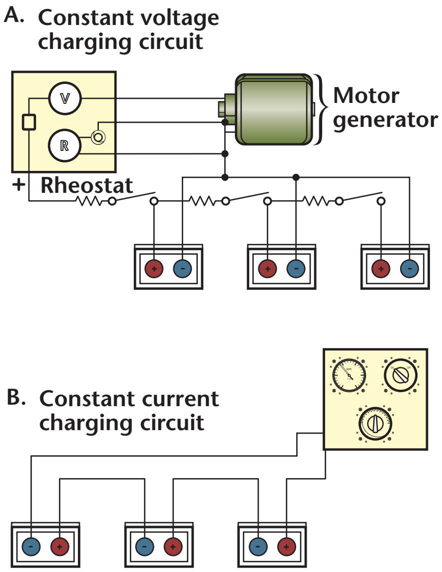


Figure 11-7-6. Battery charging methods.

battery can be completely discharged within a few minutes, or it may never be discharged if the generator provides sufficient charge.

High-discharge rates specify the capacity of a battery when current is drawn out over a shorter period of time. Two common high-discharge rates are the 20-minute rating and the 5-minute rating. They specify the amount of current that can be drawn from a fully charged battery to drop the open cell voltage to 1.75 volts in 20 or 5 minutes, respectively.

Servicing and Charging

Inspection and servicing. Lead-acid batteries are inspected for signs of electrolyte leakage, loose or missing holddown fittings or hardware, loose or broken terminals, loose or missing vent caps, and for proper electrolyte level. Battery vent lines should be checked for proper attachment, and for cuts, kinks, or blockages.

Lead-acid batteries are prone to self-discharge if they are not kept clean. The residue, which forms on the battery case during use, is both conductive and corrosive. This material must be removed to prolong battery life.

Lead-acid batteries may be cleaned with a solution of bicarbonate of soda (baking soda) and water. A soft brush may be used to loosen deposits of residue that may have formed.

Always use a non-conductive brush when cleaning the battery, and do not allow any of the bicarbonate solution to enter the cells, since this would neutralize the electrolyte.

The specific gravity of a cell is reliable only if nothing has been added to the electrolyte except occasional small amounts of distilled water to replace that lost through evaporation.

Hydrometer readings should always be taken before adding distilled water, never after. This allows the water to mix thoroughly with the electrolyte and to avoid drawing up into the hydrometer syringe a sample that does not represent the true strength of the solution.

Extreme care should be exercised when making the hydrometer test of a lead-acid cell. The electrolyte should be handled carefully, for sulphuric acid will burn clothing and skin. If the acid does contact the skin, the area should be washed thoroughly with water and then bicarbonate of soda should be applied.

Following a specific gravity check, the cell electrolyte level may be adjusted, if necessary. The level should be slightly above the top of the plates or up to the bottom of a ring in the cell filler neck, as specified by the battery manufacturer. It is not usually necessary to add electrolyte unless some spillage has occurred. Then add only distilled or demineralized water.

Charging Methods

A storage battery may be charged by passing DC current through the battery in a direction opposite to that of the discharge current.

A larger voltage is needed for charging because of the voltage drop in the battery caused by the internal resistance. Batteries are charged by either the constant-voltage or constant-current method.

When a storage battery is being charged, it generates a certain amount of hydrogen and oxygen.

Figure 11-7-7. Battery quick disconnect assembly.

Since this is an explosive mixture, it is important that steps be taken to prevent ignition of the gas mixture. The vent caps should be loosened and left in place. No open flames, sparks, or other source of ignition should be permitted in the vicinity. Before disconnecting or connecting a battery to the charge, always turn off the power by means of a remote switch.

Constant-voltage method. In the constant-voltage method shown in Figure 11-7-6A, a motor-generator set with a constant, regulated voltage forces the current through the battery. In this method, the current at the start of the process is high but automatically tapers off, reaching a value of approximately 1 ampere when the battery is fully charged. The constant-voltage method requires less time and supervision than does the constant-current method. In the aircraft, the storage battery is charged by DC from the aircraft generator system. This method of charging is the constant-voltage method, since the generator voltage is held constant by use of a voltage regulator.

Constant-current method. In the constant-current method, Figure 11-7-6B, the current remains almost constant during charging. This method requires a longer time to charge a battery fully and, toward the end of the process, presents the danger of overcharging if care is not exercised. Constant-current chargers can be used to charge several batteries at once, by connecting the batteries in a series and adjusting the charger accordingly.

Battery Installation

Batteries are generally contained inside a box, which is placed in a mount or on a platform that has been coated, to protect it from the corrosive effects of electrolyte spills and other corrosive by-products of the battery. The battery is held securely in the mount or on the platform using hold down brackets and other common hardware.

The battery box has a removable top with a vent-tube nipple at each end. When the battery is installed in an airplane, a vent-tube is attached to each nipple. One tube is the intake tube and is exposed to the slipstream, and the other is the exhaust vent tube.

The exhaust vent tube is attached to the battery drain sump, which is a glass jar containing a felt pad moistened with a concentrated solution of sodium bicarbonate (baking soda). With this arrangement, the airstream is directed through the battery case where battery gases are picked up, neutralized in the sump, and then expelled overboard without damage to the airplane.

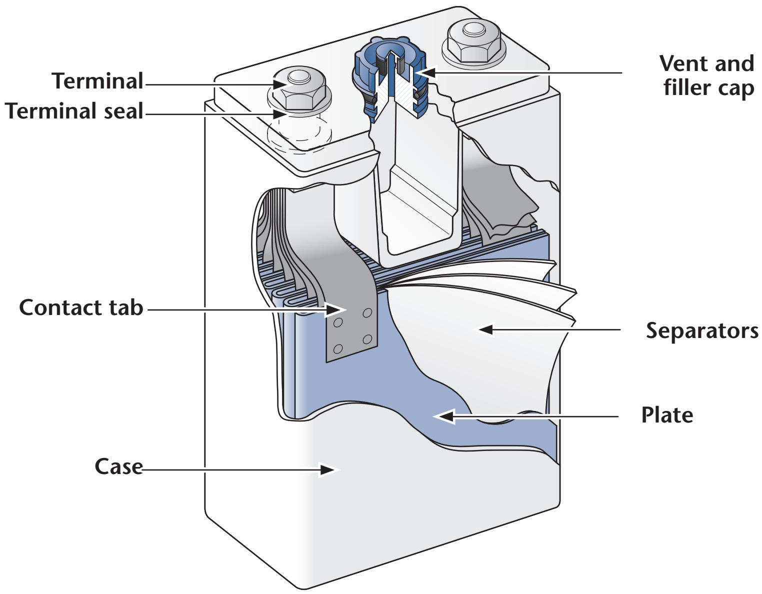


Figure 11-7-8. Nickel-cadmium cell construction.

To facilitate installation and removal of the battery in some aircraft, a quick-disconnect assembly is used to connect the power leads to the battery. This assembly, which is shown in Figure 11-7-7, attaches the battery leads in the aircraft to a receptacle mounted on the side of the battery. The receptacle covers the battery terminal posts and prevents accidental shorting during installation and removal. The plug consists of a socket and a handwheel with a coarse-pitch thread. It can be readily connected to the receptacle by the handwheel. Another advantage of this assembly is that the plug can be installed in only one position, eliminating the possibility of reversing the battery leads.

Freezing. A fully charged lead-acid battery will not freeze because, at a specific gravity of 1.300, the electrolyte freezing point is -90°F (-67°C).

Nickel-Cadmium Batteries

Although available for quite some time, *nickel-cadmium batteries* were not used extensively in aviation until increases in the number of commercial and executive jet aircraft made them economically practicable. The many advantages of the nickel-cadmium battery were well known, but its initial cost was several times that of the lead-acid battery. The increasing use of the nickel-cadmium battery (often referred to by a variety of trade names) stems largely from the low maintenance cost derived from the long service life of the battery. Additionally, the nickel-cadmium battery has a short recharge time, excellent reliability, and good starting capability (Figure 11-7-8).

Observation	Probable cause	Corrective action
High-trickle charge; when charging at constant voltage of 28.5 (±0.1) volts, current does not drop below 1 amp after a 30-minute charge	Defective cells	While still charging, check individual cells. Those below 0.5 volts are defective and should be replaced. Those between 0.5 and 1.5 volts may be defective or may be unbalanced. Those above 1.5 volts are OK.
High-trickle charge after replacing defective cells, or battery fails to meet amp-hour capacity check	Cell imbalance	Discharge battery and short out individual cells for 8 hours. Charge battery using constant-current method. Check capacity and, if OK, recharge using constant current method.
Battery fails to deliver rated capacity	Cell imbalance or fault cells	Repeat capacity check, discharge and constant-current charge a maximum of 3 times. If capacity does not develop, replace faulty cells.
No potential available	Complete battery failure	Check terminals and all electrical connections. Check for dry cell. Check for high-trickle charge.
Excessive white crystal deposits on cells (There will always be some potassium carbonate present due to normal gassing.)	Excessive spewage	Battery subject to high charge current, high temperature, or high liquid level. Clean battery, constant-current charge and check liquid level. Check charger operation.
Distortion of cell case	Overcharge or high heat	Replace cell
Foreign material in cells; black or gray particles	Impure water, high heat, high concentration of KOH, or improper water level	Adjust specific gravity on electrolyte level. Check battery for cell imbalance or replace defective cell.
Excessive corrosion of hardware	Defective or damaged plating	Replace parts
Heat or blue marks on hardware	Loose connections causing overheating of intercell connector or hardware	Clean hardware and properly torque connectors.
Excessive water consumption; dry cell	Cell imbalance	Proceed as above for cell imbalance.

Table 11-7-2. Nickel-cadmium troubleshooting chart.

Construction. As with the lead-acid battery, the cell is the basic unit of the nickel-cadmium battery. It consists of positive and negative plates, separators, electrolyte, cell vent, and cell container. The positive plates are made from a porous plaque on which nickel-hydroxide has been deposited. The negative plates are similar plaques, with cadmium-hydroxide deposits.

The porous plaque in both positive and negative plates is obtained by sintering nickel powder to a fine-mesh wire screen. Sintering is a process that fuses together extremely small granules of powder at a high temperature. After the active positive and negative materials are deposited on the plaque, it is formed and cut into the proper plate size.

A nickel tab is then welded to a corner of each plate and the plates are assembled with the tabs welded to the proper terminals. The plates are separated from each other by a continuous strip of porous plastic.

The electrolyte used in the nickel-cadmium battery is a 30 percent solution (by weight) of potassium hydroxide (KOH) in distilled water. The specific gravity of the electrolyte remains between 1.240 and 1.300 at room temperature. No appreciable changes occur in the electrolyte during charge or discharge. As a result, the battery charge cannot be determined by a specific gravity check of the electrolyte. The electrolyte level should be maintained just above the tops of the plates.

Chemical changes during charge. When a charging current is applied to a nickel-cadmium battery, the negative plates lose oxygen and begin forming metallic cadmium. The active material of the positive plates, nickel-hydroxide, becomes more highly oxidized. This process continues while the charging current is applied or until all the oxygen is removed from the negative plates and only cadmium remains.

Toward the end of the charging cycle and when overcharged the cells emit gas. This gas is caused by decomposition of the water in the electrolyte into hydrogen at the negative plates and oxygen at the positive plates. The voltage used during charging, as well as the temperature, determines when gassing will occur. To completely charge a nickel-cadmium battery, some gassing, however slight, must take place; thus, some water will be used.

Chemical changes during discharge. The chemical action is reversed during discharge.

The positive plates slowly give up oxygen, which is regained by the negative plates. This process results in the conversion of the chemical energy into electrical energy.

During discharge, the plates absorb a quantity of the electrolyte. On recharge, the level of the electrolyte rises and, at full charge, will be at its highest level. Therefore, water should be added only when the battery is fully charged.

Servicing nickel-cadmium batteries. There are significant differences in the servicing methods required for the nickel-cadmium batteries and those of the lead-acid batteries. The most important points to be observed are as follows:

- Separate storage and maintenance areas should be provided for nickel-cadmium and lead-acid batteries. The electrolyte in nickel-cadmium batteries is chemically opposite to the sulphuric acid used in a lead-acid battery. Fumes from a lead-acid battery can contaminate the electrolyte in a nickel-cadmium battery.
- This separation precaution should include equipment such as hand tools and hydrometer syringes used with lead-acid batteries. All steps must be taken to keep anything containing acid away from the nickel-cadmium battery shop.
- The potassium hydroxide electrolyte used in nickel-cadmium batteries is extremely corrosive. Protective goggles, rubber gloves, and rubber aprons should be used to handle and service batteries.
- Suitable washing facilities should be provided in case electrolyte is spilled on clothing or the skin. Such exposures should be rinsed immediately with water or vinegar, lemon juice, or a boric acid solution. When potassium hydroxide and distilled water are mixed to make electrolyte, the potassium hydroxide should be added slowly to the water, not vice versa.
- Severe arcing may result if a wire brush is used to clean a battery. The vent plugs should be closed during the cleaning process and the battery should never be cleaned with acids, solvents, or any chemical solution.
- Spilled electrolyte can react with carbon dioxide to form crystals of potassium carbonate. Both nontoxic and noncorrosive, these crystals can be loosened with a fiber brush and wiped off with a damp cloth.
- When potassium carbonate forms on a properly serviced battery, it may indicate the battery is overcharging because the voltage regulator is out of adjustment.
- Additional water should never be added to the battery earlier than 3-4 hours after it has been fully charged. If necessary, use only distilled or demineralized water.

Since the electrolyte does not react chemically with the cell plates, the specific gravity of the electrolyte does not change appreciably. Thus, it is not possible to determine the state of charge of the battery with a hydrometer; nor can the charge be determined by a voltage test because the voltage of a nickel-cadmium battery remains constant during 90 percent of the discharge cycle.

Nickel-cadmium batteries should be serviced at regular intervals based on experience since water consumption varies with ambient temperature and operating methods. At greater intervals the battery should be removed from the aircraft and given a bench check in the shop.

If a battery is completely discharged, some cells may reach zero potential and charge in the reverse direction, affecting the battery in such a manner that it will not retain a full capacity charge. In such cases the battery should be discharged and each cell short-circuited to obtain a zero potential cell balance before recharging the battery. This process is called *equalization.*

Charging can be accomplished by either the constant-voltage or the constant-current method. Always follow the recommendations and procedures in the battery and equipment manufacturer's manuals.

For constant-voltage charging, maintain a constant charging voltage until the current decays to 3 amperes or less, assuring that the battery cell temperature does not exceed 100°F (38°C).

A cell demonstrating a rise in temperature is an indication of a breakdown of the celophane-type insulation between the plates. If a nickel cadmium cell is subjected to an excessively high charge rate it becomes overheated. When this occurs, its internal resistance drops. The lower internal resistance allows the cell to take more current from the charger, and more heat is generated. This condition is known as thermal runaway. If this occurs, the cell must be inspected.

For constant-current charging, continue charging until the voltage reaches the desired level, then reduce the current level to 4 amperes. Continue until its desired voltage is reached or until the battery temperature exceeds 100°F (38°C) and the voltage begins to decline.

The chart in Table 11-7-2 can be used as a guide in troubleshooting battery malfunctions.

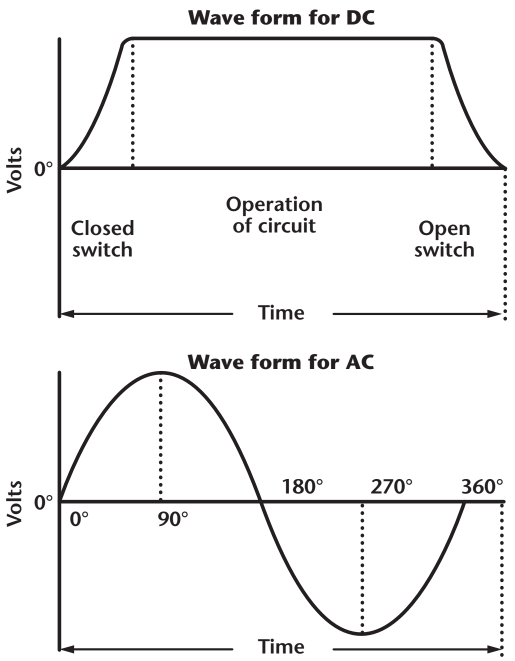


Figure 11-8-1. DC and AC voltage curves.

While nickel-cadmium and lead-acid batteries are normally interchangeable, special precautions must be taken when interchanging them.

When replacing a lead-acid battery with a nickel-cadmium battery, the battery compartment must be clean, dry, and free of all traces of acid from the old battery.

The compartment must be washed out and neutralized with boric acid solution, allowed to dry thoroughly, and then painted with an alkali-resisting varnish.

The pad in the battery sump jar should be saturated with a 3 percent (by weight) solution of boric acid and water before connecting the battery vent system.

Section 8

Alternating Current

Advantages of Alternating Current Over Direct Current

Alternating current has largely replaced DC in commercial power systems for a number of reasons. Power transmitted at a high voltage and a low amperage loses a much smaller amount of energy than a similar amount of power transmitted at a high amperage and a low voltage. Amperage causes heat and energy loss during transmission. Alternating current voltages can be easily increased or decreased by means of transformers. This allows AC to be transmitted over long distances more readily and more economically than DC.

Additionally, space and weight can be saved since AC devices such as motors are smaller and simpler than DC devices. In most AC motors, no brushes are required and commutation trouble at high altitude is eliminated. Circuit breakers will operate satisfactorily under load at high altitudes in an AC system, whereas arcing is so excessive on DC systems that circuit breakers must be replaced frequently. Finally, most aircraft using a 24-volt DC system have special equipment that requires a certain amount of 400-Hz AC power.

Many of the principles, characteristics, and effects of AC are similar to those of DC. There are also a number of differences. These are explained in detail in a later section. Direct current flows constantly, in only one direction, with a constant polarity. It changes magnitude only when the circuit is opened or closed, as shown in the DC wave form in Figure 11-8-1. Alternating current changes direction at regular intervals, increases in value at a definite rate from zero to a maximum positive strength, and decreases back to zero; then it flows in the opposite direction, similarly progressing to a maximum negative value and again returning to zero.

Since AC constantly changes direction and magnitude, two effects take place in AC circuits that do not occur in DC circuits. They are inductive reactance and capacitive reactance, both of which are discussed later in this chapter.

Generation of Alternating Current Electricity

The discovery that an electric current flowing through a conductor creates a magnetic field around the conductor triggered considerable scientific speculation about whether a magnetic field could create a current flow in a conductor. In 1831, the English scientist Michael Faraday demonstrated that it could. This discovery is the basis for the operation of the generator, signaling the beginning of the electrical age.

Figure 11-8-2 demonstrates how an electric current can be created by a magnetic field. Several turns of a conductor are wrapped around a cylindrical form, and the ends of the conductor are connected together to form a complete circuit, which includes a galvanometer.

If a simple bar magnet is plunged into the cylinder, the galvanometer can be observed to deflect in one direction from its zero (center) position (Figure 11-8-2A). When the magnet is

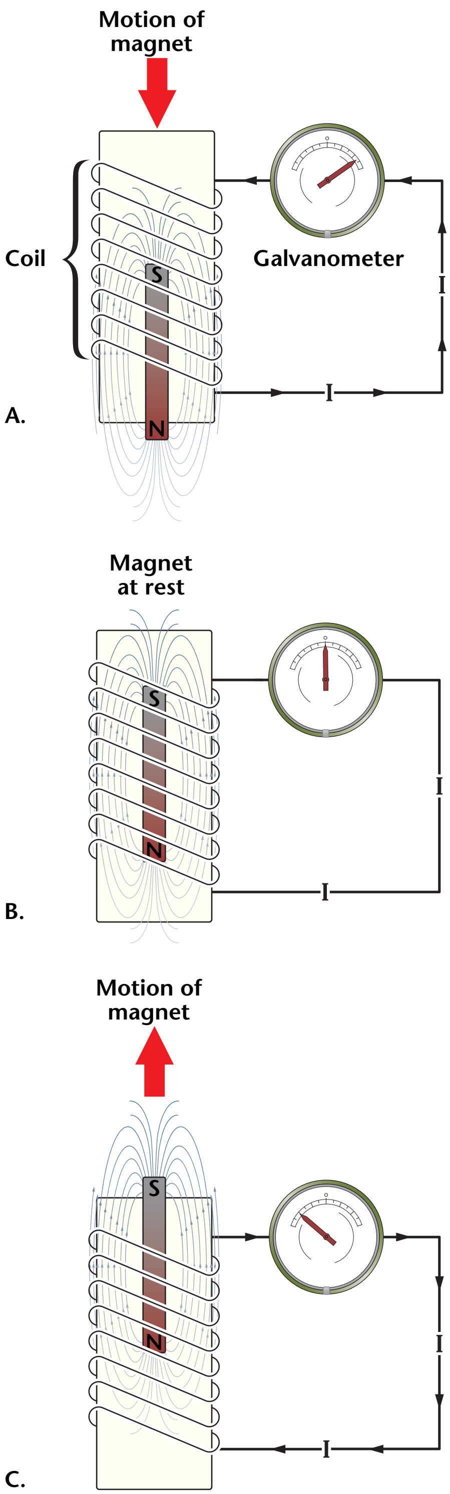


Figure 11-8-2. Inducing a current flow.

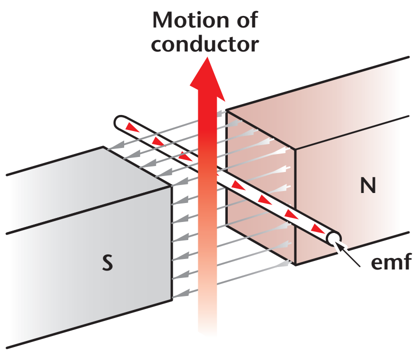


Figure 11-8-3. Inducing an emf in a conductor.

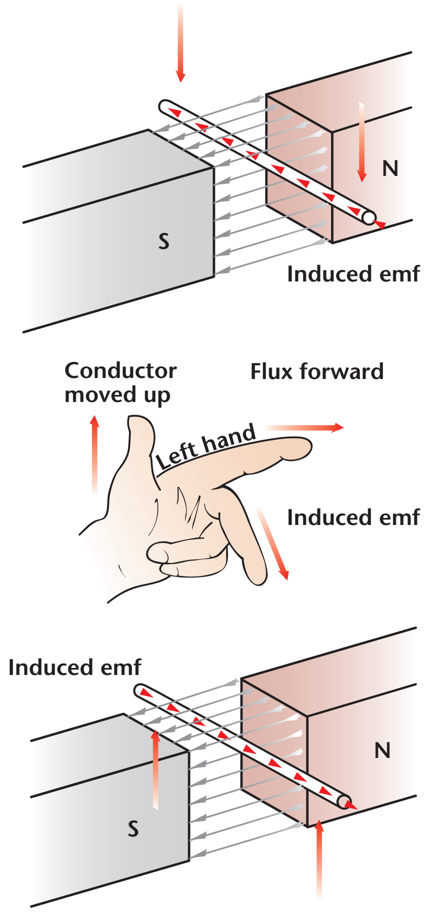


Figure 11-8-4. Application of the generator left-hand rule.

at rest inside the cylinder, the galvanometer shows a reading of zero, indicating that no current is flowing (Figure 11-8-2B).

The galvanometer in Figure 11-8-2C, indicates a current flow in the opposite direction when the magnet is pulled from the cylinder.

The same results may be obtained by holding the magnet stationary and moving the cylinder over the magnet, indicating that a current flows when there is relative motion between the wire coil and the magnetic field. These results obey a law first stated by the Estonian scientist, Heinrich Lenz (1804-1865).

Lenz's law states that the induced current caused by the relative motion of a conductor and a magnetic field always flows in such a direction that its magnetic field opposes the motion.

When a conductor is moved through a magnetic field, as shown in Figure 11-8-3, an electromotive force (emf) is induced in the conductor. The

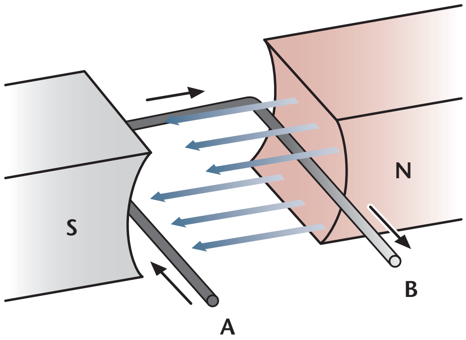


Figure 11-8-5. Voltage induced in a loop.

direction (polarity) of the induced emf is determined by the magnetic lines of force and the direction the conductor is moved through the magnetic field.

The generator left-hand rule (not to be confused with the left-hand rules used with a coil) can be used to determine the direction of the induced emf, as shown in Figure 11-8-4. The first finger of the left hand is pointed in the direction of the magnetic lines of force (north to south), the thumb is pointed in the direction of movement of the conductor through the magnetic field, and the second finger points in the direction of the induced emf. When two of these three factors are known, the third may be determined by the use of this rule.

When a loop conductor is rotated in a magnetic field, as shown in Figure 11-8-5, a voltage is induced in each side of the loop. The two sides cut the magnetic field in opposite directions, and although the current flow is continuous, it moves in opposite directions with respect to the two sides of the loop. If sides A and B and the loop are rotated half a turn and the sides of the conductor have exchanged positions, the induced emf in each wire reverses its direction. This happens because the wire formerly cutting the lines of force in an upward direction is now moving downward.

The value of an induced emf depends on three factors:

- The number of wires moving through the magnetic field
- The strength of the magnetic field
- The speed of rotation

Generators used to produce an alternating current are called AC generators or alternators. The simple generator shown in Figure 11-8-6 illustrates one method of generating an alternating voltage.

The basic generator consists of a rotating loop (marked A and B) placed between two magnetic poles (N and S). The ends of the loop are connected to two metal slip or collector rings (C1 and C2). Current is taken from the collector rings by brushes. If the loop is considered as separate wires A and B, and the left-hand rule for generators (not to be confused with the left-hand rule for coils) is applied, then it can be observed that as wire A moves up across the field, a voltage is induced which causes the current to flow inward.

As wire B moves down across the field, a voltage is induced that causes the current to flow outward. When the wires are formed into a loop, the voltages induced in the two sides of the loop are combined. Therefore, for explanatory

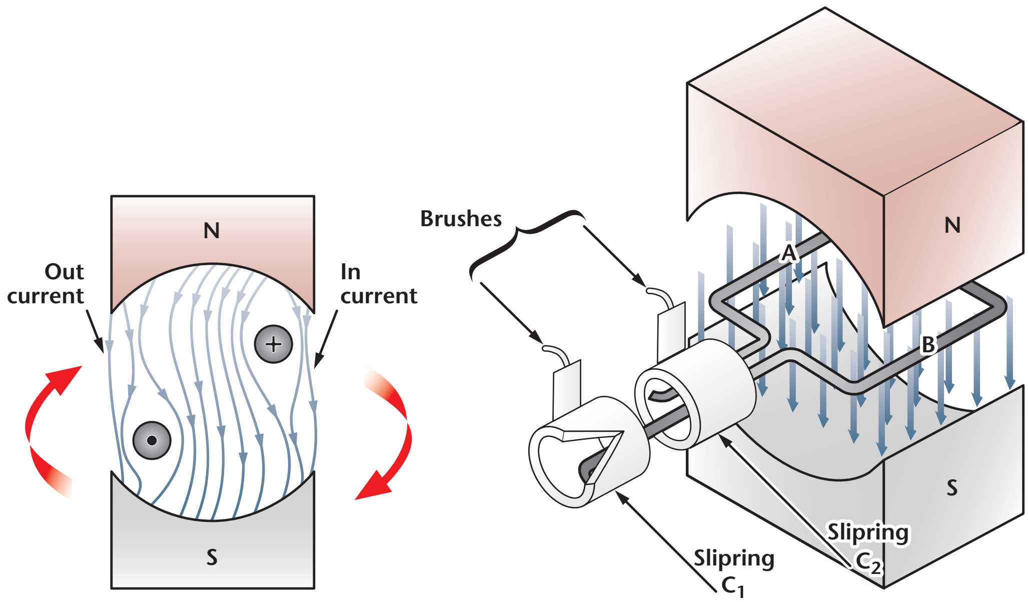


Figure 11-8-6. A simple generator.

Position 1

Rotating conductors moving parallel to magnetic field, cutting minimum lines of force.

Position 2
One-quarter turn completed

Conductors cutting directly across the magnetic field as conductor A passes across the north magnetic pole and B passes across the south pole.

Position 3
One-half turn completed

Conductors again moving parallel to magnetic field cutting minimum lines of force.

Position 4
Three-quarter turn completed

Conductors again moving directly across magnetic field A passes across south magnetic pole and B across north magnetic pole.

Position 5
Full turn completed

Conductor A has made one complete cycle and is in same position as position 1. The generator has generated one complete cycle of alternating voltage or current.

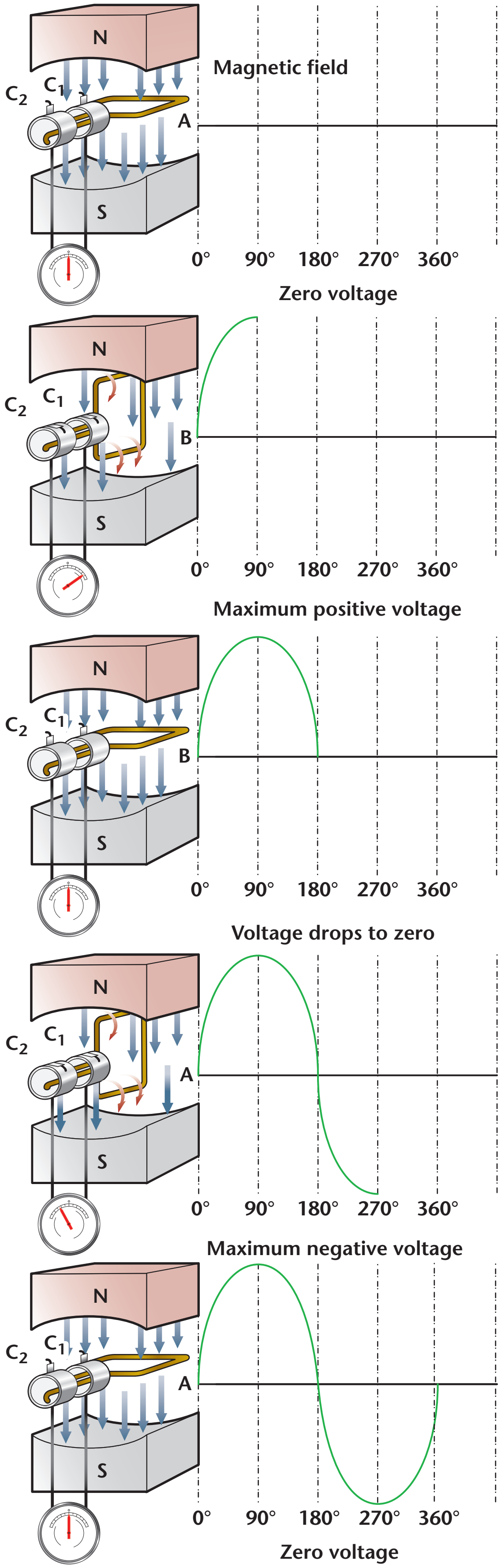


Figure 11-8-7. Generation of a sine wave.

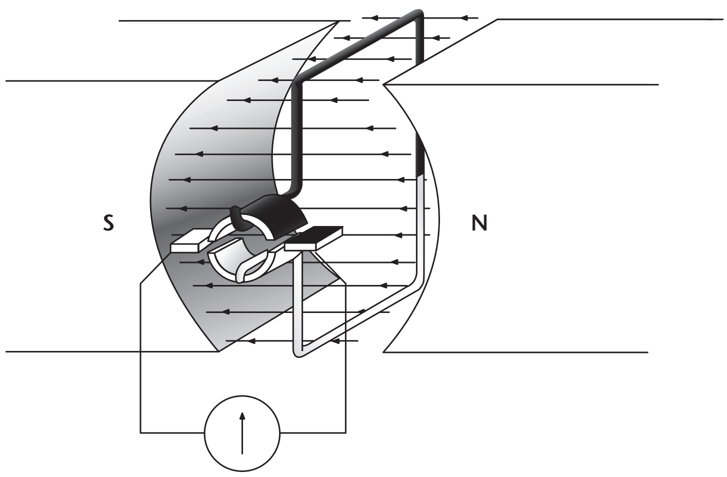


Figure 11-8-8. Basic DC generator.

purposes, the action of either conductor, A or B, while rotating in the magnetic field is similar to the action of the loop.

The generation of AC with a simple loop conductor rotating in a magnetic field is illustrated in Figure 11-8-7. As it is rotated in a counterclockwise direction, varying values of voltages are induced in it.

At position 1, conductor A moves parallel to the lines of force. Since it cuts no lines of force, the induced voltage is zero. As the conductor advances from position 1 to position 2, the voltage induced gradually increases.

At position 2, the conductor moves perpendicular to the flux and cuts a maximum number of lines of force; thus, a maximum voltage is induced. As it moves beyond position 2, it cuts a decreasing amount of flux at each instant, and the induced voltage decreases.

At position 3 the conductor has made one-half of a revolution and again moves parallel to the lines of force, and no voltage is induced in the conductor. As the A conductor passes position 3, the direction of induced voltage reverses since the A conductor now moves downward, cutting flux in the opposite direction.

As the A conductor moves across the south pole, the induced voltage gradually increases in a negative direction until at position 4 the conductor again moves perpendicular to the flux and generates a maximum negative voltage. From position 4 to 5 the induced voltage gradually decreases until the voltage is zero, and the conductor and wave are ready to start another cycle.

The curve shown at position 5 is called a sine wave. It represents the polarity and the magnitude of the instantaneous values of the voltages generated. The horizontal baseline is divided into degrees of rotation, or time, and the vertical distance above or below the baseline represents the value of voltage at each particular point in the rotation of the loop.

Direct Current Generators

A basic DC generator is made by replacing the slip rings in an AC generator with two half cylinders called commutators.

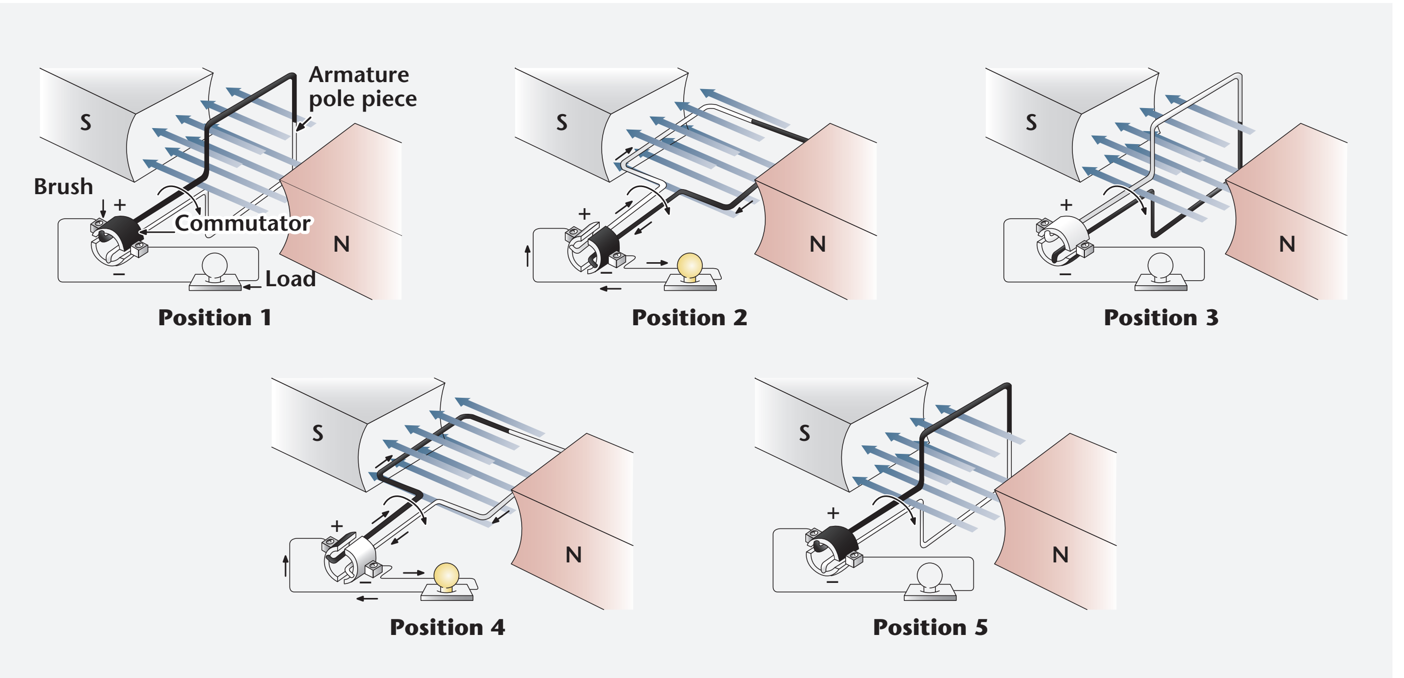


Figure 11-8-9. Simple DC generator.

In Figure 11-8-8, the black side of the coil is connected to the black commutator and the white side of the coil to the white commutator. They are insulated from each other. The two stationary brushes, one positive and one negative, are placed on opposite sides of the commutator and are mounted so that each brush contacts each commutator as it revolves with the loop. The rotating parts of the DC generator, loops or coils and commutator, make up the armature.

The generation of voltage in the rotating loop, inside the magnetic field, is the same for both AC and DC generators, but the action of the commutator produces a DC voltage. The following sequence referring to Figure 11-8-9 explains the process:

The loop in position 1 is rotating clockwise but no lines of force are cut by the coil and no voltage is generated. The positive brush is shown coming into contact with the white segment of the commutator and the negative brush is just coming into contact with the black segment.

In position 2 the flux is cut at a maximum rate and the induced voltage is at maximum. At this time, the positive brush is contacting the white segment and the negative brush is contacting the black segment. The current flow is toward the load, the light.

At position 3 the loop has completed 180° of rotation. Again, no flux lines are being cut and the output voltage is zero. The important condition to observe at position 3 is the action of the segments and brushes. The positive brush at the 180° angle is contacting both black and white segments on one side of the commutator and the white brush is contacting both segments on the other side of the commutator. After the loop rotates slightly past the 180° point, the positive brush is contacting only the white segment and the negative brush is contacting only the black segment.

As the loop continues to rotate to position 4, the maximum number of flux lines is cut and the voltage is at maximum. In position 5 the loop is not cutting any flux lines, so the voltage is once again zero.

Because of this switching of the commutator elements, the negative brush is always in contact with the coil side moving downwards, and the positive brush is always in contact with the coil side moving upwards. Though the current actually reversed its direction in the loop exactly the same way as in the AC generator, commutator action causes the current to flow always in the same direction through the external circuit (Figure 11-8-10).

The voltage generated by the basic DC generator varies from zero to its maximum value twice during each revolution of the loop. This variation of DC voltage, or "ripple", (Figure 11-8-11A) is reduced by using more loops or coils. As the number of loops is increased, the variation between maximum and minimum values is reduced and the output voltage of the generator approaches a steady value (Figure 11-8-11B).

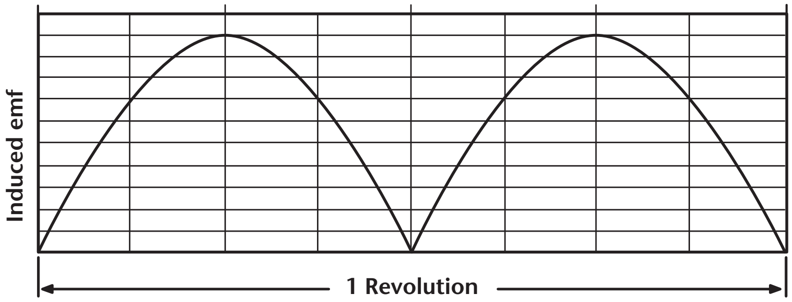


Figure 11-8-10. DC voltage wave form.

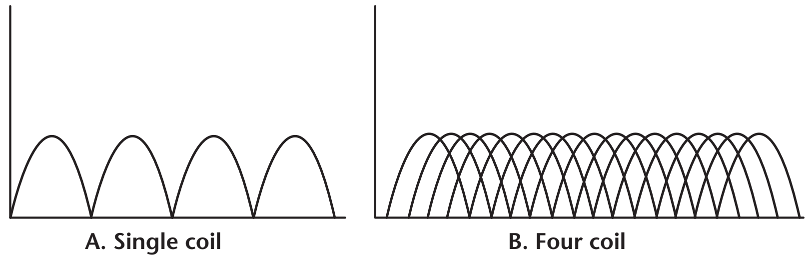


Figure 11-8-11. Voltage from a single coil and multiple coil DC generator.

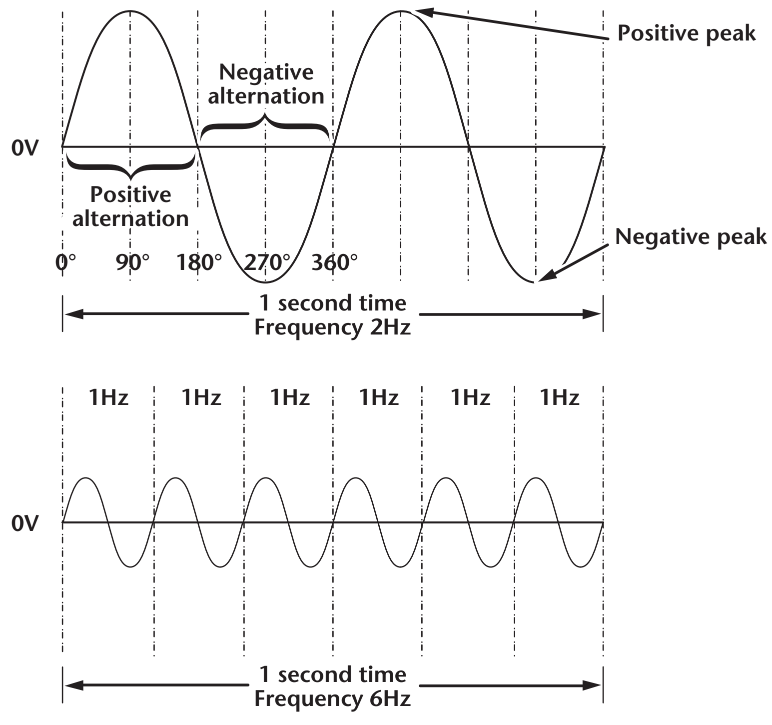


Figure 11-8-12. Frequency in cycles per second.

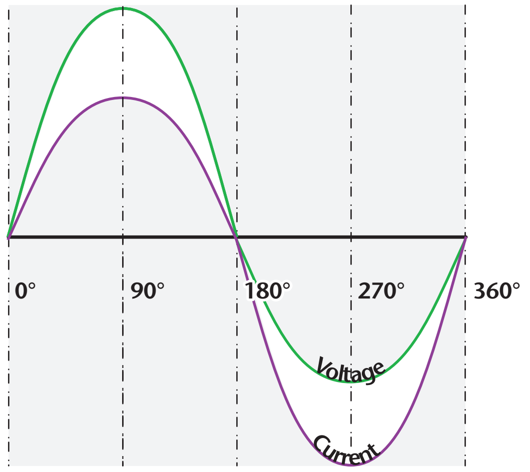


Figure 11-8-13. In-phase condition of current and voltage.

Alternating Current Terms and Values

The following terms and values apply to alternating current:

Cycle. Whenever a voltage or current passes through a series of changes, returns to the starting point, and then again starts the same series of changes, the series is called a cycle. The cycle is represented by the tilde symbol (~).

Alternation. In the cycle of voltage shown in Figure 11-8-12, the voltage increases from zero to a maximum positive value, decreases to zero, then increases to a maximum negative value, and again decreases to zero. At this point it is ready to go through the same series of changes. There are two alternations in a complete cycle, the positive alternation and the negative. Each is one-half a cycle.

Period. The length of time required for one cycle is referred to as the period of the cycle. The relationship of period (time) and frequency can be expressed as F = I/T where F represents frequency in hertz and T represents time in seconds.

Frequency. The number of times each cycle occurs in a period of time is called the frequency. The frequency of an electric current or voltage indicates the number of cycles that occur in one second. With the unit of frequency being the hertz, 10 cycles per second is referred to as a frequency of 10 hertz and is written 10 Hz.

In a generator, the voltage and current pass through a complete cycle of values each time a coil or conductor passes under a north and south pole of the magnet. The number of cycles per revolution of the coil or conductor is always equal to the number of pairs of poles. The frequency, then, is equal to the number of cycles in one revolution multiplied by the number of revolutions completed per second.

Expressed in equation form,

$$F = \frac{\text{Number of poles}}{2} \times \frac{\text{r.p.m.}}{60}$$

where $^{P}/_{2}$ is the number of pairs of poles, and $^{\text{r.p.m.}}/_{60}$ is the number of revolutions per second. If in a two-pole generator, the conductor is turning at 3,600 r.p.m., the revolutions per second (r/s) are:

$$r/s = \frac{3{,}600}{60} = 60 \text{ revolutions per second}$$

Since there are 2 poles, $^{P}/_{2}$ is 1 and the frequency is 60 Hz. In a 4-pole generator with an armature speed of 1,800 r.p.m., substitute in the equation:

$$F = \frac{P}{2} \times \frac{\text{r.p.m.}}{60} \text{ as follows}$$

$$F = \frac{4}{2} \times \frac{1{,}800}{60}$$

$$F = 2 \times 30$$

$$F = 60 \text{ Hz}$$

Phase. In addition to frequency and cycle characteristics, alternating voltage and current also have a relationship called *phase*.

In a circuit that is supplied by one alternator, there must be a certain phase relationship between voltage and current if the circuit is to function efficiently. In a system supplied by two or more alternators, not only must there be a certain phase relationship between voltage and current of one alternator, but there must be a phase relationship between the individual voltages and the individual currents. Also, two separate circuits can be compared by comparing the phase characteristics of one to the phase characteristics of the other.

When two or more sine waves pass through 0° and 180° at the same time and reach their peaks at the same time, an in-phase condition exists, as shown in Figure 11-8-13. The peak values do not have to be the same for the in-phase condition to exist.

When the sine waves pass through 0° and 180° at different times and reach their peaks at different times, an out-of-phase condition exists, as shown in Figure 11-8-14. The amount that the waves are out of phase is indicated by the number of electrical degrees between corresponding peaks on the sine waves. In Figure 11-8-14, the current and voltage are 30° out of phase.

Power

According to Ohm's law, circuit power is obtained by the equation P = E × I, (watts equal volts times amperes). Thus, if 1 ampere of current flows in a circuit at a pressure of 200 volts, the power is 200 watts.

True power in a circuit is the product of the volts and the amperes.

Apparent power. Apparent power in an AC circuit is the product of the effective voltage, indicated by the voltmeter, and the effective current, indicated by the ammeter. Only when the AC circuit is made up of pure resistance is the apparent power equal to the true power.

Power factor. The power factor is the ratio of the true power to the apparent power and is usually expressed in percent. When there is capacitance or inductance in the circuit, the current and voltage are not exactly in phase, and the true power is less than the apparent power. The true power is obtained by a wattmeter reading. In equation form, the relationship is:

$$\text{Power Factor} = \frac{100 \times \text{Watts (True Power)}}{\text{Volts} \times \text{Amperes (Apparent Power)}}$$

In a sample power problem, a 220-volt AC motor takes 50 amperes from the line, but a wattmeter in the line shows that only 9,350 watts are taken by the motor, What is the apparent power and the power factor?

Solution:

Apparent power = Volts × Amperes

Apparent power = 220 × 50 = 11,000 watts or volt-amperes

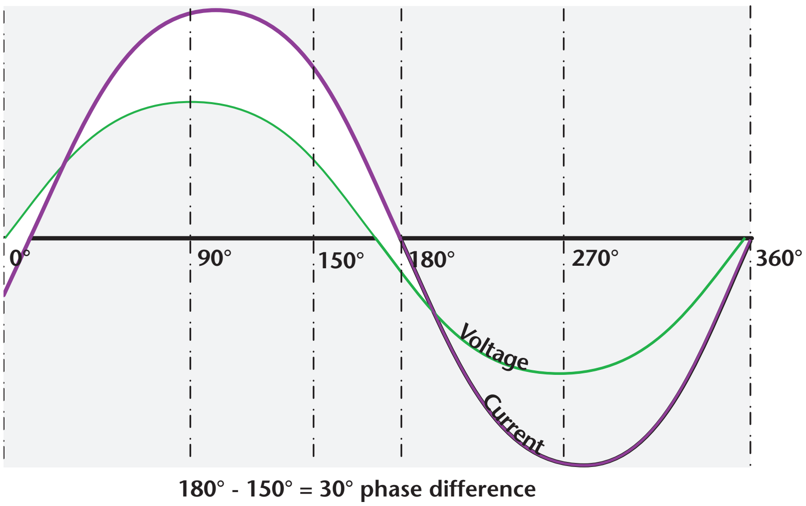


Figure 11-8-14. Out-of-phase condition of current and voltage.

$$PF = \frac{\text{Watts (True Power) x 100}}{\text{VA (Apparent Power)}}$$

$$PF = \frac{9{,}350 \text{ x}100}{11{,}000}$$

$$PF = 85 \text{ or } 85\%$$

Sine-wave values. There are four values of AC that must be considered. They are maximum (or peak), peak-to-peak, average, and effective values.

Peak value. The maximum value is the largest instantaneous value, and is frequently referred to as the peak value. The largest positive value occurs when the sine wave is at 90°, and the largest negative value occurs when it is at 270°. The peak value is 1.41 times the effective value (Figure 11-8-15).

Peak-to-peak value. During each cycle of AC, there are always two maximum or peak values; one for the positive alternation and one for the negative alternation. The distance

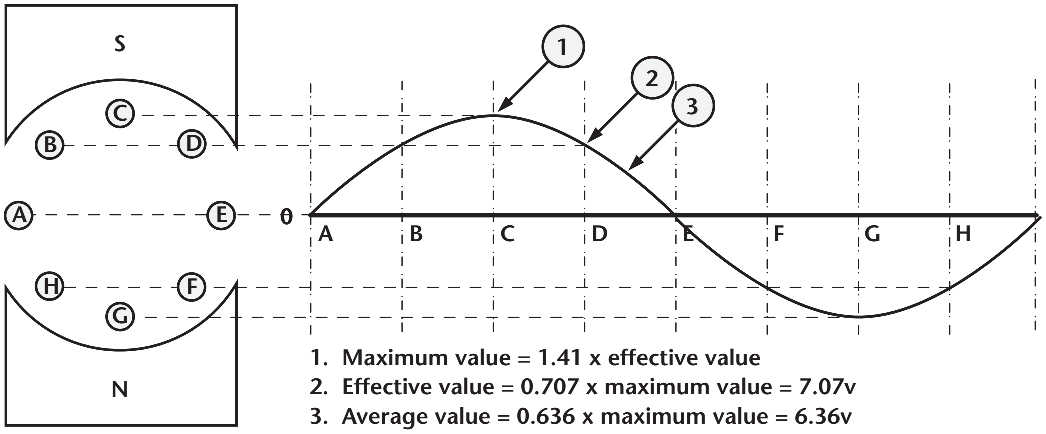


Figure 11-8-15. Effective, average, and maximum values of voltage.

between the positive peak value and the negative peak value is known as the peak-to-peak value. Therefore, the peak-to-peak value can be found by multiplying the peak value times two. Conversely, if the peak-to-peak value is known, the peak value can be found by dividing the peak-to-peak value by two. For example, if the peak value is 10 volts, the peak-to-peak value would be 20 volts.

Average value. The average value of an AC sine wave is the average of all of the values during one alternation. Since the voltage increases from zero to peak and back to zero during the alternation, the average must be some value between those limits. Averaging all the values between 0° and 180° results in a value that can be found by multiplying the peak value times 0.636. For example, if the peak value is 10 volts, multiplying by 0.636 equals an average value of 6.36 volts.

Effective value. Also referred to as the *root-mean-square* (rms), the effective value of AC is the same as the value of DC, which will produce an equal heating effect. That is, the AC and DC values are *effectively* the same.

The method of determining the rms voltage involves squaring all of the values for a large number of points along the AC waveform, and then finding the average of the squared values. The square root of the average is then taken, hence the phrase *root of the average* (mean) of the squares.

The effective value is equal to 0.707 times the maximum value. Thus, the 115-volt value given for AC supplied to homes represents only 0.707 times the effective value of 162.61 volts.

In the study of AC, any values given for current or voltage are assumed to be effective values unless otherwise specified; and in practice, only the effective values of voltage and current are used. Similarly, AC voltmeters and ammeters measure the effective, or rms, value.

Section 9

Alternating Current Circuits

Alternating current in a circuit containing only resistance. In AC circuits, resistance is referred to as impedance (Z). If an AC circuit consists of resistance only, the value of the impedance is the same as the resistance, and Ohm's law for an AC circuit, I=E/Z, is exactly the same as for a DC circuit. A series circuit containing a lamp with 11 ohms resistance is connected across a 110-volt power source. To find how much current will flow if 110 volts DC are applied and how much current will flow if 110 volts AC are applied:

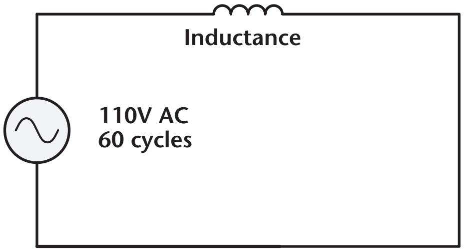


Figure 11-9-1. AC circuit containing inductance.

$$I = \frac{E}{R}$$
$$= \frac{110V}{11\Omega}$$
$$= 10 \text{ amperes DC}$$
$$I = \frac{E}{Z} \text{ (where } Z = R)$$
$$= \frac{110V}{11\Omega}$$
$$= 10 \text{ amperes AC}$$

Inductance

When an alternating current flows through a coil of wire, the rise and fall of the current flow, first in one direction and then in another, sets up an expanding and collapsing magnetic field about the coil. A voltage is induced in the coil that is opposite in direction to the applied voltage and that opposes any change in the alternating current. The induced voltage is called the counter-electromotive force (abbreviated *cemf*), since it opposes the applied voltage. This property of a coil to oppose any change in the current flowing through it is called inductance (Figure 11-9-1).

Factors affecting inductance. The inductance of a coil is measured in henrys (L). In any coil, the inductance depends on several factors, principally the number of turns, the cross-sectional area of the coil, and the material in the center of the coil or core. A core of magnetic material greatly increases the inductance of the coil.

Remember that even a straight wire has inductance, small though it may be when compared to that of a coil. AC motors, relays, and transformers all contribute inductance to a circuit. Practically all AC circuits contain inductive elements.

Series and parallel connection of inductors. Inductors may be connected in a circuit in the same manner as resistors. When connected in series, the total inductance is the sum of the inductances of the inductors, or

$L_T = L_1 + L_2 + L_3$, etc.

When two or more inductors are connected in parallel, the total inductance is, like resistances in parallel, less than that of the smallest inductor, or:

$$L_T = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3}}$$

The total inductance of inductors connected in series-parallel can be computed by combining the parallel inductances and then adding the series values. In all cases, these formulas are valid, providing the magnetic fields of the inductors do not interact.

Time constant of inductors. When a power source is connected across an inductance, the current buildup is gradual because of the counter emf generated by the coil. When the current starts to flow, the magnetic flux lines begin to move outward from the coil. These lines cut the turns of wire on the inductor and produce a counter emf that opposes the emf of the power source. This opposition causes a delay in the time it takes the current to build up to its maximum value. Disconnecting the power source causes these lines of flux to collapse. The lines of flux again cut the turns of the inductor and build up an emf that tends to prolong the flow of current. The time required for the power source voltage to rise to 63.2 percent of its maximum value is referred to as the time constant of the circuit.

The curcuit shown in Figure 11-9-2 contains both resistance and inductance and is known as a R-L series circuit.

The time constant for an R-L is determined by the value of inductance and resistance in series in the circuit. In the circuit shown in Figure 11-9-2A, when switch 1 is closed, current will begin to rise, (Figure 11-9-2B). After one time constant, the current will have risen to 63.2 percent of its maximum value. During discharge (Figure 11-9-2), the current will decay to 36.8 percent of its maximum value (it will have decayed 63.2 percent of its maximum value, down to 36.8 percent of maximum).

The formula for computing an inductive time constant is given as:

$$T = \frac{L}{R}$$

T = Time in seconds

L = Inductance in henrys

R = Resistance in ohms

A circuit containing 5 Henrys of inductance in series with 100 ohms would have a time constant of 5H/100 ohms = 0.05 seconds, or 50 milliseconds.

Inductive reactance. The opposition to the flow of current that inductances put in a circuit is called inductive reactance. The symbol for inductive reactance is X_L and is measured in ohms, just as resistance is.

In any circuit in which there is only resistance, the expression for the relationship of voltage and current is Ohm's law: I=E/R. When there

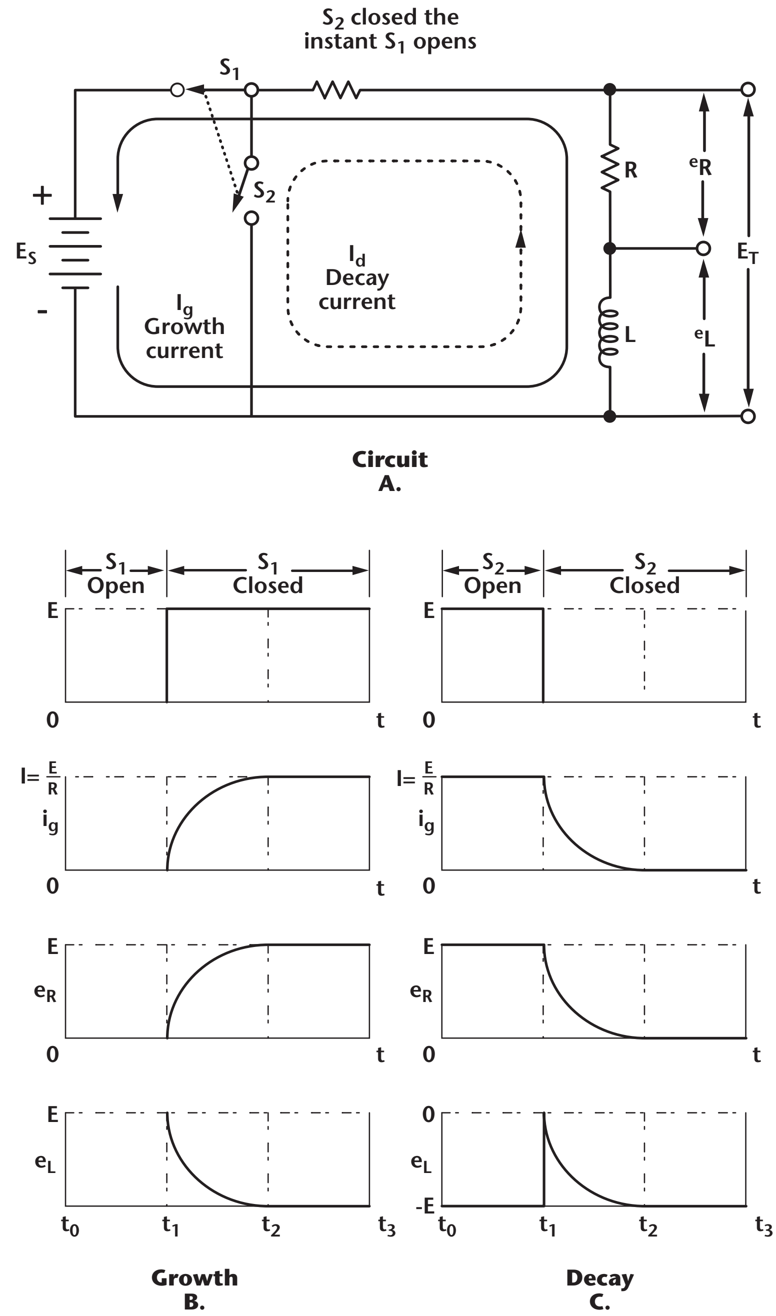


Figure 11-9-2. Growth and decay of current in a R-L series circuit.

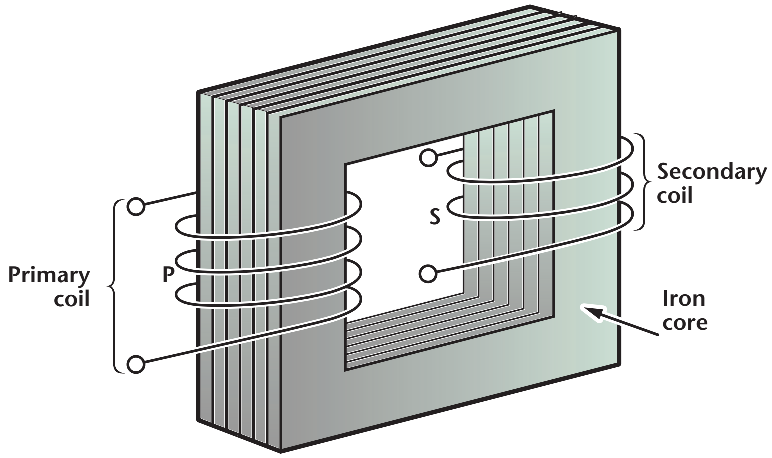


Figure 11-9-3. A laminated iron-core transformer.

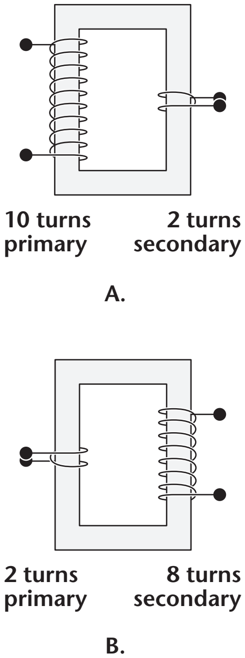


Figure 11-9-4. A step-down and a step-up transformer.

is inductance in an AC circuit, the relationship between voltage and current can be expressed:

$$\text{Current} = \frac{\text{Voltage}}{\text{Reactance}} \quad \text{or } I = \frac{E}{X_L}$$

X_L = inductive reactance of the circuit in ohms

If all other circuit values remain constant, the greater the inductance in a coil, the greater the effect of self-induction, or opposition to the change in the value of current. As the frequency increases, the inductive reactance increases, since the greater the rate-of-current change, the more the opposition to change by the coil increases. Therefore, inductive reactance is proportional to inductance and frequency or:

$$X_L = 2\pi fL$$

X_L = inductive reactance in ohms

f = frequency in Hz

π = 3.1416

L = henrys

Mutual inductance. When two coils are located such that the flux from one coil links with the turns of the other coil, a change in flux in the first coil causes an emf to be induced in the second coil. This process permits energy from one coil to be transferred to another coil. When this occurs, the coils are said to be linked by a property known as mutual inductance.

The amount of mutual inductance is dependent upon the relative positions and separation between the coils. If the coils are separated by a considerable distance, mutual inductance is low. However, if the coils are relatively close together such that nearly all of the lines of flux of the first coil link the turns of the second coil, the mutual inductance is high. This property of mutual inductance is used extensively in transformers.

Types of Practical Inductors

Inductors have many applications in electric circuits. Two of the most common inductors are choke filters and transformers.

Choke filters. Inductors may be used in circuits to block out a particular frequency or group of frequencies. Circuits of this type are referred to as filter circuits, and inductors in this application are called chokes. That is, they *choke* off certain frequencies.

Transformers. A transformer changes electrical energy of a given voltage into electrical energy at a different voltage level. It consists of two coils that are not electrically connected, but that are arranged in such a way that the magnetic field surrounding one coil cuts through the other coil. When an alternating voltage is applied to (across) one coil, the varying magnetic field set up around that coil creates an alternating voltage in the other coil by mutual induction. A transformer can also be used with pulsating DC, but a pure DC voltage cannot be used, since only a varying voltage creates the varying magnetic field, which is the basis of the mutual induction process.

Transformer construction. A transformer consists of three basic parts, as shown in Figure 11-9-3. These are an iron core, which provides a circuit of low reluctance for magnetic lines of force, a primary winding, which receives the electrical energy from the source of applied voltage, and a secondary winding, which receives electrical energy by induction from the primary coil.

The primary and secondary of this closed-core transformer are wound on a laminated closed core to obtain maximum inductive effect between the two coils. The laminations are soft iron and concentrate the flux lines.

Step-up or Step-down Transformers

There are many types of voltage transformers. Most of these are either step-up or step-down transformers. The factor that determines whether a transformer is a step-up or step-down type is the *turns* ratio.

The turns ratio is the ratio of the number of turns in the primary winding to the number of turns in the secondary winding. For example, the turns ratio of the step-down transformer shown in Figure 11-9-4A is 5 to 1, since there are five times as many turns in the primary as in the secondary. The step-up transformer shown in Figure 11-9-4B has a 1-to-4 turns ratio.

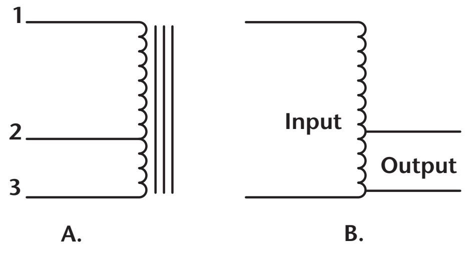


Figure 11-9-5. Autotransformers.

The ratio of the transformer input voltage to the output voltage is the same as the turns ratio if the transformer were 100 percent efficient (which is not physically possible). Theoretically, when 10 volts are applied to the primary of the transformer shown in Figure 11-9-4A, two volts are induced in the secondary. If 10 volts are applied to the primary of the transformer in Figure 11-9-4B, the output voltage across the terminals of the secondary will be 40 volts.

No transformer can be constructed that is 100 percent efficient, although iron-core transformers can approach this figure. This is because all the magnetic lines of force set up in the primary do not cut across the turns of the secondary coil.

A certain amount of the magnetic flux, called leakage flux, leaks out of the magnetic circuit. The measure of how well the flux of the primary is coupled into the secondary is called the *coefficient of coupling.* For example, if it is assumed that the primary of a transformer develops 10,000 lines of force and only 9,000 cut across the secondary, the coefficient of coupling would be 0.9 or, stated another way, the transformer would be 90 percent efficient.

When an AC voltage is connected across the primary terminals of a transformer, current will flow and self-induce a voltage in the primary coil, which is opposite and nearly equal to the applied voltage. The difference between these two voltages allows just enough current in the primary to magnetize its core. This is called the exciting, or magnetizing, current.

The magnetic field caused by this exciting current cuts across the secondary coil and induces a voltage by mutual induction. If a load is connected across the secondary coil, the load current flowing through the secondary coil will produce a magnetic field, which will tend to neutralize the magnetic field produced by the primary current. This will reduce the self-induced (opposition) voltage in the primary coil and allow more primary current to flow.

The primary current increases as the secondary load current increases and decreases as the secondary load current decreases. When the secondary load is removed, the primary current is again reduced to the small exciting current sufficient only to magnetize the iron core of the transformer.

If a transformer steps up the voltage, it will step down the current by the same ratio. Consider the power formula: $P = I \bullet E$, if the primary coil has an input of 10 volts and 4 amps (40 watts) are used in the primary to produce a magnetic field, then 40 watts will be developed in the secondary coil. If the transformer has a step-up ratio of 4:1, the voltage across the secondary will be 40 volts and the amperage will be one fourth or 1 amp. The voltage is four times greater, the current is one quarter the primary but the wattage stays the same.

When the turns ratio and the input voltage are known, the output voltage can be determined as follows:

$$\frac{E_2}{E_1} = \frac{N_2}{N_4}$$

Where E_1 is the voltage of the primary, E_2 is the output voltage of the secondary, and N_1 and N_2 are the number of turns of the primary and secondary, respectively.

Transposing the equation to find the output voltage gives:

$$E_2 = \frac{E_1 N_2}{N_4}$$

Autotransformers. Autotransformers are normally used in power circuits; however, they may be designed for other uses. Two different symbols for autotransformers used in power or audio circuits are shown in Figure 11-9-5. If used in an RF communication or navigation circuit (Figure 11-9-5B), it is the same, except there is no symbol for an iron core. The autotransformer uses part of a winding as a primary; and, depending on whether it is step-up or step-down, it uses all or part of the same winding as the secondary.

Current Transformers

Current transformers are used in AC power supply systems to sense generator line current and to provide a current, proportional to the line current, for circuit protection and control devices.

The current transformer is a ring-type transformer using a current-carrying power lead as a primary (either the power lead or the ground lead of the AC generator). The current in the primary induces a current in the secondary by magnetic induction.

Material	K (dielectric constant)
Air	1.0
Resin	2.5
Asbestos paper	12.7
Hard rubber	2.8
Dry paper	3.5
Isolantite	3.5
Common glass	4.2
Quartz	4.5
Mica	4.5 - 7.5
Porcelain	5.5
Flint glass	7.0
Crown glass	7.9

Table 11-10-1. Dielectric constants.

The sides of all current transformers are marked H1 and H2 on the unit base. The transformers must be installed with the H1 side toward the generator in the circuit in order to have proper polarity.

The secondary of the transformer should never be left open while the system is being operated; to do so could cause dangerously high voltages and could overheat the transformer. Therefore, the transformer output connections should always be connected with a jumper when the transformer is not being used but is left in the system.

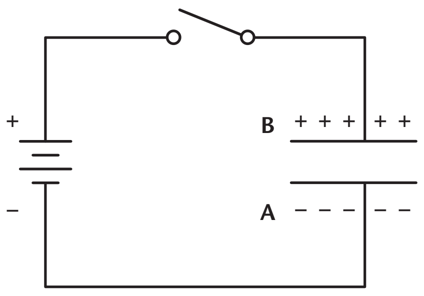


Figure 11-10-1. Capacitor in a DC circuit.

Section 10

Capacitance

Another important property in AC circuits, besides resistance and inductance, is capacitance. While inductance is represented in a circuit by a coil, capacitance is represented by the capacitor symbol ⫞. Variable capacitors are represnted by the symbol ⫞.

Any two conductors separated by a nonconductor, called a dielectric, constitute a capacitor. In an electrical circuit, a capacitor serves as a reservoir or storehouse for an electrical charge.

The plates may be made of copper, tin, or aluminum. Frequently, they are made of foil (metals compressed into thin sheets and capable of being rolled).

The dielectric may be air, glass, mica, or an electrolyte made by an oxide film, but the type used will determine the amount of voltage that may be applied and the quantity of energy that will be stored.

The dielectric materials have different atomic structures and present different quantities of atoms to the electrostatic field.

All dielectric materials are compared to a vacuum and are given a numerical value according to the capacity ratio between them. The number given to a material is based on the same area and thickness as used in the vacuum. The numbers used to express this ratio are called dielectric constants and are expressed as the letter *K*. The chart in Table 11-10-1 gives the K-value of some materials used.

When a capacitor is connected across a source of current, such as the storage battery in the circuit shown in Figure 11-10-1, and the switch is then closed, the plate marked B becomes positively

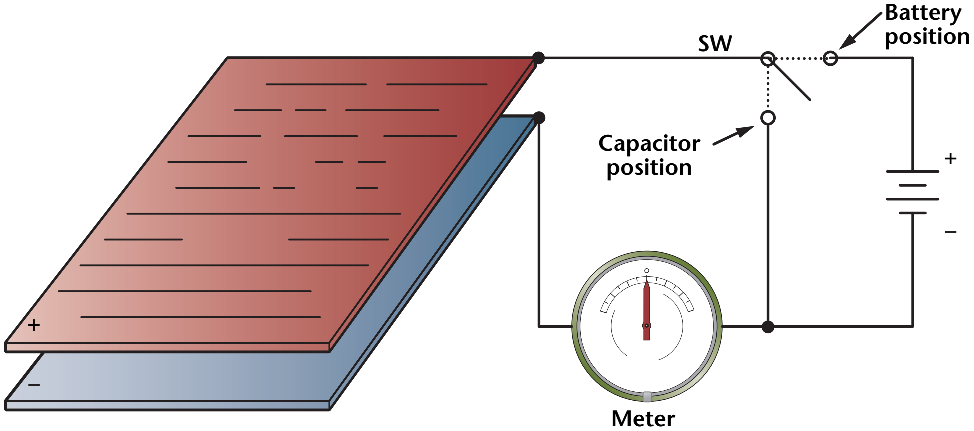


Figure 11-10-2. A basic capacitor circuit.

charged and the A plate negatively charged. Current flows in the external circuit during the time the electrons are moving from B to A.

The current flow in the circuit is maximum at the instant the switch is closed, but continually decreases thereafter until it reaches zero. The current becomes zero as soon as the difference in voltage of A and B becomes the same as the voltage of the battery.

If the switch is opened, the plates remain charged. However, the capacitor quickly discharges when its plates are shorted together.

Energy stored in electrostatic fields. Two flat metal plates are placed close to each other (but not touching), as shown in Figure 11-10-2. Usually the plates are electrically neutral; that is, no electrical charge will be evident on either plate. At the instant the switch is closed to the battery position, the meter will show a definite current surge in one direction, but almost instantly will return to zero.

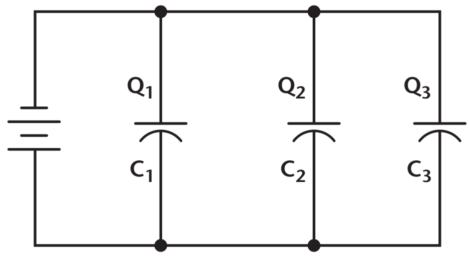
If the battery is taken out of the circuit, shown in Figure 11-10-2, and the switch closed in the capacitor position, the meter would show a momentary current surge, but this time in an opposite direction. From this experiment, it is apparent that the two plates store energy when connected to a voltage source and release the energy when short-circuited. The two plates make up a simple electrical capacitor, or condenser, and possess the property of storing electricity. The energy is actually stored in the electric, or dielectric, field between the plates.

During the time the capacitor is being charged or discharged, there is current in the circuit, even though the circuit is broken by the gap between the plates. However, there is current only during the time of charge and discharge, and this period of time is very short. There can be no continuous movement of DC through a capacitor. A good capacitor will block DC (not pulsating DC) and will pass the effects of AC.

Factors Affecting Capacitance

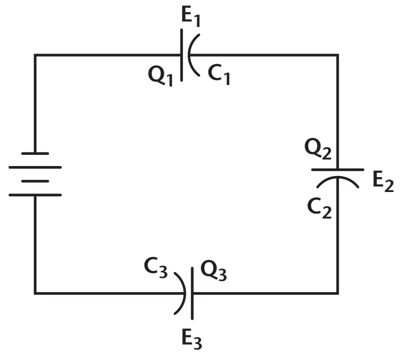
The amount of electrical charge a capacitor can store depends on several factors, including the type of material of the dielectric, the plate area, and the distance between the plates.

The dielectric constants, previously described, affect the capacity of the capacitor. Using air as a reference standard of one, dielectrics with a constant greater than one increase the capacity of the capacitor because of the increased distortion of the electron orbits within the dielectric.



$$C_t = C_1 + C_2 + C_3$$

A. Parallel



$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

B. Series

Figure 11-10-3. Capacitors in parallel and in series.

A capacitor's stored charge is directly proportional to the plate area. The larger the plate area the greater the number of electrons can be stored on that plate. One method of creating larger plates involves rolling the plates and dielectric in a manner similar to a sleeping bag.

The stored charge of a capacitor is inversely proportional to the distance between the plates. Greater distances require a greater expenditure of energy for the electrons to transit through the dielectric, resulting in a weaker charge. If the plates are too close the dielectric may be damaged creating a conductive path that shorts the capacitor, rendering it useless.

Series and parallel connectors of capacitors. Capacitors may be combined in series or parallel to give equivalent value, which may be either the sum of the individual values (in parallel) or a value less than that of the smallest capacitor (in series). Figure 11-10-3 shows the parallel and series connections.

Two units used in the measurement of capacitance are the *farad* and the *coulomb*. The farad is the amount of capacitance present in a capacitor when 1 coulomb of electrical energy is stored on the plates and 1 volt is applied across the capacitor. One coulomb is the electrical charge

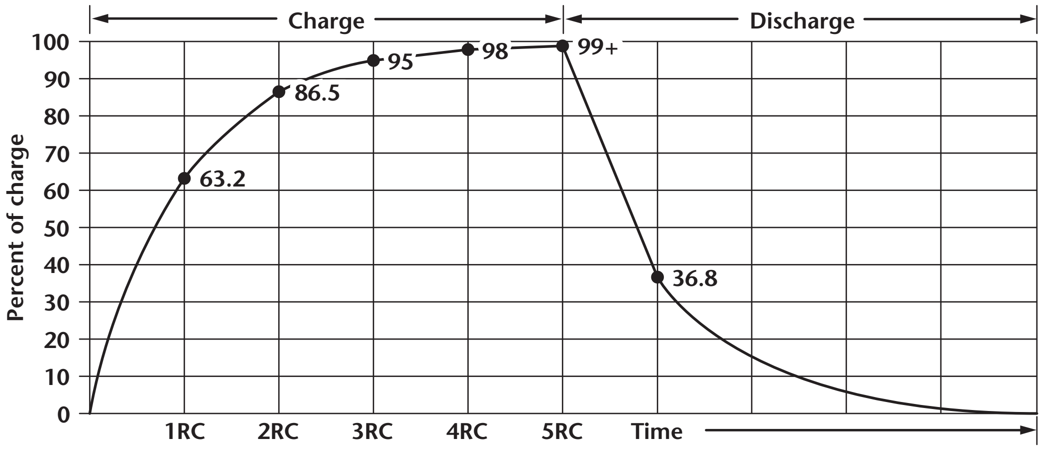


Figure 11-10-4. RC time constant.

of 6.28 billion billion electrons. From this it can be seen that:

$$C(\text{in farads}) = \frac{Q(\text{in coulombs})}{E(\text{in volts})}$$

Capacitors in series. Series capacitors are combined by rules that are similar to those used for combining resistors in parallel. In the series arrangement, (Figure 11-10-3B) the current is the same in all parts of the circuit. Each capacitor develops a voltage during charge, and the sum of the voltages of all the capacitors must equal the applied voltage, E. By the capacitor equation, the applied voltage, E, is equal to the total charge divided by the total capacitance, or:

$$E = \frac{Q_t}{C_t}$$

E = Voltage

Q_t = Total Charge

C_t = Total Capacitance

The total charge, Q_t, is equal to the charge on any one of the capacitors because the same current flows in all for the same length of time, and because the charge equals current multiplied by time in seconds ($Q_t = I \times T$). Therefore:

$$Q_t = Q_1 = Q_2 = Q_3$$

And, since in a circuit with capacitors in series:

$$E_t = E_1 + E_2 + E_3$$

where E_1, E_2, and E_3 are the voltages of the three capacitors. Then:

$$\frac{Q_t}{C_t} = \frac{Q_t}{C_1} + \frac{Q_t}{C_2} + \frac{Q_t}{C_3}$$

Dividing both sides of the equation by Q_t gives

$$\frac{1}{C_t} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

The reciprocal of the total capacitance of any number of capacitors in series is the reciprocal of the individual values:

$$C_t = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \ldots}$$

Series Capacitors

Series capacitors combine by a rule similar to that for combining parallel resistors. In the series arrangement of two capacitors, C_1 and C_2, that are of unequal value:

$$C_t = \frac{C_1 \times C_2}{C_1 + C_2}$$

When multiple capacitors are in series and are of equal value then:

$$C_t = \frac{C}{N}$$

Capacitors in parallel. In Figure 11-10-3A, the voltage, E, is the same for all the capacitors. The total charge, Q_t, is the sum of all the individual charges, Q_1, Q_2, and Q_3.

Using the basic equation for the capacitor,

$$C = \frac{Q}{E}$$

the total charge is $Q_t = C_tE$, where C_t is the total capacitance. Since the total charge on capacitors in parallel is the sum of the individual capacitor charges,

$$Q_t = Q_1 + Q_2 + Q_3$$

Using both equations for total charge develops the equation

$$C_tE = C_1E + C_2E + C_3E$$

Dividing both sides of this equation by E gives

$$C_t = C_1 + C_2 + C_3$$

This formula is used to determine the total capacitance of any number of capacitors in parallel.

Parallel capacitors combine by a rule similar to that used to combine resistors in series.

Time Constant of Capacitors

The time which is required to charge a capacitor to 63.2 percent of the maximum voltage applied to it, or the time it takes to discharge the capacitor to 36.8 percent of the maximum voltage it was charged to, is known as the time constant (abbreviated TC) of the circuit.

The charge and discharge curves of the capacitor are similar to those of the inductor discussed earlier. The time constant for a capacitance-resistance combination may be determined by applying the formula:

$$TC = R \times C$$

TC= time constant in seconds
R= series resistance
C= capacitance in farads

As an example, a 50 μF and a 1 kilohm resistor combination would have a time constant of $50 \times 10^{-6} \times 1 \times 10^{3} = 50 \times 10^{-3}$ or 50 milliseconds. If the voltage is 100 volts, the capacitor would charge to 63.2 percent, or 63.2 volts, in 50 milliseconds. Five time constants are required to charge or discharge a capacitor completely.

In this example, the time to charge the capacitor to approximately 100 percent of the applied voltage would require 5 times 50 milliseconds, or 250 milliseconds (Figure 11-10-4).

Capacitive Reactance

Factors affecting capacitive reactance. Capacitance, like inductance, offers opposition to the flow of current. This opposition is called capacitive reactance and is measured in ohms. The symbol for capacitive reactance is X_c.

$$\text{Current} = \frac{\text{Voltage}}{\text{Capacitive reactance}} \text{ or } I = \frac{E}{X_c}$$

The equation is similar to Ohm's law and the equation for current in an inductive circuit. The greater the frequency, the less the reactance. Hence, the capacitive reactance,

$$X_c = \frac{1}{2\pi \times f \times C}$$

f = frequency in Hz
C = capacity in farads
2π = 6.28

In the following problem, a series circuit is assumed in which the impressed voltage is 110 volts at 60 Hz and the capacitance of a condenser is 80 μF. To find the capacitive reactance and the current flow, use the following equation:

$$X_c = \frac{1}{2\pi \times f \times C}$$

First, the capacitance, 80 μF, is changed to farads by dividing 80 by 1,000,000, since 1 million microfarads is equal to 1 farad. This quotient equals 0.000080 farad. This is substituted in the equation and:

$$X_c = \frac{1}{6.28 \times 60 \times 0.000080}$$

X_c = 33.2 ohms reactance

Find the current flow:

$$I = \frac{E}{X_c}$$

$$I = \frac{110}{33.2}$$

$I = 3.31$ amperes

Capacitive reactances in series and in parallel. When capacitors are connected in series, the total reactance is equal to the sum of the individual reactances. Thus:

$$(X_c)_t = (X_c)_1 + (X_c)_2$$

The total reactance of capacitors connected in parallel is found in the same way total resistance is computed in a parallel circuit:

$$(X_c)_t = \frac{1}{\frac{1}{(X_c)_1} + \frac{1}{(X_c)_2} + \frac{1}{(X_c)_3}}$$

Phase shift in reactive circuits. When current and voltage pass through zero and reach maximum value at the same time, the current and voltage are said to be *in phase* (Figure 11-10-5, illustration A). If the current and voltage pass through zero and reach the maximum values at different times, the current and voltage are said to be out of phase. When the current lags or leads the voltage in a circuit, the amount depends on the relative amounts of resistance, inductance and capacitance in the circuit.

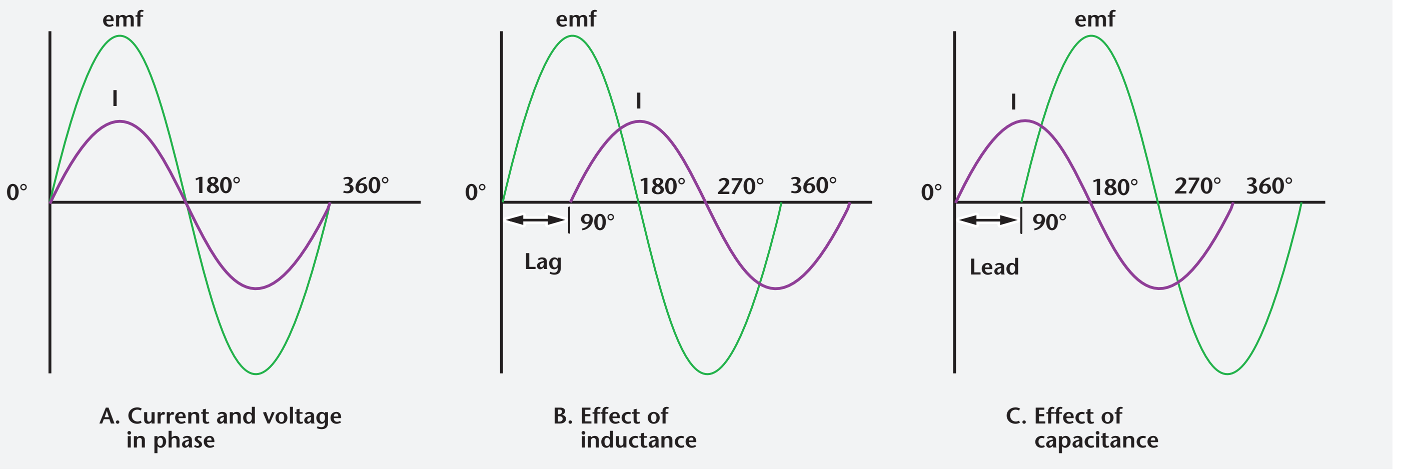


Figure 11-10-5. Phase of current and voltage.

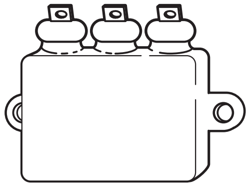


Figure 11-10-6. Oil capacitor.

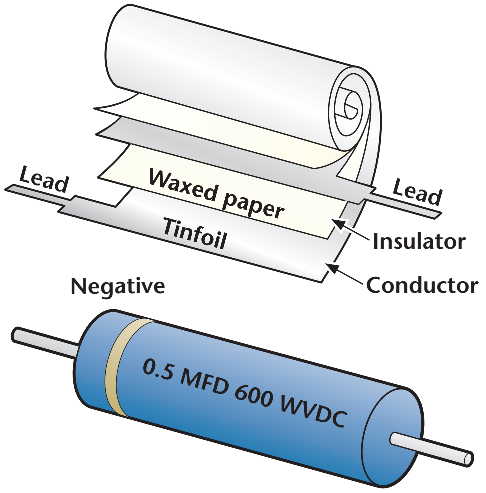


Figure 11-10-7. Paper capacitors.

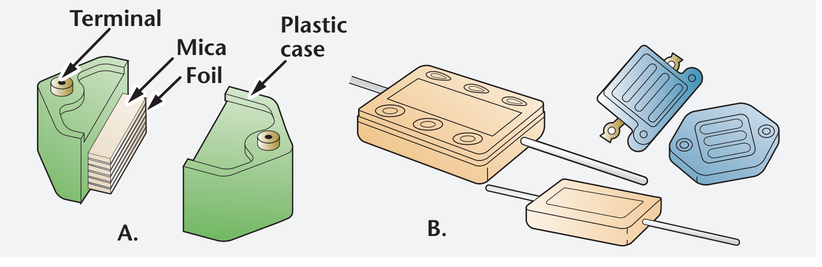


Figure 11-10-8. Mica capacitors.

In a circuit containing only inductance, the current reaches a maximum value later than the voltage, lagging the voltage by 90°, or one-fourth cycle (Figure 11-10-5B).

In a circuit containing only capacitance, the current reaches its maximum value ahead of the voltage, leading by 90°, or one-fourth cycle (Figure 11-10-5C).

Power in a capacitive circuit. When an alternating voltage is applied to a capacitor, power is taken from the source and stored in the capacitor. As the voltage decreases from maximum to zero, the capacitor discharges and returns power to the source. No power is consumed since the power flows alternately to and from the source. Power returned to the source by the capacitor is referred to as reactive power.

Types of Practical Capacitors

Capacitors may be divided into two groups: fixed and variable. The fixed capacitors may then be further categorized, according to the type of dielectric used, as either non-electrolytic or electrolytic.

Paper capacitors. The plates of paper capacitors are strips of metal foil separated by waxed paper (Figure 11-10-7). The capacitance of paper capacitors ranges from about 200pF to several μF. The strips of foil and paper are rolled together to form a cylindrical cartridge, which is then sealed in wax to keep out moisture and to prevent corrosion and leakage. Two metal leads are soldered to the plates, one extending from each end of the cylinder. The assembly is enclosed either in a cardboard cover or in a hard, molded plastic covering.

Oil capacitors. In radio and radar transmitters, voltages high enough to cause arcing, or breakdown, of paper dielectrics are often employed. Consequently, in these applications capacitors that use oil or oil-impregnated paper for the dielectric material are preferred. Capacitors of this type are considerably more expensive than ordinary paper capacitors, and their use is generally restricted to radio and radar transmitting equipment (Figure 11-10-6).

Mica capacitors. The fixed mica capacitor is made of metal foil plates that are separated by sheets of mica, which form the dielectric. The whole assembly is covered in molded plastic, which keeps out moisture. Mica is an excellent dielectric and will withstand higher voltages than paper without allowing arcing between the plates. Common values of mica capacitors range from approximately 50 pF, to about 0.02 μF. Mica capacitors are shown in Figure 11-10-8.

Electrolytic capacitors. For capacitances greater than a few microfarads, the plate areas of paper or mica capacitors must become very large; thus, electrolytic capacitors are usually employed instead. These units provide large capacitance in small physical sizes. Their values range from 1 to about 1,500 microfarads. Unlike the other types, electrolytic capacitors are generally polarized and should be subjected to direct voltage or pulsating direct voltage only; however, a special type of electrolytic capacitor is made for use in motors.

The electrolytic capacitor is widely used in electronic circuits and consists of two metal plates separated by an electrolyte. The electrolyte in contact with the negative terminal, either in paste or liquid form, comprises the negative electrode. The dielectric is an exceedingly thin film of oxide deposited on the positive electrode of the capacitor. The positive electrode, which is an aluminum sheet, is folded to achieve maximum area. The capacitor is subjected to a forming process during manufacture, in which current is passed through it. The flow of current results in the deposit of the thin coating of oxide on the aluminum plate.

The close spacing of the negative and positive electrodes gives rise to the comparatively high capacitance value, but it allows greater possibility of voltage breakdown and leakage of electrons from one electrode to the other.

Two kinds of electrolytic capacitors in use are *wet-electrolytic* and *dry-electrolytic* capacitors.

In wet-electrolytic capacitors, the electrolyte is a liquid and the container must be leakproof. This type should always be mounted vertically.

The electrolyte of the dry-electrolytic capacitor is a paste contained in a separator made of an absorbent material such as gauze or paper. The separator not only holds the electrolyte in place but also prevents short-circuiting between the plates. Dry-electrolytic capacitors are made in both cylindrical and rectangular-block form and may be contained within either cardboard or metal covers. Since the electrolyte cannot spill, the dry capacitor may be mounted in any convenient position. Electrolytic capacitors are shown in Figure 11-10-9.

Variable capacitors are designed to allow changing the value of capacitance easily.

Changing the area of the plates. A typical variable capacitor is the rotor-stator type capacitor shown in Figure 11-10-10. It is made of two sets of metal plates, which can be moved to mesh with each other and thereby change the value of capacitance. Moving the plates into mesh effectively increases the plate area and causes capacitance to increase. Moving the plates out of mesh will cause the plate area to be smaller and capacitance to decrease.

Figure 11-10-9. Electrolytic capacitors.

Changing the spacing between the plates. Some variable capacitors employ a principle involving the change in the spacing between plates. As plate spacing is increased, capacitance decreases; as the plates move closer together, capacitance increases. Small capacitors referred to as trimmers employ this principle. The plates are separated by a thin layer of mica. To increase capacitance, the plates are tightened, that is, they are squeezed closer together, increasing capacitance.

Changing the dielectric constant of the material between the plates can also cause capacitance to change. This principle is employed in capacitance-type fuel indicating systems used in some aircraft. The aircraft fuel acts as the dielectric between the plates of a capacitor. As fuel level drops, the dielectric value of the material between the plates will vary, causing capacitance to change.

Section 11

Series Alternating Current Circuits

Several factors affect the voltage and current flow through alternating current series circuits. They include impedance, resistance & capacitance.

Impedance

When AC circuits contain resistance and either inductance or capacitance, the impedance (Z) is not the same as the resistance (R). The impedance of a circuit is the circuit's total opposition to

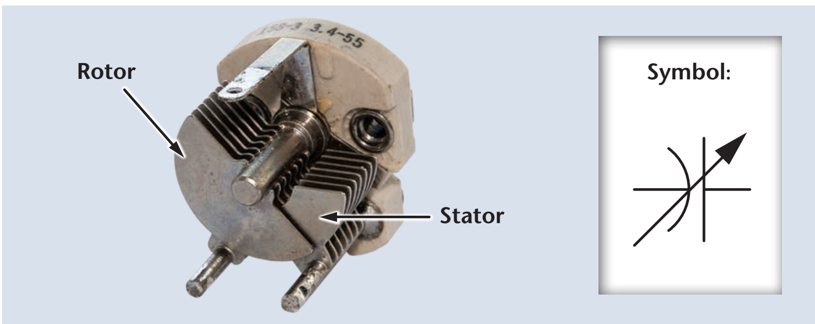


Figure 11-10-10. Rotor-stator variable capacitor.

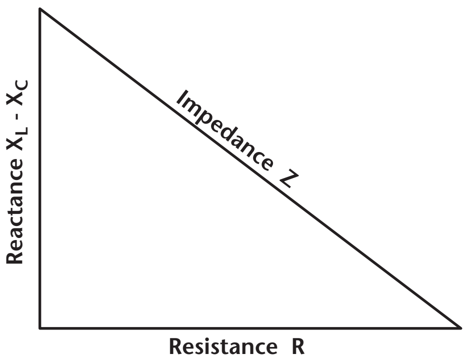


Figure 11-11-1. Impedance.

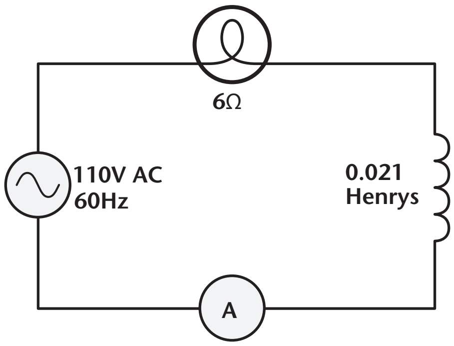


Figure 11-11-2. A circuit containing resistance and inductance.

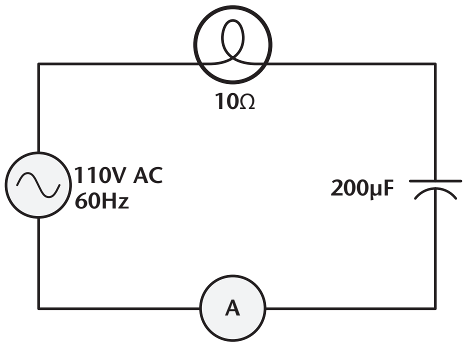


Figure 11-11-3. A circuit containing resistance and capacitance.

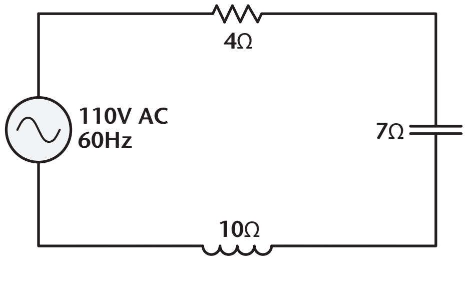


Figure 11-11-4. A circuit containing resistance, inductance, and capacitance.

the flow of current. In an AC circuit, this opposition consists of resistance and reactance, either inductive or capacitive, or elements of both.

Resistance and reactance cannot be added directly, but they can be considered as two forces acting at right angles to each other. Thus, the relation between resistance, reactance, and impedance may be illustrated by a right triangle, as shown in Figure 11-11-1.

Since these quantities may be related to the sides of a right triangle, the formula for finding the impedance, or total opposition to current flow in an AC circuit, can be found by using the law of right triangles.

This theorem, called the *Pythagorean theorem*, applies to any right triangle. It states that the square of the hypotenuse is equal to the sum of the squares of the other two sides. Thus, the value of any side of a right triangle can be found if the other two sides are known.

Circuits Having Resistance and Inductance

If an AC circuit contains resistance and inductance, as shown in Figure 11-11-2, the relation between the sides can be stated as:

$$Z^2 = R^2 + X_L^2$$

The square root of both sides gives:

$$Z = \sqrt{R^2 + X_L^2}$$

This formula can be used to determine the impedance when the values of inductive reactance and resistance are known. It can be modified to solve for impedance in circuits containing capacitive resistance by substituting X_C in the formula in place of X_L. In circuits containing resistance with both inductive and capacitive reactance, the reactances can be combined, but because their effects in the circuit are exactly opposite, the are combined by subtraction:

$$X = X_L - X_C \text{ or } X = X_C - X_L$$

(Smaller is always subtracted from the larger.)

In Figure 11-11-2, a series circuit consisting of resistance and inductance connected in series is connected to a source of 110 volts at 60 cycles per second. The resistive element is a lamp with 6 ohms resistance, and the inductive element is a coil with an inductance of 0.021 henry. What is the value of the impedance and the current through the lamp and the coil?

Solution: First the inductive reactance of the coil is computed:

$X_L = 2\pi \times f \times L$

$X_L = 6.28 \times 60 \times 0.021$

$X_L = 8$ ohms inductive reactance

Next, the total impedance is computed:

$$Z = \sqrt{R_2 + X_L^2}$$

$$Z = \sqrt{6^2 + 8^2}$$

$$Z = \sqrt{36+64}$$

$$Z = \sqrt{100}$$

Then the current flow,

$$I = \frac{E}{Z}$$

$$I = \frac{110}{10}$$

I = 11 amperes current

The voltage drop across the resistance (E_R) is

$E_R = I \times R$
$E_R = 11 \times 6 = 66$ volts

The voltage drop across the inductance (E_{XL}) is

$E_{XL} = I \times X_L$
$E_{XL} = 11 \times 8 = 88$ volts

The sum of the two voltages is greater than the impressed voltage. This results from the fact that the two voltages are out of phase and, as such, represent the maximum voltage. If the voltage in the circuit is measured by a voltmeter, it will be approximately 110 volts, the impressed voltage. This can be proved by the equation:

$$E = \sqrt{(E_R^2)+(E_{XL})^2}$$

$$E = \sqrt{66^2+88^2}$$

$$E = \sqrt{4{,}356 + 7{,}744}$$

$$E = \sqrt{12{,}100}$$

E = 110 volts

Circuits Having Resistance and Capacitance

In Figure 11-11-3, a series circuit is illustrated in which a capacitor of 200 μF is connected in series with a 10-ohm lamp. What is the value of the impedance, the current flow, and the voltage drop across the lamp?

First, the capacitance is changed from μF to farads. Since 1 million microfarads equal 1 farad, then:

$$X_C = \frac{1}{2\pi f C}$$

$$200\mu F = \frac{200}{1{,}000{,}000} = 0.0002000 \text{ farads}$$

$$X_C = \frac{1}{6.28 \text{ X } 60 \text{ X } 0.0002000 \text{ farads}}$$

$$X_C = \frac{1}{0.07536}$$

$X_C = 13.3$ ohms capacitive reactance

To find the impedance:

$$Z = \sqrt{R^2 + X_C^2}$$

$$Z = \sqrt{10^2 + 13^2}$$

$$Z = \sqrt{100 + 169}$$

$$Z = \sqrt{269}$$

Z = 16.4 ohms capacitive reactance

To find the current:

$$I = \frac{E}{Z}$$

$$I = \frac{110 \text{ V}}{16.4\ \Omega}$$

I = 6.7 amperes

The voltage drop across the lamp (E_R) is:

$E_R = I \times R$
$E_R = 6.7 \times 10$
$E_R = 67$ volts

The voltage drop across the capacitor E_{X_C} is:

$E_{X_C} = I \times X_C$
$E_{X_C} = 6.7 \times 13$
$E_{X_C} = 87.1$ volts

Circuits Having Resistance, Inductance, and Capacitance

When the circuit contains resistance, inductance, and capacitance, the equation

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

is used to find the impedance.

Example: What is the impedance of a series circuit (shown in Figure 11-11-4), consisting of a capacitor with a reactance of 7 ohms, an inductor with a reactance of 10 ohms, and a resistor with a resistance of 4 ohms?

Solution:

$$Z = \sqrt{R^2+(X_L - X_C)^2}$$

$$Z = \sqrt{4^2+(10-7)^2}$$

$$Z = \sqrt{4^2+3^2}$$

$$Z = \sqrt{25}$$

$$Z = 5 \text{ ohms}$$

Assuming that the reactance of the capacitor is 10 ohms and the reactance of the inductor is 7 ohms, then X_C is greater than X_L. Thus,

$$Z = \sqrt{R^2+(X_L - X_C)^2}$$

$$Z = \sqrt{4^2+(7-10)^2}$$

$$Z = \sqrt{4^2+(-3)^2}$$

$$Z = \sqrt{16+9}$$

$$Z = 5 \text{ ohms}$$

Section 12

Parallel Alternating Current Circuits

The methods used in solving parallel AC circuit problems are basically the same as those used for series AC circuits.

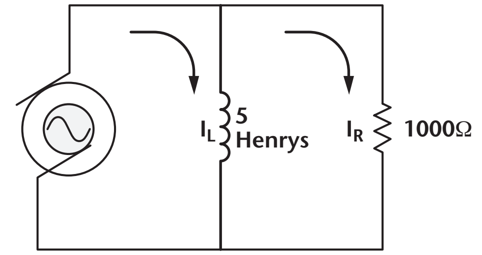


Figure 11-12-1. AC parallel circuit containing inductance and resistance.

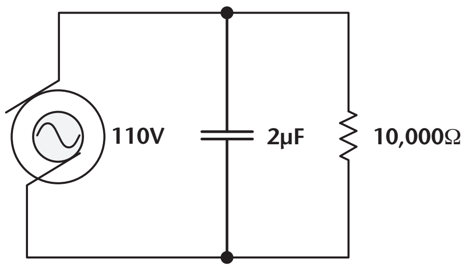


Figure 11-12-2. A parallel AC circuit containing capacitance and resistance.

Out-of-phase voltages and currents can be added by using the law of right triangles, but in solving circuit problems, the currents through the branches are added, since the voltage drops across the various branches are the same and are equal to the applied voltage.

A parallel AC circuit containing an inductance and a resistance is shown schematically in Figure 11-12-1. The current flowing through the inductance, I_L, is 0.0584 ampere, and the current flowing through the resistance is 0.11 ampere. What is the total current in the circuit?

Solution:

$$I_T = \sqrt{I_L^2 + I_R^2}$$

$$= \sqrt{(0.0584)^2 + (0.11)^2}$$

$$= \sqrt{0.0155}$$

$$= 0.1245 \text{ ampere}$$

Since inductive reactance causes voltage to lead the current, the total current, which contains a component of inductive current, lags the applied voltage. If the current and voltages are plotted, the angle between the two, called the phase angle, illustrates the amount the current lags the voltage.

To demonstrate the calculation of impedance and current flow in parallel AC circuits, using Figure 11-12-2, a 110-volt generator is connected to a load consisting of a 2-µF capacitance and a 10,000-ohm resistance in parallel. To find the value of the impedance and current flow, first, find the circuit's capacitive reactance:

$$X_C = \frac{1}{2\pi fC}$$

Changing 2µF to farads and entering the values into the formula given:

$$= \frac{1}{2 \text{ X } 3.14 \text{ X } 60 \text{ X } 0.000002}$$

$$= \frac{1}{0.00075360} \text{ or } \frac{10{,}000}{7.536}$$

$$X_C = 1{,}327\Omega \text{ capacitive reactance}$$

To find the impedance, the impedance formula used in a series AC circuit must be modified to fit the parallel circuit:

$$Z = \frac{RX_C}{\sqrt{R^2+X_C^2}}$$

$$= \frac{10{,}000 \text{ X } 1{,}327}{\sqrt{10{,}000^2 + (1.327)^2}}$$

$$= 0.1315\Omega \text{ (approx)}$$

To find the current through the capacitance:

$$I_C = \frac{E}{X_C}$$

$$= \frac{110}{1{,}327}$$

$$= 0.0829 \text{ ampere}$$

To find the current flowing through the resistance:

$$I_R = \frac{E}{R}$$

$$= \frac{110}{10{,}000}$$

$$= 0.011 \text{ ampere}$$

To find the total current in the circuit:

$$I_T^2 = \sqrt{I_R^2 + I_C^2}$$

$$I_T = \sqrt{(0.011)^2 + (0.0829)^2}$$

$$= 0.0836 \text{ ampere (approx)}$$

Section 13

Resonance in Alternating Current Circuits

Series resonant circuit. It has been shown that both inductive reactance ($X_L = 2\pi$ fL) and capacitive reactance ($X_c = 1/2\pi$ fC) are functions of an AC frequency. Decreasing the frequency decreases the ohmic value of the inductive reactance, but a decrease in frequency increases the capacitive reactance.

At some particular frequency, known as the resonant frequency, the reactive effects of a capacitor and an inductor will be equal. Since these effects are the opposite of one another, they will cancel, leaving only the ohmic value of the resistance to oppose current flow in a circuit. If the value of resistance is small or consists only of the resistance in the conductors, the value of current flow can become very high.

In a circuit where the inductor and capacitor are in series and the frequency is the resonant frequency, or frequency of resonance, the circuit is said to be *in resonance* and is referred to as a series resonant circuit. The symbol for resonant frequency is F_R.

If, at the frequency of resonance, the inductive reactance is equal to the capacitive reactance, then:

$$X_L = X_C, \text{ or}$$

$$2\pi fL = \frac{1}{2\pi fC}$$

Dividing both sides by 2fL,

$$F_R^2 = \frac{1}{(2\pi)^2 LC}$$

Extracting the square root of both sides gives:

$$F_R = \frac{1}{2\pi\sqrt{LC}}$$

Where F_R is the resonant frequency in hertz, C is the capacitance in farads and L is the inductance in henrys. With this formula the frequency at which a capacitor and inductor will be resonant can be determined.

To find the inductive reactance of a circuit use

$$X_L = 2(\pi)fL$$

Parallel resonant circuit. The impedance formula used in a series AC circuit must be modified to fit a parallel circuit.

$$Z = \frac{R_{XL}}{\sqrt{R^2 - XL^2}}$$

To find the parallel networks of inductance and capacitive reactors, use:

$$X = \frac{X_L X_C}{\sqrt{X_L + X_C}}$$

To find the parallel networks with resistance capacitive, and inductance, use:

$$Z = \frac{RX_L X_C}{\sqrt{X_L^2 + X_C^2 + (RX_L - RX_C)^2}}$$

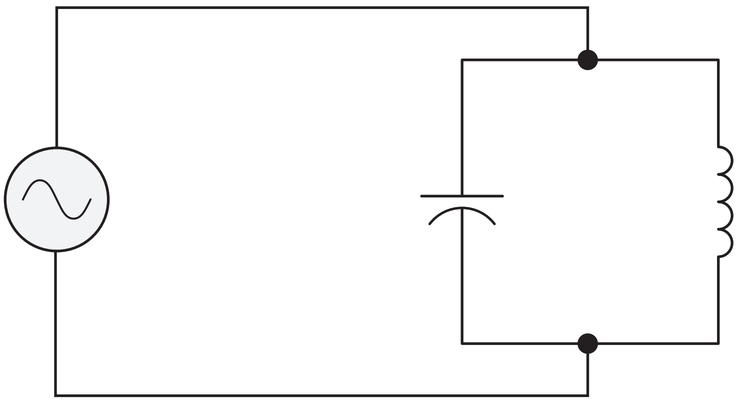


Figure 11-13-1. A parallel resonant circuit.

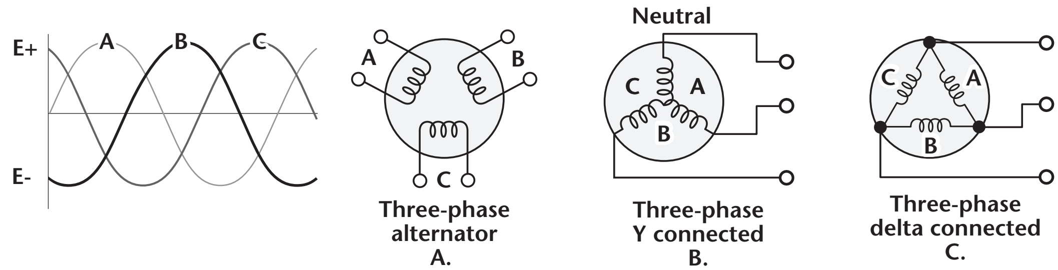


Figure 11-14-1. Three-phase alternator connections.

Since at the resonant frequency X_L cancels X_C, the current can become very high, depending on the amount of resistance. In such cases, the voltage drop across the inductor or capacitor will often be higher than the applied voltage.

In a parallel resonant circuit (Figure 11-13-1), the reactances are equal and equal currents will flow through the coil and the capacitor.

Since the inductive reactance causes the current through the coil to lag the voltage by 90°, and the capacitive reactance causes the current through the capacitor to lead the voltage by 90°, the two currents are 180° out of phase.

The canceling effect of such currents would mean that no current would flow from the generator and the parallel combination of the inductor and the capacitor would appear as an infinite impedance.

In practice, no such circuit is possible, since some value of resistance is always present, and the parallel circuit (sometimes called a tank circuit) acts as a very high impedance. It is also called an anti-resonant circuit, since its effect in a circuit is opposite to that of a series-resonant circuit, in which the impedance is very low.

Section 14

Three-Phase Alternating Circuit

Y-Connected Alternators

The early three-phase generators were connected to their loads with six wires; and all six leads in the circuit carried the current. Later, experiments proved that the generator would furnish as much power with the coils connected so that only three wires were needed for all three phases as shown in Figure 11-14-1. The use of three wires is standard for the transmission of three-phase power today. The return current from any one alternator coil always flows back through the other two wires in the three-phase circuit.

The three-phase alternator has three windings spaced 120° apart. Illustrations A and B of Figure 11-14-1 show two methods by which this may be accomplished. Rather than having six wires coming out of the alternator, as noted above and shown in Figure 11-14-1A, the same leads from each phase may be connected to form a Y arrangement as shown in Figure 11-14-1B.

In practice, an alternator with Y windings is connected in series to loads across two of the phases. The voltage across each of the loads is larger than the voltage across each phase. The total voltage or line voltage across any two phases is the vector sum of the individual phase voltages. For balanced conditions, the line voltage is 1.73 times the phase voltage. Since there is only one path for current in a line wire and the phase to which it is connected, the line current is equal to the phase current.

Delta-connected alternators. A three-phase stator may be arranged within an alternator so that the phases are connected end-to-end. This is referred to as a delta connection and is shown in Figure 11-14-1C.

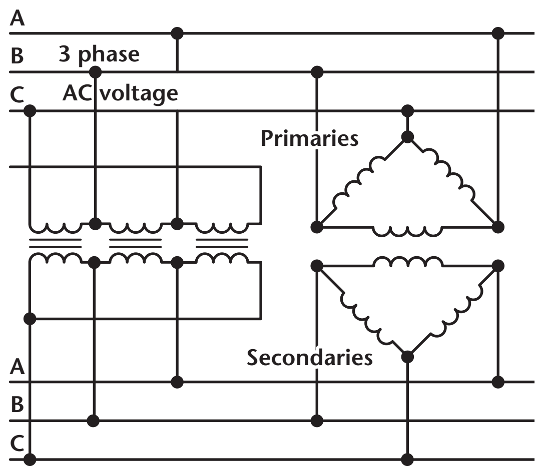


Figure 11-14-2. Delta-to-delta connection.

In the delta connection, line voltages are equal to phase voltages, but each line current is equal to 1.73 times the phase current.

Three-phase transformers. The three-phase transformer, as shown in Figure 11-14-2 consists of the normal primary and secondary windings, but with a delta connection. With this type of connection the transformer has the same voltage output as the line voltage. Assuming a line voltage of 240, between any two phases the voltage is 240 volts. In this type of connection, wires A, B, and C can furnish 240-volt, three-phase power for the operation of three-phase equipment.

When the Y connection is used in three-phase transformers, a fourth, or neutral, wire may be used. The neutral wire connects single-phase equipment to the transformer. Voltages between any one of the three-phase lines and the neutral wire are used for powering devices such as lights or single-phase motors.

All four wires in combination can furnish power at 208 volts, three-phase, for operating three-phase equipment, such as three-phase motors or rectifiers. When only three-phase equipment is used, the ground wire may be omitted. This leaves a three-phase, three-wire system as illustrated in Figure 11-14-3.

The type of connection used for the primary coils may or may not be the same as the type of connection used for the secondary coils. For example, the primary may be a delta connection and the secondary a wye connection. This is called a delta-wye-connected transformer. Other combinations are delta-delta, wye-delta, and wye-wye.

When a delta-wound primary is connected to a wye-wound secondary, the secondary voltage is 1.73 times higher than the primary voltage.

If the primary is wye-wound and the secondary is delta-wound, the secondary voltage will only be 0.5780 (1/1.73) times the value of the primary voltage.

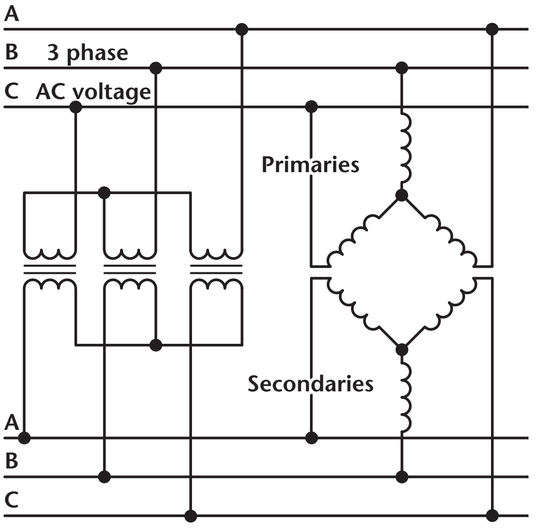


Figure 11-14-3. Y to Y connection.

Section 15

Converting Alternating Current into Direct Current

Diode Rectifier

Diode rectifiers are used in aircraft electrical systems, especially when high voltage DC is desired for light loads. They may be used as either half-wave or full-wave rectifiers; they may be used singly, in parallel, or in bridge circuits. As shown in Figure 11-15-1, a half-wave rectifier contains two tube elements (plate and cathode). A full-wave rectifier contains three elements (two plates and a cathode).

Vacuum tubes. Inside the glass container of a vacuum tube type rectifier are an electrode, called the cathode, a plate, and a heating element. When current is applied to the vacuum tube, the cathode and plate become heated by the heating element. As the cathode becomes heated, the electrons within the cathode loose their bond and are attracted to the plate during current flow in a positive direction. As the alternating current reverses direction, electrons do not flow from the plate to the cathode. The result is that current is allowed to flow in only one direction, which is direct current.

Dry-disk rectifiers operate on the principle that electric current flows through a junction of two dissimilar conducting materials more readily in one direction than it does in the opposite

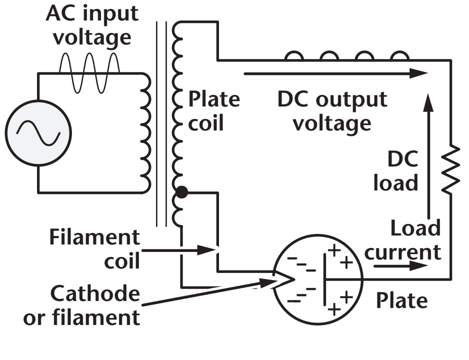


Figure 11-15-1. Half-wave vacuum tube rectifier circuit.

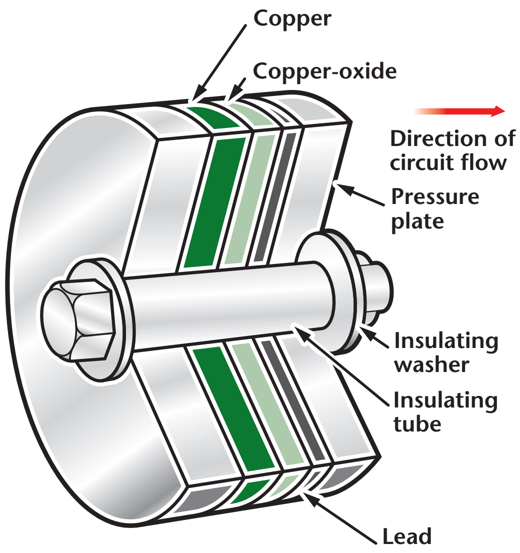


Figure 11-15-2. Copper-oxide dry-disk rectifier.

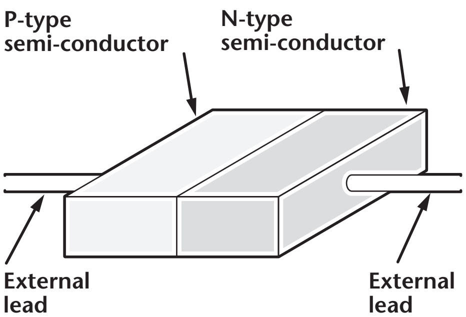


Figure 11-15-3. Junction diode.

direction. This is true because the resistance to current flow in one direction is low, while in the other direction it is high. Depending on the materials used, several amperes may flow in the direction of low resistance, but only a few milliamperes flow in the direction of high resistance.

Dry-disk diodes. Three types of dry-disk rectifiers may be found in aircraft: the copper-oxide rectifier, the selenium rectifier, and the magnesium copper-sulfide rectifier.

The copper-oxide rectifier (Figure 11-15-2) consists of a copper disk upon which a layer of copper oxide has been formed by heating. It may also consist of a chemical copper-oxide preparation spread evenly over the copper surface. Metal plates, usually lead plates, are pressed against the two opposite faces of the disk to form a good contact. Current flow is from the copper to the copper oxide.

The selenium rectifier consists of an iron disk, similar to a washer, with one side coated with selenium. Its operation is similar to that of the copper-oxide rectifier. Current flows from the selenium to the iron.

The magnesium copper-sulfide rectifier is made of washer-shaped magnesium disks coated with a layer of copper sulfide. The disks are arranged similarly to the other types. Current flows from the magnesium to the copper sulfide.

Solid-state diodes. Solid-state diodes are manufactured from semiconductor material, consisting of an N-type and a P-type material joined in a single crystal. The most common semiconductor materials are germanium and silicon. This is discussed in greater detail later in this chapter, in the section on semiconductor devices.

The point, or junction, where the two materials are in contact is called a P-N junction. This type of semiconductor, regardless of rating or size, is called a junction diode. A typical junction diode is shown in Figure 11-15-3.

Another type of semiconductor is called the point-contact diode. It utilizes a single type of semiconductor material, against which a tungsten or phosphor-bronze wire, called a *cat whisker*, is pressed or fused. The point-contact diode has been largely replaced by the junction diode because of its limited current-carrying capabilities.

The positive terminal of the battery in Figure 11-15-4 is connected to the P-type semiconductor material, and the negative terminal is connected to the N-type. This arrangement constitutes a forward bias.

The current in the P-type material is in the form of holes, and in the N-type material it is in the form of electrons. The holes in the P-type material are repelled from the positive terminal and move toward the junction. This is called the depletion area. The electrons in the N-type material are repelled from the negative

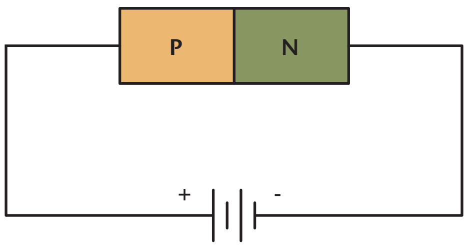


Figure 11-15-4. Forward bias on a junction diode.

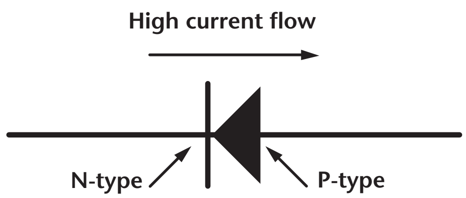


Figure 11-15-5. Semiconductor diode symbol.

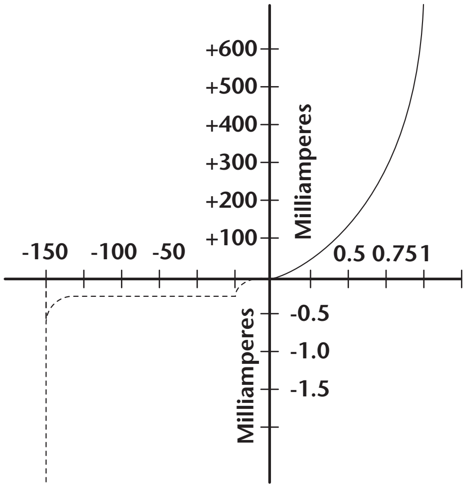


Figure 11-15-6. Typical junction diode characteristic curve.

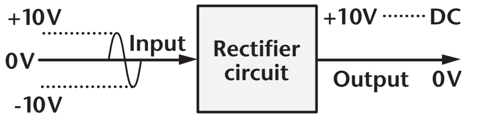


Figure 11-15-7. Rectification process.

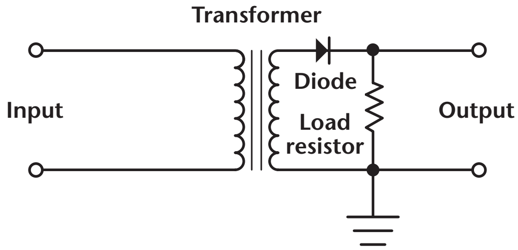


Figure 11-15-8. Half-wave rectifier circuit.

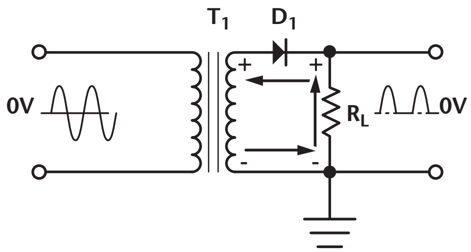


Figure 11-15-9. Output of a half-wave rectifier.

terminal and, likewise, move toward the junction. This decreases the space charge existing at the depletion area, and electron current flow is maintained through the external circuit.

If the forward bias is increased, current flow will increase. If the forward bias is increased excessively, it will cause excessive current. The excessive current will increase thermal agitation and the crystal structure will break down. One important fact worth remembering is that all solid-state devices are sensitive to heat and will be destroyed if the heat becomes too intense.

If the battery connections shown in Figure 11-15-4 are reversed, the junction diode is reverse-biased. Now the holes are attracted toward the negative terminal and away from the junction. The electrons are attracted toward the positive terminal, also away from the junction. This widens the depletion region, increases the space charge and reduces current to a minimum. It is possible to apply too high a reverse bias. When this happens, the crystal structure will break down.

The symbol for the semiconductor diode is shown in Figure 11-15-5. Note that this is the same symbol used for other types of diodes, such as the copper-oxide and selenium dry-disk rectifiers. The forward-bias, or high-current, direction is always against the arrow of the symbol.

A characteristic curve for a junction diode is shown in Figure 11-15-6. As forward bias is increased a small amount, current flow is increased a considerable amount. For this reason, solid-state devices are said to be current-operated devices, since it is easier to measure the relatively large changes in current flow as compared to the small changes in applied voltage.

With forward bias applied, the diode displays a low-resistance characteristic. On the other hand, with reverse bias applied, a high-resistance state exists.

The most important characteristic of a diode is that it allows current to flow in one direction only. This permits solid-state devices to be used in rectifier circuits.

AC to DC Rectification

Half-wave rectifier. *Rectification* is the process of changing AC to DC. When a semi-conductor rectifier, such as a junction diode, is connected to an AC voltage source, it is alternately biased forward and reverse in step with the AC voltage, as shown in Figure 11-15-7. But if a diode is placed in series with a source of AC power and a load resistor, as shown in Figure 11-15-8, the result is a half-wave rectifier circuit.

The transformer provides the AC input to the circuit and the diode provides the rectification of the AC. The load resistor limits the amount of current flow in the circuit to a safe level, and it develops an output signal due to the current flow through it.

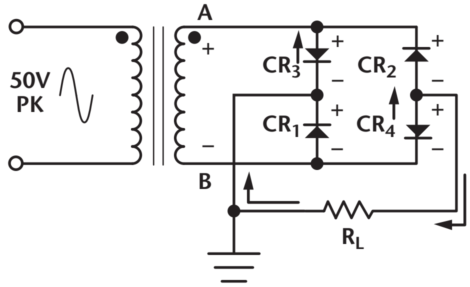


Figure 11-15-12. Redrawn bridge rectifier circuit.

Referring to Figure 11-15-9, assume that the top of the transformer secondary is positive and the bottom negative.

The diode is forward-biased with this polarity, resistance is very low, and current flows through the circuit in the direction of the arrows. The output (voltage drop) across the load resistor follows the wave shape of the positive half of the AC input. When the AC input goes in a negative direction, the top of the transformer secondary becomes negative and the diode becomes reverse-biased.

With reverse bias applied to the diode, the resistance of the diode becomes very great, and current flow through the diode and load resistor becomes zero. (Remember that a very small current will flow through the diode.) The output, taken across the load resistor, will be zero. If the position of the diode were reversed, the output would be negative pulses.

Full-wave rectifier. In a half-wave rectifier, a half cycle of power is produced across the load resistor for each full cycle of input power. To increase the output power, a full-wave rectifier can be used. Figure 11-15-10 shows a full-wave rectifier, which is, in effect, two half-wave rectifiers combined into one circuit.

In this circuit a load resistor is used to limit current flow and develop an output voltage, two diodes provide rectification, and a transformer provides the AC input to the circuit. The transformer, used in full-wave rectifier circuits, must be center tapped to complete the path for current flow through the load resistor.

Assuming the polarities shown on the transformer, diode D_1 will be forward-biased and current will flow from ground through the load resistor, through diode D_1, to the top of the transformer.

When the AC input changes direction, the transformer secondary will assume an opposite polarity. Diode D_2 is now forward-biased and current will flow in the opposite direction, from ground through the load resistor, through diode D_2, to the bottom half of the transformer.

When one diode is forward-biased, the other is reverse-biased. No matter which diode is forward-biased, current will flow through the load resistor in the same direction; so the output will be a series of pulses of the same polarity. By reversing both diodes, the output polarity will be reversed.

The voltage which is felt across a rectifier when reverse bias is being applied is often referred to as *the inverse peak voltage*. By definition, this is the peak value of the instantaneous voltage across the rectifier during the half-cycle in which current does not flow or that reverse bias is applied.

If an inverse voltage is applied that is too large, the rectifier will be destroyed. The term *breakdown voltage* is often used instead of the term *inverse peak voltage rating*, but both terms have the same meaning.

Breakdown voltage is the maximum voltage that the rectifier can stand while it is not conducting (reverse-biased); the inverse peak voltage is the voltage actually being applied to the rectifier. As long as the inverse peak voltage is lower than breakdown voltage, there will be no problem of rectifier destruction.

Bridge-type, full-wave rectifier. An advantageous modification of the full-wave diode rectifier is the bridge rectifier. The bridge rectifier differs from the full-wave rectifier in that a

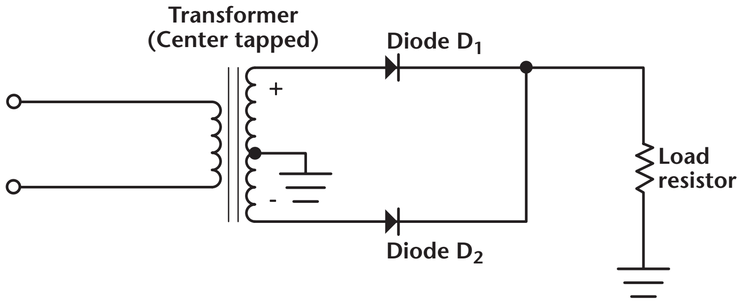


Figure 11-15-10. Full-wave rectifier.

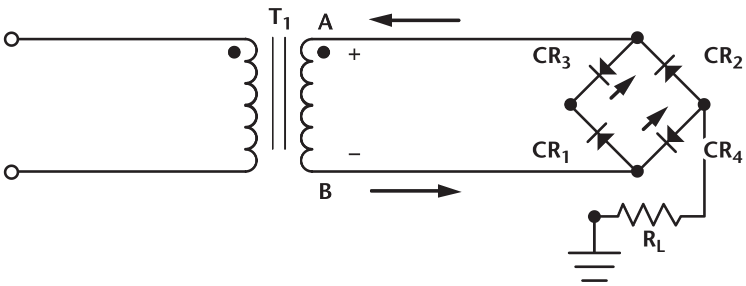


Figure 11-15-11. Diode bridge rectifier.

bridge rectifier does not require a center-tapped transformer, but does require two additional diodes.

To illustrate how a bridge rectifier performs, consider a sine wave input, which is on its positive alternation as denoted on the schematic of Figure 11-15-11. With the secondary of T_1 functioning as the bridge rectifier's power supply, point A is the most positive point of the bridge, while B is the most negative. Current flow will be from B to A through the forward-biased diodes.

As an aid in finding the path of electron flow, consider the redrawn bridge circuit in Figure 11-15-12. The forward-biased diodes, CR_3 and CR_4, are easily recognized. Voltage is dropped across each voltage loop as indicated. Thus, on the positive half-cycle input, CR_3 and CR_4 are both forward-biased and CR_1 and CR_2 are reverse-biased.

As long as diode breakdown voltage is not exceeded, current flow will be from point B up and across CR_4, down and to the left across R_L. After current crosses R_L, it will flow to point A through CR_3. Notice that current flow across R_L is from right to left, or in respect to polarity, a negative half-cycle output for positive half-cycle input.

Remember that when tracing current flow for the negative half-cycle, electron flow through a diode is against the symbolic arrow and from negative to a less negative or positive point. Therefore, no confusion should arise when tracing electron flow up to and away from the common point between CR_3 and CR_1. Although it may appear that CR_1, as well as CR_4, is forward-biased, such is not the case. The collector of CR_1 is more negative than its emitter; therefore, it is reverse-biased.

On the negative half-cycle, CR_1 and CR_2 are forward-biased, and the output signal on the negative half-cycle is negative.

Both half-cycles of the input signal result in negative output pulses, so the bridge rectifier has accomplished the same goal as the full-wave diode rectifier.

Filters

That part of the rectification process that involves the converting of an AC voltage into pulses of DC voltage has been treated in the discussion of vacuum tube, dry-disk, and semiconductor diodes.

To complete the rectification process, so that the pulses of voltage are changed to an acceptable approximation of smooth DC involves a process called filtering.

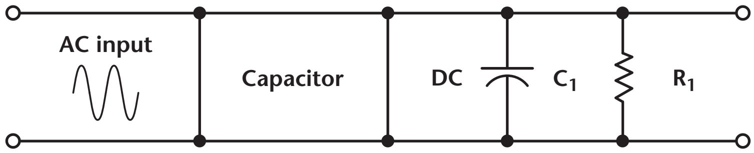


Figure 11-15-13. A capacitor used as a filter.

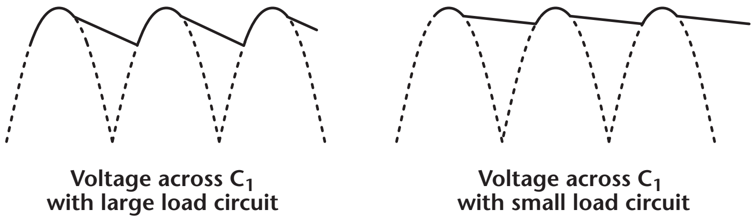


Figure 11-15-14. Half-wave and full-wave rectifier outputs using capacitor filter.

Any reactance which opposes a change in voltage (or current) by storing energy and then releasing this energy back to the circuit may be used as a filter.

Capacitance-input filters. In the study of capacitors, it was demonstrated that a capacitance opposes a voltage change across its terminal by storing energy in its electrostatic field. Whenever the voltage tends to rise, the capacitor converts this voltage change to stored energy. When the voltage tends to fall, the capacitor converts this stored energy back to voltage. The use of a capacitor for filtering the output of a rectifier is illustrated in Figure 11-15-13. The rectifier is shown as a block, and the capacitor C_1 is connected in parallel with the load R_1.

The capacitor C_1 is chosen to offer very low impedance to the AC ripple frequency and very high impedance to the DC component. The ripple voltage is therefore bypassed to ground through the low impedance path, while the DC voltage is applied unchanged to the load.

The effect of the capacitor on the output of the rectifier can be seen in the wave shapes shown in Figure 11-15-14. Dotted lines show the rectifier output; solid lines show the effect of the capacitor. Full-wave rectifier outputs are shown. The capacitor C_1 charges when the rectifier voltage output tends to increase and discharges when the voltage output tends to decrease. In this manner, the voltage across the load R_1 is kept fairly constant.

Choke-input filters. An inductance may be used as a filter, because it opposes a change in current through it by storing energy in its electromagnetic field whenever current

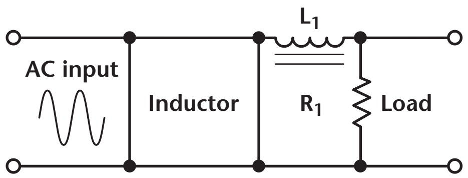


Figure 11-15-15. An inductor used as a filter.

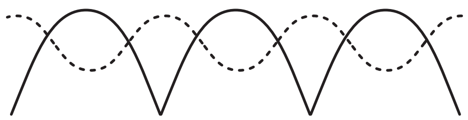


Figure 11-15-16. Output of an inductor filter rectifier.

increases. When the current through the inductor decreases, the inductor supplies the energy to maintain the flow of current. The use of an inductor for filtering the output of a rectifier is shown in Figure 11-15-15. Note that the inductor L_1 is in series with the load R_1.

The inductance L_1 is chosen to offer high impedance to the AC ripple voltage and low impedance to the DC component. Therefore, for the AC ripple, a very large voltage drop occurs across the inductor and a very small voltage drop across the load R_1.

For the DC component, while a very small voltage drop occurs across the inductor, a very large voltage drop occurs across the load. The effect of an inductor on the output of a full-wave rectifier is shown in the output wave shape in Figure 11-15-16. Note that the ripple has been attenuated (reduced) in the output voltage.

Pi-type filters. Capacitors and inductors are combined in various ways to provide more satisfactory filtering than can be obtained with a single capacitor or inductor. These are referred to collectively as LC filters. Several combinations are shown schematically in Figure 11-15-17. Note that the L- or inverted-L-type and the T-type filter sections resemble schematically the corresponding letters of the alphabet. The pi-type filter section resembles the Greek letter pi (π) schematically.

All the filter sections shown are similar in that the inductances are in series and the capacitances are in parallel with the load. Additional filter sections may be combined to improve the filtering action.

The inductances must, therefore, offer a very high impedance and the capacitors a very low impedance to the ripple frequency. Since the ripple frequency is comparatively low, the inductances are iron-core coils having large values of inductance (several henrys). Because they offer such high impedance to the ripple frequency, these coils are called chokes.

The capacitors must also be large (several microfarads) to offer very little opposition to the ripple frequency. Because the voltage across the capacitor is DC, electrolytic capacitors are frequently used as filter capacitors. The correct polarity in connecting electrolytic capacitors should always be observed.

LC filters are also classified according to the position of the capacitor and inductor. A capacitor-input filter is one in which the capacitor is connected directly across the output terminals of the rectifier. A choke-input filter is one in which a choke precedes the filter capacitor.

If it is necessary to increase the applied voltage to more than a single rectifier can tolerate, the usual solution is to stack rectifiers in series.

These rectifiers are similar to resistors added in series. Each resistor will drop a portion of the applied voltage rather than the total voltage. The same theory applies to rectifiers added in series, or stacked.

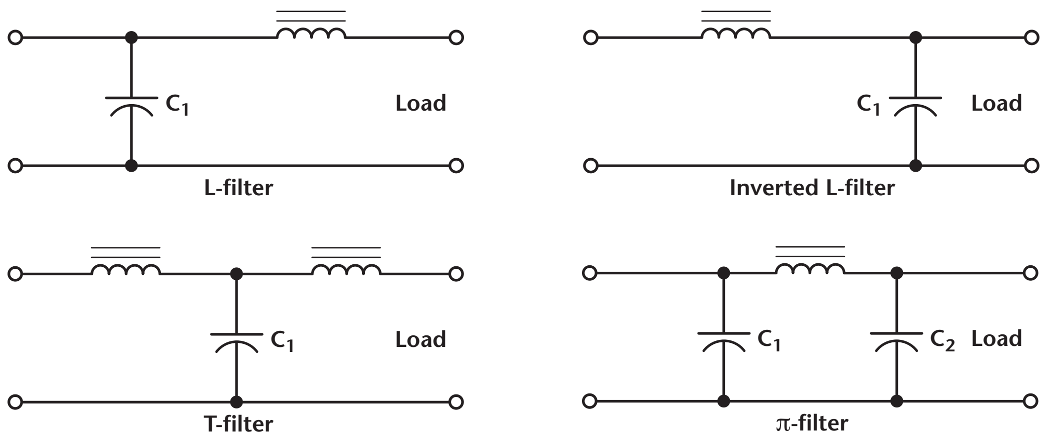


Figure 11-15-17. LC filters.

Series stacking increases the voltage rating. If, for example, a rectifier will be destroyed with an applied voltage exceeding 50 volts, and it is to be used in a circuit with an applied voltage of 150 volts, stacking of diodes can be employed. The result is shown in Figure 11-15-18.

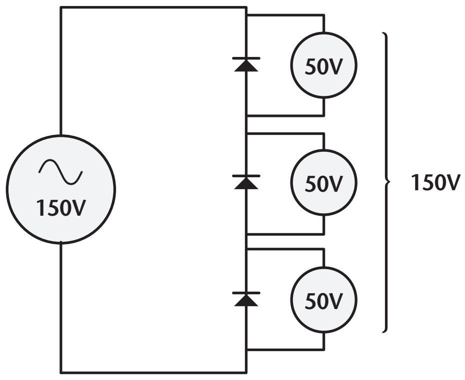


Figure 11-15-18. Stacking diodes in a circuit.

Section 16

Electron Control Devices

Vacuum Tubes

The use of the vacuum tube in aircraft electrical and avionics systems has practically ceased because of the many advantages of transistors and other solid-state electronic devices. However, a few systems still employ vacuum tubes in special applications, and some older model aircraft still in service are equipped with devices that use vacuum tubes. In any case, a general study of vacuum tubes is considered a part of the aviation maintenance program.

Originally, vacuum tubes were developed for radio work. They are used in radio transmitters as amplifiers for controlling voltage and current, as oscillators for generating audio and radio frequency signals, and as rectifiers for converting AC into DC.

When a piece of metal is heated, the speed of the electrons in the metal is increased. If the metal is heated to a high enough temperature, the electrons are accelerated to the point where some of them actually leave the surface of the metal, as shown in Figure 11-16-1.

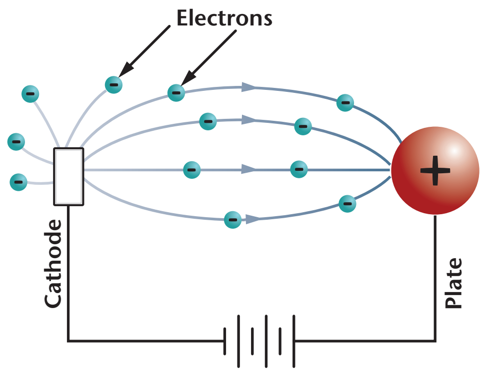


Figure 11-16-1. Principle of vacuum tube operation.

In a vacuum tube, electrons are supplied by a piece of metal, called a cathode, which is heated by an electric current. Within limits, the hotter the cathode the greater the number of electrons it will give off or emit. To increase the number of electrons emitted, the cathode is usually coated with special chemical compounds.

If the emitted electrons are not drawn away by an external field, they form about the cathode into a negatively charged cloud called the space charge. The accumulation of negative electrons near the emitter repels others coming from the emitter.

If insulated, the emitter becomes positive because of the loss of electrons. This establishes an electrostatic field between the cloud of negative electrons and the now positive cathode. A balance is reached when only enough electrons flow from the cathode to the area surrounding it to supply the loss caused by diffusion of the space charge.

Types of vacuum tubes. There are many different types of vacuum tubes, most of which fall into four general types:

- Diode
- Triode
- Tetrode
- Pentode

In some vacuum tubes, the cathode is heated by DC and is both the electron emitter and current-carrying member, while in others the cathode is heated by AC.

Tubes designed for AC operation employ a special heating element that heats the electron emitter (cathode) indirectly.

Diodes

When a DC potential is applied between the cathode and another element in the tube called a plate, with the positive side of the voltage connected to the plate, the electrons emitted by

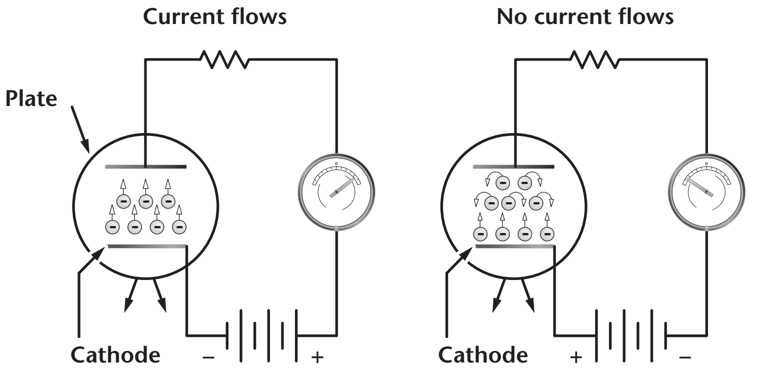


Figure 11-16-2. Diode tube operation.

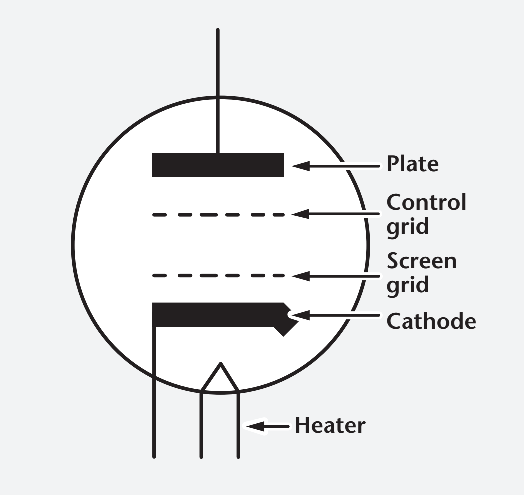


Figure 11-16-4. Tetrode schematic.

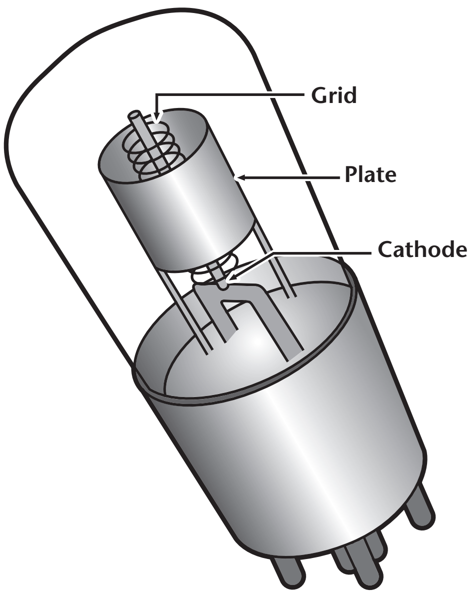


Figure 11-16-3. Triode tube.

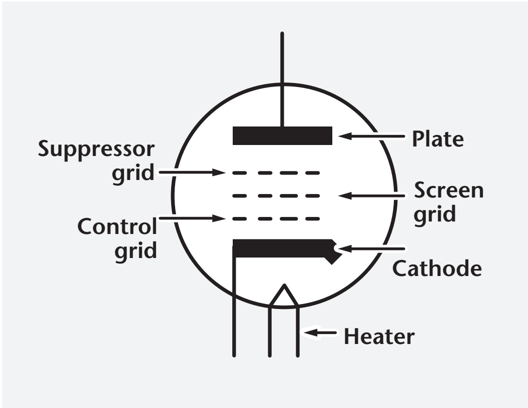


Figure 11-16-5. Pentode tube schematic.

the cathode are attracted to the plate. These two elements constitute the simplest form of vacuum tube, which is the diode.

In the diode, electrons are attracted to the plate when it is more positive than the cathode and are repelled when the plate is less positive than the cathode. The diode is used almost exclusively for changing AC current to DC current.

Current flows through the tube when it is connected in a circuit only when the plate is positive with respect to the cathode. Current does not flow when the plate is negative (less positive) with respect to the cathode as illustrated in Figure 11-16-2. This characteristic gives the diode its principle use, that of rectification, or the changing of AC into DC.

In the half-wave circuit, current flows only during the positive half of the cycle of the applied voltage (plate positive, cathode negative for electron flow). It flows from the cathode to the plate and then through the load back to the cathode. On the negative cycle of the applied voltage, no current flows through the tube. As a result, the rectified output voltage is DC, but it consists of pulses, or half cycles, of current.

In a vacuum tube connected as a full-wave rectifier, current flows to the load on both half cycles of the alternating voltage. In the full-wave rectifier, current flows from the top plate through the DC load on one alternation, and on the next alternation, current flows to the lower plate and through the load in the same direction.

Vacuum tube rectifiers have been replaced to a great degree in aircraft systems by dry-disk or semiconductor diodes. In the study of solid-state devices, the process of rectification is treated in greater detail.

Triodes

The triode tube is a three-element tube. In addition to the plate and cathode, there is a third element, called the grid, located between the cathode and the plate as shown in Figure 11-16-3.

The grid is a fine-wire mesh or screen that serves to control the electron flow between the cathode and the plate. Whenever the grid is made more positive than the cathode, there is an increase in the number of electrons attracted to the plate, resulting in an increase in plate current flow. If the grid is made negative with respect to the cathode, electron movement to the plate is retarded and plate current flow decreases.

Usually the grid is negative with reference to the cathode. One method of making the grid negative is to use a small battery connected in series with the grid circuit. This negative voltage applied to the grid is called bias.

The most important use of a triode is as an amplifier tube. When a resistance or impedance is connected in series in the plate circuit, the voltage drop across it, which depends upon the current flowing through it, can be changed by varying the grid voltage. A small change in grid voltage will cause a large change in the voltage drop across the plate impedance. Thus, the voltage applied to the grid is amplified in the plate circuit of the tube.

Tetrodes

A tetrode tube is a four-element tube, the additional element being the screen grid (Figure 11-16-4). This grid is located between the control grid and the plate. The screen grid is operated at a positive voltage somewhat lower than the plate voltage.

The screen grid reduces the sometimes undesirable effect in tube operation caused by energy fed from the output of a tube back into the input (grid) circuit. Under certain operating conditions, this feedback action is very pronounced in a triode and causes the tube to act as an oscillator instead of an amplifier.

The chief advantages of tetrodes over triodes are greater amplification for smaller input voltages and less feedback from the plate to the grid circuit.

An undesirable characteristic of the tetrode tube is secondary emission. Secondary emission is the term applied to the condition where electrons are knocked out of the plate into the space between the elements of a tube by rapidly moving electrons striking the plate.

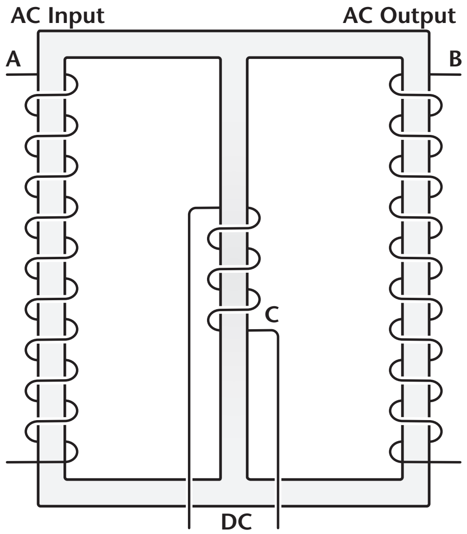


Figure 11-16-6. Magnetic amplifier circuit.

In triode tubes, since the grid is negative with respect to the cathode, it repels the secondary electrons and tube operation is undisturbed.

In the tetrode, the effect of secondary emission is especially noticeable since the screen grid, which is positive with respect to the cathode, attracts the secondary electrons and causes a reverse current to flow between the screen and plate.

Pentodes

The effects of secondary emission are overcome by adding a third grid, called the suppressor grid, between the screen grid and the plate. This grid repels the secondary electrons toward the plate. A tube with three grids is called a pentode, which has a high amplification factor and is used to amplify weak signals. The schematic of a pentode is shown in Figure 11-16-5.

Magnetic Amplifier

The magnetic amplifier is a control device employed in many aircraft electrical and electronic systems. The principles on which the magnetic amplifier operates can best be explained by reviewing the operation of a simple transformer. If an AC voltage is applied to the primary of an iron core transformer, the iron core will be magnetized and demagnetized at the same frequency as that of the applied voltage. This, in turn, will induce a voltage in the transformer secondary. The output voltage across the terminals of the secondary will depend on the relationship of the number of turns in the primary and the secondary of the transformer.

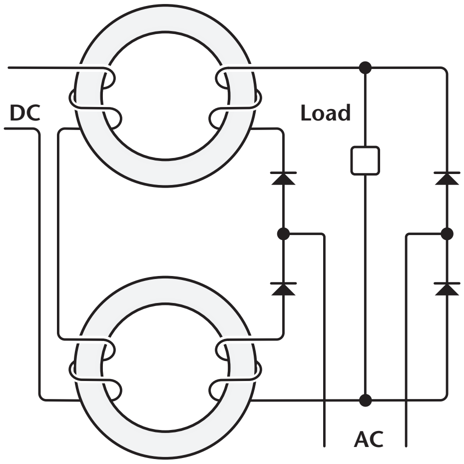


Figure 11-16-7. Self-saturating, full-wave magnetic amplifier.

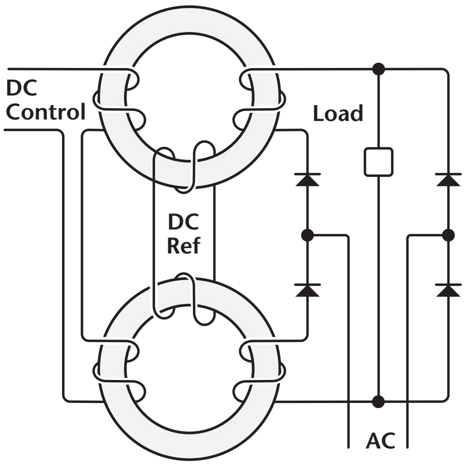


Figure 11-16-8. Basic preamplifier circuit.

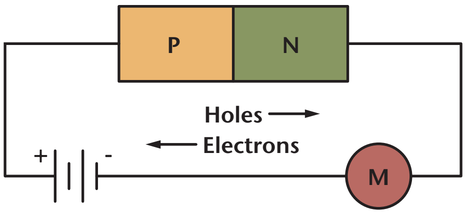


Figure 11-16-9. Electron and hole flow in a diode with forward bias.

Figure 11-16-10. Schematic representation of a diode.

The iron core of the transformer has a saturation point after which the application of a greater magnetic force will produce no change in the intensity of magnetization. Hence, there will be no change in transformer output, even if the input is greatly increased.

How a simple magnetic amplifier functions is explained using the magnetic amplifier circuit in Figure 11-16-6. Assume that there is 1 ampere of current in coil A, which has 10 turns of wire. If coil B has 10 turns of wire, an output of 1 ampere will be obtained if coil B is properly loaded. By applying DC to coil C, the core of the magnetic amplifier coil can be further magnetized. Assume that coil C has the proper number of turns and, upon the application of 30 mA, that the core is magnetized to the point where 1 ampere on coil A results in only 0.24 ampere output from coil B.

By making the DC input to coil C continuously variable from 0 to 30 mA and maintaining an input of 1 ampere on coil A, it is possible to control the output of coil B to any point between 0.24 ampere and 1 ampere in this example. The term *amplifier* is used for this arrangement because, by use of a few mA, control of an output of 1 or more amperes is obtained.

By controlling the extent of magnetization of the iron ring, it is possible to control the amount of current flowing to the load, since the amount of magnetization controls the impedance of the AC input winding. This type of magnetic amplifier is called a simple saturable reactor circuit.

Adding a rectifier to such a circuit would remove half the cycle of the AC input and permit a DC to flow to the load. The amount of DC flowing in the load circuit is controlled by a DC control winding (sometimes referred to as bias). This type of magnetic amplifier is referred to as being self-saturating.

In order to use the full AC input power, a circuit such as that shown in Figure 11-16-7 may be used. This circuit uses a full-wave bridge rectifier. The load will receive a controlled DC by using the full AC input. This type of circuit is known as a self-saturating, full-wave magnetic amplifier.

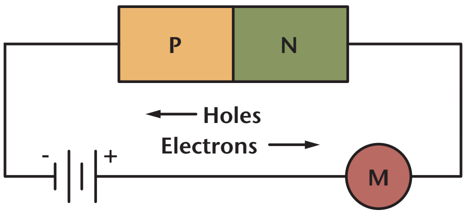


Figure 11-16-11. Electron and hole flow in a diode with reverse bias.

It is assumed that the DC control winding in Figure 11-16-8 is supplied by a variable source such as a sensing circuit. In order to control such a source and use its variations to control the AC output, it is necessary to include another DC winding that has a constant value. This winding, referred to as the reference winding, magnetizes the magnetic core in one direction.

The DC control winding, acting in opposition to the reference winding, either increases (degenerative) or decreases (regenerative) the magnetization of the core to change the amount of current flowing through the load. This is essentially a basic preamplifier.

Semiconductor Devices

Before any in-depth discussion on semiconductors can occur, an understanding of the behavior of the materials is necessary.

Silicon and germanium are the two basic elements used in semiconductor devices. On their own, these materials are similar, neither are good conductors of electricity. This is because they both have an atom with an outer shell with four electrons each. They also have room for four more electrons in that same shell. These electrons are tightly bound to the atom and are not easily disturbed. Therefore, they do not conduct electricity very well.

To produce a material that will become a semiconductor a certain amount of impurities are added during the crystal growth period. This is called “doping”. To produce a material that has an excess of electrons, elements having five electrons in their outer shells are added to the original material. This fifth electron is free to wander about the crystal lattice of the material and the material is known as a “donor,” or N-type material. Other materials have a deficiency of electrons in their outer shells that when combined with either silicon or germanium creates a hole in the outer shell. These are known as “acceptors,” or P-type materials.

These materials N and P are called semiconductors because they only conduct electricity under certain conditions.

Diodes. Figure 11-16-9 illustrates a germanium diode and consists of two different types of semiconductor materials. With the battery connected as shown, positive holes and electrons are repelled by the battery toward the junction, causing an interaction between the holes and electrons. This results in electrons flowing through the junction to the holes and to the positive terminal of the battery. The holes move toward the negative terminal of the battery. This is called the forward direction and is a *high* current. Figure 11-16-10 is the schematic drawing of a diode.

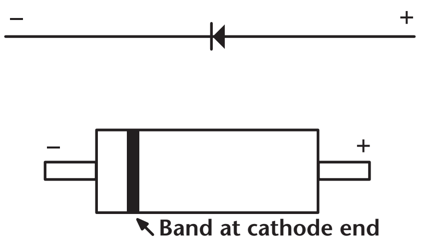


Figure 11-16-12. A diode illustrating cathode position.

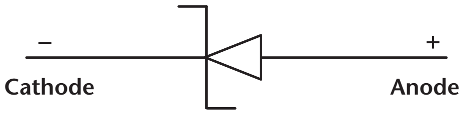


Figure 11-16-13. Schematic representation of a Zener diode.

Connecting the battery as shown in Figure 11-16-11 causes the holes and electrons to be pulled away from the junction, and little interaction between holes and electrons occurs at the junction. This results in very little current flow, called reverse current.

The potential on the electrodes of the transistor diodes applied from the battery is called bias. It may be either forward or reverse bias, that is, in a high-current or a low-current direction.

Because all diodes are biased , polarity must be observed when they are connected into a circuit. A dark band on the diode indicates the cathode, or negative end (Figure 11-16-12). If the diode is installed backwards, it will act as a very effective check valve until it fails. A failed diode will conduct in both directions and no longer serve as a flow control device in the circuit.

The N-germanium is manufactured with an impurity, such as arsenic, added to give it an excess of electrons. Arsenic gives up its electrons readily and can be used as a carrier. The P-germanium has an impurity, such as indium, added. This takes the electrons from the germanium and leaves holes, or positive carriers.

Zener diodes. Zener diodes (sometimes called *breakdown diodes*) are used primarily for voltage regulation. They are designed so that they will break down (allow current to pass) when the circuit potential is equal to or in excess of the desired voltage. Below the desired voltage the Zener blocks the circuit like any other diode biased in the reverse direction.

Because the Zener diode allows free flow in one direction, two diodes connected in opposite directions must be used when it is used in an AC circuit. This takes care of both alternations of current. The schematic representation of a Zener diode is shown in Figure 11-16-13

Transistors. A transistor is a semiconductor device consisting of two types of materials each of which exhibits electrical properties. Semiconductors are materials whose resistive characteristics fall approximately midway between those of good conductors and insulators. The interface between the parts is called a junction. Selenium and germanium diodes (rectifiers) are examples of such devices and are called junction diodes. Most transistors are made of germanium to which certain impurities are added to impart certain characteristics. The impurities used are generally arsenic or indium.

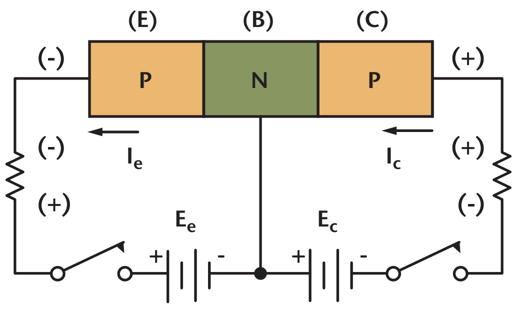


Figure 11-16-16. Transistor hole flow.

The type of transistor that largely replaced the triode tube is the *junction* transistor, which actually has two junctions. It has an emitter, base and collector, which correspond to the cathode, grid, and plate, respectively, in the triode tube. Junction transistors are of two types, the NPN type and the PNP type (Figure 11-16-14).

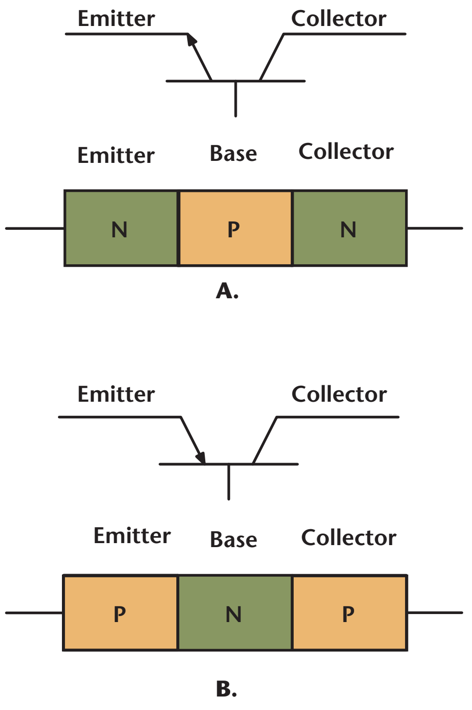


Figure 11-16-14. NPN and PNP transistors.

Theory of Transistor Operation

Before transistor operation and the meaning of *N* and *P* can be explained, it is necessary to consider the theory of transistor action.

An electron is a negatively charged particle. In any material, there are electrons separated from each other by some minute distance. Wherever there is an electron, there is a negative charge. An atom of the semiconductor material has a specified number of electrons, depending on the type of material. If one of the electrons is removed, the hole from which the electrons moved is more positive than the electron that was removed.

The hole is considered to have a positive charge. If an electron from a neighboring atom moves into the hole, the hole apparently moves to the place from which the electron came. The hole does not really move; it is filled in one place and formed in another. In Figure 11-16-15A, the electrons are represented as black dots and the holes as filled circles.

In Figure 11-16-15B, the electrons have moved one space to the left of their position occupied in Figure 11-16-15A. In effect, the holes have, therefore, moved one space to the right.

The movement of the electrons is current. In the same sense, the movement of holes is current also. Electron current moves in one direction; hole current travels in the opposite direction. The movement of the charge is a current. In transistors both electrons and holes act as carriers of current.

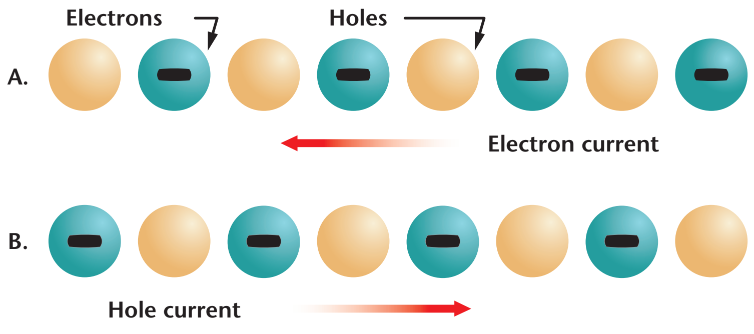


Figure 11-16-15. Electrons and holes in transistors.

In transistors, materials referred to as N-materials and P-materials are used. The N-materials, or donors, are rich in electrons and, therefore, electrons act as the carriers. The P-materials are lacking in electrons and, therefore, have holes as carriers, or acceptors.

An NPN transistor is not interchangeable with a PNP transistor and vice versa. However, if all power supplies are reversed, they may be interchanged.

Since temperature is critical in a transistor circuit, there must be sufficient cooling for the transistors.

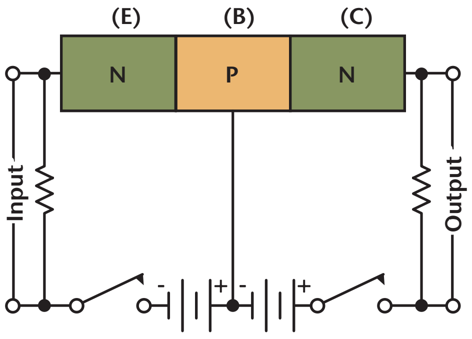


Figure 11-16-18. NPN transistor circuit.

PNP transistor. Figure 11-16-16 shows a transistor circuit powered by batteries. The emitter circuit is biased by the battery E_e in the forward, or high-current-flow, direction. The collector circuit is biased by battery E_c in the reverse, or low-current-flow, direction.

If the switch in the emitter circuit were closed (collector switch open), a high emitter current would flow since it is biased in the forward direction. (If the collector switch were closed (emitter switch open), a low current would flow since it is biased in the reverse direction).

At the same time, a hole current is flowing in the opposite direction in the same circuit, as shown in Figure 11-16-17. Hole current flows from the positive terminal of the battery, whereas electron current originates at the negative terminal.

The operation with both switches closed is the same as with a PNP transistor, except that the emitter now ejects electrons instead of holes into the base, and the collector, being positive, will collect the electrons. There is again a large increase in collector current with the emitter switch closed. With the emitter switch open, the collector current will be small, since it is biased for reverse flow.

At first glance it may appear that the transistor cannot amplify, since there is less current in the collector than in the emitter circuit. Remember, however, that the emitter is biased in the forward direction and a small voltage causes a large current, which is equivalent to a low resistance. The collector circuit is biased in the reverse direction, and a large voltage causes a small current, which is the equivalent of a high resistance.

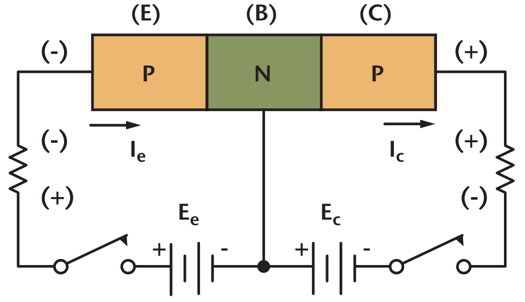


Figure 11-16-17. Transistor hole current flow.

When both switches are closed, a phenomenon known as transistor action occurs. The emitter, biased in the forward direction, has its positive holes ejected through the junction into the *N* region of the base. (The positive battery terminal repels the holes through the junction.) The collector, being biased negatively, will now attract these holes through the junction from the base to the collector.

This collecting of holes by the collector causes a much greater reverse current than there would be if the emitter switch were open. The large increase of reverse collector current is caused by so-called transistor action, whereby holes from the emitter pass to the collector. Instead of holes flowing through the base and back to the emitter, they flow through the collector, E_c and E_e, to the emitter; the actual base current is very small.

The sum of collector current and base current equals the emitter current. In typical transistors the collector current can be 80 to 99 percent of the emitter current, with the remainder flowing through the base.

NPN transistor. In Figure 11-16-18 an NPN transistor is connected into a circuit. Notice that the battery polarities are reversed from those for the PNP transistor. But with the types of transistor material reversed, the emitter is still biased in the forward direction, and the collector is still biased in the reverse direction.

A small signal applied to the input terminal in this circuit causes a small change in both emitter and collector currents. However, the collector, being a high-resistance, requires only

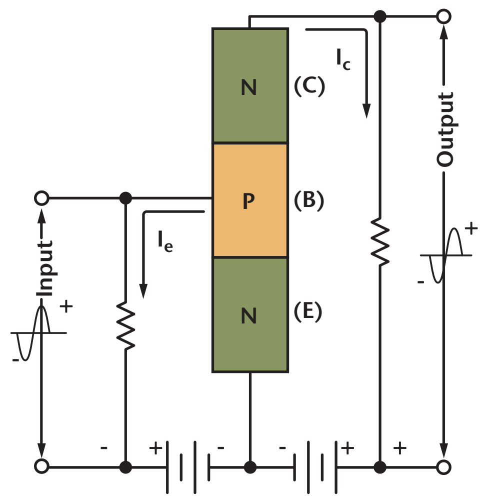


Figure 11-16-19. A grounded-emitter amplifier circuit.

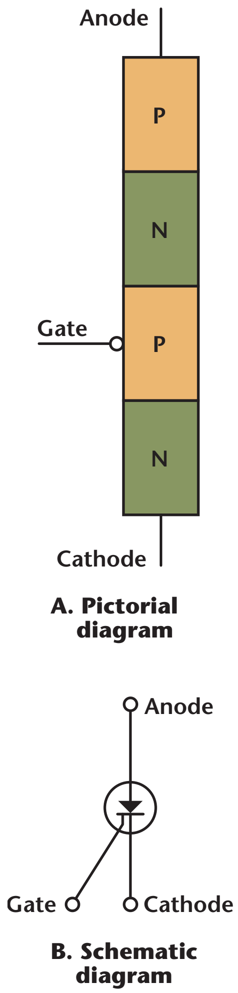


Figure 11-16-20. Silicon controlled rectifier (SCR) structure.

a small current change to produce large voltage changes. Therefore, an amplified signal appears at the output terminals.

The circuit in this illustration is called a grounded base amplifier, because the base is common to input and output (emitter and collector) circuits.

Figure 11-16-19 shows a different type of circuit connection. This is called a grounded-emitter amplifier and is similar to a conventional triode amplifier. The emitter is like a cathode, the base like a grid, and the collector like a plate. The collector is biased for a reverse current flow.

If the input signal swings positive, as shown in Figure 11-16-19, it will aid the bias and increase base and emitter current. This increases collector current, making the upper output terminal more negative. On the next half cycle, the signal will oppose the bias and decrease emitter and collector current. Therefore, the output will swing positive. It is 180° out of phase with the input just as in the conventional triode tube amplifier.

Since the base current is a very small part of the total emitter current, it requires only a very small change in base current to cause a large change in collector current. Therefore, it again amplifies the signal. This circuit has the highest gain (output/input) of the various transistor amplifiers. A PNP transistor could also be used if battery polarities were reversed.

The common collector circuit is just opposite the common emitter. It has a high Z input and low Z output.

Silicon-controlled rectifiers (SCR). The silicon-controlled rectifier (SCR) is one of a family of four-layer semiconductor devices referred to as thyristors. The SCR has three electrodes: a cathode, an anode, and a gate, as shown in Figure 11-16-20. As the name implies, the SCR will conduct current in only one direction. The SCR differs from a conventional diode in that it will not begin conduction until a certain minimum voltage is exceeded, or until a voltage is applied to the gate terminal.

Increasing the anode to cathode potential will cause the SCR to begin conduction. The potential at which this conduction occurs is called the forward breakover potential. Once this potential is reached, the SCR will remain in conduction until the current drops below a specific value known as the holding current. Dropping below holding current will cause the SCR to revert to the *off* state.

The second means of causing the SCR to break into conduction involves the application of a small positive potential to the gate electrode. This potential will forward bias the gate-cathode junction as the SCR is said to be triggered. After the SCR is turned on by the gate voltage, the forward current through the SCR is independent of gate voltage or current. It will remain in the conducting state until the anode current drops below the holding current value as noted above. It is important to remember that the SCR is a unilateral, or half-wave, device. That is, it will only conduct in one direction, similar to the conventional diode.

Triac. The triac is a three-terminal device, which is similar in function and construction to the SCR. The most significant difference is that the triac will conduct current in both directions. It may, therefore, be used in alternating current circuits to exercise full-wave control. The triac terminals are referred to as Main Terminal 1, Main Terminal 2, and gate, as shown in Figure 11-16-21. This method of labeling is required due to two back-to-back SCRs. The triac is capable of performing full-wave power control as shown in Figure 11-16-22.

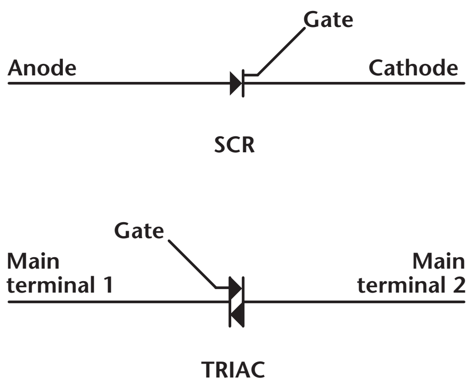


Figure 11-16-21. Comparison of SCR and triac symbols.

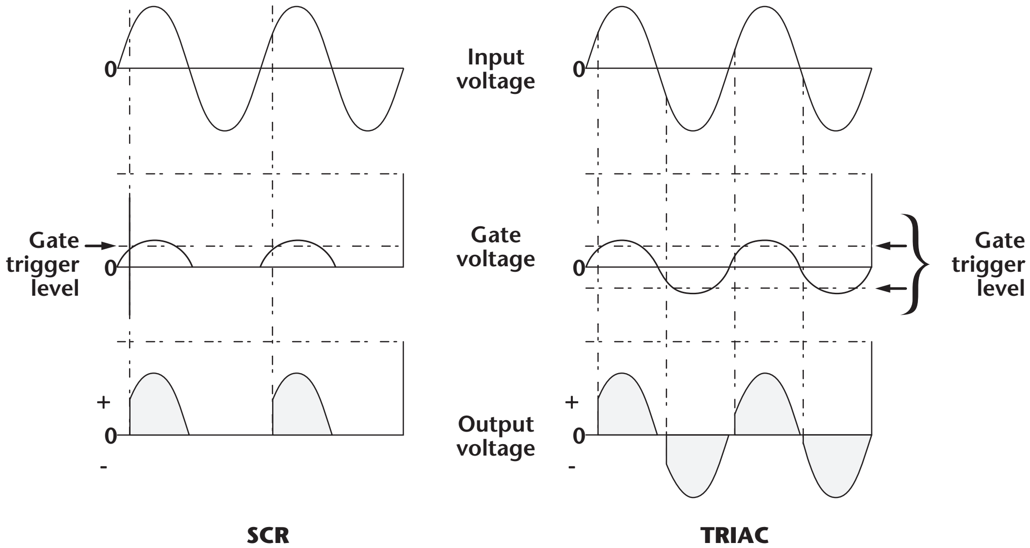


Figure 11-16-22. Comparison of SCR and triac waveforms.

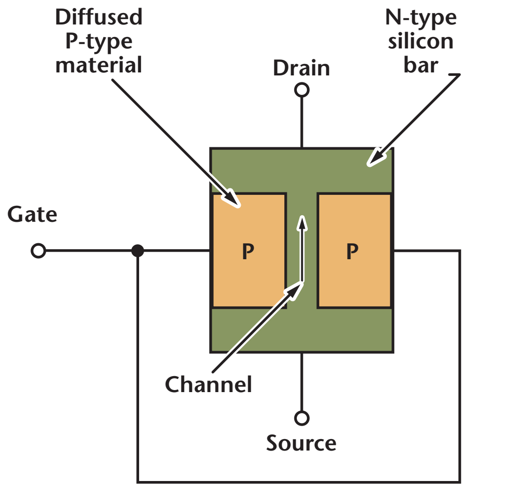


Figure 11-16-23. JFET structure.

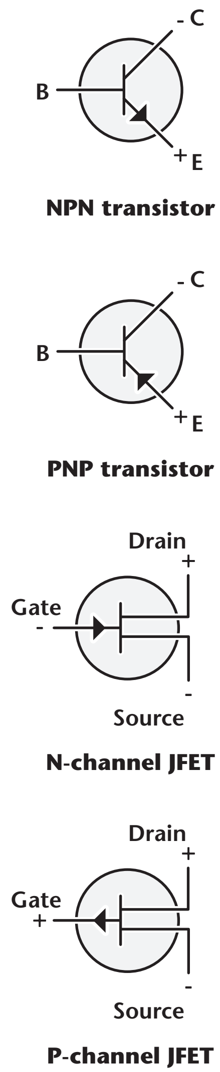


Figure 11-16-24. Symbols and bias voltages for transistors and JFET.

Field-effect transistor (FET). Also known as the bipolar junction transistor (NPN and PNP), the FET has revolutionized the world of electronics. However, it has one undesirable characteristic. It has low input impedance associated with its base-emitter junction, which causes problems in matching impedances between stages in amplifier circuits.

The junction field-effect transistor (JFET or FET) overcomes this problem. The bipolar junction transistor (BJT) is a current-controlled device, using base current to control collector current. Conversely, the FET is a voltage-controlled device, using a potential on the gate terminal to control current through a semiconductor channel of either P-type or N-type material. Figure 11-16-23 illustrates the basic construction of an N-channel FET. Applying a potential to the gate element creates a field that blocks the flow of electrons through the channel. If a sufficiently large potential is applied to the gate, the flow of electrons is *pinched-off* completely (which is analogous to pinching a liquid-filled tube until fluid flow in the tube is stopped).

Since the FET is a voltage-controlled device, and since essentially no current flows from the gate to the channel, the input impedance to the FET is very high. This makes it a desirable device to use in circuits where impedance matching or amplifier load isolation is important. Figure 11-16-24 identifies the terminals of the schematic symbol of the FET and shows a comparison of the BJT terminals.

An additional type of FET has been developed in recent years that has some advantages over the JFET. This device is constructed of metallic oxide semiconductor material and is therefore known as the metallic oxide semiconductor field-effect transistor (MOSFET). The MOSFET has an even higher input impedance than the JFET and has much less loading effect on associated circuits. The MOSFET may operate in one of two basic modes.

The depletion mode MOSFET incorporates a heavily doped channel and requires reverse bias application on the gate to cause a depletion of carriers in the channel.

The enhancement mode MOSFET utilizes a lightly doped channel and requires forward bias to enhance the current carriers in the channel. Schematic symbols for MOSFETs are shown in Figure 11-16-25.

Uni-junction transistor (UJT). The UJT is a three-terminal device with only one PN junc-

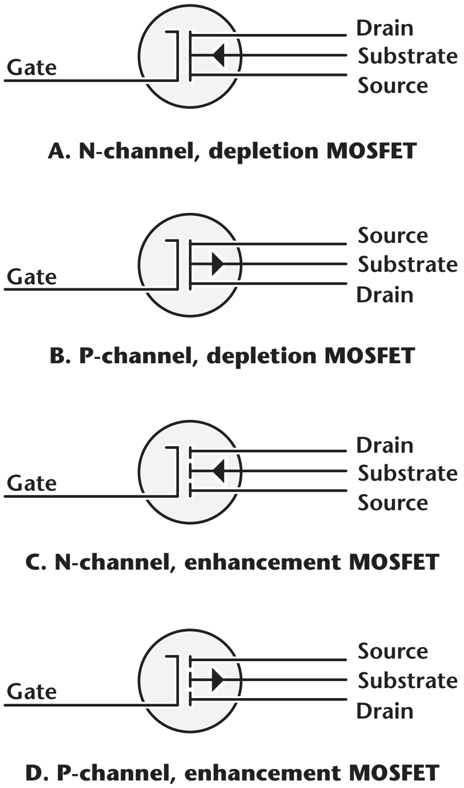


Figure 11-16-25. MOSFET symbols.

tion. Figure 11-16-26 illustrates the difference between a BJT and the UJT.

The area of N-type material between base 1 and base 2 of the UJT acts as a variable resistor. The emitter of the UJT is comparable to the wiper arm of a variable resistor. Conduction in the UJT occurs when the emitter is more positive than the voltage gradient at the emitter-base contact point.

The UJT is used in switching circuits, oscillators, and control circuits for SCRs and triacs.

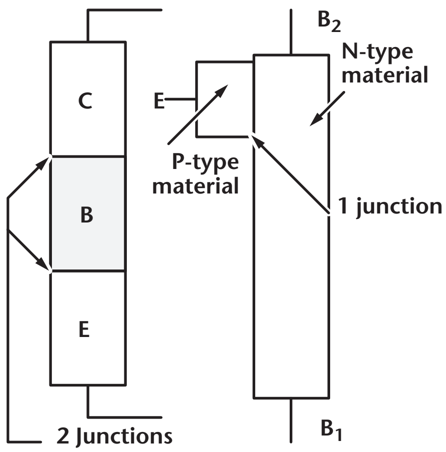


Figure 11-16-26. BJT and UJT comparison.

Optoelectronic Devices

Photodiodes. The photodiode is a light-activated variable resistor. In the complete absence of light, it has a very high resistance and will, therefore, conduct very little current. When the diode junction is exposed to a source of light, the internal resistance decreases and current flow will pass through the diode. This characteristic of the photodiode makes it useful in control circuits where light intensity varies. The speed with which the photodiode responds to light changes makes them useful in digital circuits as well. The schematic symbols for photodiodes and other optoelectronic devices are shown in Figure 11-16-27.

Phototransistor. Another optoelectronic device is the phototransistor. The phototransistor is more sensitive to changes in light and conducts more current for a specific level of light than the photodiode. Light striking the base of the phototransistor causes base current and therefore collector current of the transistor to change.

Light emitting diode (LED). The LED was originally developed to replace incandescent bulbs in indicator light circuits. The incandescent bulb has a shorter lifespan consumes more power than the LED. When the LED is forward-biased, it produces visible light. The LED may produce red, green, amber, or blue white depending on the material from which it is constructed. On an actual LED, the cathode, or negative, side has two distinguishing features. The cathode lead is shorter than the anode, and that side of the LED has a flat spot. This allows a technician to install it with the correct polarity in a circuit (Figure 11-16-27). LEDs may be combined on a single device to form a seven-segment display to display numbers. A typical LED operating voltage is small, approximately 1.6 volts with a current flow of about 10 milliamps.

Section 17

Basic Semiconductor Circuits

Amplifiers. Amplifier circuits using transistors are capable of taking input signals (voltage or current) and changing them to smaller or larger output signals (voltage or current). The transistor is able to do this due to the change in resistance across the transistor output caused by the input signal.

The amplifier circuit shown in Figure 11-17-1A will be used to illustrate how a transistor amplifier operates. The circuit shown is referred to as a common-emitter amplifier since the signal input, the emitter of the transistor, and the output signal share a common ground.

Capable of quite high voltage gain, this circuit and other, more advanced and complex versions of it have widespread use in electronic equipment. The signal input to the circuit is through the coupling capacitor to the base of the transistor, and the output signal is taken from the collector to ground.

Before a common-emitter circuit can amplify signals, it must be biased correctly. That is, the base of the transistor must be made more positive than the emitter (NPN transistor, PNP requires opposite polarity) to forward bias the base-emitter junction. In the circuit shown, this is accomplished by connecting a reasonably high value of resistance between the source voltage (V_{cc}) and the transistor base. This will permit base current to flow and will turn the transistor on. Once biased *on*, the transistor will conduct electrons from ground, through the emitter-collector junction, and through the load resistor (R_L), to the voltage source. The small base current (usually microamps) will, therefore, be able to control a much larger collector current. The ratio between base current and collector current may be thought of as the gain of the transistor.

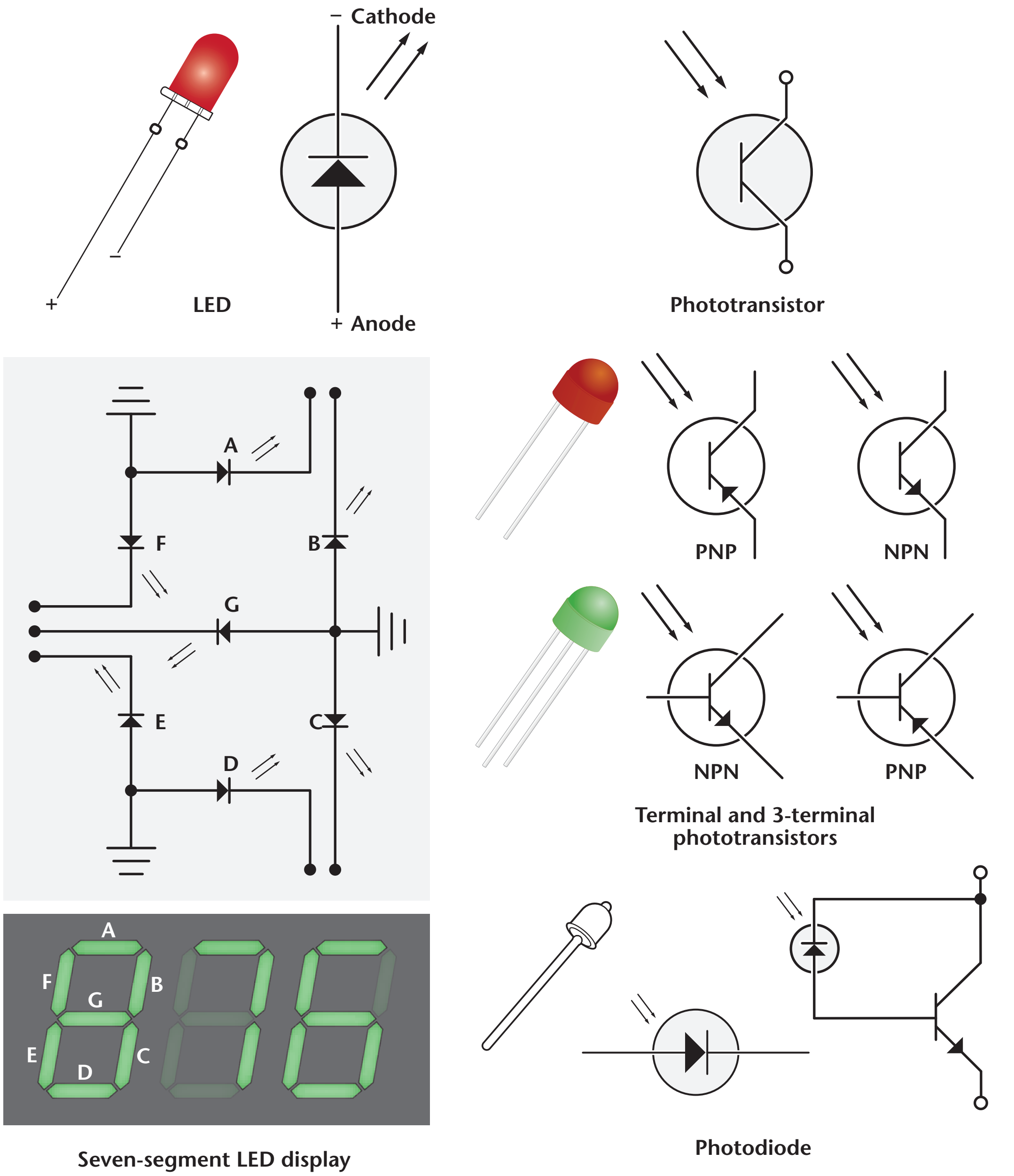


Figure 11-16-27. Optoelectric devices.

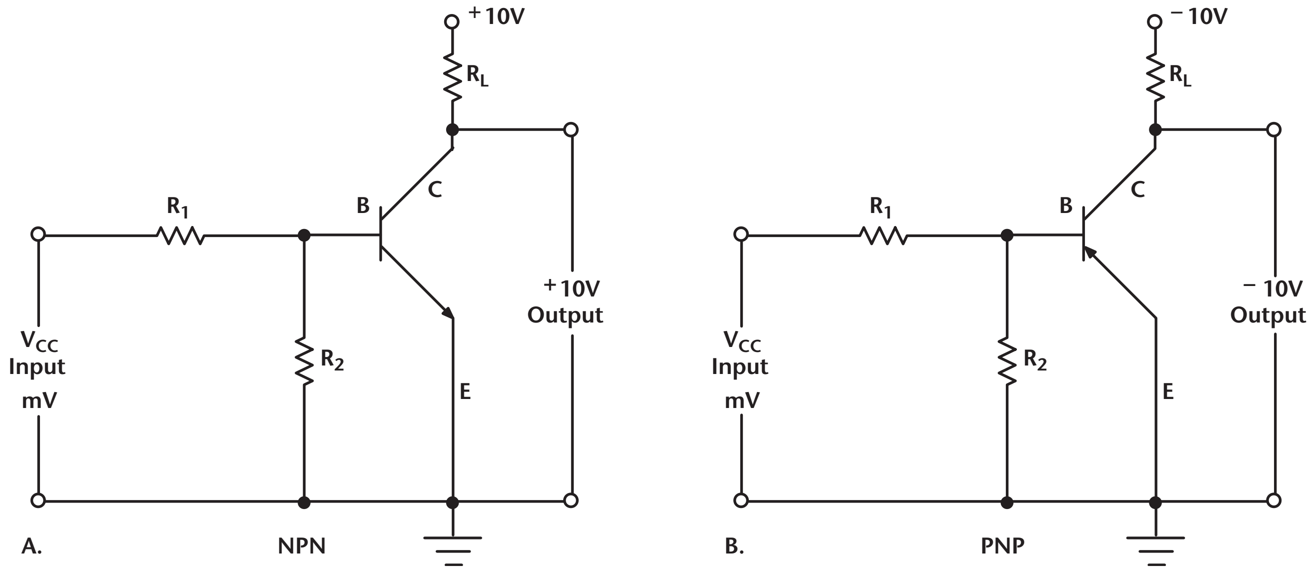


Figure 11-17-1. Basic transistor amplifier.

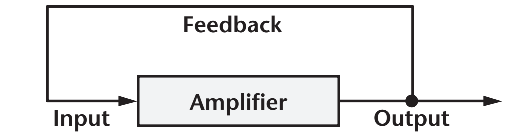


Figure 11-17-2. Basic oscillator block diagram.

Applying a small AC signal to the base, as shown in the diagram (Figure 11-17-1A), once the transistor is turned on, will cause the base current to vary above and below the DC level established by the biasing resistor, R_2. Small changes in the base current will cause larger changes (on the order of 100) in the collector current, hence the transistor has amplified the input signal. It is important to note that the phase of the input signal has been inverted from the base to the collector; phase inversion is one of the characteristics of a common-emitter amplifier.

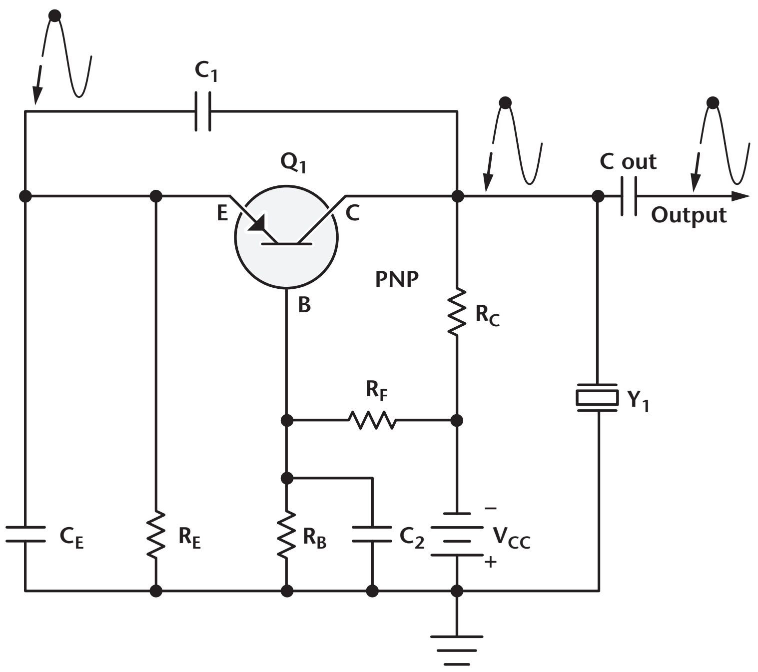


Figure 11-17-3. Crystal-controlled oscillator, common-base configuration.

The operation of the NPN circuit has been described in this example. The PNP circuit shown in Figure 11-17-1B, works in the same manner, except for the polarity of the voltage source.

Oscillators. An oscillator is basically an amplifier circuit that has been modified slightly to allow it to generate an output waveform. Oscillators may be classified as being either sinusoidal or nonsinusoidal. This discussion will be confined to sinusoidal, or sine-wave, oscillators. Oscillator circuits use the characteristic of parallel resonance (discussed in section 13) to produce a sine-wave output of a particular frequency.

The block diagram for a typical oscillator is illustrated in Figure 11-17-2. The feedback in this case must be regenerative, that is, it must be in-phase with the input. An out-of-phase feedback signal would cancel a portion of the input signal and would not sustain oscillation.

When an oscillator is initially turned on, no signal is present at the output to be fed back to the input except random, wide-band, noise produced by the transistor. A parallel resonant network consisting of an RC or LC circuit is used to determine which frequency seen in the output will be fed back to the input of the oscillator circuit. Often, a phase-shifting circuit must be employed to correct for phase-inver-

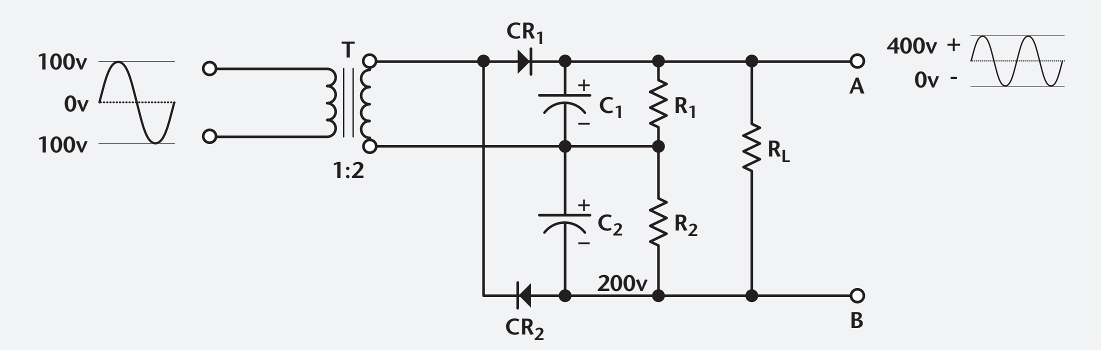


Figure 11-17-4. Full-wave voltage doubler.

sion between the base and collector of a transistor. Remember, the feedback in an oscillator circuit must be in-phase.

The frequency of an oscillator may also be determined through the use of a crystal. The quartz crystal is typically used in oscillator circuits. Quartz crystals exhibit a characteristic known as piezoelectric effect. They are also temperature sensitive. This effect is the property of certain materials by which mechanical forces may produce electricity, and vice versa. All crystals will have a particular frequency at which they operate, referred to as their natural resonant frequency.

A crystal-controlled oscillator is shown in Figure 11-17-3. The feedback path is from the output of the transistor at the collector, through the crystal, Y_1, to the base of the transistor.

Voltage Control Circuits

Electronic circuits may also be used to change the value of voltage in a circuit, or to regulate the output voltage of a power supply. One method of increasing voltage in circuits is known as voltage multiplication. Circuits of this type may double, triple, or even quadruple circuit voltage, but will keep circuit current at a low level.

Full-wave voltage doubler. One such circuit is the full-wave voltage doubler circuit shown in Figure 11-17-4. A significant advantage of the full-wave doubler is improved voltage regulation. The circuit is, essentially, two half-wave rectifiers. These rectifiers function as series-aiding devices. During the positive alternation, capacitor C_1 will charge to the peak value of the transformer secondary voltage through CR_1. During the negative alternation, C_2 will charge to the peak value of the transformer secondary through CR_2. Resistors R_1 and R_2 are equalizing resistors and will balance the voltages across the two capacitors. Since the capacitors are connected in series with each other and across the load resistor R_L, their combined voltages will be seen across R_L, hence doubling the voltage from the transformer secondary.

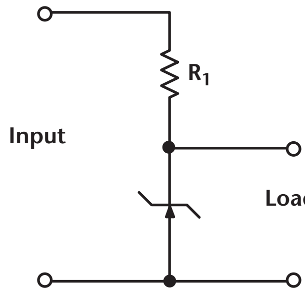


Figure 11-17-5. Shunt Zener voltage regulator.

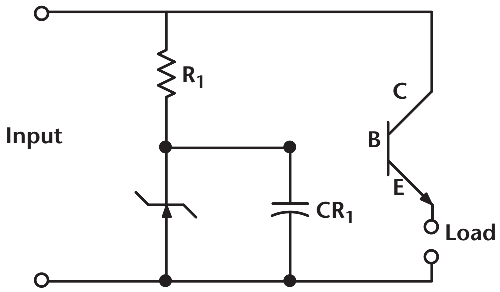


Figure 11-17-6. Series Zener voltage regulator.

Voltage regulator. The voltage output from power supplies should be at a constant level. Unfortunately, this is not always the case. A change in input voltage, or a change in load-current requirements, may cause the power supply outward to vary. One circuit used to correct this problem is the Zener diode regulator. The Zener may either be connected in series or parallel (shunt) to regulate voltage in a load circuit.

In a shunt Zener voltage regulator circuit (Figure 11-17-5), the Zener is placed in parallel with the load and will, therefore, regulate the voltage in the load circuit. Resistor R_1 is placed in series with the Zener and the load to limit the total current to a value that will prevent destruction of the diode.

Figure 11-18-1. D'Arsonval meter movement.

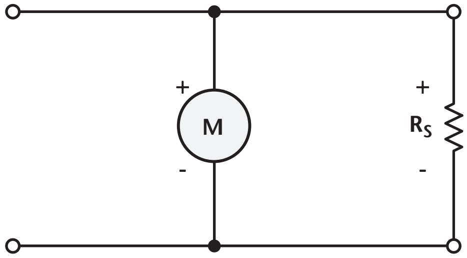


Figure 11-18-2. Meter movement with shunt.

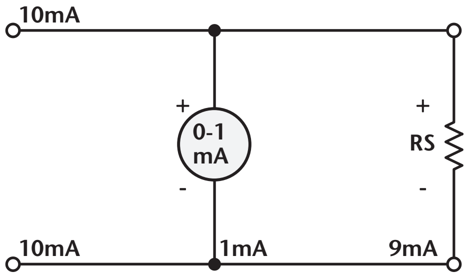


Figure 11-18-3. Schematic for shunt resistor.

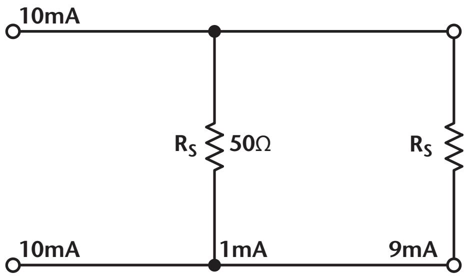


Figure 11-18-4. Equivalent meter circuit.

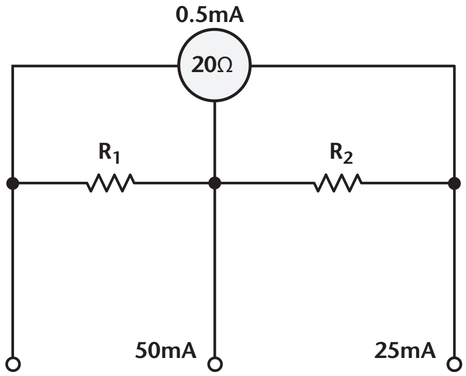


Figure 11-18-5. Universal ammeter shunt.

Zener current and load current flow through R_1 and determine the voltage drop across R_1. The voltage across the load circuit is the difference between the input voltage to the regulator circuit (from the power supply) and the voltage drop across R_1. The voltage across the load is determined by the Zener.

In the series Zener voltage regulator, if the input voltage decreases, the current through CR_1 will decrease. Since CR_1 is in parallel with the load, total current will decrease. The decrease in total current will result in a smaller voltage drop across R_1. The decrease in voltage across R_1 follows the decrease in input voltage so the voltage across the load decreases only slightly (Figure 11-17-6).

Section 18

Electrical Measuring Instruments

D'Arsonval meter. The basic DC meter movement is known as the D'Arsonval meter movement because it was first employed by the French scientist Jacques-Arséne d'Arsonval (1851-1940) in making electrical measurement. Mr. Weston developed the type of meter movement around the same time. As seen in Figure 11-18-1, this type of meter movement is a current-measuring device that is used in the ammeter, voltmeter, and ohmmeter. Basically, both the ammeter and the voltmeter are current-measuring instruments, the principal difference being the method in which they are connected in a circuit. While an ohmmeter is also basically a current-measuring instrument, it differs from the ammeter and voltmeter in that it provides its own source of power and contains other auxiliary circuits.

Meter ratings and terms. The sensitivity of meter movement is usually expressed as the amount of current required to give full-scale deflection. In addition, the sensitivity may be expressed as the number of millivolts (mV) across the meter when full-scale current flows through it. This voltage drop is obtained by multiplying the full-scale current by the resistance of the meter movement. A meter movement, whose resistance is 50 ohms and which requires 1 milliampere (mA) for full-scale reading, may be described as a 50-mV 0-1 milliammeter.

Ammeters, Milliammeters, and Microammeters

The D'Arsonval ammeter is an instrument designed for measuring DC flowing in an electrical circuit and consists of the following parts: a permanent magnet, a moving element mounting, bearings and a case that includes terminals, a dial, and screws. Each part and its function are described in the discussion that follows.

Extending the range of an ammeter. A 0-1 milliammeter movement may be used to measure currents greater than 1 mA by connecting a resistor in parallel with the movement. The parallel resistor is called a shunt because it bypasses a portion of the current around the movement, extending the range of the ammeter. A schematic drawing of a meter movement with a shunt connected across it to extend its range is shown in Figure 11-18-2.

Determining the value of a shunt. The value of a shunt resistor can be computed by applying the basic rules for parallel circuits. If a 50 mV 0-1 milliammeter is to be used to measure values of current up to 10 mA, the following procedure can be used: The first step involves drawing a schematic of the meter shunted by a resistor labeled R_s (shunt resistor), as shown in Figure 11-18-3.

Since the sensitivity of the meter is known, the meter resistance can be computed. The circuit is then redrawn as shown in Figure 11-18-4, and the branch currents can be computed, since a maximum of 1 mA can flow through the meter. The voltage drop across R_s is the same as that across the meter, R_m:

$$E = IR$$
$$= 0.001 \times 50$$
$$= 0.050 \text{ volt}$$

$$R_S = \frac{E_{RS}}{I_{RS}}$$
$$= \frac{0.050}{0.009}$$
$$= 5.55 \text{ ohms}$$

R_s can be found by applying Ohm's law:

The value of the shunt resistor (5.55 Ω) is very small, but this value is critical. Resistors used as shunts must have close tolerances, usually 1 percent.

Universal ammeter shunt. The schematic drawing in Figure 11-18-5, the universal shunt, shows an arrangement whereby two or more ranges are provided by tapping the shunt resistor at the proper points. In this arrangement, a 0-5 mA movement with a resistance of 20 ohms is shunted to provide a 0-25 mA range and a 0-50 mA range.

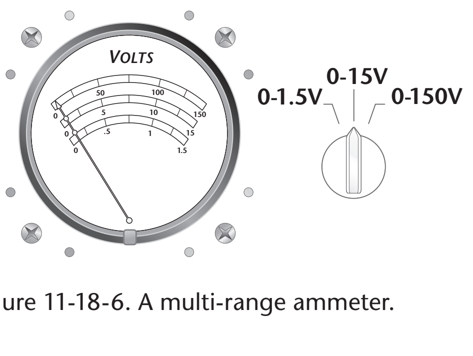


Figure 11-18-6. A multi-range ammeter.

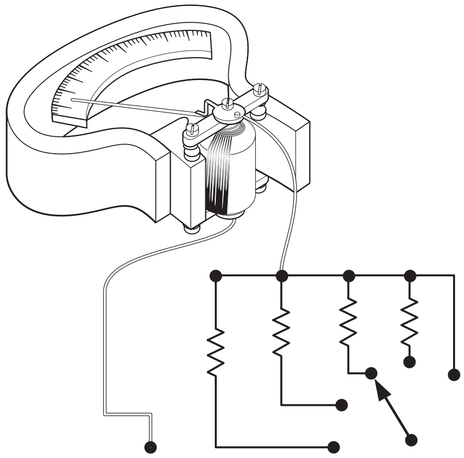


Figure 11-18-7. Voltmeter simplified diagram.

Ammeters having a number of internal shunts are called multi-range ammeters. A scale for each range is provided on the meter face (Figure 11-18-6). Some multimeters avoid internal switching through the use of external shunts. Changing ammeter ranges involves the selection and installation on the meter case of the proper size shunt.

Several precautions to be observed when using an ammeter are summarized as follows:

- Always connect an ammeter in series with the element through which the current flow is to be measured.
- Never connect an ammeter across a source of voltage, such as a battery or generator. Remember that the resistance of an ammeter, particularly on the higher ranges, is extremely low and that any voltage, even a volt or so, can cause very high current to flow through the meter, causing damage to it.
- Use a range large enough to keep the deflection less than full scale. Before measuring a current, form some idea of its magnitude. Then switch to a large enough scale or start with the highest range and work down until the appropriate scale is reached. The most accurate readings are obtained at approximately half-scale deflection. Many milliammeters have been ruined by attempts to measure amperes. Therefore, be sure to read the lettering either on the dial or on the switch positions and choose the proper scale before connecting the meter into the circuit.
- Observe proper polarity when connecting the meter into the circuit. Current must flow through the coil in a definite direction in order to move the indicator needle up-scale. Current reversal because of incorrect connection in the circuit results in a reversed meter deflection and frequently

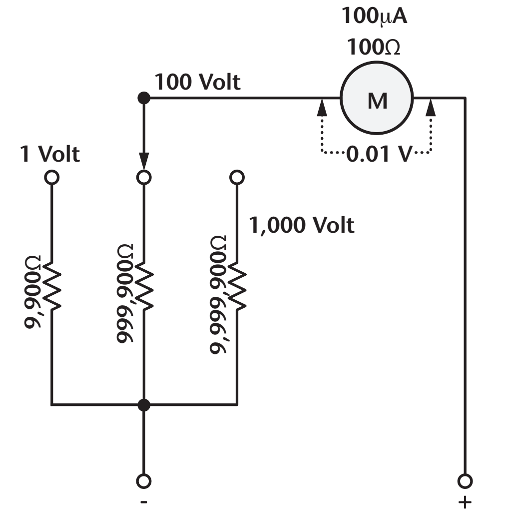


Figure 11-18-8. Multirange voltmeter schematic.

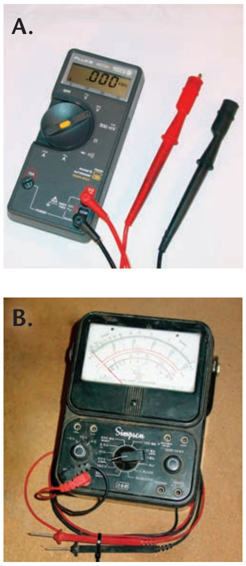


Figure 11-18-9. Typical multirange voltmeters (A) Digital (B) Analog.

causes bending of the meter needle. Avoid improper meter connections by observing the polarity markings on the meter.

Voltmeter. The D'Arsonval meter movement can be used either as an ammeter or a voltmeter (Figure 11-18-7). Thus, an ammeter can be converted to a voltmeter by placing a resistance in series with the meter coil and measuring the current flowing through it. In other words, a voltmeter is a current-measuring instrument, designed to indicate voltage by measuring current flow through a resistance of known value.

Various voltage ranges can be obtained by adding resistors in series with the meter coil. For low-range instruments, this resistance is mounted inside the case with the D'Arsonval movement and usually consists of resistance wire having a low-temperature coefficient, which is wound either on spools or card frames.

For higher voltage ranges, the series resistance may be connected externally. When this is done, the unit containing the resistance is commonly called a multiplier.

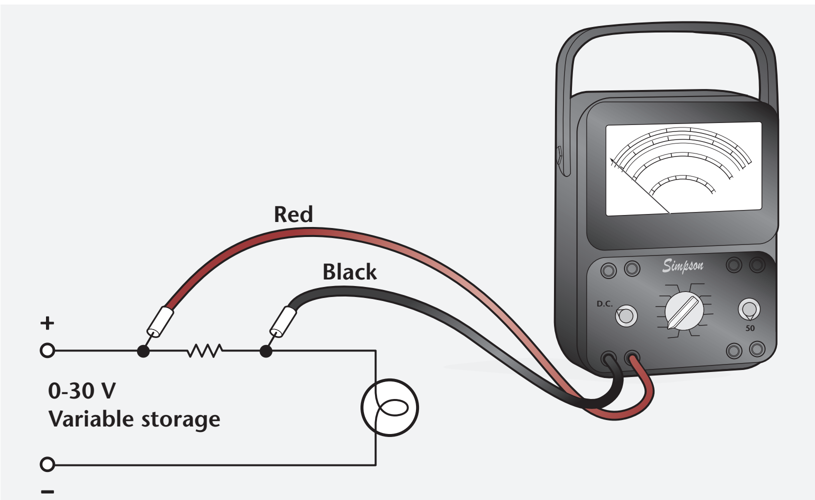


Figure 11-18-10. A multimeter connected to measure a circuit voltage drop.

Extending the voltmeter range. The value of the necessary series resistance is determined by the current required for full-scale deflection of the meter and by the range of voltage to be measured. Because the current through the meter circuit is directly proportional to the applied voltage, the meter scale can be calibrated in volts for a fixed series resistance.

Assume that the basic meter (microammeter) is to be made into a voltmeter with a full-scale reading of 1 volt. The coil resistance of the basic meter is 100 ohms, and 0.0001 ampere (100 microamperes) causes a full-scale deflection. The total resistance, R, of the meter coil and the series resistance is:

$$R = \frac{E}{I} = \frac{1}{0.0001} = 10{,}000 \text{ ohms}$$

and the series resistance alone is:

$$R_s = 10{,}000 - 100 = 9{,}900 \text{ ohms}$$

Multirange voltmeters utilize one meter movement with the required resistances connected in series with the meter by a convenient switching arrangement. A multirange voltmeter circuit with three ranges is shown in Figure 11-18-8. The total circuit resistance for each of the three ranges beginning with the 1-volt range is:

$$R = \frac{E}{I} = \frac{1}{0.0001} = 0.01 \text{ megohm}$$

$$\frac{100}{0.0001} = 1 \text{ megohm}$$

$$\frac{1{,}000}{0.0001} = 10 \text{ megohm}$$

Multirange voltmeters, like multirange ammeters, are used frequently. They are physically very similar to ammeters, and their multipliers are usually located inside the meter with suitable switches or sets of terminals on the outside of the meter for selecting ranges (Figure 11-18-9).

Voltage-measuring instruments are connected across (in parallel with) a circuit. If the approximate value of the voltage to be measured is not known, it is best, when using an ammeter, to start with the highest range of the voltmeter and progressively lower the range until a suitable reading is obtained.

The voltmeter is not a central-zero indicating instrument. Thus, it is necessary to observe the proper polarity when connecting the instrument to the circuit, as with the DC ammeter.

The positive terminal of the voltmeter is always connected to the positive terminal of the source

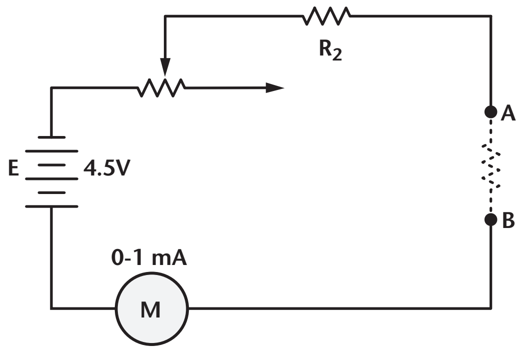


Figure 11-18-11. Ohmmeter circuit.

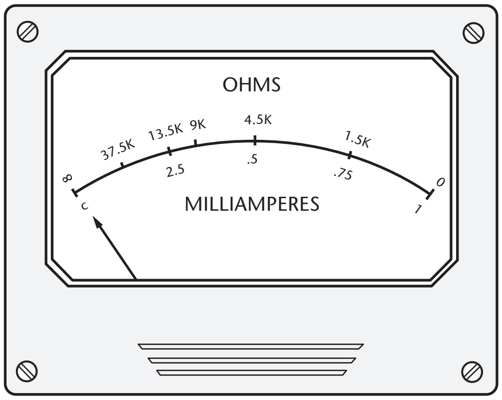


Figure 11-18-12. A typical ohmmeter scale.

and the negative terminal to the negative terminal of the source, when the source voltage is being measured. In any case, the voltmeter is connected so that electrons will flow into the negative terminal and out of the positive terminal of the meter.

A multimeter is properly connected to a circuit in Figure 11-18-10 to measure the voltage drop across a resistor. The function switch is set at the DC volts position and the range switch is placed in the 50-volt position.

The function of a voltmeter is to indicate the potential difference between two points in a circuit. When the voltmeter is connected across a circuit, it shunts the circuit. If the voltmeter has low resistance, it will draw an appreciable amount of current. The effective resistance of the circuit will be lowered, and the voltage reading will consequently be lowered.

When voltage measurements are made in high-resistance circuits, it is necessary to use a high-resistance voltmeter to prevent the shunting action of the meter. The effect is less noticeable in low-resistance circuits.

Voltmeter sensitivity. The sensitivity of a voltmeter is given in ohms per volt (Ω/E) and is determined by dividing the resistance (R_M) of the meter plus the series resistance (R_s) by the full-scale reading in volts.

$$\text{sensitivity} = \frac{R_M + R_S}{E}$$

This is the same as saying that the sensitivity is equal to the reciprocal of the current (in amperes); that is:

$$\text{sensitivity} = \frac{\text{ohms}}{\text{volts}} = \frac{1}{\frac{\text{volts}}{\text{ohms}}} = \frac{1}{\text{ampere}}$$

Thus, the sensitivity of a 100-microampere movement is the reciprocal of 0.0001 ampere, or 10,000 ohms per volt.

The sensitivity of a voltmeter can be increased by increasing the strength of the permanent magnet, by using lighter weight materials for the moving element (consistent with increased number of turns on the coil), and by using sapphire jewel bearings to support the moving coil.

Voltmeter accuracy. The accuracy of a meter is generally expressed in percent. For example, a meter with an accuracy of 1 percent will indicate a value within 1 percent of the correct value. The statement means that, if the correct value is 100 units, the meter indication may lie anywhere within the range of 99 to 101 units.

Use of the voltmeter. The following precautions should be observed when using a voltmeter:

- Always connect the voltmeter in parallel with the circuit element or device across which voltage is to be measured.
- Never connect the voltmeter in series with the circuit or device being tested. The voltage readings in this instance would be incorrect and damage to the meter can occur.
- Always observe correct meter polarity. Remember to connect the meter positive lead to the most positive point of the device being tested, and connect the negative lead to a more negative point or to ground. Failure to do this will result in the meter movement operating in a reverse direction, and damage to the meter is certain.
- Select a meter range that will provide approximately half-scale deflection at the voltage being measured. When measuring an unknown voltage, start with the highest meter range and progress down to the scale, which gives half-scale deflection.

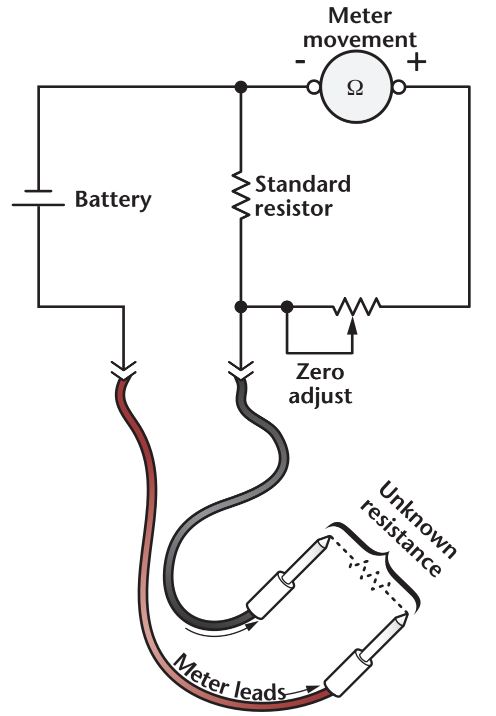


Figure 11-18-13. Potentiometer-type ohmmeter.

Ohmmeters

The ohmmeter is widely used to measure resistance and to check the continuity of electrical circuits and devices. The range of a typical ohmmeter extends from a few ohms to a few megohms. When precision measurements are required, or when very low values of resistance must be measured, a milliohmmeter or resistance bridge circuit may be required. The megohmmeter, or megger, may have occasional application to measure extremely high resistance. Ohmmeters may be of the series potentiometer, or shunt type.

Series-type ohmmeters. A simplified schematic of an ohmmeter is shown in Figure 11-18-11. E is a source of emf, R_1 is a variable resistor used to zero the meter, R_2 is a fixed resistor used to limit the current in the meter movement, and A and B are test terminals across which the resistance to be measured is placed.

If A and B are connected together (short-circuited), the meter, the battery, and resistors R_1 and R_2 form a simple series circuit. With R_1 adjusted so that the total resistance in the circuit is 4,500 ohms, the current through the meter is 1 mA and the needle deflects full scale. Since there is no resistance between A and B, this position of the needle is labeled zero (Figure 11-18-12). If a resistance equal to 4,500 ohms is placed between terminals A and B, the total resistance is 9,000 ohms and the current is 0.5 mA.

This causes the needle to deflect half scale. This half-scale reading, labeled 4.5 k ohms, is equal to the internal resistance of the meter, in this instance 4,500 ohms.

If a resistance of 9,000 ohms is placed between terminals A and B, the needle deflects one-third scale. Resistances of 13.5 k and 1.5 k placed between terminals A and B will cause a deflection of one-fourth and three-fourths scale, respectively.

If terminals A and B are not connected (open-circuited), no current flows and the needle does not move. The left side of the scale is, therefore, labeled infinity to indicate an infinite resistance.

A typical ohmmeter scale is shown in Figure 11-18-12. Note that the scale is not linear and is crowded at the high resistance end. For this reason, it is good practice to use an ohmmeter range in which the readings are not too far from mid-scale — a range in which the reading obtained does not exceed ten times, or is not less than one-tenth, the mid-scale reading. The useful range of the scale shown is, by this rule, from 450 ohms to 45,000 ohms.

Most ohmmeters have more than one scale. Additional scales are made possible by using various values of limiting resistors and battery voltages. Some ohmmeters have a special scale called a low-ohm scale for reading low resistances. A shunt-type ohmmeter circuit is used for this scale.

Potentiometer-type ohmmeter. One problem with the series ohmmeter is crowding of resistances on the high end of the scale. One method of solving this problem is in using a potentiometer-type ohmmeter, shown in Figure 11-18-13.

The potentiometer-type ohmmeter design inserts a low-value resistance, referred to as a standard resistor, in series with the unknown resistance being measured and the ohmmeter battery. The multiplier resistance, zero adjustment variable resistance, and meter movement are tapped off this circuit, forming a voltage divider. Therefore, the voltage across the standard resistor is proportional to the current flow through the resistance being measured.

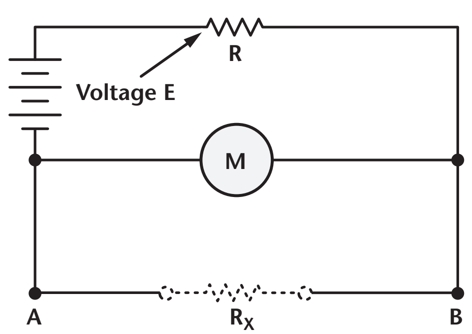


Figure 11-18-14. Shunt-type ohmmeter circuit.

The meter movement is designed to measure the voltage drop across the standard resistor. The meter scale is calibrated in ohms rather than volts. Shorting the meter test leads together will result in all of the battery voltage being dropped across the standard resistor, and the meter-adjust resistance can be set to provide full-scale defection, or zero ohms.

Shunt-type ohmmeter. Shunt-type ohmmeters are used to measure small values of resistance. In the circuit shown in Figure 11-18-14, voltage E is applied across a limiting resistor R and a meter movement in series. Resistance and battery values are chosen so that the meter movement deflects full scale when terminals A and B are open.

When the terminals are short-circuited, the meter reads zero; the short circuit conducts all the current around the meter. The unknown resistance R_x is placed between terminals A and B in parallel with the meter movement. The smaller the resistance value being measured, the less current flows through the meter movement.

The value of the limiting resistor R is usually made large compared to the resistance of the meter movement. This keeps the current drawn from the battery practically constant. Thus, the value of R_x determines how much of this constant current flows through the meter and how much through R_x.

Note that in a shunt-type ohmmeter, current is always flowing from the battery through the meter movement and the limiting resistor. Therefore, when using an ohmmeter with a low-ohm scale, do not leave the switch in low-ohm position.

Megger (megohmmeter). The megger is a high-range ohmmeter used to test insulation resistance and other very high resistance values.

In order to test resistance values in this range, it is necessary to use a much higher potential than could be furnished by an ordinary ohmmeter battery. This potential is provided by an internal hand-driven generator. Due to the high potential needed to perform very high resistance checks, the megger may have restrictions placed on its use by some maintenance agencies.

When using a megger, always observe the following safety precautions:

- Use meggers for high-resistance measurements only.
- Never touch the test leads while the generator is being cranked.
- De-energize the circuit completely before connecting a megger.

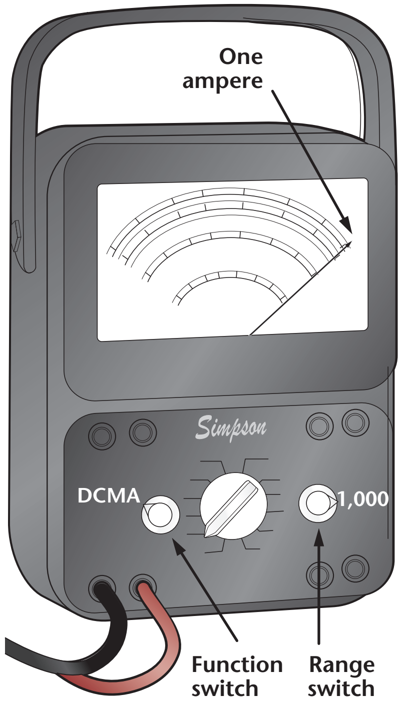


Figure 11-18-15. A multimeter set to measure one ampere.

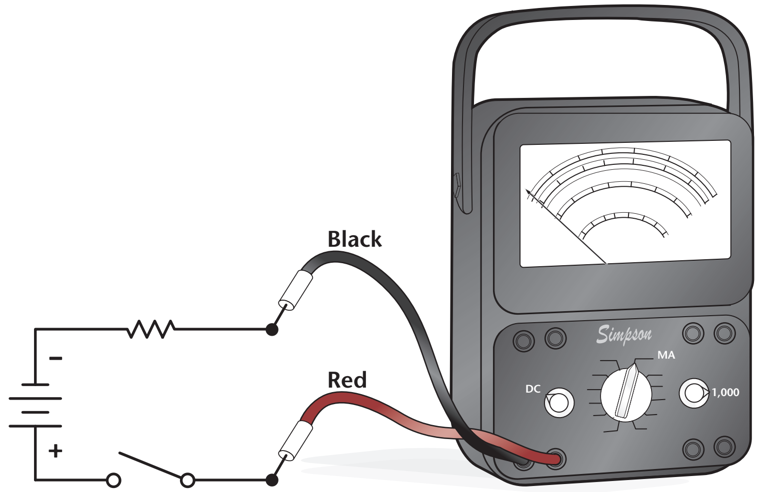


Figure 11-18-16. A multimeter set to measure current flow.

- Never use a megger on an aircraft if conditions do not absolutely require it.

Use of the Ohmmeter

The ohmmeter is not as accurate a measuring device as the ammeter or the voltmeter because of the associated circuitry. Thus, resistance values cannot be read with greater than 5 to 10 percent accuracy. While there are instruments that read the resistance of an element with very great accuracy, they usually are more complicated to use.

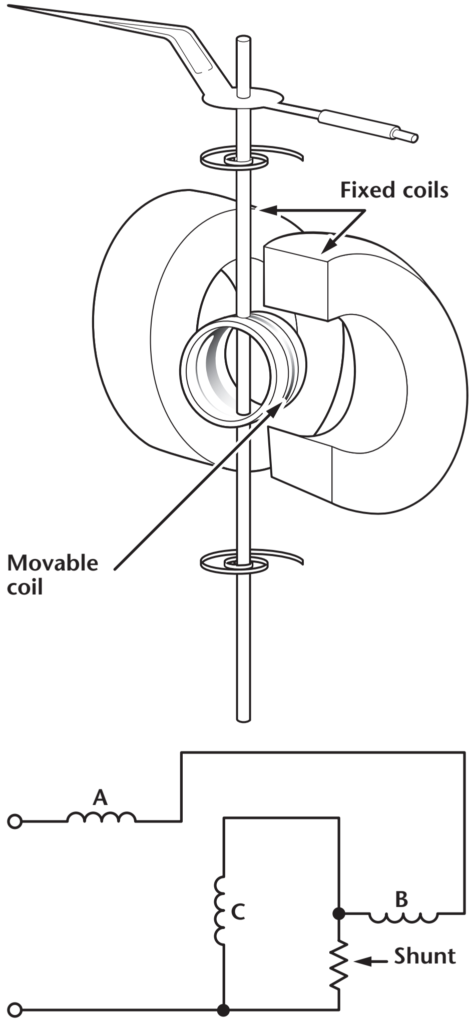


Figure 11-18-17. Simplified diagram of an electrodynamometer movement.

In addition to measuring resistance, the ohmmeter is a very useful instrument for checking continuity in a circuit. Often, when troubleshooting electronic circuits or wiring a circuit, visual inspections of all parts of the current path cannot be readily accomplished.

It is not always apparent whether a circuit is complete or whether current might be flowing in the wrong part of the circuit because of contact with adjacent circuits. The best method of checking a circuit under these conditions is to send a current through the circuit. The ohmmeter is the ideal instrument for checking circuits in this manner. It provides the power and the meter to indicate whether the current is flowing.

Never use an ohmmeter to check continuity of a circuit that includes explosive devices such as fire extinguisher cartridges, cable cutters, emergency jettison features, etc. The voltage and current flow caused by the ohmmeter battery, although small, may be enough to fire these devices.

Multimeters

Ammeters are commonly incorporated in multiple-purpose instruments such as multimeter or volt-ohm-milliammeters. These instruments vary somewhat according to the design used by different manufacturers, but most incorporate the functions of an ammeter, a voltmeter, and an ohmmeter in one unit.

A typical multimeter is shown in Figure 11-18-15. This multimeter has two selector switches: a function switch and a range switch. Since a multimeter is actually three meters in one case, the function switch must be placed in proper position for the type of measurement to be made.

The function switch in Figure 11-18-15 is shown in the ammeter position to measure DC mA and the range switch is set at 1000. Set in this manner, the ammeter can measure up to 1,000 mA, or 1 ampere.

Multimeters have several scales, and the one used should correspond properly to the position of the range switch. If current of unknown value is to be measured, always select the highest possible range to avoid damage to the meter.

The test leads should always be connected to the meter in the manner prescribed by the manufacturer. Usually the red lead is positive and the black lead is negative, or common.

Many multimeters employ color-coded jacks as an aid in connecting the meter into the circuit to be tested. In Figure 11-18-16, a multimeter properly set to measure current flow is connected into a circuit.

Electrodynamometer

The electrodynamometer meter can be used to measure alternating or direct voltage and current. It operates on the same principles as the permanent magnet moving-coil meter, except that the permanent magnet is replaced by an air-core electromagnet. The field of the electrodynamometer meter is developed by the same current that flows through the moving coil (Figure 11-18-17).

Inside the electrodynamometer, two stationary field coils are connected in series with the movable coil. The movable coil is attached to the central shaft and rotates inside the two stationary field coils. The spiral springs provide the restraining force for the meter and also a means of introducing current to the movable coil.

When current flows through field coils A and B and movable coil C, coil C rotates in opposition to the springs and places itself parallel to the field coils. The more current flowing through the coils, the more the moving coil overcomes the opposition of the springs and the farther the pointer moves across the scale. If the scale is properly calibrated and the proper shunts or multipliers are used, the dynamometer movement will indicate current or voltage.

Although electrodynamometer meters are very accurate, they do not have the sensitivity of D'Arsonval meters and, for this reason, are not widely used outside the laboratory.

Electrodynamometer wattmeter. Electric power is measured by means of a wattmeter. Because electric power is the product of current and voltage, a wattmeter must have two elements, one for current and the other for voltage, as indicated in Figure 11-18-18. For this reason, wattmeters usually use the electrodynamometer.

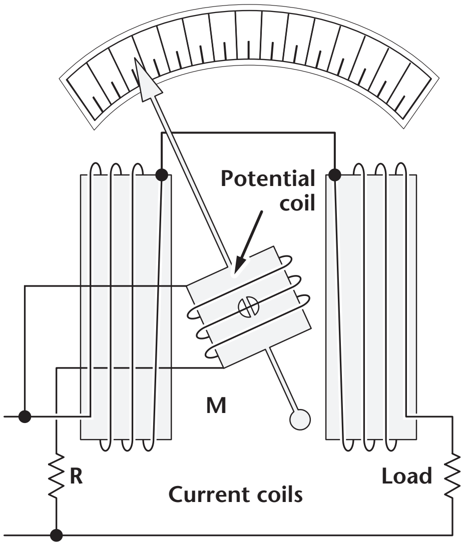


Figure 11-18-18. Simplified electrodynamometer wattmeter circuit.

The movable coil with a series resistance forms the voltage element, and the stationary coils constitute the current element. The strength of the field around the potential coil depends on the amount of current that flows through it. The current, in turn, depends on the load voltage applied across the coil and the high resistance in series with it. The strength of the field around the current coils depends on the amount of current flowing through the load.

Meter deflection is proportional to the product of the voltage across the potential coil and the current through the current coils. The effect is almost the same (if the scale is properly calibrated) as if the voltage applied across the load and the current through the load were multiplied together.

If the current in the line is reversed, the direction of current in both coils and the potential coil is reversed, the net result is that the pointer continues to read up-scale. Therefore, this type of wattmeter can be used to measure either AC or DC power.

Electrodynamometer ammeter. In the electrodynamometer ammeter, low resistance coils produce only a small voltage drop in the circuit measured.

An inductive shunt is connected in series with the field coils. This shunt, similar to the resistor shunt used in DC ammeters, permits only part of the current being measured to flow through the coils. As in the DC ammeter, most of the current in the circuit flows through the shunt; but the scale is calibrated accordingly, and the meter reads the total current.

An AC ammeter, like a DC ammeter, is connected in series with the circuit in which current is measured. Effective values are indicated by the meter. A schematic diagram of an electrodynamometer ammeter circuit is shown in Figure 11-18-19.

Electrodynamometer voltmeter. In the electrodynamometer voltmeter, field coils are wound with many turns of small wire. Approximately 0.01 ampere of current flow through both coils is required to operate the meter. Resistors of a noninductive material, connected in series with the coils, provide for different voltage ranges. Voltmeters are connected in parallel across the unit in which voltage is to be measured. The values of voltages indicated are effective values. A schematic diagram of an electrodynamometer voltmeter is shown in Figure 11-18-20.

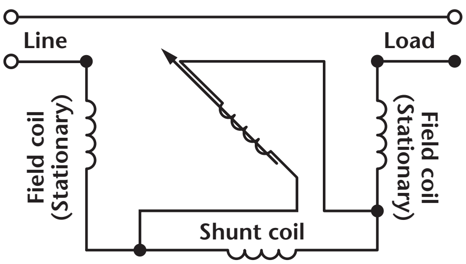


Figure 11-18-19. Electrodynamometer ammeter circuit.

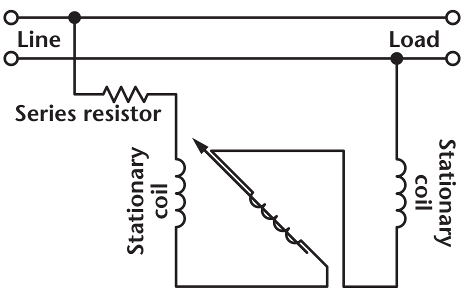


Figure 11-18-20. Electrodynamometer voltmeter circuit.

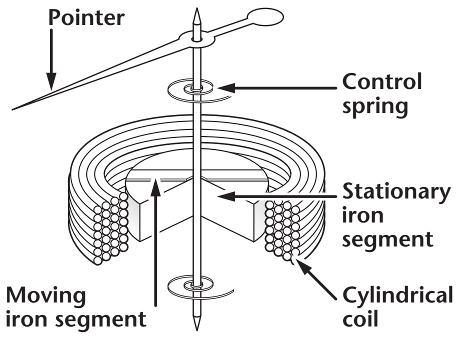


Figure 11-18-21. Moving vane type meter.

Moving Iron-Vane Meter

The moving iron-vane meter is another basic type of meter. It can be used to measure either AC or DC. Unlike the D'Arsonval meter, which employs permanent magnets, it depends on induced magnetism for its operation.

Utilizing the principle of magnetic repulsion, it consists of two concentric iron vanes, one fixed and one movable, placed inside a solenoid, as shown in Figure 11-18-21. A pointer is attached to the movable vane.

The movable vane is rectangular in shape and the fixed vane is tapered. This design permits the use of a relatively uniform scale.

When no current flows through the coil, the movable vane is positioned so that it is opposite the larger portion of the tapered fixed vane and the scale reading is zero. The amount of magnetization of the vanes depends on the strength of the field, which, in turn, depends on the amount of current flowing through the coil.

The force of repulsion is greater opposite the larger end of the fixed vane than it is nearer the smaller end. Therefore, the movable vane moves toward the smaller end through an angle that is proportional to the magnitude of the coil current. The movement ceases when the force of repulsion is balanced by the restraining force of the spring.

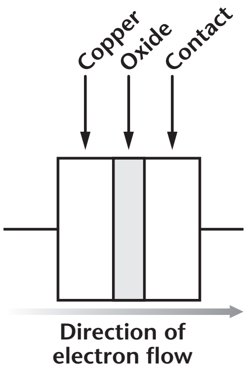


Figure 11-18-22. Copper-oxide rectifier.

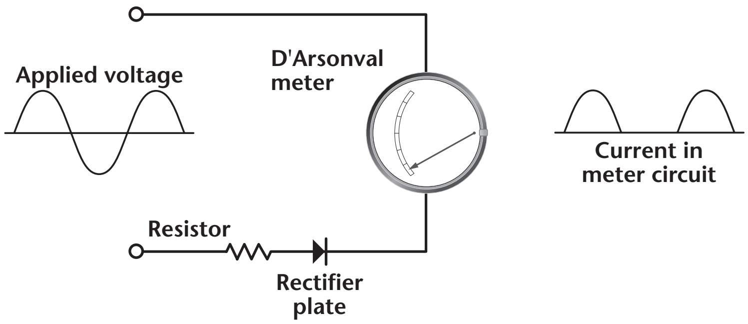


Figure 11-18-23. A half-wave rectifier circuit.

Because the repulsion is always in the same direction (toward the smaller end of the fixed vane), regardless of the direction of current flow through the coil, the moving iron-vane instrument operates on either DC or AC circuits.

Mechanical damping in this type of instrument can be obtained by the use of an aluminum vane attached to the shaft so that, as the shaft moves, the vane moves in a restricted airspace.

When the moving iron-vane meter is designed to be used as an ammeter, the coil is wound with relatively few turns of large wire in order to carry the rated current.

When the moving iron-vane meter is designed to be used as a voltmeter, the solenoid is wound with many turns of small wire. Portable voltmeters are made with self-contained series resistance for ranges up to 750 volts. Higher ranges are obtained by the use of additional external multipliers.

The moving iron-vane instrument may be used to measure DC, but has an error due to residual magnetism in the vanes. The error may be minimized by reversing the meter connections and averaging the readings.

When used on AC circuits, the instrument has an accuracy of 0.5 percent. Because of its simplicity, its relatively low cost and the fact that no current is conducted to the moving element, this type of movement is used extensively to measure current and voltage in AC power circuits.

Because the reluctance of the magnetic circuit is high, the moving iron-vane meter requires much more power to produce full-scale deflection than is required by a D'Arsonval meter of the same range. Therefore, the moving iron-vane meter is seldom used in high-resistance, low-power circuits.

D'Arsonval Meters with Rectifiers

Copper-oxide rectifiers are generally used with D'Arsonval DC meter movements to measure AC and voltage. However, there are many types of rectifiers that may be used, some of which are included in the discussion of alternator systems.

A copper-oxide rectifier allows current to flow through a meter in only one direction. As shown in Figure 11-18-22, the copper-oxide rectifier consists of copper-oxide disks separated alternately by copper disks and fastened together as a single unit.

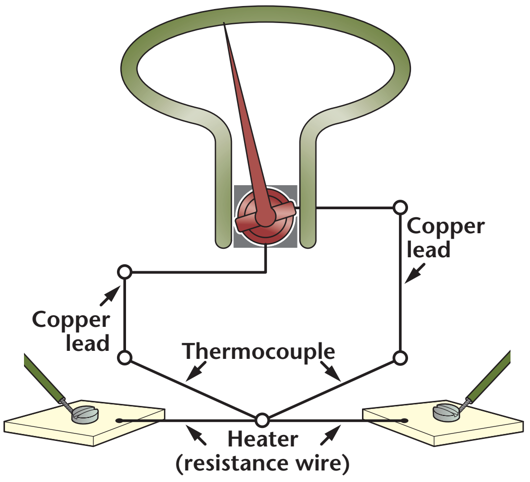


Figure 11-18-24. Simple diagram of a thermocouple meter.

Current flows more readily from copper to copper oxide than from copper oxide to copper. When AC is applied, therefore, current flows in only one direction, yielding a pulsating DC output as shown by the output wave shapes in Figure 11-18-23. This current can then be measured as it flows through the meter movement.

In some AC meters, selenium or vacuum tube rectifiers are used in place of the copper-oxide rectifier. The principle of operation, however, is the same in all meters employing rectifiers.

Thermocouple-Type Ammeters

If the ends of two dissimilar metals are welded together and this junction is heated, a DC voltage is developed across the two open ends. The voltage developed depends on the material of which the wires are made and on the difference in temperature between the heated junction and the open ends.

In one type of instrument, the junction is heated electrically by the flow of current through a heater element. It does not matter whether the current is alternating or direct because the heating effect is independent of current direction.

The maximum current that can be measured depends on the current rating of the heater, the heat that the thermocouple can stand without being damaged and on the current rating of the meter used with the thermocouple.

Voltage can also be measured if a suitable resistor is placed in series with the heater. In meter applications, a D'Arsonval meter is used with a resistance wire heater, as shown in Figure 11-18-24.

As current flows through the resistance wire, the heat developed is transferred to the contact point and develops an emf that causes current to flow through the meter. The coil rotates and causes the pointer to move over a calibrated scale. The amount of coil movement is dependent on the amount of heat, which varies as the square of the current. Thermocouple meters are used extensively in AC measurements.

Vibrating-Reed Frequency Meter

The vibrating-reed type of frequency meter is one of the simplest devices for indicating the frequency of an AC source. A simplified diagram of one type of vibrating-reed frequency meter is shown in Figure 11-18-25.

The current whose frequency is to be measured flows through the coil and exerts maximum attraction on the soft-iron armature twice during each cycle (Figure 11-18-25A). The armature is attached to the bar, which is mounted on a flexible support.

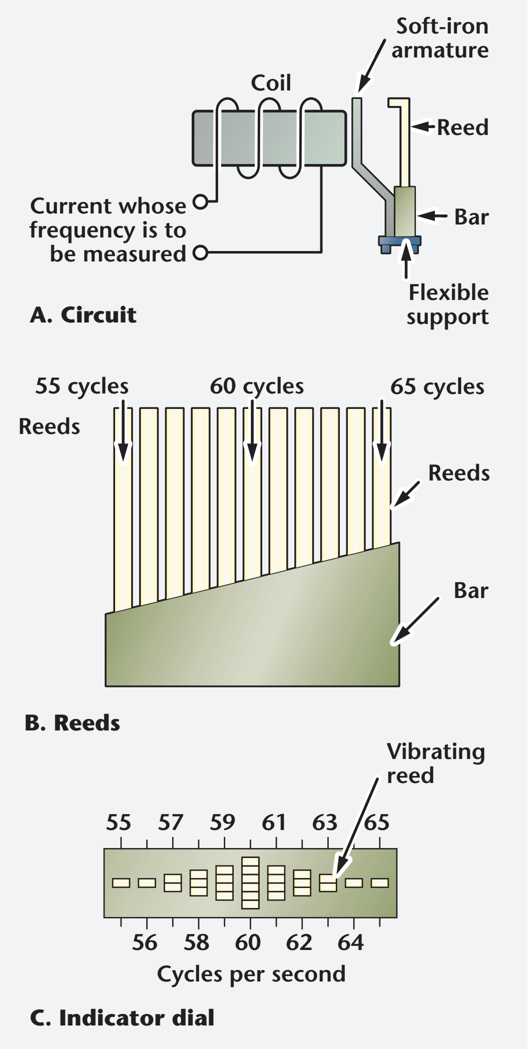


Figure 11-18-25. Vibrating reed frequency meter.

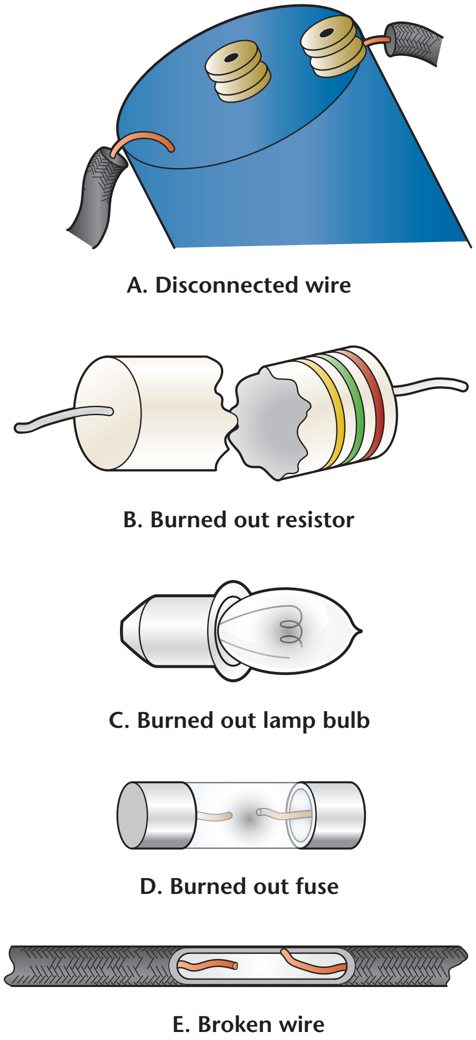


Figure 11-19-1. Common causes of open circuits.

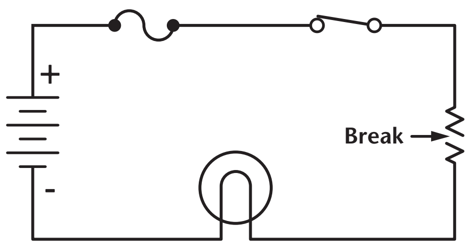


Figure 11-19-2. An open circuit.

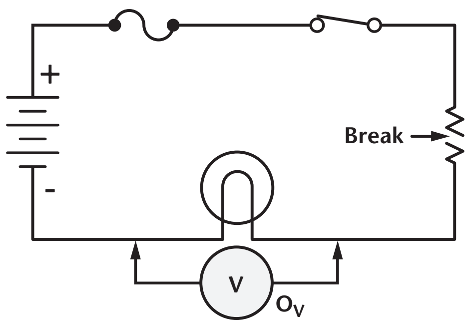


Figure 11-19-3. Voltmeter across a lamp in an open circuit.

Reeds of suitable dimensions for natural vibration frequencies of 110, 112, 114, and so forth, up to 130 Hz are mounted on the bar (Figure 11-18-25B). The reed with a frequency of 110 Hz is marked 55 Hz; the one with a frequency of 130 Hz is marked 65 Hz; the one with a frequency of 120 Hz is marked 60 Hz, and so forth.

In some instruments the reeds are the same lengths but are weighted by different amounts at the top, so that they will have different natural rates of vibration.

When the coil is energized with a current having a frequency between 55 and 65 Hz, all the reeds are vibrated slightly; but the reed having a natural frequency closest to that of the energizing current (whose frequency is to be measured) vibrates through a larger amplitude.

The frequency is read from the scale value opposite the reed having the greatest amplitude of vibration. An end view of the reeds is shown in the indicator dial (Figure 11-18-25C). If the energizing current has a frequency of 60 Hz, the reed marked 60 Hz will vibrate the greatest amount, as shown.

Section 19

Circuit Analysis and Troubleshooting

Principles of Troubleshooting

One of the most important facets of an aircraft maintenance technician's job is troubleshooting. The technician must be able to analyze circuit problems and determine probable causes of malfunctions with minimal time and effort.

Troubleshooting is the process of locating causes for malfunctions or trouble in a circuit. The following are definitions of key terms.

Short circuit. A short circuit is a low resistance path. It can be across the power source or between the sides of a circuit. It usually creates high current flow, which will burn out or cause damage to the circuit conductor or components.

Open circuit. An open circuit is a circuit that is not complete or continuous.

Continuity. Continuity is the state of being continuous, or connected together; it describes a circuit that is not broken or does not have an open.

Discontinuity. The opposite of continuity, indicating that a circuit is broken or not continuous.

Open Circuits

The open circuits shown in Figure 11-19-1 can often be located by visual inspection, but many circuit opens cannot be seen. In such cases, a meter must be used.

Some common sources of open circuits, commonly called *opens* or *an open*, are shown in Figure 11-19-1. A loose connection or no connection is a frequent cause of an open circuit.

In Figure 11-19-1A, the end of a conductor has separated from the battery terminal. This type of malfunction opens a circuit and stops the flow of current.

Another type of malfunction that will cause an open circuit is a burned-out resistor, shown in Figure 11-19-1B. When a resistor overheats, its resistance value changes, and, if the current flow through it is great enough, it can burn and open the circuit.

Illustrations C, D, and E of Figure 11-19-1 show three more common causes of opens.

The circuit shown in Figure 11-19-2 is designed to cause current to flow through a lamp, but because of the open resistor, the lamp will not light. To locate this open, a voltmeter or an ohmmeter can be used.

If a voltmeter is connected across the lamp, as shown in Figure 11-19-3, the voltmeter will read zero. Since no current can flow in the circuit because of the open resistor, there is no voltage drop across the lamp. This illustrates an important troubleshooting rule: When a voltmeter is connected across a good (not defective) component in an open circuit, the voltmeter will read zero.

Next, the voltmeter is connected across the open resistor, as shown in Figure 11-19-4. The voltmeter has closed the circuit by shunting (paralleling) the burned-out resistor, allowing current to flow.

Current will flow from the negative terminal of the battery, through the switch, through the voltmeter and the lamp, back to the positive terminal of the battery. However, the resistance of the voltmeter is so high that only a very small current flows in the circuit.

The current is too small to light the lamp, but the voltmeter will read the battery voltage, illustrating another troubleshooting rule. When a voltmeter is placed across an open

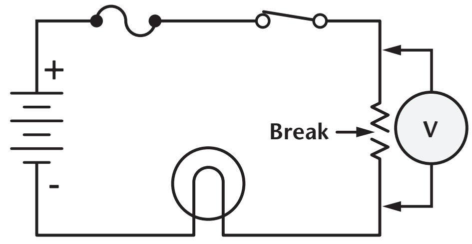


Figure 11-19-4. Using a voltmeter to check a circuit component.

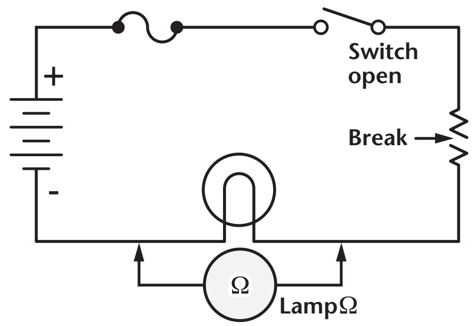


Figure 11-19-5. Ohmmeter across a resistor in an open circuit.

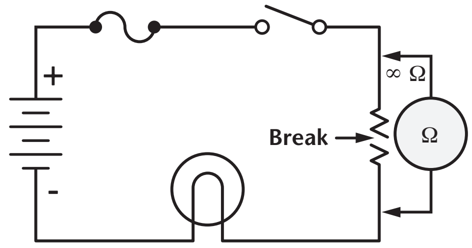


Figure 11-19-6. Using an ohmmeter to check an open in a circuit component.

component in a series circuit, it will read the battery, or applied voltage.

This type of open circuit malfunction can also be traced by using an ohmmeter. When an ohmmeter is used, the circuit component to be tested must be isolated and the power source removed from the circuit.

In the example shown in Figure 11-19-5, these requirements can be met by opening the circuit switch. The ohmmeter is zeroed and placed across (in parallel with) the lamp.

In this circuit, some value of resistance is read. This illustrates another important troubleshooting rule: When an ohmmeter is properly connected across a circuit component and a resistance reading is obtained, the component has continuity and is not open.

When the ohmmeter is connected across the open resistor, as shown in Figure 11-19-6, it indicates

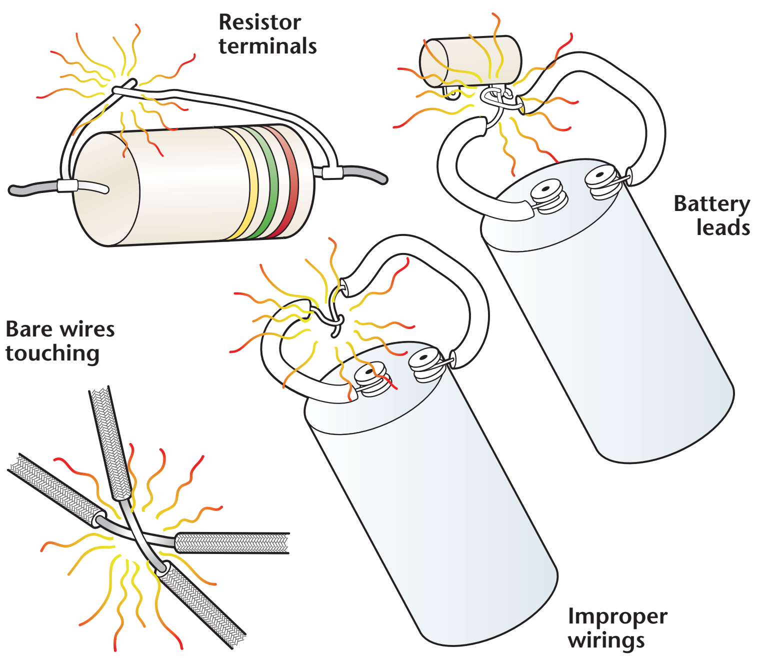


Figure 11-19-7. Common causes of short circuits.

infinite resistance, or a discontinuity. Thus, the circuit open has been located with both a voltmeter and an ohmmeter.

Short Circuits

An open in a series circuit will cause the current flow to stop. A short circuit, or short, will cause the opposite effect. A short across a series circuit produces a greater-than-normal current flow. Some examples of shorts, as shown in Figure 11-19-7, are two bare wires in a circuit that are touching each other, two terminals of a resistor connected together, etc. Thus, a short can be described as a connection of two conductors of a circuit through a very low resistance.

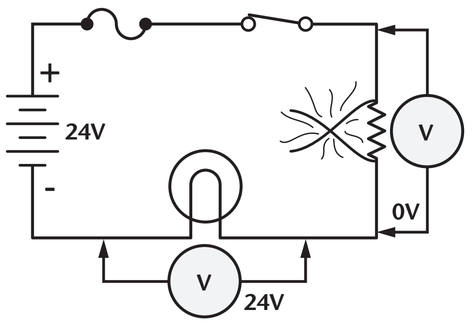


Figure 11-19-8. A shorted resistor.

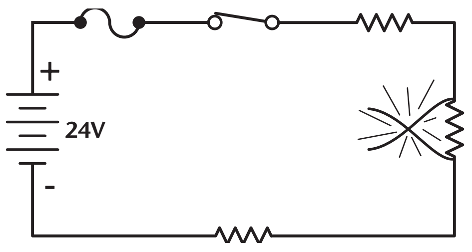


Figure 11-19-9. A short that does not open the circuit.

A circuit designed to light a lamp is shown in Figure 11-19-8. A resistor is connected in the circuit to limit current flow. If the resistor is shorted, as shown in the illustration, the current flow will increase and the lamp will become brighter. If the applied voltage were high enough, the lamp would burn out but, in this case, the fuse would protect the lamp by opening first.

Usually a short circuit will produce an open circuit by either blowing (opening) the fuse or burning out a circuit component. But in some circuits, such as the one illustrated in Figure 11-19-9, there may be additional resistors that do not allow one shorted resistor to increase the current flow enough to blow the fuse or burn out a component. Thus, with one resistor shorted out, the circuit will still function since the power dissipated by the other resistors does not exceed the rating of the fuse.

To locate the shorted resistor while the circuit is functioning, a voltmeter could be used. When it is connected across any of the unshorted resistors, a portion of the applied voltage will be indicated on the voltmeter scale. When it is connected across the shorted resistor, the voltmeter will read zero.

The shorted resistor shown in Figure 11-19-10 can be located with an ohmmeter. First the switch is opened to isolate the circuit components. In Figure 11-19-10, this circuit is shown with an ohmmeter connected across each of the resistors. Only the ohmmeter connected across the shorted resistor shows a zero reading, indicating that this resistor is shorted.

Troubleshooting a Parallel Circuit

The procedures used in troubleshooting a parallel circuit are sometimes different from those used in a series circuit. Unlike a series circuit, a parallel circuit has more than one path in which current flows. A voltmeter cannot be used, since, when it is placed across an open resistor, it will read the voltage drop in a parallel branch. But an ammeter or the modified use of an ohmmeter can be employed to detect an open branch in a parallel circuit.

If the open resistor shown in Figure 11-19-11 was not visually apparent, the circuit would appear to be functioning properly, since current would continue to flow in the other two branches of the circuit.

To determine that the circuit is not operating properly, the total resistance, total current, and the branch currents of the circuit should be calculated as if there were no open path in the circuit:

$$R_T = \frac{R}{N}$$

$$= \frac{30}{3}$$

$= 10\ \Omega$ total resistance

Since the voltage applied to the branches is the same and the value of each branch resistance is known,

$$I = \frac{E_1}{R_1} = \frac{30\text{ V}}{30\ \Omega} = 1\text{ ampere}$$

$$I_3 = \frac{E_3}{R_3} = \frac{30\text{ V}}{30\ \Omega} = 1\text{ ampere}$$

$$I_2 = \frac{E_2}{R_2} = \frac{30\text{ V}}{30\ \Omega} = 1\text{ ampere}$$

$$I_T = \frac{E_T}{R_T} = \frac{30\text{ V}}{30\ \Omega} = 3\text{ amperes (total current)}$$

An ammeter placed in the circuit to read total current would show 2 amperes instead of the calculated 3 amperes. Since 1 ampere of current should be flowing through each branch, it is obvious that one branch is open. If the ammeter is connected into the branches, one after another, the open branch will be located by a zero ammeter reading.

A modified use of the ohmmeter can also locate this type of open.

If the ohmmeter is connected across the open resistor, as shown in Figure 11-19-12, an erroneous reading of continuity would be obtained. Even though the circuit switch is open, the open resistor is still in parallel with R_1 and R_2, and the ohmmeter would indicate the open resistor had a resistance of 15 ohms, the equivalent resistance of the parallel combination of R_1 and R_2.

It is necessary to open the circuit as shown in Figure 11-19-13 in order to check the resistance of R_3. In this way the resistor is not shunted (paralleled) and the reading on the ohmmeter will indicate infinite resistance. On the other hand, if an open should occur in this circuit (Figure 11-19-13) between the battery and point A or between the battery and point B, current would not flow in the circuit.

As in a series circuit, a short in a parallel circuit will usually cause an open circuit by blowing the fuse. But, unlike a series circuit, one shorted component in a parallel circuit will stop current flow by causing the fuse to open.

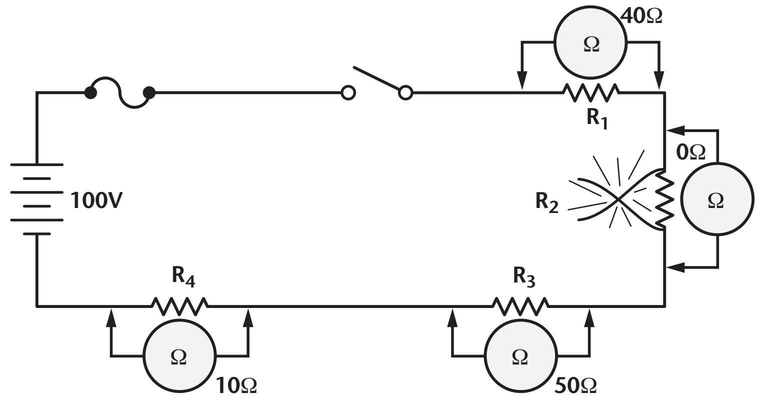


Figure 11-19-10. Using an ohmmeter to locate a shorted resistor.

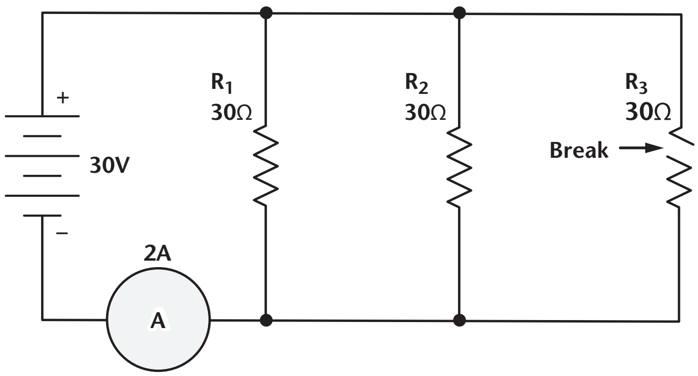


Figure 11-19-11. Finding an open branch in a parallel circuit.

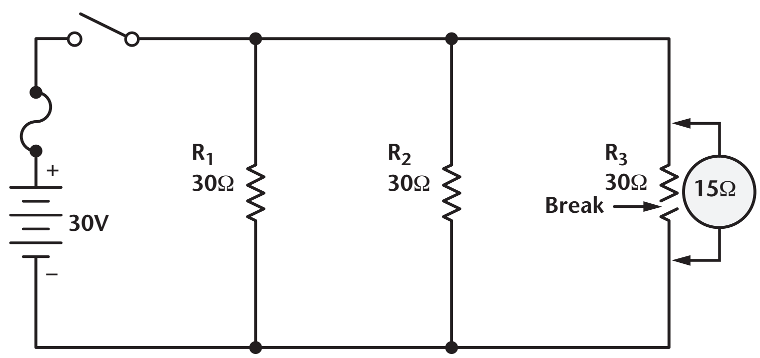


Figure 11-19-12. A misleading ohmmeter indication.

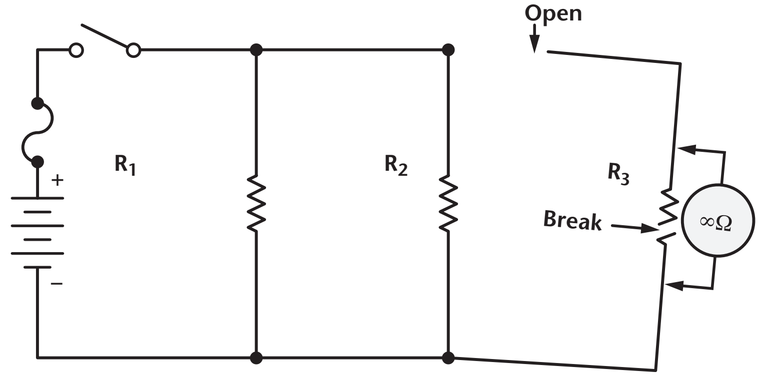


Figure 11-19-13. Opening a branch circuit to obtain an accurate ohmmeter reading.

This can be seen by referring to the circuit in Figure 11-19-14.

If resistor R_3 is shorted, a path of almost zero resistance will be offered the current, and all the circuit current will flow through the branch containing the shorted resistor. Since this is practically the same as connecting a wire between the terminals of the battery, the current will rise to an excessive value and the fuse will open.

Since the fuse opens almost as soon as a resistor shorts out, there is no time to perform a current or voltage check. Therefore, troubleshooting a parallel DC circuit for a shorted component should be accomplished with an ohmmeter. But, as in the case of checking for an open resistor in a parallel circuit, a shorted resistor can be detected with an ohmmeter only if one end of the shorted resistor is disconnected.

Troubleshooting a series-parallel resistive circuit involves locating malfunctions similar to those found in a series or a parallel circuit.

An open has occurred in the circuit shown in Figure 11-19-15, in the series portion of the circuit. When an open occurs anywhere in the series portion of a series-parallel circuit, current flow in the entire circuit will stop. In this case, the circuit will not function, and the lamp, L_1, will not be lit.

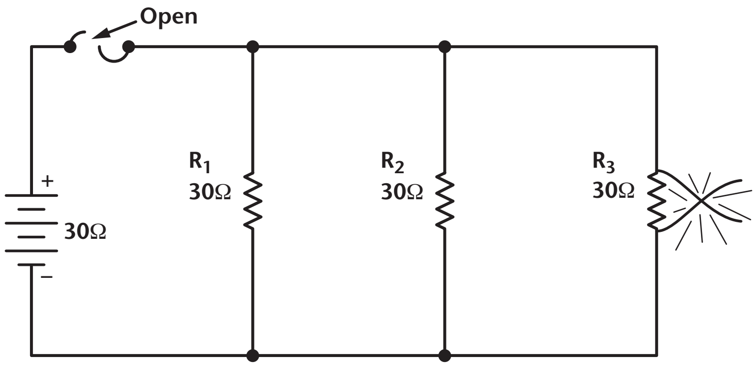


Figure 11-19-14. A shorted component causes the fuse to open.

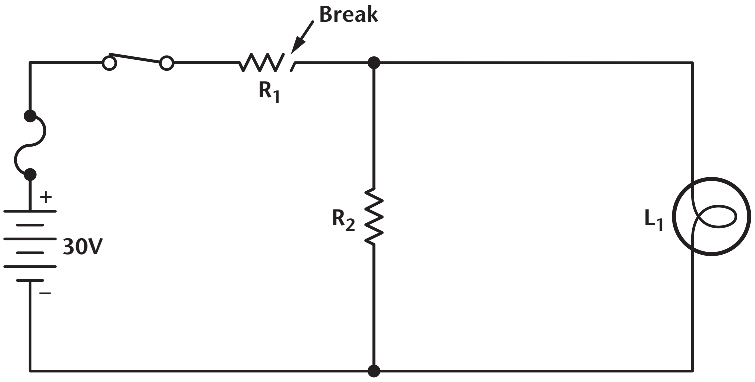


Figure 11-19-15. An open in the series portion of a series-parallel circuit.

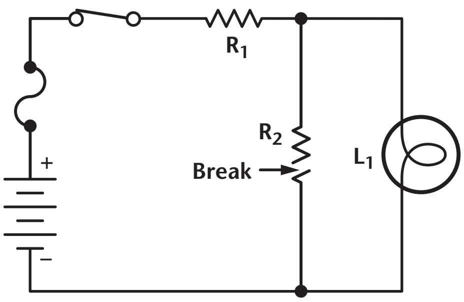


Figure 11-19-16. An open in the parallel portion of the series-parallel circuit.

If an open occurs in the parallel portion of a series-parallel circuit, as shown in Figure 11-19-16, part of the circuit will continue to function. In this case, the lamp will continue to burn, but its brightness will increase since the total resistance of the circuit has increased and the total current has decreased.

If a break occurs in the branch containing the lamp, as shown in Figure 11-19-17, the circuit will continue to function with increased resistance and decreased current, but the lamp will not burn.

To explain how the voltmeter and ohmmeter can be used to troubleshoot series-parallel circuits, the circuit shown in Figure 11-19-18 has been labeled at various points.

By connecting a voltmeter between points A and D, the battery and fuse can be checked for opens. By connecting the voltmeter between points A and B, the voltage drop across R_1 can be checked along with the switch. This voltage drop is a portion of the applied voltage.

The conductor between the negative terminal of the battery and point E can be checked for continuity by connecting the voltmeter between points A and E. If the conductor or fuse is open, the voltmeter will read zero.

If the lamp is burning, it is obvious that no open exists in the branch containing the lamp, and the voltmeter could be used to detect an open in the branch containing R_2 by removing lamp, L_1, from the circuit.

Troubleshooting the series portion of a series-parallel circuit presents no difficulties, but in the parallel portion of the circuit, misleading readings can be obtained.

An ohmmeter can be used to troubleshoot this same circuit.

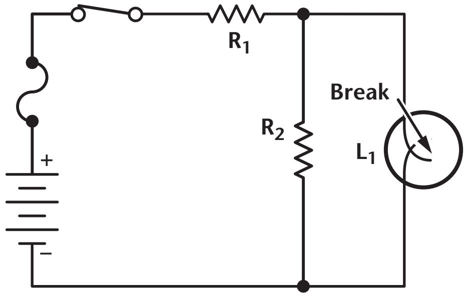


Figure 11-19-17. An open lamp in a series-parallel circuit.

With the switch open, the series portion of the circuit can be checked by placing the ohmmeter leads between this switch and point B. If R_1 or the conductor is open, the ohmmeter will read infinity; if not, the value of the resistor will be indicated on the ohmmeter.

Between points D and E, the conductor can be checked for continuity, but in the parallel portion of the circuit, care must be exercised, since misleading ohmmeter indications can be obtained.

To check between points B and E, the branch must be disconnected at one of these points and, while one of these points and the switch are open, the branch containing the lamp can be checked with the ohmmeter.

A short in the series part of a series-parallel circuit will cause a decrease in total resistance, which will cause total current to increase.

In the circuit shown in Figure 11-19-19, the total resistance is 100 ohms and the total current is 2 amperes. If R_1 became shorted, total resistance would become 50 ohms, and the total current would double to 4 amperes.

In the circuit shown, this would cause the 3-amp fuse to blow, but with a 5-amp fuse the circuit would continue to function. The result would be the same if R_2 or R_3 were to become shorted. The total resistance in either case would drop to 50 ohms.

When a short occurs in a series-parallel circuit, as has been seen, the total resistance will decrease and the total current will increase. A short will normally cause an open circuit by either blowing the fuse or burning out a circuit component. And, as in the case of an open, a short in a series-parallel circuit can be detected with either an ohmmeter or a voltmeter.

System Troubleshooting

Much of the technician's time is spent troubleshooting systems. Many of the systems aboard modern aircraft are complex and difficult to troubleshoot. The troubleshooter's job can be simplified if the following steps are considered:

- Determine what constitutes normal operation for the system being tested.
- Analyze the symptom of the problem.
- Detect and isolate the problem.
- Make repairs as necessary to correct the problem.
- Perform an operational test to verify that the repairs corrected the problem.

The aviation maintenance technician cannot possibly hope to effectively analyze problems in systems in which normal operating parameters are not known.

Consult aircraft or system manuals to determine what the minimum performance standards are before attempting to analyze the problem.

Once system operating parameters have been established, the most likely cause for the problem can be determined.

The history of the malfunctioning system may need to be checked as part of the trouble-

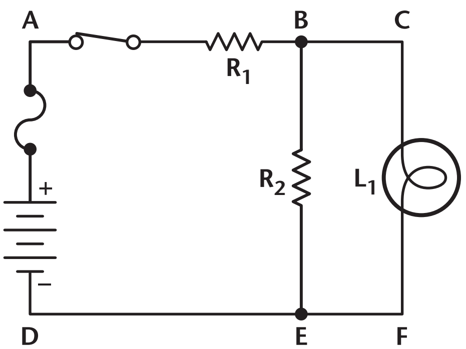


Figure 11-19-18. Using the voltmeter to troubleshoot a series-parallel circuit.

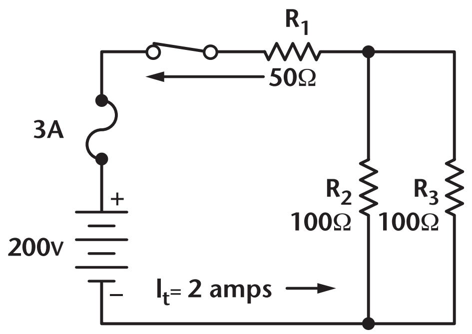


Figure 11-19-19. Finding a short in a series-parallel circuit.

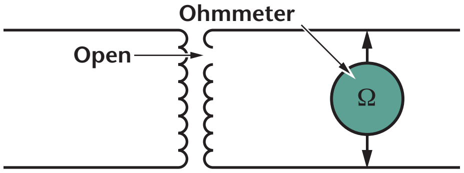


Figure 11-19-20. Checking for an open in a transformer winding.

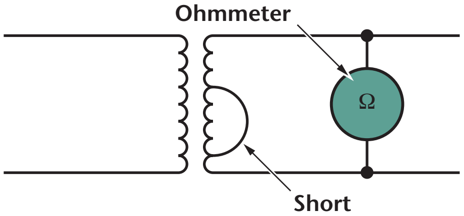


Figure 11-19-21. Checking for shorted transformer winding.

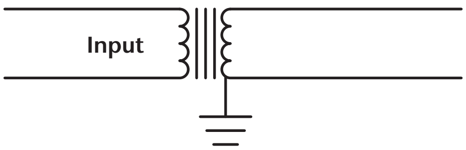


Figure 11-19-22. Part of a transformer winding grounded.

shooting process. If maintenance has recently been performed, clues may be present as to what is causing the current problem. The technician should also check for interrelated problems. For example, if a voltage control unit has recently been replaced and is again malfunctioning after working normally for a short time, perhaps an electrical connector was not tightened properly when the original component was replaced.

Component Troubleshooting

The maintenance technician needs to check specific electrical components during troubleshooting procedures. General electrical circuit troubleshooting techniques and meter usage have been discussed earlier in this chapter. Some specific components to be checked by the technician include relays, rectifier diodes, transformers, and capacitors.

Relays and contactors. Relays may be checked for two things: coil resistance and condition of contacts.

The coil resistance may be checked by removing the leads connected to the relay coil terminals and placing ohmmeter leads on the terminals with the ohmmeter set to a low resistance scale, such as R × 1 or R × 10; the resistance reading should be low but have some value. A reading of zero ohms may indicate shorted coil winding and a reading of very high resistance, or infinite ohms indicates open winding.

The relay contacts may be checked by manually or electrically closing the contacts and checking continuity. Be certain to disconnect any source of voltage from the contact circuit before making this check. Failure to do so will result in damage to the meter and may cause personal injury. With the relay contacts closed, a low-ohm reading should be observed. A resistance reading of any other value indicates dirty or pitted contacts, which will require cleaning, if possible, or replacement.

Semiconductor diodes. Another check often performed by aircraft maintenance technicians is on rectifier diodes. Diodes may open, or short, rendering them unusable.

Diodes are checked with an ohmmeter by testing the resistance of the diode and then by reversing the ohmmeter leads to test resistance in the reverse direction. The diode should have low resistance when forward-biased (positive meter lead on the anode) and high resistance when reverse-biased.

If the diode has low resistance in both directions, it is shorted; if it exhibits high resistance in both directions, it is open. In either instance, it must be replaced. It may be necessary, in many situations, to disconnect one of the diode's leads from its associated circuit before making this test.

Transformers. There are occasions when a transformer must be checked for opens or shorts, and it is often necessary to determine whether a transformer is a step-up or step-down transformer.

An open winding in a transformer can be located by connecting an ohmmeter as shown in Figure 11-19-20. Connected as shown, the ohmmeter would read infinity. If there were no open in the coil, the ohmmeter would indicate the resistance of wire in the coil. Both primary and secondary can be checked in the same manner.

The ohmmeter may also be used to check for shorted windings, as shown in Figure 11-19-21; however, this method is not always accurate. If, for example, the transformer had 500 turns and a resistance of 2 ohms and 5 turns were shorted out, the resistance would be reduced to approximately 1.98 ohms, which is not enough of a change to be read on the ohmmeter. In this case, the rated input voltage can be applied to the primary to permit measurement of the secondary output voltage.

If the secondary voltage is low, it can be assumed that the transformer has some shorted windings, and the transformer should be replaced.

If the output voltage is normal after replacement, the original transformer can be considered defective.

An ohmmeter can be used to determine whether a transformer is a step-up or step-down transformer. In a step-down transformer, the resistance of the secondary will be less than that of the primary, and the opposite will be true in the case of a step-up transformer. Another method involves applying a voltage to the primary and measuring the secondary output. The voltages used should not exceed the rated input voltage of the primary.

If a winding is completely shorted, it usually becomes overheated because of the high value of current flow. In many cases, the high heat will melt the wax in the transformer, and this can be detected by the resulting odor. Additionally, a voltmeter reading across the secondary will read zero. If the circuit contains a fuse, the heavy current may cause the fuse to blow before the transformer is heavily damaged.

One point on a transformer winding is shown connected to ground in Figure 11-19-22. If the external circuit of the transformer circuit is grounded, a part of the winding is effectively shorted. A high-resistance reading ohmmeter connected between one side of the winding and the transformer case (ground) will verify this condition with a low or zero reading. In such a case, the transformer must be replaced.

Capacitors. Capacitors are often a source of trouble in some circuits, such as power supplies. Capacitors may be checked with a tester specifically designed to test capacitance values, or they may be given a quick check with an ohmmeter.

To test capacitors with a capacitance tester, follow the instructions given by the tester manufacturer. The instructions will vary somewhat depending on the type of tester being used.

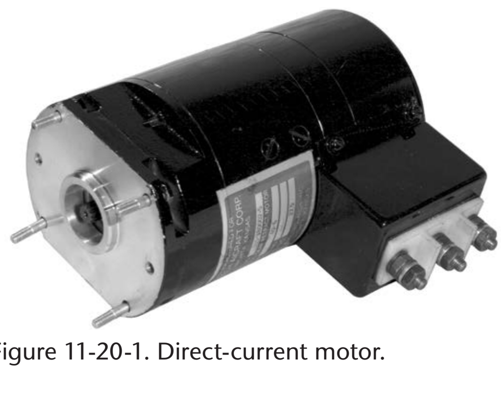


Figure 11-20-1. Direct-current motor.

To test a capacitor with an ohmmeter, first discharge the capacitor and remove it (at least one lead) from the circuit where it is connected. Set the ohmmeter to a mid-resistance scale and connect it to the capacitor and observe the meter scale for *capacitor action*. (Note: An analog meter with a needle pointer works best for this test.)

Capacitor action is observed when the meter needle moves upscale, toward zero ohms, and then slowly moves downscale toward infinite ohms. The needle action is due to the ohmmeter internal voltage source (battery) charging the capacitor. It may be necessary to try more than one resistance scale before observing any significant capacitor action. Remember to discharge the capacitor after every attempt to observe capacitor action.

A continuous low reading indicates a shorted capacitor, and a continuous high reading denotes an open capacitor. Ohmmeter checks of capacitors are not always accurate, and any suspicious capacitors may need to be tested with a capacitor analyzer.

In summary, the best tool for troubleshooting systems or components is a logical and analytical mind. Use common sense and think through the problem to determine possible causes. Above all, use appropriate procedures and observe safety precautions to avoid damage to equipment or personnel. If electrical indicators, such as voltmeters or ammeters, or other voltage sensitive devices are connected to the circuits or components being tested, it may be necessary to disconnect them before testing to prevent damage.

Section 20

DC and AC Electric Motors

Hundreds of motors of various sizes and types are used on aircraft today. They perform all kinds of jobs, from such heavy work as lowering and raising the landing gear to such fine, intricate work as precision instruments. Each job needs a motor designed for it, and for each type of motor there are many variations. It would take many volumes to describe all motors, and by the time it was published it would be obsolete. An understanding of the various types of motors will enable you to repair all motors; therefore, we will not attempt to cover any particular one.

Motors are grouped first according to the type of power they use: either direct current (DC) or alternating current (AC). Since DC motors were the first to be used in aircraft, it is only fair that we discuss them first (Figure 11-20-1).

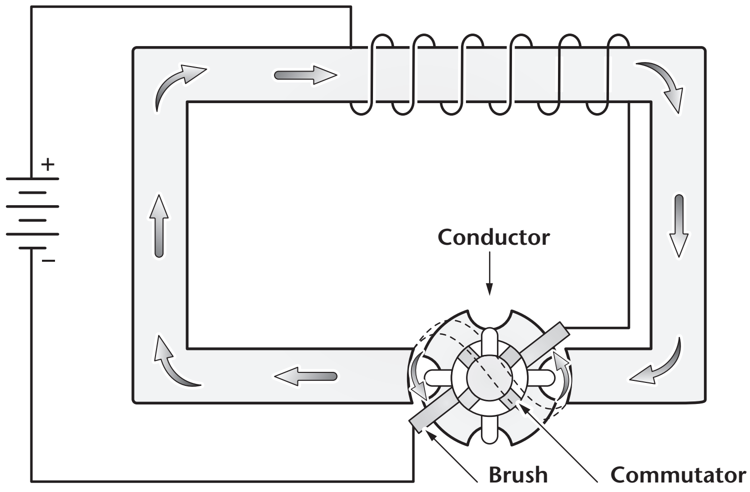


Figure 11-20-2. Loop conductors in a magnetic field.

Direct-Current Motors

Construction. A direct-current motor has five major components:

1. The frame assembly completes the magnetic circuit for the field, and it also supports the field assembly.
2. The field assembly is composed of a frame and laminated soft iron pole pieces around which the field coils are wound. These coils, each consisting of many turns of insulated wire, fit over the pole pieces. Some motors have as few as two poles, others have as many as eight.
3. The armature is a laminated soft iron core that carries a number of conductors. It is mounted on a shaft and rotates freely. Its conductors are connected to commutator segments located at one end of the armature. The commutator segments are insulated from each other and the shaft. All windings are insulated from each other.
4. The end housing contains the bearings, which support the armature assembly.
5. The brush assembly is made up of brushes, brush holders, a frame, and conductors. The brushes, usually made of graphite and carbon, are electrically interconnected by the conductors. The brush holders are held by the frame in a fixed position in the plane of commutation.

Principles of operation. Since a motor is operated by magnetic forces, some knowledge of *magnetism* is needed. For review purposes, the following statements sum up the magnetic principles involved.

- Lines of force are elastic, they never cross each other, and they exist in complete, unbroken paths.
- Air offers more reluctance to a magnetic circuit than any other magnetic substance.
- Magnetic lines of force travel externally from the north pole to the south, internally from the south pole to the north.
- Like magnetic poles repel, unlike ones attract.
- A current-carrying conductor always has a magnetic field around it, and the direction of the field is dependent upon the direction of the current flow. The direction of the field is determined by the left-hand rule, Place your left hand along the conductor so that your thumb points in the direction of electron movement, and your fingers will encircle the conductor in the same direction as that followed by the magnetic lines of force.

The operation of a DC motor is best explained through a simple two-loop conductor moving in a magnetic field between two field poles (Figure 11-20-2).

Notice that the current flow through the field coils sets up a magnetic field that extends across the gap between the pole shoes. The current flow through the loop of the armature contacting the brushes sets up a magnetic field about the conductor. This magnetic field is at right angles to the lines of force originating from the pole shoes. The field about the conductor distorts the field between the pole shoes by adding to the field strength on one side and opposing the field strength on the other side. Since lines of force have an elastic tendency, the distorted field tries to straighten out and exerts force against the current-carrying conductor of Figure 11-20-2 in a counterclockwise direction. As this loop moves out of the magnetic field between the pole shoes, its contact with the brushes is broken and the field about the conductor collapses.

As this loop breaks contact with the brushes, the next loop makes contact with them, thus

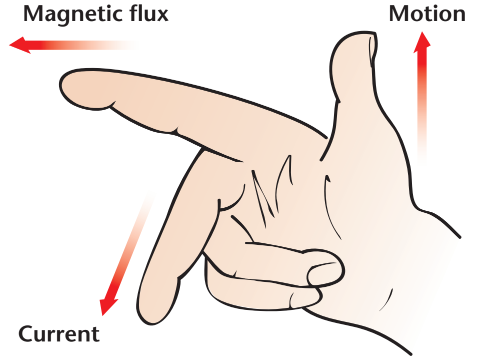


Figure 11-20-3. Right-hand motor rotation rule.

setting up another cycle in the next loop. As long as the power source is connected, this series of events is repeated, causing the armature to rotate and work to be performed.

The direction of rotation of a motor may be determined by the *right-hand motor rotation rule* (Figure 11-20-3). Place your right hand in the magnetic field with the index finger pointing in the direction of flux (magnetic line of force) from the field poles. The second finger, held at a right angle to the index finger, then will show the heading of electron flow, and the thumb will point in the direction of motion.

Series Motors

This type, as the name implies, has its field connected in series with its armature (Figure 11-20-4). This motor has a low internal resistance, because its field windings, which carry the same amount of current as the armature, have only a few turns of heavy wire. As a result, the motor has a high current draw at starting. During starting, this draw causes strong magnetic fields that produce a high starting torque. Therefore, a series motor is ideal as a starter and actuator. Moreover, it will not stall because, if the load is increased, the armature turns more slowly. Hence, since fewer lines of force are cut, the *counter-electromotive force* (discussed in Section 9 of this chapter) decreases and the current increases; consequently, the resulting stronger magnetic field increases the torque to take care of the added load. Because of these advantages, series motors are used chiefly for operations in which widely varying loads and extreme speed changes are not objectionable.

A series motor is never used if there is a chance of the load being suddenly taken away. Here is the reason: If the load is removed, the armature turns faster and CEMF increases. This action, in turn, reduces the current in the motor and weakens the magnetic field. Nevertheless,

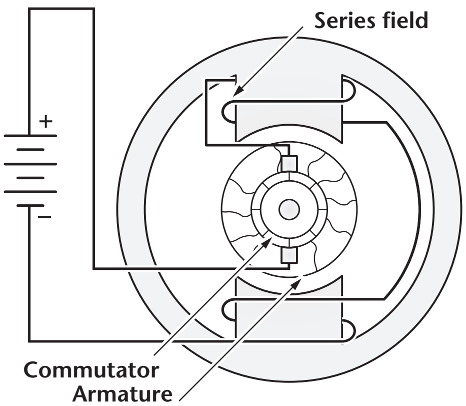


Figure 11-20-4. Series motor.

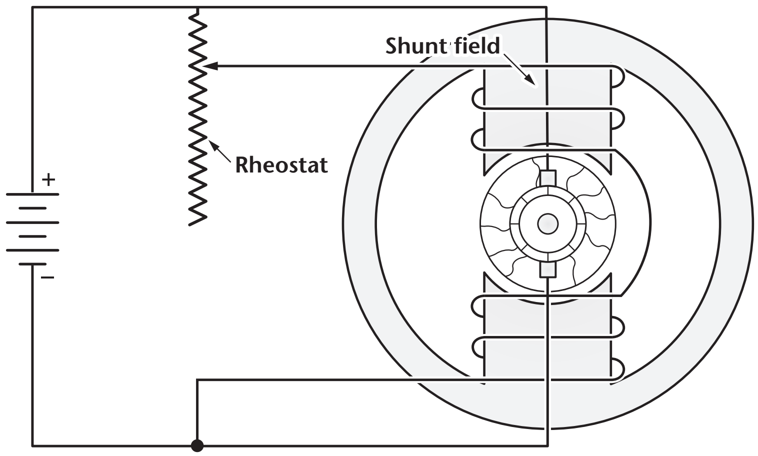


Figure 11-20-5. Shunt-wound motor.

despite this effect, the CEMF cannot ever build up to the point where it equals the applied voltage and, therefore, there will always be an accelerating force, though small at high speeds, applied to the armature. Small or not, it will cause the armature speed to keep increasing. Thus, the motor will have a dangerously high speed under a no-load condition. When a series motor is bench-tested under no-load conditions, ordinarily only half voltage is used.

The equation for torque in a series motor is:

$T = KI^2$

with

T = torque

K = 0.064 circuit constant

I = armature current

It follows, then, that in a series motor, the torque is proportional to the square of the armature current. If the armature current is doubled, the torque is quadrupled. Therefore, if the torque is 40 lb-ft at 25 amps, it would be 160 lb-ft at 50 amps, as you can observe in the following computations for this problem.

$T = 0.064 \times 25^2$	$T = 0.064 \times 50^2$
$T = 0.064 \times 625$	$T = 0.064 \times 2{,}500$
$T = 40$	$T = 160$

Remember that the armature reaction and the saturation of the iron tend to prevent the torque from increasing as rapidly as the square of the current.

Shunt Motors

A shunt motor is so named because the field is connected in parallel with the armature (Figure 11-20-5). This field, like the one in a generator,

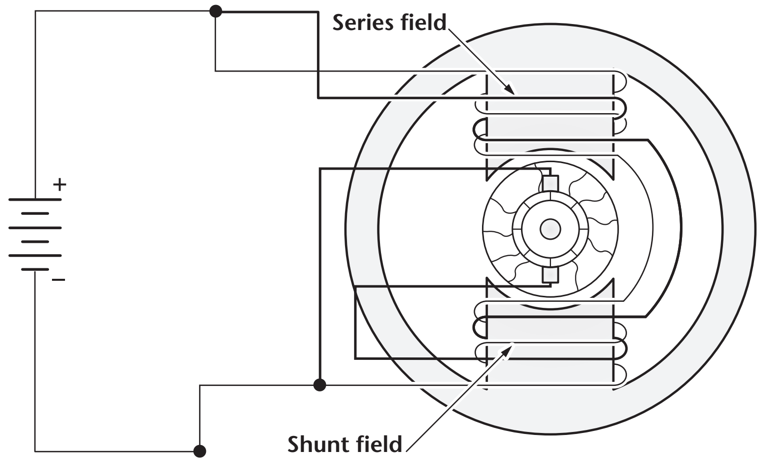


Figure 11-20-6. Differential compound motor.

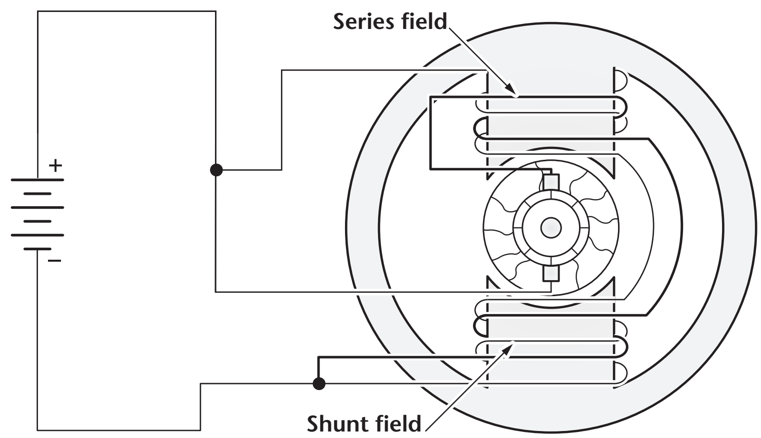


Figure 11-20-7. Cumulative compound motor.

is composed of many turns of small wire. A shunt-wound motor will maintain an almost constant speed from no-load to full-load, because the CEMF induced in the armature will not affect the parallel field strength, which will be determined by the current in the field. It, in turn, is controlled by the total resistance of the field circuit plus the applied voltage to the motor. Remember that the effective voltage is the difference between the applied voltage and the CEMF. With constant field strength, any change in armature speed will either increase or decrease the CEMF. If the CEMF goes up, the armature current goes down because of the decreased effective voltage applied to the armature. Although the CEMF does not affect the current in the field, it partially determines the current in the armature.

Any decrease in armature current will reduce the torque and the speed of the armature. Since an increase in load on the motor slows down the armature, we obtain less CEMF and more effective voltage. When this occurs, armature current is raised, and, as a result, the torque and speed of the motor is again increased.

The speed of a shunt-wound motor may be controlled in two ways: with a rheostat connected in series with the field coils or with the armature. When the rheostat is in series with the field windings (Figure 11-20-5), the field current can be increased or decreased. If increased, the field strength and the CEMF from the armature will be stepped up, armature current will decrease, and the torque and speed will drop off. Conversely, a decrease in the field current will reduce the CEMF and result in higher armature current, speed, and torque.

The second method of speed regulation is not used to any great extent, because an armature control rheostat would have to carry more current and have to be larger. Its use would also cause a greater power loss. With armature control, we have to increase the total armature circuit resistance to decrease speed. And, of course, the reverse is also possible. We can step up the current, speed, and torque by decreasing the armature circuit resistance.

Compound Motors

A DC compound motor is a combination of the series and the shunt. It has two fields connected with the armature; one is a series and the other a shunt that is wired in parallel. Also, compound motors come in two types: the differential and the cumulative.

Differential compound motor. In the differential motor (Figure 11-20-6), the two field windings counteract each other. With this arrangement, both work on the same field pole; the shunt will try to give it a north polarity at the same time that the series winding attempts to give it a south polarity. Therefore, for starting, the series field is usually shorted out.

Of the two fields, the shunt predominates. As the motor operates, an increase in load will tend to slow it down. When this happens, the CEMF goes down and the current steps up. This action then causes the strength of the series field to become greater. Since the series field opposes the shunt, which normally is stronger, the resultant field will get weaker. At this point, the motor should speed up. However, if the series has a sufficient number of turns, the increased load and the weakened field will neutralize each other and, thus, the speed will remain unchanged.

Although the motor itself has excellent speed control, it has a low torque rating and can reverse its direction of rotation under extreme overload conditions. For these reasons, this type of motor is most often used where speed control is important and torque requirements are not great.

Cumulative compound motor. The cumulative compound motor has the same two field windings as the differential compound motor. However, in this motor, both are wound in the same direction so that their effect will be additive (Figure 11-20-7).

In the cumulative, the series is the strongest of the two fields. The purpose of the shunt field is to prevent the motor from running away under a no-load condition. To discover how this is done, we first have to go back a step. Remember that, in series motors, as load decreases, armature speed increases because of the slow buildup of CEMF. Here is where the shunt field enters the picture. It will remain at about the same strength under no-load as at full-load; therefore, the amount of CEMF will not increase as much as it would in a shunt-wound motor, because the series field is predominant. The cumulative actually has a higher starting torque than a shunt motor.

Its speed control is less than that of a shunt motor and better than that of a plain series motor. With the shunt field, then, we can get better control of the motor speed in units that have to operate within a certain range, as, for example, some types of inverters.

Reversible Motors

Reversible motors may be series, shunt, or compound wound. The type that is used is determined by the load or work to be performed. For the most part, on aircraft, the reversible series motor is used.

The main difference between a normal shunt, series, or compound and the same type of reversible motor is the method of connection. To reverse the direction of a DC motor, you must reverse the direction of current in the windings of either the armature or the field.

You can see how this is done in the schematics shown in Figure 11-20-8. In Figure 11-20-8A, in which the armature turns counterclockwise, notice the polarity of the field poles and the armature, the battery connections, and the magnetic field around the loop conductor. Next, observe in Figure 11-20-8B that all the polarities, connections, and current flow are just the opposite. Now, with this arrangement, which way will the armature turn? If you answered counterclockwise, as in Figure 11-20-8A, you are right.

Let us see what will happen when we change just part of the polarities. In Figure 11-20-8C, the armature current and polarities are the same as the ones in Figure 11-20-8A. What is the difference? Notice that the field is reversed.

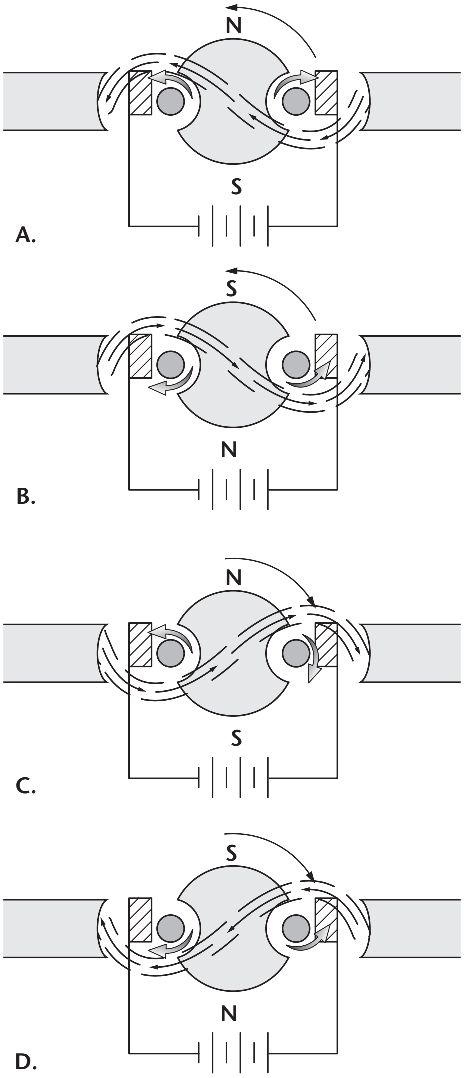


Figure 11-20-8. Illustration of polarity effect on armature rotation.

At this stage, if you apply the hand rule, you can see that the armature will turn clockwise.

Now shift your attention to Figure 11-20-8D. Here, the field polarities are the same as those in Figure 11-20-8A, but the armature current has changed. In this position, the armature also rotates clockwise, because its polarity is opposite to that of Figure 11-20-8A. These four schematics reveal two points that you must keep in mind:

1. Only one of the two current directions, field or armature, is reversed.
2. If both are reversed, the armature will still turn in the same direction.

Let's elaborate on the first point by means of Figure 11-20-9, which shows change in direction when the leads to the armature are reversed. In Figure 11-20-9A, you can see that the armature has a north polarity at the top and that the

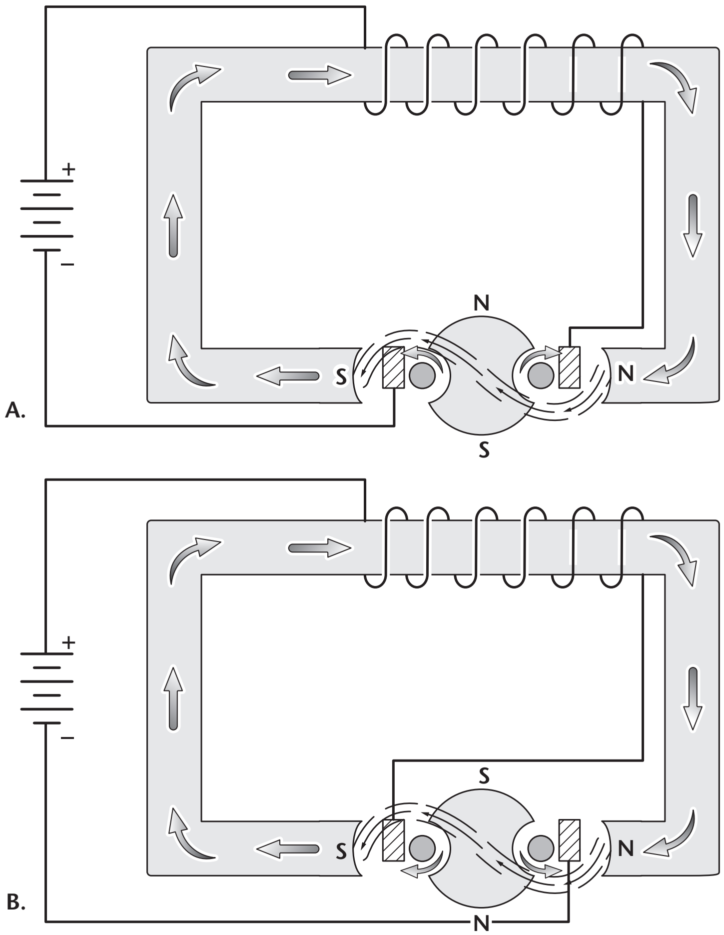


Figure 11-20-9. Changing direction by reversing lead to armature.

magnetic field around its conductors causes the armature to turn counterclockwise. But with the reversed connections in Figure 11-20-9B, the south pole is at the top; thus, the resulting magnetic field sets up a clockwise rotation.

As previously stated, you can reverse direction by way of the field. To do this, all you have to do is change the field connections, as shown in Figure 11-20-10. The new arrangement reverses the magnetic field of the field poles and causes the motor to turn in the opposite direction.

With the methods just discussed, the motor would have to be taken apart every time it had to be reversed. That would be no problem if we wanted to change the direction only once. However, for aircraft use, we need motors that can be reversed constantly. Fortunately, there is a solution. The leads for the armature and the fields have been relocated to the outside of the motor and connected to a switch. With the switch, the direction of current can be changed in either field or armature, thus controlling the rotation (Figure 11-20-11).

A double-pole, double-throw switch is needed to regulate the direction of a single-field motor. With the switch in the position shown in Figure 11-20-11, the current would flow through its lower pole and through the armature in the direction indicated by the solid arrow. From the armature, the current would then pass on to the ground by way of the upper pole of the switch and the field.

The current in the armature would reverse if the switch were in the position represented by the dashed lines. Now trace what happens in this situation. Current passes from the bottom pole (dashed line), across the jumper wire, through the armature (dashed arrow), and back to the switch. At the same time, it goes from the switch around the jumper, through the top pole, and through the field. Notice that the current does not change direction in the field.

Split-field motors. In addition to the single-field reversible motor that we have been discussing, there are other types frequently used. One is the two-pole, split-field motor, which has both fields wound opposite to each other on the same field poles; one being used for clockwise rotation and the other for counterclockwise (Figure 11-20-12A).

Then, there is the four-pole, split-field motor. One field winding energizes two of the poles, and the other takes care of the opposite two (Figure 11-20-12B). Only one of the fields is used at any one time. The two energized poles become north and the inactive ones become south poles.

Right about now, you might wonder how this can result when the field windings of the two south poles are not energized. It is possible because they serve as a path for the lines of force from the two energized poles. Their physical location in the motor causes these lines of force from each north pole to divide. Some of the lines will be attracted to the energized pole, which is situ-

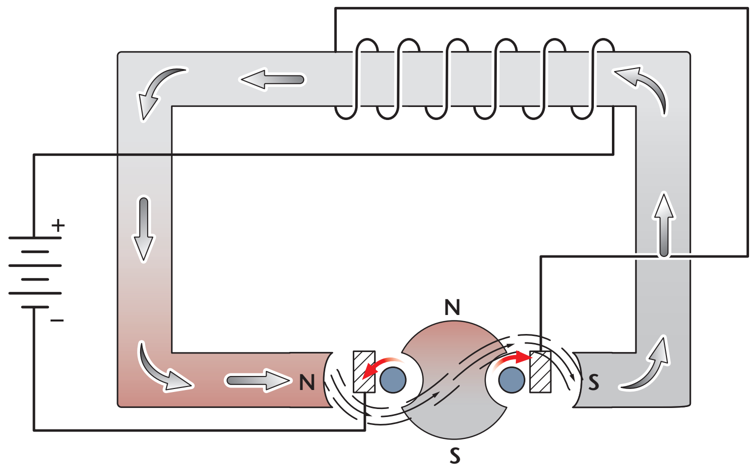


Figure 11-20-10. Reversing direction by reversing field connections.

ated clockwise, and the remainder to the counterclockwise one. Such a condition gives four arcs of force lines between the field poles; that is, one arc passing from each of the energized poles to each of those that are not energized.

Reversible motors are valuable units on modern aircraft because so many components move up and down or forward and back. Such actions require reversible motors. Therefore, you will find that they may be used to operate components such as landing gear, wing and cowl flaps, landing lights, oil cooler shutters, hoists, and fuel transfer pumps.

Bench-Check

After a motor has been removed from an aircraft and turned in to the shop, it should be bench-checked prior to disassembly. In some instances, the motor may only need new brushes, brush holders cleaned, or some other minor repairs.

Disassembly

All DC motors made by different manufacturers or for different jobs are constructed somewhat differently. No disassembly should be attempted without manufacturer's instructions at hand. Things do not always come apart as simply as they would seem to, and you could do a lot of damage to a motor without any instructions. There are, however, some universal things to consider.

Inspection and Test

Inspect all parts and replace any parts showing indication of damage, corrosion, or deterioration with a new part.

Rotor assembly. The following items will typically be checked:

- It must have no turns or windings out of place.
- Its insulation must not be broken, flaked, or brittle.
- Its windings must show no shorts, grounds, or open circuits.
- The commutator must not be worn down to the segment insulators, and the face must be concentric with the shaft.
- The shaft must be perpendicular with the bearing lands.
- The spline shaft must show no measurable wear.

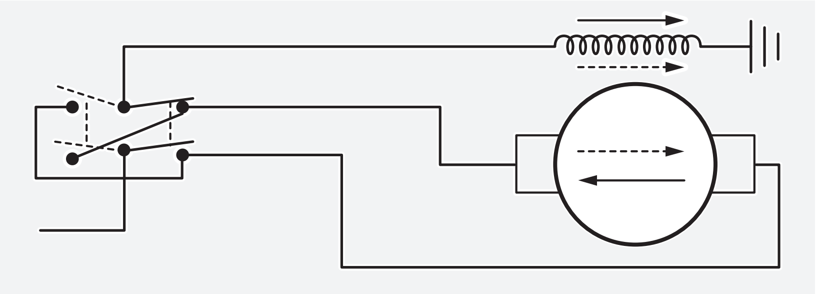


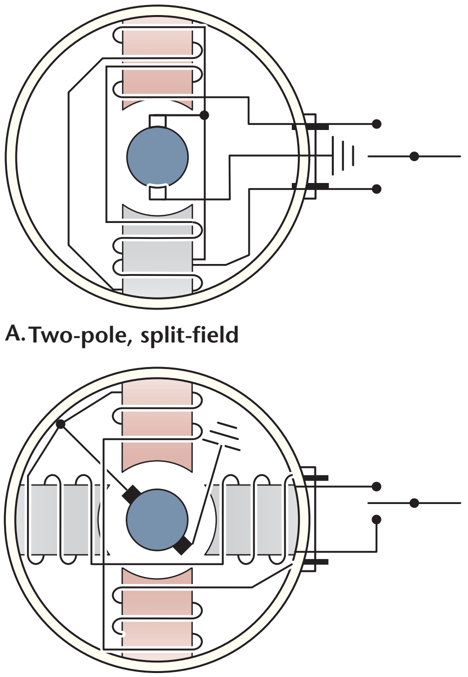
Figure 11-20-11. Reversing direction by use of a switch.

Spline gear. The internal spline must show no measurable wear, and the gear teeth must show no damage.

Stator assembly. The following items will typically be checked

- It must have no turns or windings out of place.
- The windings must show no shorts, grounds, or open circuits.
- The leads must be securely soldered in place.
- The insulation must not be broken, flaked, or brittle.

Radio noise filter. The resistance between the input terminal and the case must be infinite. The resistance between the input and the output terminals must not be less than 0.0015 ohm.



A. Two-pole, split-field

B. Four-pole, split-field

Figure 11-20-12. Split-field motors.

End bell and brush holder assembly. The brush boxes must be firmly riveted to the support ring and must show no grounds to the end bell. The brush springs must not be distorted, and they must have sufficient tension to provide a load of 2 lbs. on the brushes.

Fan. The fan must fit firmly on the rotor shaft and the set screw must fit snugly in the fan.

Repair or replacement. All defective parts must be replaced, and ball bearings and brushes are always replaced. If necessary, some rotor assembly commutators may be turned down with a very light lathe cut and dressed with No. 0000 sandpaper (no emory cloth). The segment insulators must also be undercut. The rotor assembly will be dynamically balanced after ball bearings are installed.

Lubrication. Ball bearings will be packed with grease, per manufacturer's instructions. At the time of reassembly, the gear housing will be packed with grease also. Use the correct specification of grease.

Reassembly and Test

The reassembly process is the reverse of the disassembly process. All motors will have a test procedure and must be tested in accordance with it.

> **NOTE:** If you haven't taken a motor apart before and have access to a digital camera, it might be a good idea to take more than a few pictures as you proceed. They can be invaluable in reassembly.

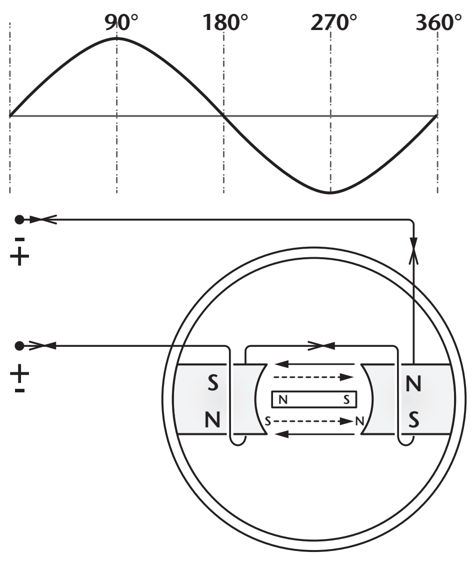


Figure 11-20-13. Two-pole, single-phase sine wave and induction motor schematic.

Alternating-Current Motors

AC motors have a number of advantages over DC motors, the main ones being:

- Less arcing at high altitudes
- Smaller size
- Lighter weight

There are two general types of AC motors that are used on aircraft: the induction and the synchronous. Further, the induction-type motors are divided into three classes: the single-, two-, and three-phase. Of these, the three-phase is the class that you will generally find on aircraft. Moreover, the grouping is according to function and not design. In fact, the motors vary quite a bit in appearance. Some look almost like generators, whereas others are light and compact. Some have dust-proof cases, others have waterproof housings.

Single-Phase Induction Motors

There are numerous single-phase induction motors. You are going to become acquainted with seven:

- Simple two-pole
- Shaded-pole
- Capacitor-start
- Coil-start
- Repulsion-start
- repulsion-start-and-run
- Universal motors

All of these are more simply constructed than the two- or three-phase motors, but their operation is more involved.

For all induction motors — single-, two-, and three-phase — the principle of operation is a rotating magnetic field. To illustrate such a field, let us consider a simple two-pole motor before we progress to the more complicated ones.

Simple two-pole motor. By wrapping a coil around two soft iron pole pieces, as shown in Figure 11-20-13, we form a two-pole magnetic field with lines of force (magnetic flux) flowing across the gap between the poles.

With this coil connected to a single-phase AC circuit, the current will flow in one direction for a fraction of a second and in the opposite direction for the same length of time. You already know that a current-carrying conductor has a magnetic field.

When we coil the conductor, the magnetic flux is concentrated in the center of the coil, and a definite polarity will be established. Remember that when you place the fingers of your left hand around the coil in the direction of current, your thumb will point toward the north magnetic pole. The reversing current in our field coil will cause the polarity to reverse with every opposite current pulsation. Since magnetic flux is always traveling from north to south outside a magnet, the flux will be from left to right across the gap at one instant, and from right to left the next.

From previous discussion on magnetism, you may recall that a soft iron bar placed near a magnetic field will assume a position parallel to that of the magnetic flux.

If this iron bar were placed horizontally between the two poles of our magnetic field, as in Figure 11-20-13, it would be parallel to the magnetic flux regardless of the direction of the flow. This being the case, our soft iron bar will not shift position when the polarity changes. To illustrate this point, we will use the sine wave of a single-phase voltage.

In Figure 11-20-13, notice that a polarity is established as the current begins to build up in the field coil. When it reaches peak value, the magnetic strength in the coil will be at a maximum. As the current begins to decrease, so will the strength of the magnetic field. As in all cases with AC, the current will drop to zero and then build up in the opposite direction. At the time of zero current, there will be no magnetic strength in our field windings. As current builds up in the opposite direction, an opposite polarity is set up in the field winding. Again, it will arrive at a maximum value and then decrease, and the field strength will do the same.

This series of events takes place with every cycle of AC applied to the coil. We must also point out at this time that a polarity opposite to that of the magnetic field will be induced in the iron bar. Since soft iron has low magnetic retentivity, the induced magnetism will decrease to zero each time the magnetic strength of the field decreases and will build up to maximum every time it builds up. Therefore, at no time will the iron bar retain enough magnetic strength to cause like poles to be opposite each other when the current changes directions. The iron bar will not move because it always remains parallel to the magnetic flux and only changes its polarity when the field does.

In this simple two-pole motor, we can make the iron bar rotate by placing it in a vertical position, perpendicular to the flux, as shown in Figure 11-20-14. If the iron bar were exactly vertical, as indicated in the top left drawing of the figure, it would not move because a polarity would be set up in the bar, causing the same effect that existed when it was in the horizontal position. However, this condition will probably never exist, for the iron bar will almost always be off center just a fraction of a turn.

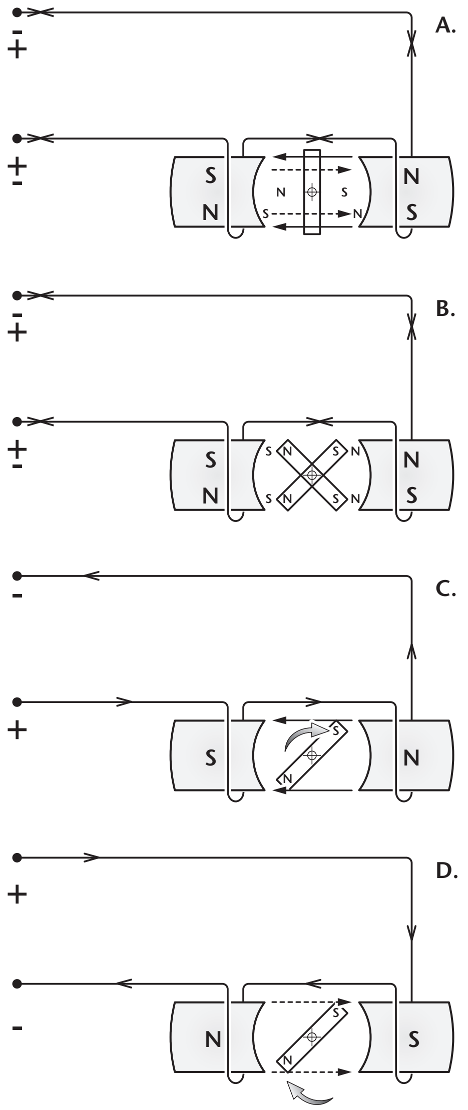


Figure 11-20-14. Two-pole motor schematic.

To see how it rotates, let us follow one impulse of AC through the field coil. This is shown in illustration B. When an impulse of voltage is applied to the field coil in the direction shown, a definite polarity will be established in the pole pieces. This will induce a polarity in the bar and the attracting force of the two magnetic polarities will cause the bar to move clockwise. As the rotor turns, it gains enough momentum to carry it through the horizontal position.

At the same time, the impulse of current will be decreasing to zero. As a result, magnetism ceases and the rotor's momentum carries it to a position similar to that represented in Figure 11-20-14A. As the iron bar continues to spin because of impetus, the second impulse of AC begins

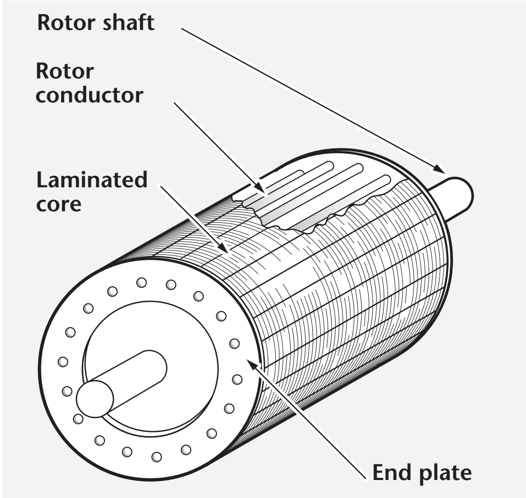


Figure 11-20-15. Induction motor squirrel-cage rotor.

to build up in the field coils. This will create a polarity such as shown in illustration C. Once again, a polarity will be induced in the iron bar. The attracting force of the two magnetic fields will cause the rotor to keep going toward the horizontal position. This chain of events lasts as long as AC is applied to the field coils.

This motor, which has to be started by hand, is suitable for such units, since they do not require much power.

Obviously, a motor that has to be actuated manually and that has a weak induced polarity and only two magnetic poles in the field will not be of any value on a modern aircraft.

Crew members just do not have the time to whirl the rotor whenever some item has to be operated. The single-phase motors that serve aircraft, therefore, must be able to start electrically. Further, these classes must have a different type of rotor. Accordingly, we should study the rotor first before taking up the other single-phase motors.

Squirrel-cage rotor. Induction motors have a rotor that is called the *squirrel cage*, for the soft iron bar is not suitable for use in an aircraft electrical motor. The squirrel-cage rotor consists of copper or aluminum conductors fixed in slots in a laminated core. These bars are soldered to metal end plates, which short them together to form a complete path for the induced current within the rotor itself (Figure 11-20-15).

The size of the applied rotor depends, to a great extent, on the frequency of its applied voltage. For example, a 25-cycle rotor may be 5-6 inches in diameter as compared to 3-4 inches for one built for 60 cycles. The speed of rotation is determined by the number of poles in the field winding and the frequency of the applied voltage.

As seen in Figure 11-20-15, there are not brushes or other electrical devices to connect the rotor to the other parts of the motor. Its operation relies entirely upon electromagnetic induction, as in the simple motor just discussed. If one of the rotor bars (conductors) is removed and inserted in the stator field, as shown in Figure 11-20-16, when the main field moves in a counterclockwise direction, it cuts across the bar and produces an induced voltage in the bar itself. As indicated, this voltage causes a current in the bar, the direction of which you can find by the left-hand generator rule.

As a result of this current, a magnetic field is set up around the bar, strengthening the main field above the bar, weakening it below. The bar moves toward the weaker field because of the combination of the two fields and assumes a new position, only to have the same thing happen again under the influence of another set of poles. In the entire squirrel-cage rotor illustrated in Figure 11-20-15, many inductors are acted upon by the rotating field and, consequently, a large total force is exerted to turn the rotor counterclockwise.

Now we have the squirrel-cage rotor. However, for simplicity, we will assume that the induction motors have the soft iron bar. What comes next in devising a single-phase motor that will

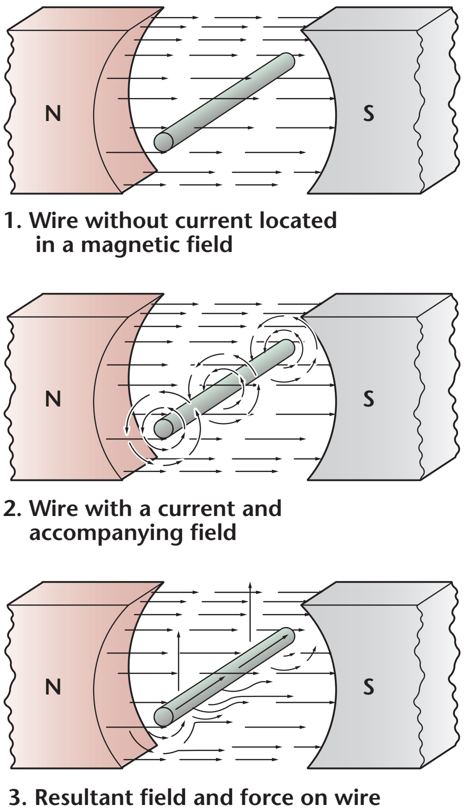


Figure 11-20-16. Induction motor field with bar inserted.

Figure 11-20-17. A shaded-pole fan motor.

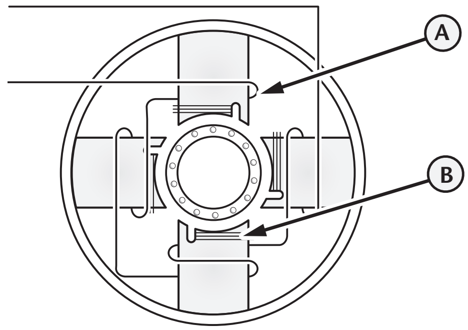


Figure 11-20-18. Shaded pole motor schematic.

start electrically? Let's return to our simple two-pole unit. To this, we can add two more poles, positioned 90° (vertically) from the first set, and another field winding. Then we can do one of three things: shade the four poles, or connect a capacitor or coil in series with either of the two sets of windings. Each of the above gives us a different class of single-phase induction motor. Therefore, let's look at each individually.

Shaded-pole induction motors. Shaded-pole motors are usually used for fans and other items requiring a low starting torque (Figure 11-20-17). As revealed in Figure 11-20-18, the shaded-pole motor has stator windings (detail A) and a shading coil (detail B) wound around a portion of the pole piece. The stator windings are connected in series and actually form one complete coil. The shading coils are small, individual wires or bands not electrically connected to each other or the rest of the motor.

As the magnetism in the stator windings builds up, the voltage induced in the shading coils sets up a polarity in the shaded portion of the pole piece, which is opposite to that in the main pole piece. However, because of the size of the shaded portion, the induced magnetism will not be strong enough to counteract the amount there is in the main pole piece. In illustration A of Figure 11-20-19, you can see that the polarity set up across the entire face of the pole piece causes the rotor to assume a position such as that shown. As the main magnetic field collapses, the polarity in the shaded portion is reversed and becomes the same as that of the main pole. As indicated in illustration B of Figure 11-20-19, since the polarity of the shaded portion only covers about half of the pole face, the magnetic field shifts slightly and the rotor follows. This initial rotor movement will be sufficient to cause the rotor to continue to turn as the polarity of the field changes.

As the main field builds up, the induced current in the rotor will setup a polarity or magnetic field, causing the rotor to move counterclockwise, that is, toward the shaded portion of the poles. As the main field collapses, polarity in the shaded portion will build up. With this continuing effect on the rotor, it rotates even more counterclockwise. As this takes place, the applied current will reverse; as a result, we get an opposite polarity that builds up on the main poles and continues the action on the rotor. Thus, you can see that the rotor is actually following the magnetic field as it rotates counterclockwise; it is not turning as fast as the magnetic field. If it were, there would be no relative motion between the two, and no voltage would be induced in the bars of the rotor. Such a condition would cause a loss of torque and slow down the rotor.

When rotor speed is reduced, though, the rotating magnetic field does not change speed. Thus, as the relative speed between the rotating field and the inductors becomes greater, voltage will again be induced in the rotor bars and we obtain more torque.

In passing, let us mention that the direction of rotation can be changed by removing the field poles from the housing and turning them 180° from their original position. Keep in mind that this arrangement is not practical and is never put into practice on shaded-pole motors that are used in aircraft. In fact, there are not too many uses for a shaded-pole motor on an aircraft. However, the next two that were developed from the simple two-pole motor, the capacitor- and coil-start, are readily adaptable for aircraft service.

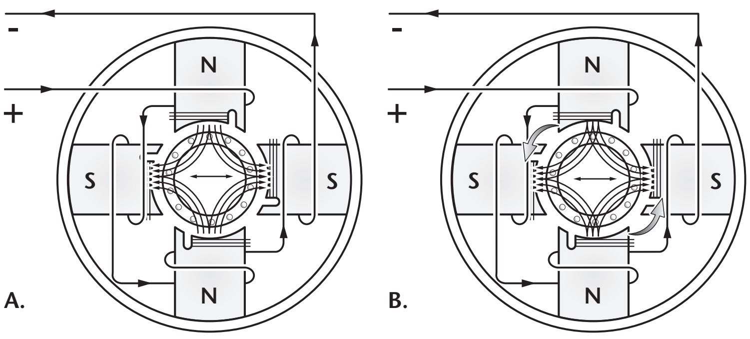


Figure 11-20-19. Shaded-pole motor operation.

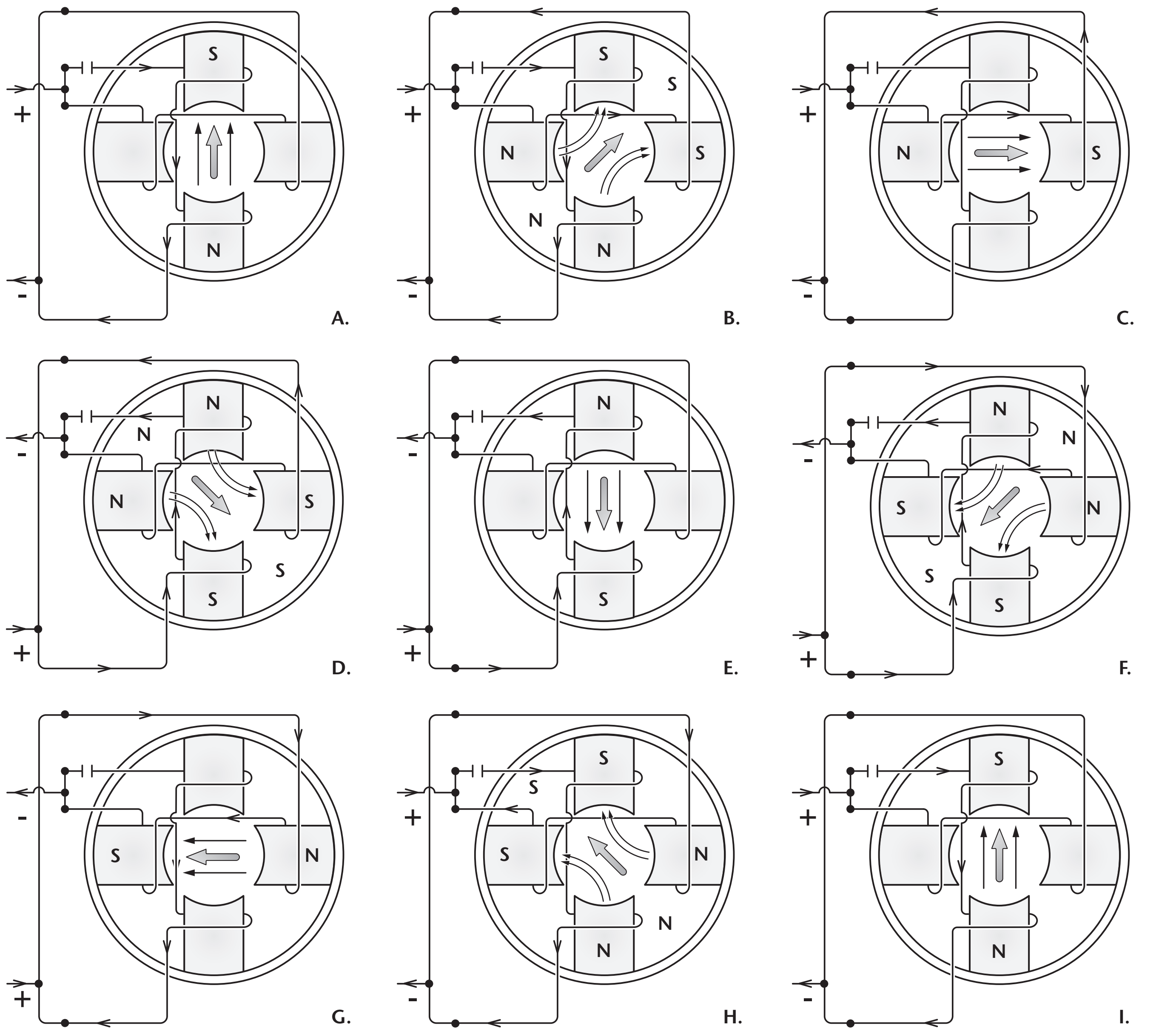


Figure 11-20-20. Four-pole, capacitor-start, induction motor, clockwise rotation.

Capacitor-start induction motors. By connecting two sets of windings, as shown in Figure 11-20-20, and a capacitor in series with one winding, a four-pole, capacitor-start induction motor is formed. Its basic operation is the same as that of the two-pole motor, except for the capacitor.

You may recall that in the discussions on capacitors, we mentioned that current leads voltage by approximately 90° when a capacitor is connected in an AC circuit. Keep this information in mind as you follow the discussion.

If an impulse of voltage were applied to the field, as shown in Figure 11-20-20A, it would actually be furnished to both coils at the same time. Since the horizontal windings have no capacitor, the current through them will lag the voltage by 90° as in any other AC coil. The capacitor, being connected in series with the vertical windings, will cause the current and voltage in this set to be in phase and, therefore, 90° ahead of the current in the horizontal windings. Actually, current will move through the vertical windings sooner than it will move through the horizontal ones. As a result, it will establish a polarity, as shown in Figure 11-20-20A. An iron bar, represented by an arrow in the drawing, takes up a vertical position in order to be parallel with the magnetic lines of force.

As the impulse of current through the vertical windings begins to die out, the one through the horizontal windings will be building up. With such a cycle going on, there will be a time when polarity in the two windings will be equal in

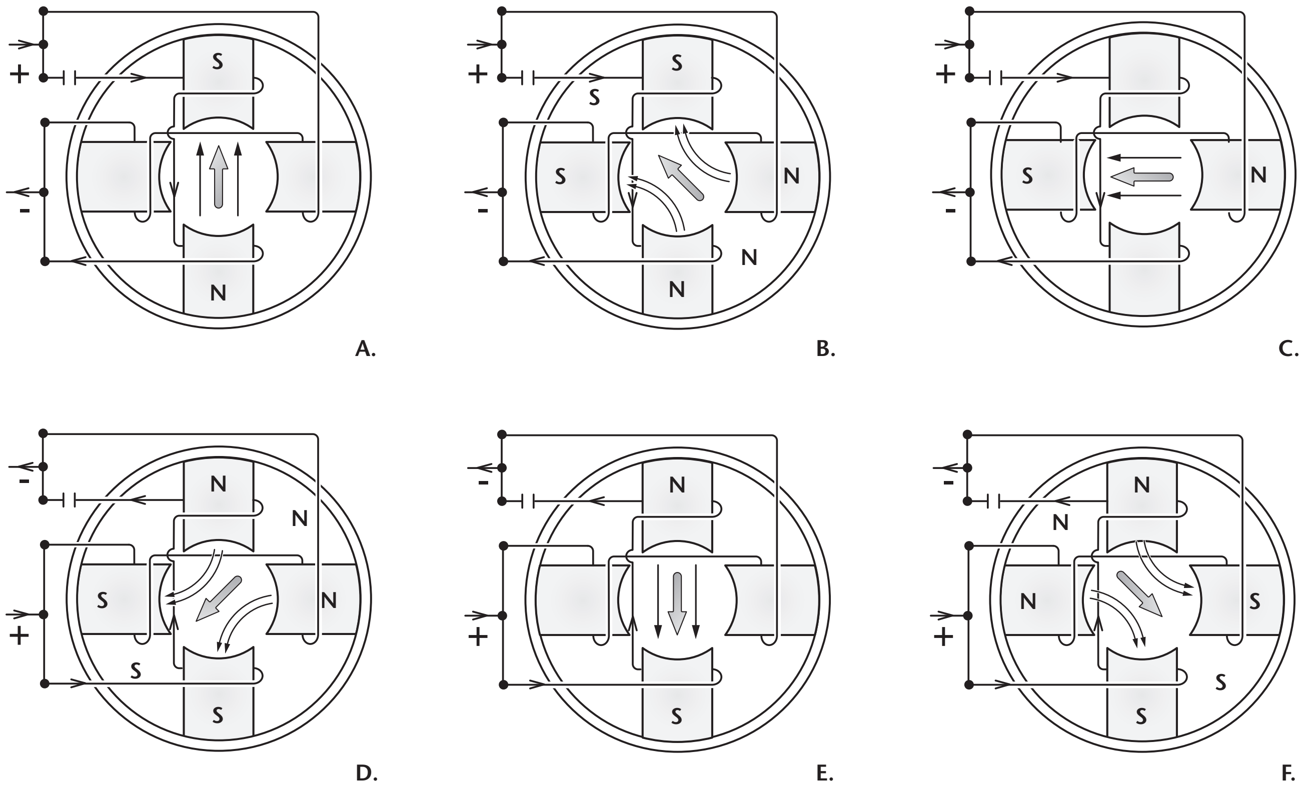


Figure 11-20-21. Four-pole, capacitor-start, induction motor, counterclockwise motion.

strength and true polarity will be halfway between. In order to remain in line with the magnetic lines of force, the iron bar will have to move 45° to the right (Figure 11-20-20B).

As the impulse of current in the vertical windings dies out, the impulse in the horizontal ones will reach a maximum, and true polarity will shift another 45°, and now the bar will be in the position shown in Figure 11-20-20C. Also, notice that the south and north poles are turning clockwise.

This rotating magnetic field is the basic principle of operation for the induction-type motor. As the impulse in the horizontal pole begins to die out, the applied voltage will change directions and a second impulse will commence to build up in the vertical windings in the opposite direction from the first one. This brings about another 45° shift (Figure 11-20-20D).

As the second impulse in the vertical windings arrives at maximum, the first impulse in the horizontal poles fades out completely. You probably have realized by now what is taking place. The polarity has traveled another 45°.

With these four changes, the iron bar has moved clockwise through 180°. As you can see, one step leads to another, which at any rate, is shown in its entirety in Figure 11-20-20. Just keep in mind these four stages:

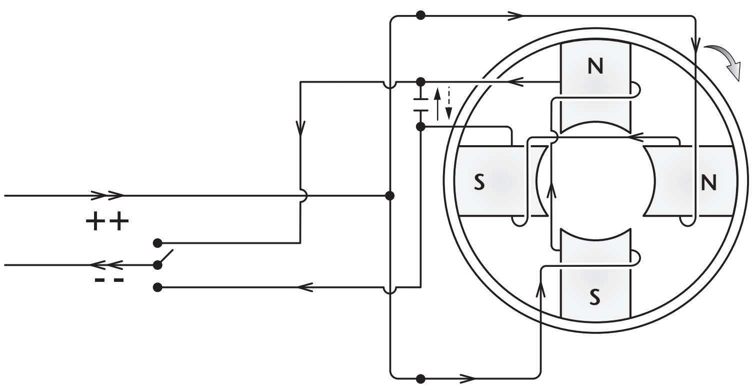


Figure 11-20-22. Induction motor.

1. When an impulse begins to decrease in the vertical windings, another starts to build up in the horizontal.
2. When it ends completely in the vertical, it is at maximum in the horizontal.
3. When the impulse in the horizontal windings commences to fade out. Another is applied to the vertical.
4. When an impulse is at its peak in the vertical windings, it disappears entirely in the horizontal. At each stage, true polarity moves 45° until the iron bar has rotated 360°. This cycle is necessary for every revolution of a four-pole, capacitor-start motor.

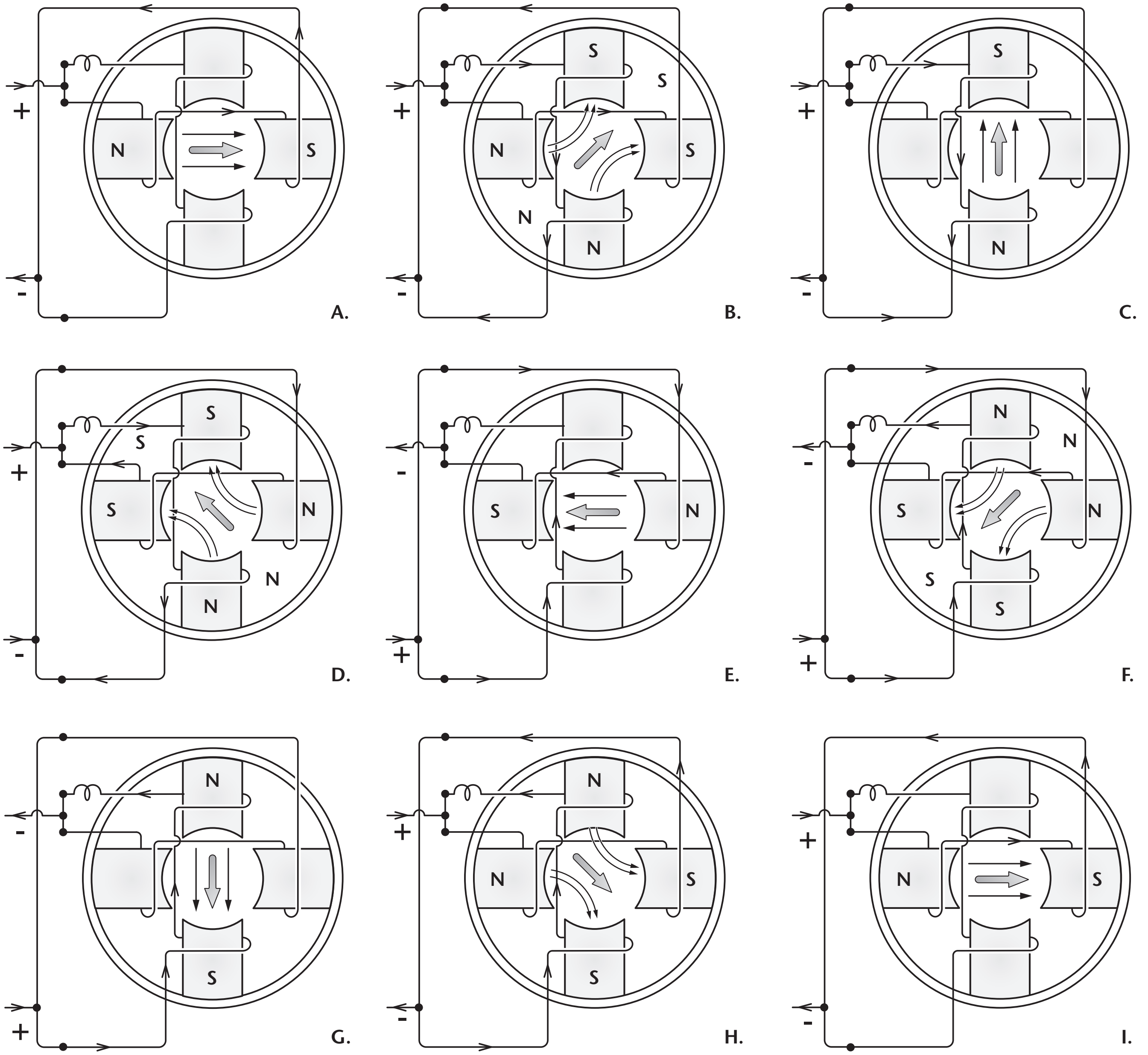


Figure 11-20-23. Coil-start induction motor, counterclockwise rotation.

In Figure 11-20-21, we have the same movement, except that it is counterclockwise. As you can see in the drawing, we merely had to change the external connections. When we did this, we reversed the direction of current in the horizontal windings and, as a result, the polarity now travels in the opposite route. After the first impulse of AC is applied to the vertical windings, we have once again the same sequence just described.

By connecting a single-pole, double-throw toggle switch, as in Figure 11-20-22, we can reverse the motor by closing the switch in one position and opening and closing it in the other. With the switch in the first position, the capacitor is connected in series with the vertical windings, in the second, with the horizontal ones. The sequence here is the same as that explained in the preceding paragraphs. Then, by using the left-hand rule for determining the polarity of a coil, when the switch is closed, you can determine the direction of rotation by following an impulse through the field windings.

Coil-start induction motors. You have learned that a coil connected in an AC circuit causes current to lag voltage by about 90°. Now we will see how this installation serves to start a four-pole motor. This motor is identical to the capacitor start, except that a coil is installed, as shown in Figure 11-20-23.

When an impulse is applied to the motor (Figure 11-20-23A), the extra coil in the vertical windings causes the current there to lag more than

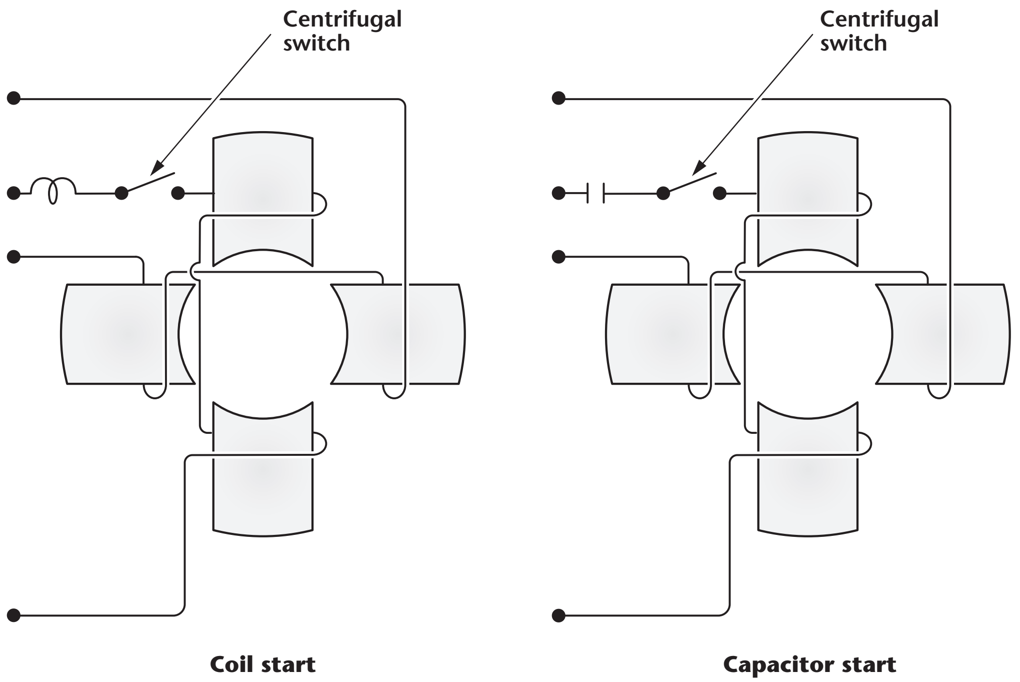


Figure 11-20-24. Four-pole stators with centrifugal switches.

it does in the horizontal windings. Therefore, the magnetic field builds up between the horizontal poles before it does between the vertical ones. In other words, the operations of the coil- and capacitor-start motors are the reverse of each other. Thus, as seen in Figure 11-20-23, the rotation is counterclockwise and the bar starts from the horizontal position.

The same series occurs as described for the capacitor-start motor; however, since we have a phase shift in the opposite sense, the last two steps in the capacitor-start sequence are the first two in the coil-start motor.

Accordingly, the first impulse goes to the horizontal windings. As it begins to die out there, it commences to build up in the vertical ones; and, of course, this results in a 45° counterclockwise polarity movement (Figure 11-20-23B). Since you should now be thoroughly familiar with the pattern, you can trace its continuation for the 360° in Figure 11-20-23 C through Figure 11-20-23I.

To reverse the direction of rotation or to control it with a switch, you follow the same procedure as for the capacitor-start motor (Figure 11-20-22).

Of the two, the capacitor-start motor is the more efficient, because the current leads the voltage, both types are manufactured in sizes up to 1/3 horsepower, and they are widely used commercially to operate items that demand a motor with a low starting torque.

Once the capacitor-start or the coil-start motors are operating, the starting fields are no longer needed. By putting a centrifugal switch in series with the starting coils, as shown in Figure 11-20-24, we can disconnect the starting windings and save on current and reduce the heat generated.

The switch is worked by flyweights mounted on the rotor shaft. As the rotor gains speed, these units move outward and open the switch. When this happens, the starting windings are disconnected. Should the motor now become overloaded, it will slow down; at this point, the flyweights return inward and close the switch. As a result, the starting windings are once again put to work. However, unless the overload is removed, they will continue to operate and the coil or capacitor will probably burn out. The centrifugal switch is set to open when the motor has reached about 75 percent of synchronous speed.

Repulsion-start induction motors. The repulsion motor, in its construction, may be thought of as a combination AC *and* DC motor. Its stator is similar to that of a single-phase induction motor, and its rotor is like that of a DC motor. It is provided with brushes that are shorted to each other but are not connected to any other part of the motor or power source.

When voltage is applied to the stator, a definite polarity is set up in the field poles (Figure 11-20-25). This magnetic force will induce a

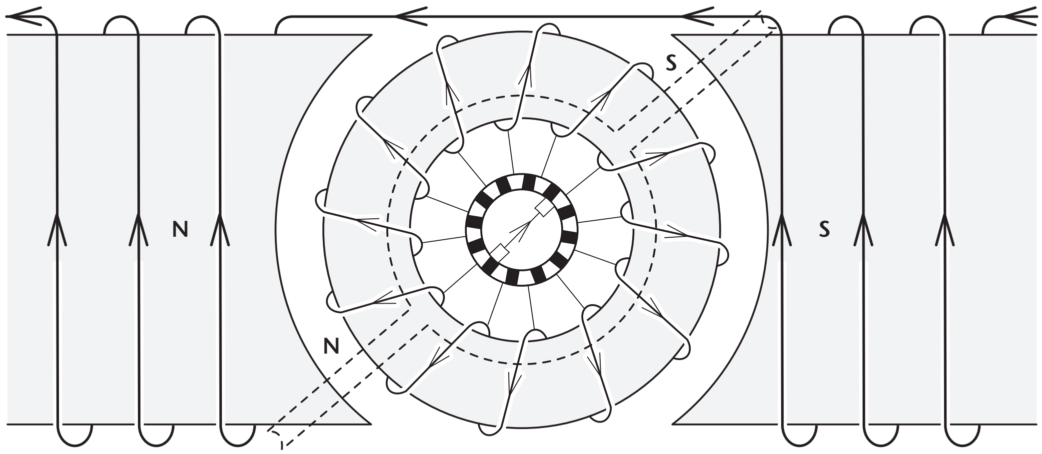


Figure 11-20-25. Repulsion-start motor schematic.

current in the rotor windings, as indicated by the arrowheads. This current will set up a polarity in the rotor that will be repelled by the field or stator. This action causes the rotor to move counterclockwise, while the polarity of the rotor remains stationary because of the commutator and brushes. In other words, as the rotor is repelled counterclockwise, its magnetic field actually moves around it in a clockwise direction and thereby remains in about the same position as before. As the current in the stator windings changes direction, so does the induced current in the rotor; the like poles will still be opposite each other and continue the repelling action. As the motor speed builds up, a set of flyweights will be put into operation. They close a short-circuiting device, which then shorts out the commutator segments and causes the motor to run as an induction motor. The rotor coil will now act the same as the copper or aluminum bars of a squirrel-cage rotor.

By shifting the brushes 90°, we can reverse the rotor polarity and run the motor clockwise.

This motor has very high starting torque and is made in sizes from 1/8 to 15 horsepower.

Repulsion-start, repulsion/induction-run motors. This motor has two separate rotor windings: the first is a squirrel cage and the second is a repulsion winding connected to a commutator by means of brushes. The motor starts in the same manner as the repulsion motor just discussed. However, since it has no device to short out the commutator segments, it will run as a repulsion motor when it approaches operating speed. In addition, the squirrel-cage windings will aid the repulsion windings once the motor starts turning. Because of the squirrel cage, this motor has constant-speed characteristics that are similar to those in the other induction motors.

You can reverse the motor by shifting the brushes. It has about the same starting torque as the capacitor-start motor and it is available in sizes ranging from 1/8 to 10 horsepower.

Universal motors. The universal motor consists of an armature and a set of field coils connected in series. It can operate either on AC or DC and has the same speed and torque characteristics as the DC series motors. In the larger capacities, it has compensating windings like the DC machines.

You reverse the universal motors just as you do the DC series wound ones: You change the connections to either the armature or the field.

These motors are seldom found on aircraft or allied work; when used, it usually is in instrument-testing devices. However, they have a wide commercial application. For example, you may come across them in electric drills, fans, and vacuum cleaners.

Two-Phase Induction Motors

The two-phase and four-pole, single-phase induction motors have the same basic construction. There are two stator windings wrapped around four stator poles, as shown in Figure 11-20-26. Note, however, that the coils are not connected together as in the single-phase motor.

Since two-phase power has four leads, we simply attach each of them to one of the coil leads. In actuality, we have then connected one phase of the power supply to one phase of the motor. As phase A of the motor begins to receive voltage from phase A of the alternator, a definite polarity is established in its poles.

An iron bar inserted in the magnetic field, just as in the single-phase, two-pole motor, would take up a position parallel to the magnetic flux. Now, by using the two-phase sine wave shown in Figure 11-20-26, you can follow the operation of the motor as each impulse of AC is applied to its respective phase winding. Figure 11-20-26B through Figure 11-20-26H show the positions the rotor assumes as the voltages are supplied.

You can see that no special devices are required to cause a rotating magnetic field in a two-phase motor. It simply follows the output of the alternator as it rotates around the stator. Since the rotor must remain in parallel with the magnetic lines of force, it trails the rotating field. Remember that this motor has a squirrel-cage rotor. The action on the bars of the rotor will be the same in multiphase motors as it was in the single-phase motors.

To change the direction of the two-phase motor, reverse the connection of either of the two phases. This will reverse polarity in one set of poles and cause the magnetic field and the rotor to rotate counterclockwise.

Single- and two-phase motors use the same formulas to determine speed and slip. These are as follows:

Speed:

$$n_s = \frac{120 \times f}{P}$$

Slip:

$$\% \text{ slip} = \frac{n_s - n}{n_s}$$

where:
n = Rated Speed
n_s = Actual Motor Speed
f = Frequency
P = Watts

Only a few two-phase motors are used in conjunction with aircraft. They serve some AC electrical instruments, but virtually no other units on an aircraft are operated by them. The majority of AC motors on aircraft are of the three-phase type.

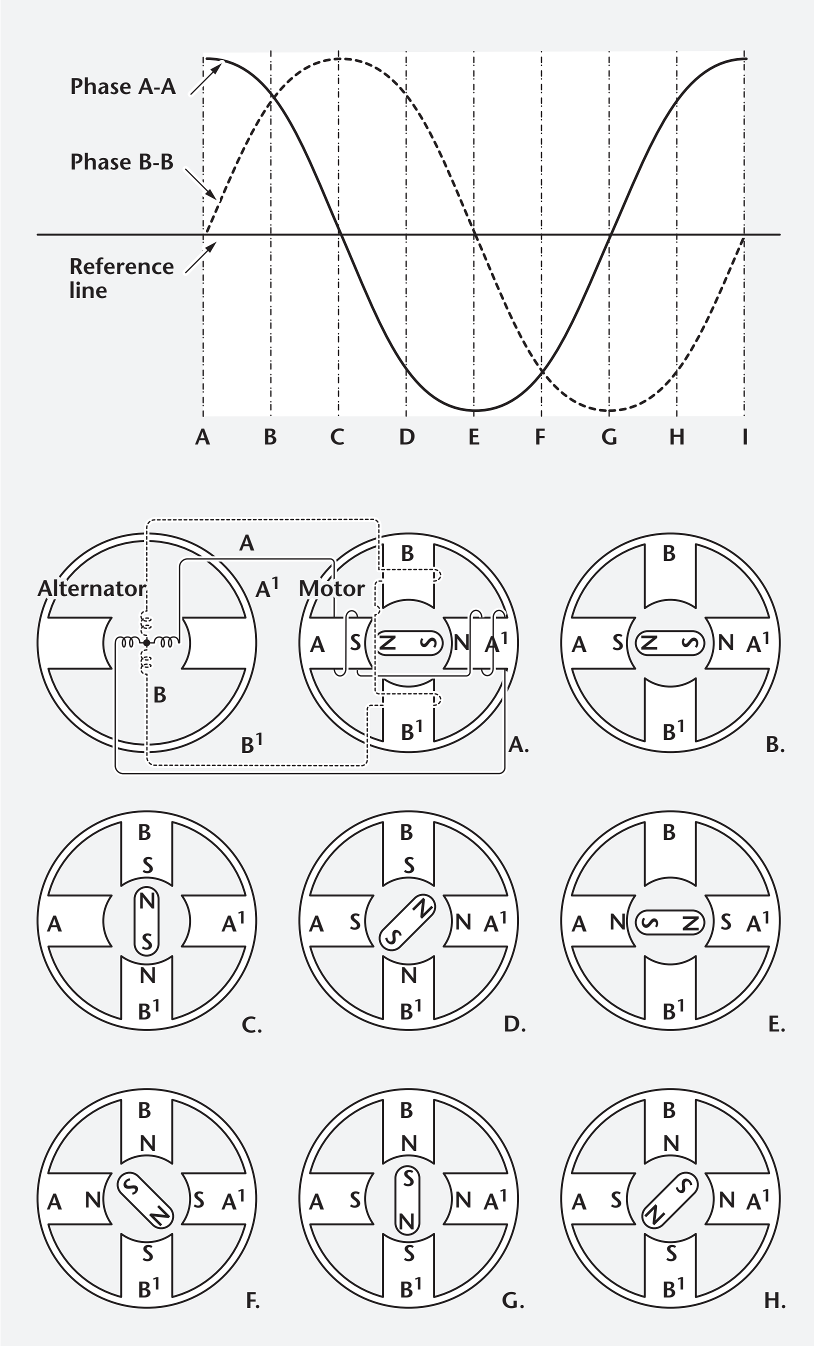


Figure 11-20-26. Operation of a two-phase induction motor.

Three-Phase Induction Motors

These motors are similar in construction and operation to the two-phase machines.

Figure 11-20-27 represents a three-phase alternator and motor connection. Although the poles of the three-phase motor are indicated as being distinct, they are, as in the case of the two-phase motors, formed coils laid into slots around the stator frame. Phase B of the alternator is connected to poles B and B^1 of the motor, and phase C with C and C^1, and phase A with A and A^1. The three leads are *star-connected* in both the alternator and the motor. With this method, only three leads have to be used between the two machines.

At the instant shown in Figure 11-20-27A, phase C of the alternator is cutting no lines of force. Therefore, it has no voltage induced. Phase A is cutting across a south pole and B, at the same rate, across part of a north pole. Phases B and A, therefore, will have equal voltages induced in them from opposite directions. Current is applied first to A and A^1 and then to B^1 and B, then back to the alternator. The resulting magnetic field is shown in Figure 11-20-27B.

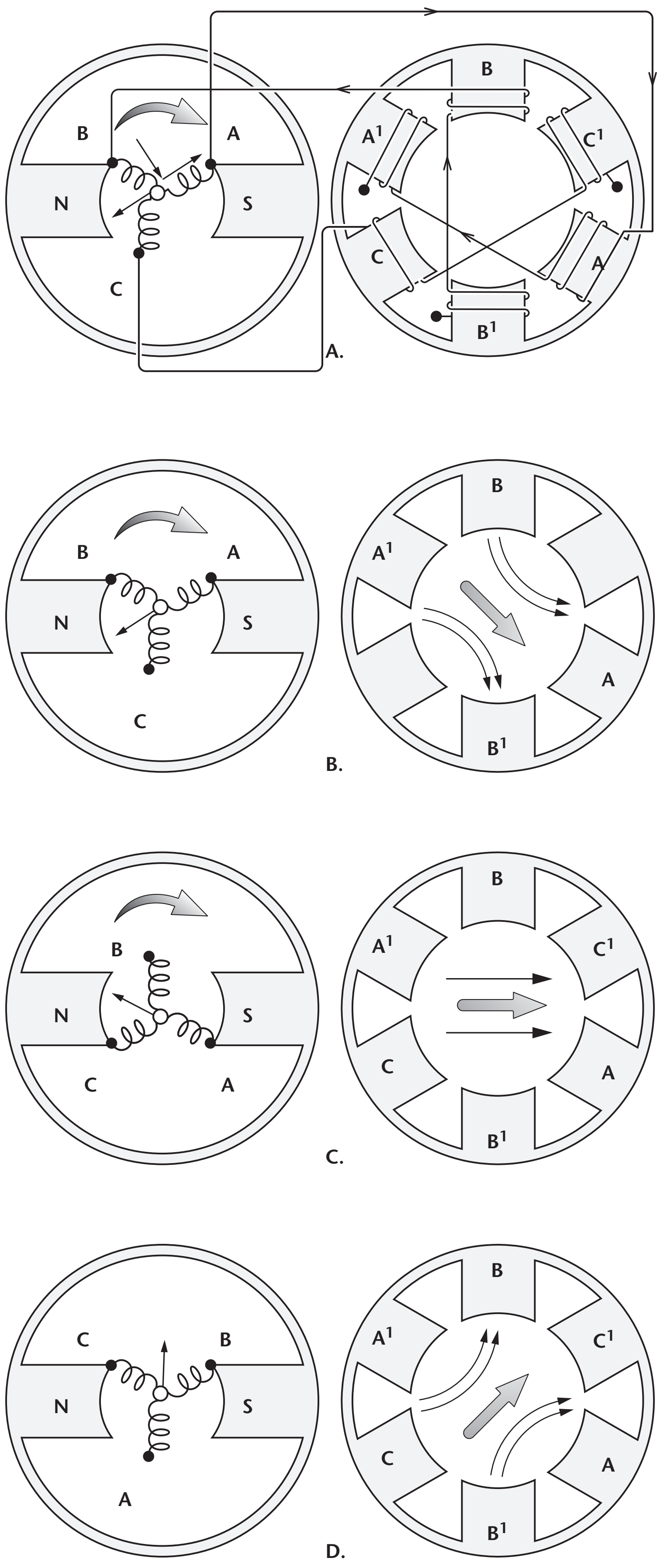


Figure 11-20-27. Three-phase induction motor and alternator.

When the rotor of the alternator has moved 60° further, phase B is no longer cutting lines of force, but phase A, which has traveled through its maximum position, still is cutting the same number as before; and this amount is equal to that of phase C, which is now out of neutral. Current continues to pass out A, around A and A^1, C and C^1 and back to the alternator. The resulting field has moved 60° counterclockwise from the original position, as shown in illustration C.

A third position of the alternator armature is illustrated in part D. Phases C and B are cutting north and south poles respectively while phase A is neutral. Current will flow out of phase B to poles B and B^1, then around C^1 and C, and return to the alternator.

From this discussion, you can see that the like phase in the motor receives the impulse produced by each phase of the alternator, and, consequently, a polarity is set up in the motor. Alternator output combines two factors; in each phase the field strength periodically increases and decreases in each half cycle.

Further, there is a time interval between the maximum field strength occurring in the separate phases so that in effect the resultant magnetic field seems to rotate in time with the rotor of the alternator. This condition establishes the rotating magnetic field, which is the principle of operation for induction-type motors. The rotor will follow this field just as it does in the single- and two-phase motors.

To reverse the motor, change any two of the three leads connected to it. In this way, you change the direction of current in two phases of the motor and cause the rotating magnetic field to move clockwise. The rotor, as before, will follow the field.

The leads can be reversed externally by means of a double-pole, double-throw toggle switch placed between any two of the three motor leads.

Some of the peculiar characteristics of the three-phase motor are as follows:

- It will run on only two phases
- It will not start on only one phase
- It will not run on only one phase
- It has a very high starting torque and great power capabilities

Although this motor will function on two phases, it will not carry a very large load, because of the loss of one-third of its full strength. The motor might start on two phases under very slight loads, but certainly not under normal loads.

Two-speed, three-phase motor. One of the more unusual three-phase, induction-type motors is the two-speed. This motor has two separate stator windings imbedded in the same frame. It is these items that make the two speeds possible.

In our discussions on speed control later in the chapter, you will discover that speed can be changed by adding or taking away poles in the stator winding. If we increase them, we decrease motor speed, because the rotor will have to take more steps to travel 360°. And the opposite also holds: fewer poles, more speed.

However, if we used this method, we would need a specially designed gang-type switch and several special connections on the motor stator, each of which is highly impractical for aircraft purposes. So what can be done?

We can build a motor with two or more stator windings, each of these having a different number of poles. The materials are right at hand; we use the housing and pole pieces of a standard three-phase AC motor. By wrapping one set of coils around all of the pole pieces, we have formed a two-speed, three-phase induction motor.

As seen in Figure 11-20-28, the stator with fewer poles would be the high-speed windings, and the one with more would be the low-speed windings. (In the diagram, the number of poles is indicated by the number of turns in each coil.) This motor is very easily controlled by means of a triple-pole, double-throw toggle switch, one side of which is connected to the high-speed windings, the other to the low-speed.

In order to change the direction of the two-speed, three-phase motor, reverse any two leads in both the high- and low-speed stator windings. If you reversed the leads of only the high-speed set, the motor would rotate in a direction opposite to that which would result from energizing the low-speed windings. Thus, if the motor were connected in this manner and then used to operate wing flaps, they would extend at one speed and retract at another.

As in the cases of the other motors, we can use a switch for reversal. This motor, however, requires two double-pole, double-throw toggle switches (Figure 11-20-29). By closing the high-low switch in HIGH and then closing the double-pole switch in the high circuit, we cause the motor to run in one direction at the greater speed.

When we reverse the position of the double-pole switch, the motor, of course, changes its rotation. The speed, however, remains the same. For low speed, close the high/low switch in LOW, and use the double-pole switch, which is connected to the low-speed windings.

Since toggle switches are rather awkward to use, a pair of relays are usually used instead.

Synchronous Motors

The basic parts of a synchronous motor are the rotor and the stator. The rotor is composed of permanent magnets or one whose poles are excited by a source of DC and whose polarity does not change; the stator consists of several pairs of poles and is excited by AC. If you compare Figures 11-20-25 and 11-20-30 you can see that a repulsion-start motor and a synchronous motor operate much the same.

In the synchronous, however, the rotor polarity is established by the furnishing of a DC source through the brushes to the rotor windings. By using a multi-pole stator, as in the three-phase induction motors, we can obtain a rotating field when poly-phase AC is applied to the stator.

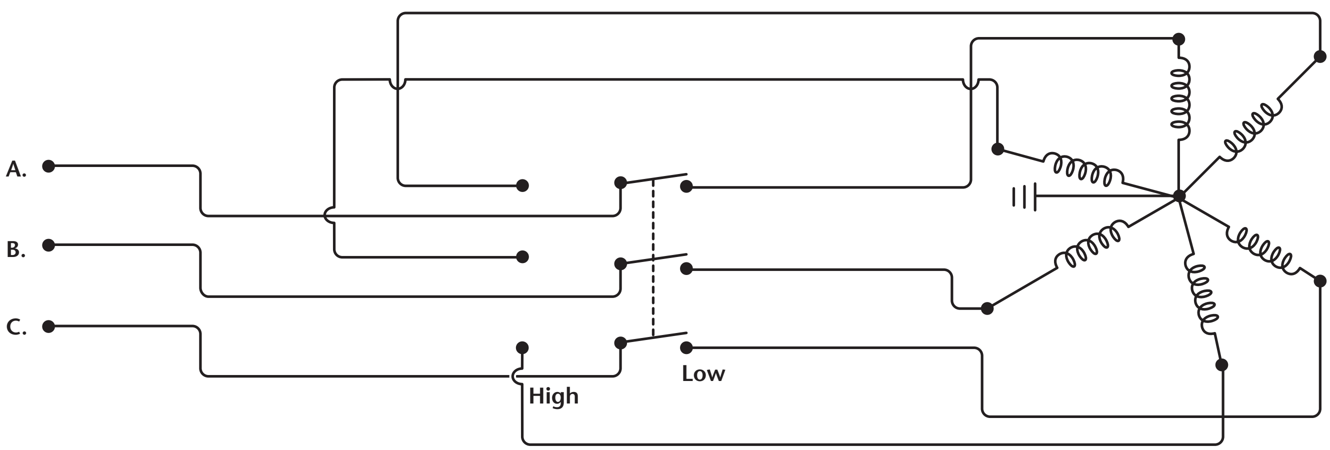


Figure 11-20-28. Two-speed, three-phase induction motor.

When DC is supplied through slip rings to the rotor windings, a fixed polarity is produced at each pole. These poles lock in step with those of the rotating field, and the rotor is pulled around as the stator magnetic field turns.

Because of the lockage, the rotor travels at the same speed as the rotating field. In other words, the rotor speed is synchronized with that of the stator field. From this design, the motors derive their name.

Now, suppose that the stator and rotor are energized at the same time. According to the laws of magnetism, the stator poles will attract the unlike poles of the rotor. If the motor is a four-pole type and draws 60-cycle current, the synchronous speed of the field will be 180° r.p.m. as soon as the field is excited. However, the rotor can't jump from a standstill to 180° r.p.m. instantly. If the rotor is brought up to a speed that is the same or nearly equal to that of the rotating field, it will lock in step and be towed around by the field at synchronous speed. The method for bringing this condition about is simple. We start synchronous motors as induction types. A squirrel-cage winding is placed upon the rotor. Then the DC field on the rotor is de-energized, and the stator is energized. When the motor comes up to an r.p.m. that is slightly less than synchronous speed, the DC field on the rotor will be excited and the lockage will occur.

To reverse a synchronous motor, we change the direction of current in the rotor, or shift the brushes as in the repulsion-start motor. In both cases, we reverse the polarity of the rotor. The synchronous type is used in a few instruments and electric clocks, but these are about the only places on aircraft where there is need for such motors.

Speed Regulation

The synchronous speed of an induction motor is the speed at which the magnetic field rotates. It depends upon the number of poles for which the stator is wound and the frequency of the applied voltage.

Even at no-load, an induction motor will not reach synchronous speed because there must be a difference in relative speed between the stator field and the rotor in order for induction to take place. It is only attained by synchronous motors with DC excited rotors. Before we proceed, you have to learn two formulas — the first is for synchronous speed and the other is for slip, which is the difference between the speed of the rotating field and the rotor. This formula begins where the first formula leaves off. These two formulas were introduced in the section on two-phase induction motors.

This value varies from 4-8.5 percent at full load for motors of from 1-75 horsepower. At two to four times its normal rated load, an AC induction motor may be expected to stall. The reason is breakdown torque, the point at which the rotor is so heavily overloaded that the magnetic field no longer has enough strength to turn the rotor. When this occurs, not only will the rotor stall, but the stator also will overheat in the same manner as an overloaded transformer. Needless to say, this condition is dangerous. For safety, then, always be sure that maximum load limits for an induction motor are never surpassed.

Obviously, speed regulation is an important consideration. Unfortunately, however, once an AC motor is designed, there are no efficient methods by which we can change its speed. In

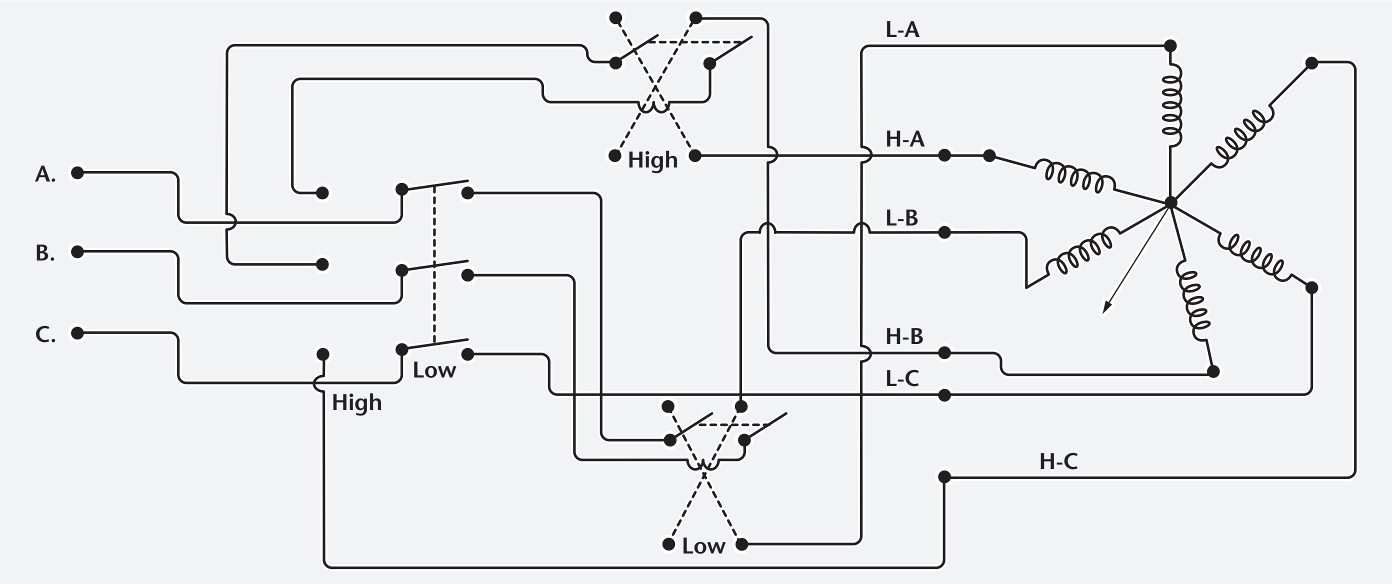


Figure 11-20-29. Two-speed, three-phase induction motor, reversed.

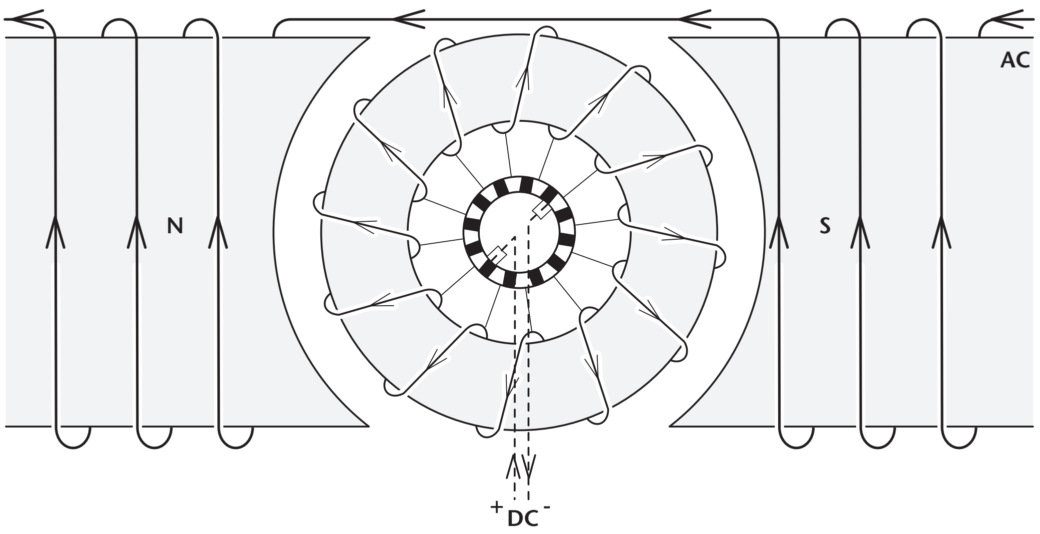


Figure 11-20-30. Synchronous motor schematic.

small motors, like the shaded-pole, we can control the speed by regulating the applied voltage. But this method will not do for large motors.

Another method is to vary the frequency of the applied voltage. The change in speed is affected by altering the frequency of the supply, because the speed of induction motors is equal to the frequency of the supply, divided by the number of poles in each phase. The objection here, though, is that a separate alternator would be needed to operate each motor.

A third way to alter speed is to vary the number of poles per phase. You already know that the speed of the revolving field is one of the factors that controls rotor speed. Therefore, by adding more poles, the speed of this field can be reduced. In turn, the rotor slows down. In simple terms, we might compare the movement of the rotating field around the motor housing to a man walking in a circle. The field poles are like the steps taken by the man. By increasing the poles (steps), we decrease the speed of rotation. This method is sometimes used in two- and three-speed motors. Here too, it is not always satisfactory, for it gives only change in speed and not a gradual speed control.

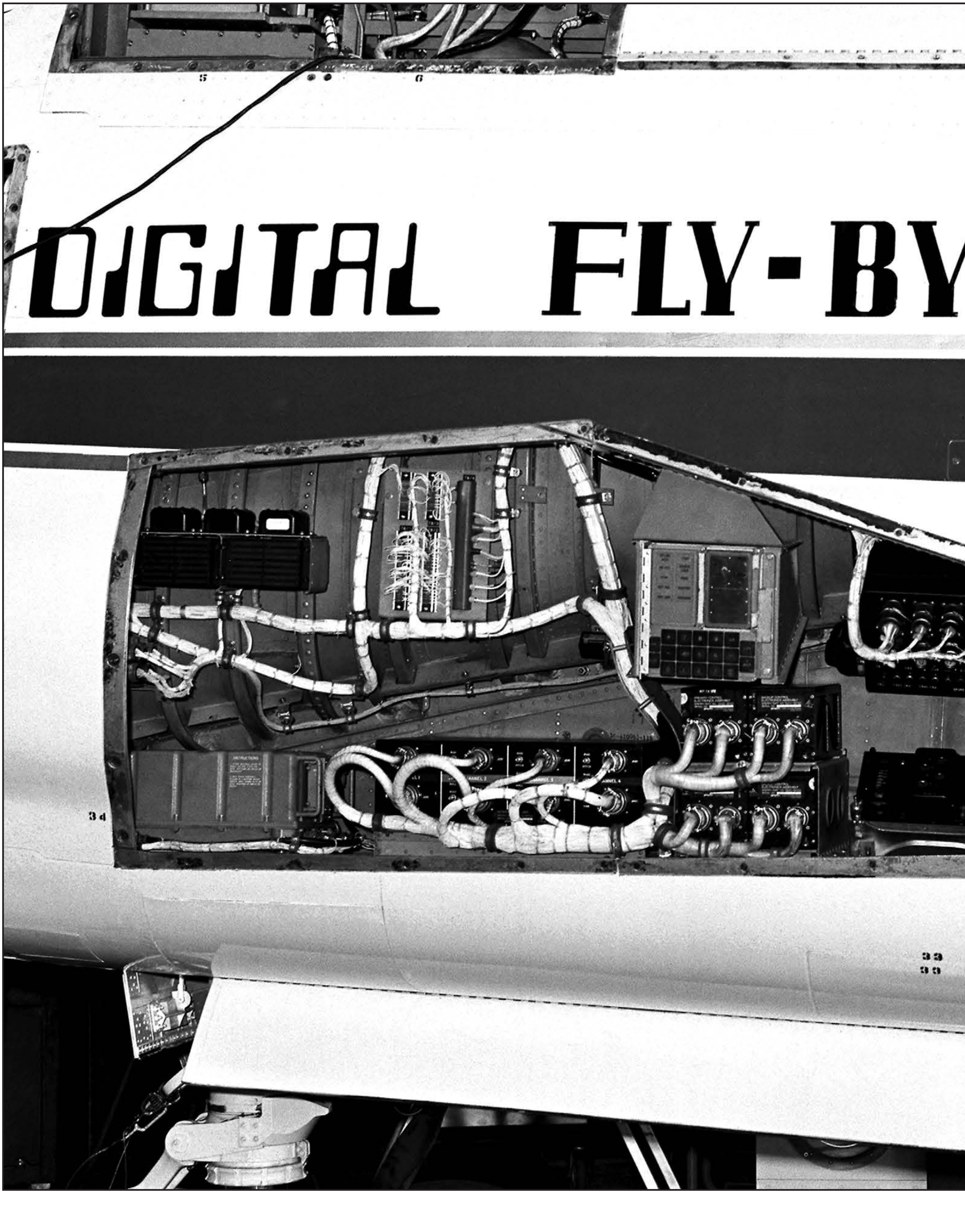
The speed of induction motors with wound rotors can be varied in two ways. The first is by inserting resistances in series with the rotor windings. When we do this, we increase slip and thereby reduce the motor speed. The speed will then vary with the load, but not by very much. There is also the complication of having to make an adjustment every time there is a load change on the motor.

The second method involves the introduction of a foreign voltage. If it is in opposition to that which is induced in the rotor, it cuts down the speed; if it is in the same direction, it raises the speed. Of all the methods discussed, this one is the most practical, for with it we can obtain a wide variety of speed regulation without wasting any power.

Overhaul

After a motor has been removed, it should be bench-checked. Too many pieces of electrical equipment are sent to repair stations and come back marked NFF (No Fault Found).

Because AC motors have no brushes, there isn't much of an inspection process. Besides bearings, most defects come from a problem with the operating environment. Before sending a pact out, make sure that you have fully troubleshot the system. Most smaller shops do not have the testing facilities for AC motors. Generally, it is best to send them to a certified repair station for overhaul.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12

Binary Logic

Section 1

Introduction to Binary Logic

The objective of this chapter is to provide a solid foundation in binary logic theory so that the student will be prepared to understand and apply this knowledge in the study of the aircraft maintenance technician curriculum and in the maintenance of actual aircraft systems. Solid state binary digital devices are used in many of the systems typically found on aircraft. Simple instruments, warning lights, annunciator panels, fuel controllers, flight instruments, and autopilots are just a few examples of their use.

Other functions within an aircraft, even those functions that contain no digital devices at all, can be analyzed as binary functions. Consequentially, maintenance manuals (MM) and training manuals frequently use binary schematics to explain the logical processes within a system. To maintain modern aircraft, it is absolutely essential that the aviation maintenance technician has an understanding of binary functions and the logic of their operation. This chapter will provide the foundation for that understanding.

Before discussing binary logic, it is useful to introduce a few basic concepts, which will be used as defined below.

Function. The action a component, or set of components, is designed to perform.

State. A configuration or set of circumstances that characterizes a function.

System. A set of components or functions that are assembled to perform some larger function.

Learning Objectives

DESCRIBE
- Binary numbers
- Binary logic basic concepts, function and operators

EXPLAIN
- Combinations of logical operators
- Troubleshooting basic theory and concepts
- Binary logic and its basic operations

Left. The NASA proof of concept airplane for digital fly-by-wire concept is an excellent example of where applied Binary Logic Troubleshooting would apply. This process is used to develop the written troubleshooting guides found in system maintenance manuals. It is also the only real method to use when something outside of the manual's charts develops.

Binary. A function or system that has only two states and always is in one or the other of these two states.

Logic. The science and study of the principles of correct reasoning. It is the study of what is expected from known cause and effect relationships.

Binary States

There are many functions within physical systems, as well as within social systems, that can be in only one of two possible states or configurations. These possible states usually are referred to by terms such as "high/low," "on/off," "yes/no," or "true/false." Such items that offer only two choices are called binary functions. For example, a simple light switch performs a binary function. It always exists in one of two possible binary states: ON or OFF. The number "1" frequently is used to designate the positive binary state (high, on, yes, or true) and the number "0" is used to designate the inverse binary state (low, off, no, or false).

The binary state of a function often is determined by its relationship to a reference standard. For example, the output of an electronic device usually is evaluated as being in the HIGH state or LOW state relative to a reference voltage. More specifically, the device might be in its HIGH state if the input voltage is five volts or higher and in its LOW state if the voltage is less than five volts.

Logic Gates

Logic gates are electronic devices that perform specific binary functions. These devices can be combined on small, lightweight silicon chips to provide highly accurate, dependable control and calculation functions ranging from simple instruments to complex electronic flight control systems and digital processors. Such devices are used throughout modern aircraft. Although each logic gate produces a binary output, they frequently are arranged in arrays such that there may be eight, sixteen, or more digital outputs from the array. However, it is important to remember that the output from each individual logic gate in the array still is a binary function.

Logical Operators

A common mistake is to assume that only electronic logic gates are involved in binary operations. Other types of devices perform many of the functions within an aircraft system, but they, too, only perform a few basic logical operations in which the output consistently changes to one of two possible logical states as compared to a specified reference standard.

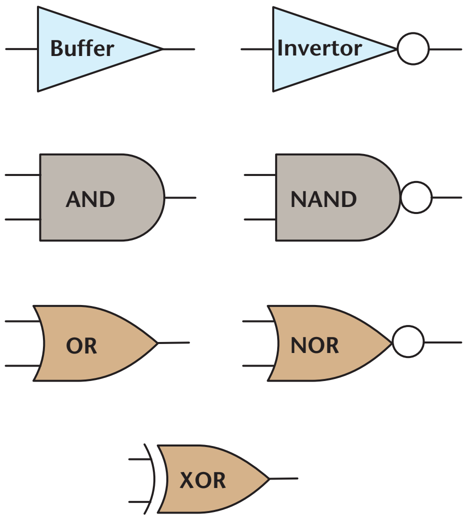


Figure 12-1-1. Basic logical operators.

Each binary function is designed such that there is a logical relationship between its input and the resultant output. For example, in a simple light circuit, if the switch is in the ON (closed) position, the resultant output is an illuminated light. If the switch is not in the ON position, the light is not illuminated. There is a direct logical relationship between the input (the switch) and the output (the light). That relationship is called the logical operator of that circuit. The physical appearance of a solid state logic gate looks nothing at all like this electrical light circuit, but, as described below, the logical operator of a certain type of logic gate is exactly the same as that of the light circuit. If the input to the gate (in this case, a voltage) is sufficient, there is a specific output from the gate. Otherwise, there is not a sufficient output.

As previously discussed, various terms such as high/low, yes/no, and true/false are used to describe the logical states of a function, depending upon its application. For simplicity, the term HIGH will be used herein when referring to inputs and outputs that meet design specifications, and LOW will be used when referring to an input or output that does not meet design specifications. A HIGH input or output will be indicated by a "1," and a LOW input or output will be indicated by a "0." The other terms are used elsewhere in other applications when more appropriate. The logic is the same regardless of the terms used.

There are seven basic types of logical operators. Many other types of logical operation can be achieved by combining these basic types as needed to achieve the desired logic.

Logical Operator Symbols

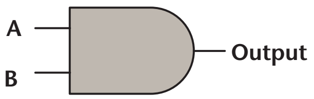
A standard symbol exists for each of the basic logical operators, as shown in Figure 12-1-1. Each will be introduced and discussed in this chapter.

Since the application of logical operators is so universal, many MMs and training manuals present logical operator symbol schematics for various systems. Such a schematic enables the technician to understand the processes of the system (how it works) by simply examining its logic. Such schematics are extremely useful when troubleshooting the system. Obviously, the technician must be able to recognize each symbol and understand the logic that the symbol represents.

Truth Tables

A standard method also exists for displaying the logic of a specific function or system. It consists of a table that lists each possible combination of input states and the resultant output state. Figure 12-1-2 shows two versions of such a table for a type of basic logical operator that has two binary inputs and one binary output. Since there are two inputs, there are four (2 × 2) possible combinations of input states as shown. Each such table that lists all possible combinations of inputs and resultant outputs for a specific function is called a truth table. This name comes from its historic use in formal logic. The most universal terminology in analyzing any logic problem is to answer the question: Is it true or is it false? This applies to verbal and written statements, to the design criteria of aircraft systems, and to anything else that is to be analyzed.

When analyzing a verbal statement, one determines whether the statement is in fact true or false. When analyzing an aircraft system, one determines whether it is true that the input meets the design specification and whether it is true that the resultant output meets the design specification. Frequently, truth tables use "T" and "F" to indicate TRUE and FALSE as indicated in the first table in Figure 12-1-2. In the analysis of technical systems, the numbers "1" and "0" frequently are used as depicted in the second table in Figure 12-1-2 and are interpreted as HIGH and LOW instead of as TRUE and FALSE. The logic is the same regardless of the terminology used. In the illustrations that follow, the terms HIGH and LOW will be used and will be designated by 1 and 0 respectively.



A	B	Output
T	T	T
T	F	F
F	T	F
F	F	F

A	B	Output
1	1	1
1	0	0
0	1	0
0	0	0

Figure 12-1-2. Truth tables.

Although many functions are performed within each aircraft system, each of these functions performs in accordance with the seven basic logical operators, which are combined to form the logic of the respective system. These basic logical operators are as follows.

The Buffer or YES Logical Operator

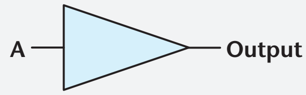
The most basic logical operator is the BUFFER or YES operator. Its logical rule, in terms of its input, is as follows:

If, and only if, the input to the function is HIGH, the output from the function is HIGH. Otherwise, the output from the function is LOW.

The rule, stated in terms of its output, is:

The output will be HIGH if, and only if, the input is HIGH. Otherwise, the output will be LOW.

The symbol for the BUFFER operator and the truth table for this operator are shown in Figure 12-1-3. The logic of the BUFFER logical operator is the same as that of the simple electrical circuit previously discussed and now shown in Figure 12-1-3. Assuming no fault in the circuit, if the switch is closed, the light is illuminated. If the switch is open, the light in not illuminated. In more general terms, if the input is HIGH, then the output is HIGH; if the input is LOW, then the output is LOW.



A	Output
1	1
0	0

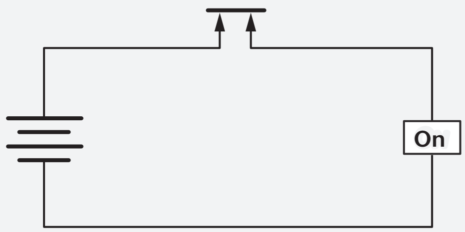
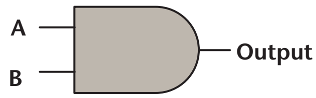


Figure 12-1-3. Buffer logical operator.



A	B	Output
1	1	1
1	0	0
0	1	0
0	0	0

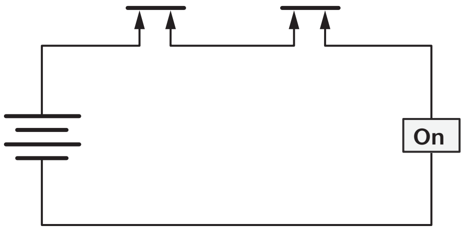
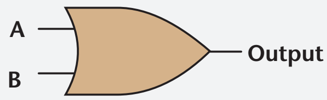


Figure 12-1-4. AND logical operator.



A	B	Output
1	1	1
1	0	1
0	1	1
0	0	0

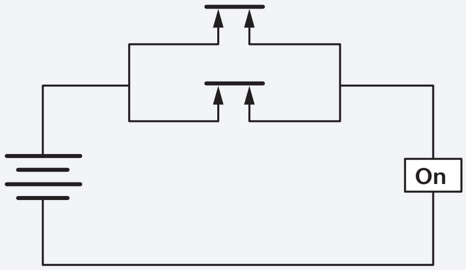


Figure 12-1-5. OR logical operator.

Although simple in its logical operation of merely transferring the input to the output, logic gates of this type are quite useful. In some cases, they are used to act simply as a "buffer" between the output of one function and the input to another. In other cases, they provide a "fan out" function. The output from other types of logic gates are limited in the number of inputs they can feed into the next set of logic gates. When more feeds are required than the output of one of these gates can support, a BUFFER gate is inserted which can "fan out" its output to many more functions than the other gate can provide.

The AND Logical Operator

The AND logical operator conforms to the following rule in terms of its inputs:

If, and only if, all inputs are HIGH, then the output is HIGH. Otherwise, the output is LOW.

In terms of the output, the rule is:

The output will be HIGH if, and only if, all inputs are HIGH. Otherwise the output will be LOW.

The truth table and the symbol for the AND logical operator are shown in Figure 12-1-4. Both are shown with only two inputs, but additional inputs are possible. The rule remains the same regardless of the number of inputs: the output will be HIGH if, and only if, all inputs are HIGH.

The electrical circuit shown in Figure 12-1-4 illustrates the AND logical operator with two inputs. If the left switch AND the right switch are both closed, the light illuminates. Otherwise, the light is not illuminated. If more than two switches were in series within the circuit, all of them would have to be closed before the light would illuminate.

The OR Logical Operator

The rule for the OR logical operator, stated in terms of its inputs, is:

If, and only if, one or more of the inputs is HIGH, then the output is HIGH. Otherwise, the output is LOW.

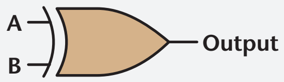
Stated in terms of the output, the rule is:

The output will be HIGH if, and only if, at least one of the inputs is HIGH. Otherwise the output will be LOW.

The symbol for the logical OR operator and its truth table are shown in Figure 12-1-5.

The electrical circuit shown in Figure 12-1-5 illustrates the OR logical operator. If either switch is closed, the light will illuminate. Otherwise, the light is not illuminated.

Note the logical difference between the AND operator and the OR operator. The AND operator requires all inputs to be HIGH for a HIGH output. The OR operator only requires one input to be HIGH to obtain a HIGH output.



A	B	Output
1	1	0
1	0	1
0	1	1
0	0	0

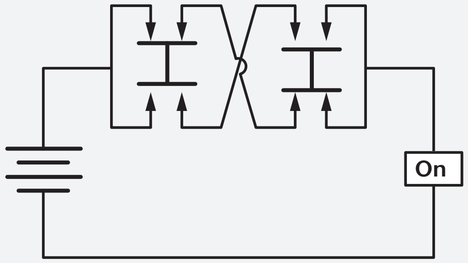
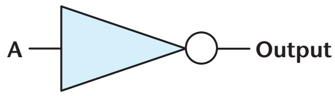


Figure 12-1-6. XOR logical operator.



A	Output
1	0
0	1

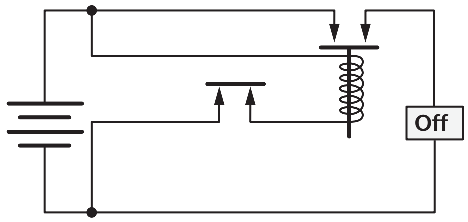


Figure 12-1-7. INVERTER logical operator.

The XOR (EXCLUSIVE OR) Logical Operator

The rule for the XOR (Exclusive OR) logical operator, stated in terms of its inputs is:

If one, but not both, of the inputs is HIGH, then the output is HIGH. Otherwise, the output is LOW. If both inputs are HIGH, the output is LOW.

Stated in terms of the output, the rule is:

The output will be HIGH if, and only if, one of the inputs is HIGH and the other input is not HIGH. Otherwise the output will be LOW.

The symbol for the XOR logical operator and its truth table are shown in Figure 12-1-6.

The electrical circuit shown in Figure 12-1-6 illustrates the XOR logical operator. If either switch is in the DOWN position, which closes the top portion of the switch and opens the bottom portion, and the other switch is not in the DOWN position, the light will illuminate. If both switches are either in the UP or DOWN position, the light will not illuminate.

Inverse Logical Operators

For each logical operator discussed thus far, a HIGH output occurs if, and only if, certain specified input conditions occur; otherwise the output is LOW. Logical operators also exist whose logic is the inverse of the BUFFER, AND, and OR operators. In these cases, a LOW output occurs if, and only if, similar specified input conditions occur; otherwise the output is HIGH. Such inverse logical operations are used extensively in the design of logic gate arrays. One example of this logic is in the design of annunciators and warning lights, which are designed to remain off when the inputs from the system being monitored are normal (HIGH) and illuminated only if the inputs from the system are not normal (LOW). Once again, it is essential that the aviation maintenance technician understands the logic of these functions and how to apply this knowledge to analyze and troubleshoot the systems that use them.

The INVERTER or NOT Logical Operator

The INVERTER logical operator is the inverse of the BUFFER or YES operator. In other words, it inverts the output from each input.

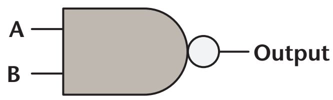
The rule for the INVERTER operator, stated in terms of its input is:

If, and only if, the input is HIGH, then the output is LOW. Otherwise, the output is HIGH.

Stated in terms of the output, the rule is:

The output will be LOW if, and only if, the input is HIGH. Otherwise, the output will be HIGH.

The symbol and the truth table for the INVERTER logical operator are shown in Figure 12-1-7. Note that the symbol is the same as for the BUFFER operator with the addition of a circle at its output. This circle is used to indicate that it is the inverse of the BUFFER operator. Each of the inverse operators will have a similar circle at its output.



A	B	Output
1	1	0
1	0	1
0	1	1
0	0	1

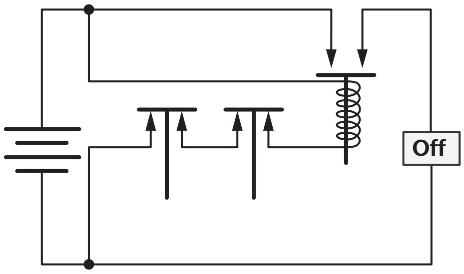
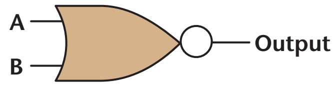


Figure 12-1-8. NAND logical operator.



A	B	Output
1	1	0
1	0	0
0	1	0
0	0	1

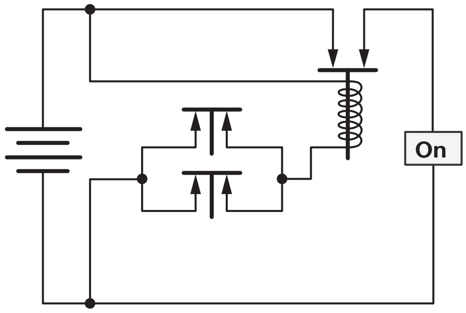


Figure 12-1-9. NOR logical operator.

The electrical circuit in Figure 12-1-7 illustrates the logic of the INVERTER logical operator. If the switch is closed, the normally closed relay is opened and the light is not illuminated. Otherwise, the light is illuminated.

The NAND (NOT AND) Logical Operator

The NAND logical operator is the inverse of the AND operator. Its rule, in terms of its inputs is:

If, and only if, all inputs are HIGH, then the output is LOW. Otherwise, the output is HIGH.

In terms of the its output, the rule is:

The output will be LOW if, and only if, all inputs are HIGH. Otherwise, the output will be HIGH.

The truth table and the symbol for the NAND logical operator are shown in Figure 12-1-8. The NAND symbol is the same as the AND symbol with the circle added to denote that its logic is the inverse of the AND operator. As with the AND operator, this symbol is shown with only two inputs, but additional inputs are possible. The rule remains the same regardless of the number of inputs: the output will be LOW if, and only if, all inputs are HIGH.

The electrical circuit shown in Figure 12-1-8 illustrates the logic of a NAND operator. Note that if the left switch and the right switch are both closed, the normally closed relay will open and the light will not be illuminated. Otherwise the light will be illuminated. The logic would be the same if additional switches were added in series.

The NOR (NOT OR) Logical Operator

The NOR logical operator is the inverse of the OR operator. Its rule, stated in terms of its inputs is:

If, and only if, one or more input is HIGH, then the output is LOW. Otherwise, the output is HIGH.

Stated in terms of the output, the rule is:

The output will be LOW if, and only if, at least one input is HIGH. Otherwise the output will be HIGH.

The truth table and the symbol for the NOR logical operator are shown in Figure 12-1-9. Once again, the symbol is the same as its counterpart, the OR symbol, with a circle added to denote that it is the inverse of the OR logical operator.

The electrical circuit shown in Figure 12-1-9 illustrates a logical NOR operation. If either switch is closed, the normally closed relay will open and the light will not be illuminated. Otherwise the light will be illuminated.

Section 2

Combinations of Logical Operators

Any of the seven basic logical operators can be combined with an INVERTER operator to obtain its inverse as illustrated in Figure 12-2-1.

Selections from the seven basic logical operators also can be combined to obtain additional logical operations. For example, one might need a gate array with two inputs and with logic such that a HIGH output occurs only when Input A is LOW and Input B is HIGH as depicted in the truth table shown in Figure 12-2-2. One solution would be to connect an XOR gate and an AND gate as shown in Figure 12-2-3. The student should complete the *combo* truth table to verify that this arrangement does meet the design requirement.

As a learning exercise, the student also should determine whether the desired logical outputs would occur if the positions of the XOR gate and the AND gate were swapped.

As the number of inputs increase, the number of possible combinations of inputs increases exponentially at a rate of 2^x where x is the number of inputs. As previously noted, if there are two inputs, then four (2^2) combinations must be examined.

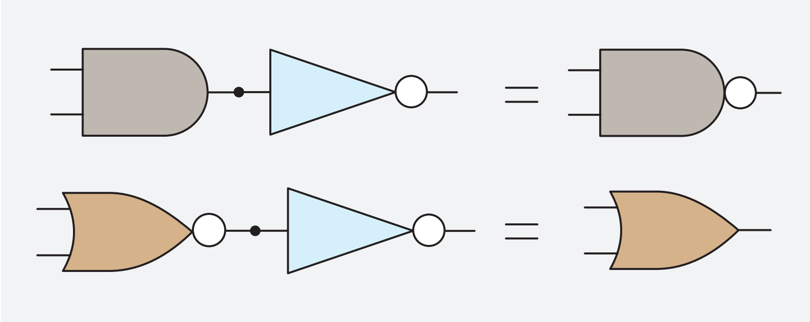


Figure 12-2-1. Logical operators combined with INVERTER operator.

A system with four inputs, as illustrated in Figure 12-2-4, has sixteen (2^4) combinations of inputs that must be considered.

Figure 12-2-5 is the truth table for this system. The student should work through these combinations of inputs for practice and to verify the accuracy of the table.

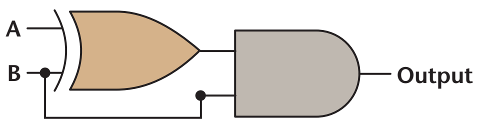
Combo

A	B	Output
1	1	0
1	0	0
0	1	1
0	0	0

Figure 12-2-2. Combo truth table.

Application to Aircraft Systems

Control devices, computer processors, and such that are composed of arrays of logic gates are designed in accordance with the logical operators of the various logic gates. The logical processes of these devices are obvious. However, it may not be so obvious that the other functions within aircraft systems also perform in a similar logical manner. The following example illustrates this reasoning.



XOR

A	B	Output
1	1	0
1	0	1
0	1	1
0	0	0

AND

A	B	Output
1	1	1
1	0	0
0	1	0
0	0	0

Combo

A	B	Output
1	1	
1	0	
0	1	
0	0	

Figure 12-2-3. Connection of XOR gate and an AND.

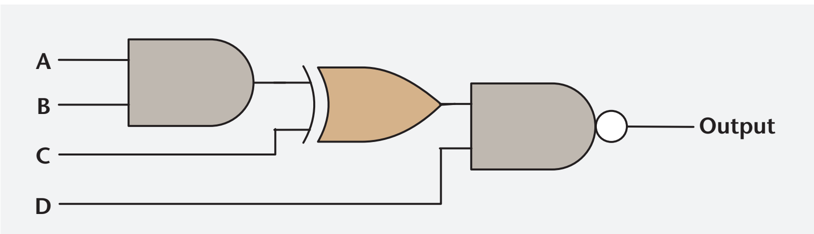


Figure 12-2-4. A system with four inputs.

A	B	C	D	Output
1	1	1	1	1
1	1	1	0	1
1	1	0	1	0
1	1	0	0	1
1	0	1	1	0
1	0	1	0	1
1	0	0	1	1
1	0	0	0	1
0	1	1	1	0
0	1	1	0	1
0	1	0	1	1
0	1	0	0	1
0	0	1	1	0
0	0	1	0	1
0	0	0	1	1
0	0	0	0	1

Figure 12-2-5. Truth table for system in Figure 12-2-4.

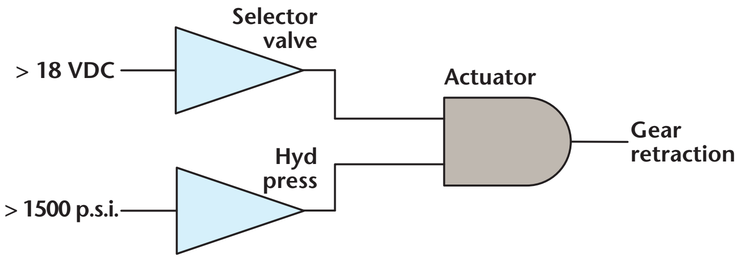


Figure 12-2-6. Simplified schematic of landing gear operation.

10^8	10^7	10^6	10^5	10^4	10^3	10^2	10^1	10^0

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Figure 12-3-1. Base 10 decimal system, Base 2 binary system.

If sufficient (HIGH) hydraulic pressure is applied to the UP side of a landing gear actuator, it will move to its UP position (its output is HIGH). The logic of the actuator is that of a simple BUFFER logical operator. Assume that the operation of the landing gear requires sufficient hydraulic pressure to move the actuator and sufficient electrical power to a selector valve to direct the hydraulic pressure to the actuator. Then the function of retracting the landing gear has an AND logical operation. Figure 12-2-6 uses logical operators to illustrate a simplified schematic of this landing gear operation. If sufficient electrical power is applied to the selector valve AND sufficient hydraulic pressure is available, then the landing gear will retract. Otherwise, the landing gear will not retract. It should be noted that if the electrical power is HIGH and the hydraulic pressure is HIGH and the landing gear fails to retract, a malfunction has occurred. Application of logical operators to the analysis of aircraft systems will be covered in detail in the *Troubleshooting* section of this chapter.

Section 3

Binary Numbers

Any number consists of one or more individual digits. In our normal Base 10 decimal system, a digit can be in any one of 10 possible states: 0, 1, 2, 3, 4, 5, 6, 7, 8, or 9. All numbers in this system, regardless of size, are made up of combinations of digits in these ten states. This Base 10 decimal system is the numerical language and logic of conventional counting and computation, but other number systems exist that are more useful in specialized cases. The most basic number system is the Base 2 binary system, consisting of only two digits. It is the system used internally in all digital applications. The Base 8 octal number system, consisting of 8 digits, and the Base 16 hexadecimal number system, consisting of 16 digits, are quite useful in interfacing between the human operator and these digital devices.

In any number system, a specific number is constructed by assigning digits to place positions. Each place value is determined by its relative position within the number. The place value at the rightmost position represents the base raised to the zero power, as shown in Figure 12-3-1 for the Base 10 decimal system and for the Base 2 binary system.

Proceeding from right to left, the place value at each position represents the base raised to the next power: x^0, x^1, x^2, x^3, etc. Using Figure 12-3-2 for reference, and recalling that $x^0 = 1$ for any number greater than 0, one can verify that the number 11,011 in the Base 10 decimal system actually is a summation of place values as follows:

$1 \times 10^0 = 1$
$1 \times 10^1 = 10$
$0 \times 10^2 = 0$
$1 \times 10^3 = 1{,}000$
$1 \times 10^4 = 10{,}000$
Total = 11,011

In a similar manner, the same number 11011 in the Base 2 binary system can be converted to its Base 10 decimal value by calculating the decimal value at each place position, from right to left, and then summing the results:

$1 \times 2^0 = 1$
$1 \times 2^1 = 2$
$0 \times 2^2 = 0$
$1 \times 2^3 = 8$
$1 \times 2^4 = 16$
Total = 27

Since each consecutive place position, from right to left, raises its Base 2 binary place value to the next higher power of 2, one can simply multiply any place value by 2 to obtain the Base 10 decimal place value of the next place position to the left or divide the place value by 2 to obtain the next decimal place value to the right, as shown in Figure 12-3-3. For example, for the binary number 11011, the Base 10 decimal place values, as summed from right to left, still are 1 + 2 + 0 + 8 + 16 = 27. For practice to increase understanding, the student should perform the same calculations, but proceed from left to right instead of from right to left and verify that the results are the same.

Bits

In the binary number system, the digit in each place position is called a bit. Since the rightmost bit has the lowest value, it is referred to as the least significant bit, and the leftmost bit, which has the highest value, is referred to as the most significant bit. The current example of 11011 represents five bits of data, which can be converted to a Base 10 decimal system number as demonstrated above, or used for other purposes, such as inputs to logic gates. The five inputs to a logic gate will have $2^5 = 32$ input combinations, which must be analyzed during design and troubleshooting.

The colors available in a computer graphics display are a common example of the significance of the number of bits input to a system. The following table of common graphics color configurations is calculated, as usual, as 2^x where x is the number of bits.

Bits	Number of colors
1	2
4	16
8	256
16	65,536
24	16,777,216

In general, each bit is used to set one place position in a register to a HIGH/ LOW or ON/ OFF state. For example, a small four bit device can set four switches ON or OFF or control 2^4 = 16 possible configurations of a system. A 32-bit device can control 4,294,967,296 possible configurations of a system. It is not unusual for 64-bit and 128-bit devices to be used in high precision applications. Calculation of their possible configurations is left as an exercise for the student.

Octal and Hexadecimal Number Systems

Logic gate circuits can be integrated quite easily to handle Base 2 binary numbers. However, the number of digits required for a specific quantity becomes quite large in comparison to the number of decimal digits required for the same quantity. For example, the largest number that can be expressed by 16 binary bits is 1111111111111111 which, in the decimal system, is $(1 \times 2^{15}) + (1 \times 2^{14}) + (1 \times 2^{13}) + (1 \times 2^{12}) + (1 \times 2^{11}) + (1 \times 2^{10}) + (1 \times 2^{9}) + (1 \times 2^{8}) + (1 \times 2^{7}) + (1 \times 2^{6}) + (1 \times 2^{5}) + (1 \times 2^{4}) + (1 \times 2^{3}) + (1 \times 2^{2}) + (1 \times 2^{1}) + (1 \times 2^{0})$ which computes to 32,768 + 16,384 + 8,192 + 4,096 + 2,048 + 1,024 + 512 + 256 + 128 + 64 + 32 + 16 + 8 + 4 + 2 + 1 = 65,535. The careful student will note that the calculation could have been done more quickly by remembering that the least significant value, the rightmost value, is $2^0 = 1$ and then simply doubling the value for each position to obtain the value for the next position to the left. An even easier way to obtain the value would be to calculate the number of possible decimal numbers represented by a 16 bit binary number, which is 2^{16} = 65,536, then remembering that the first digit is 0, not 1, and subtracting 1 from 65,536 to account for this.

2^8	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0

Figure 12-3-2. Example of binary numbers.

Position	8	7	6	5	4	3	2	1	0
Value	256	128	64	32	16	8	4	2	1

Figure 12-3-3. Value and position of binary numbers.

It is important to remember that this scheme only works to calculate the maximum decimal value that can be represented by a specific binary number. Obviously, it cannot be valid without adjustment when the binary number contains even one zero. How to make such an adjustment is left as an exercise for the student. The 16-bit number, and much longer binary numbers, can be handled quite easily by binary gate circuits, but such lengthy numbers become difficult for humans to input and interpret. Although a human operator would be most comfortable using the common Base 10 decimal number system, digital devices work with bits of binary input. To accommodate this difference, two other number systems, based upon a specific place position in the binary system are used.

The octal number system is based upon the fourth binary placeholder, 2^3, which is equivalent to decimal value 8. This octal system uses the first 8 numbers of the decimal system, 0, 1, 2, 3, 4, 5, 6, and 7, for its notation, which makes it easier for a human operator to use, but still easy to convert back to a binary number when needed since it is based upon the binary number system.

The hexadecimal number system is based upon the fifth binary placeholder, 2^4, the equivalent of decimal value 16. Its notation is composed of the 10 decimal digits plus the first six letters of the alphabet (0, 1, 2, 3, 4, 5, 6, 7, 8, 9, A, B, C, D, E, and F). Larger values can be expressed with a given number of digits in this system than even in the decimal system. Figure 12-3-4 shows the relationship between all possible four bit binary numbers and the equivalent values in hexadecimal and decimal number systems.

Binary	Hexadecimal	Decimal
0000	0	0
0001	1	1
0010	2	2
0011	3	3
0100	4	4
0101	5	5
0110	6	6
0111	7	7
1000	8	8
1001	9	9
1010	A	10
1011	B	11
1100	C	12
1101	D	13
1110	E	14
1111	F	15

Figure 12-3-4. Hexadecimal, decimal values.

Position	8	7	6	5	4	3	2	1	0
Value	FF	8F	4F	2F	F	8	4	2	1

Figure 12-3-5. Binary numbers calculation.

Binary numbers consisting of four bits are called *nibbles*. As indicated in Figure 12-3-4, all possible 4-bit binary numbers (all nibbles) can be represented by a single digit in the hexadecimal number system.

Binary numbers consisting of eight bits (two nibbles) are called bytes. Digital computers basically manipulate bits of binary data as bytes with the binary number 11111111 being the largest number that a computer can address or store in one byte. From previous discussion, the student should be able to convert this binary byte to its decimal equivalent of 255. This means that the eight bit binary byte can represent all 256 decimal values from 0 to 255. This explains why the magic number of 256 and multiples of it, such as 512 and 1024, occur so often in the specification of computer capabilities.

As indicated in Figure 12-3-4, each 4-bit nibble can be represented by a one-digit hexadecimal number up to the maximum binary value of 1111, which is equivalent to the hexadecimal digit *F*. Two such nibbles can be combined as 1111 1111 to create the maximum value byte which can be represented by the hexadecimal equivalent of FF. To check the validity of this procedure, the hexadecimal value of the maximum binary byte of 11111111 can be calculated by beginning with the least significant rightmost digit and doubling the value to obtain the next value while moving from left to right as usual. However, the place values will now be in hexadecimal numbers, as shown in Figure 12-3-5, and hexadecimal arithmetic will be needed to sum the calculation. Referring to Figure 12-3-5 and summing from right to left, the calculation becomes:

1 + 2 + 4 + 8 + F + 2F + 4F + 8F;

But 1 + 2 + 4 + 8 = F;

Substituting F + F + 2F + 4F + 8F = 8F + 8F;

8F + 8F = FF

Since the maximum byte value of 11111111 can be represented by two hexadecimal digits, obviously all other one-byte numbers also can be represented by two hexadecimal digits. The ability to use only two digits to represent any 8-bit byte of binary data makes the hexadecimal system extremely important in computer applications and related computations.

Section 4

Summary of Binary Logic

The universal use of binary logic throughout all areas of aircraft maintenance requires a thorough understanding of it and its application to aircraft systems. The objective of this chapter has been to provide a solid foundation in this subject, which will allow the student to understand and apply the concepts throughout the remainder of the aviation maintenance technician curriculum.

The concepts of binary logic and its basic operation, as they apply to the work of aviation maintenance technicians, were presented. The seven basic logical operators, with their respective symbols and truth tables, were introduced, and it was shown how these operators could be combined to represent the various functions within aircraft systems and used in the analysis of these systems.

The Base 2 binary number system was introduced and calculations were made to compare this system with the familiar Base 10 decimal number system. Calculations applicable to the logical operators of aircraft systems were demonstrated with both number systems.

The binary four bit nibble and the eight bit byte were introduced because of their importance in digital devices which use the byte as the standard unit for addressing and storing data and for making computations. The octal and hexadecimal number systems then were introduced because of their usefulness in simplifying the interface between human operators, who normally operate with Base 10 decimal numbers, and digital devices that carry out binary operations.

Section 5

Basic Troubleshooting Theory

Troubleshooting can be defined as the process by which a malfunction is analyzed, the cause of the malfunction is determined, a corrective procedure is prescribed, and the system is tested to verify that the prescribed procedure did, in fact, correct the malfunction. It is a reasoning process similar to that used by a medical physician who diagnoses a patient's symptoms, makes observations and tests to determine the cause of the problem, prescribes medicine or surgery to correct the problem, and follows up until satisfied that the patient has recovered.

Effective troubleshooting by the aviation maintenance technician allows the aircraft to be repaired efficiently and returned to service in minimum time. Inept troubleshooting not only delays return of the aircraft to service but frequently involves the cost of replacing components that do not correct the malfunction. An organization's troubleshooting capability has a significant impact upon its profitability. Obviously, a person with expert troubleshooting skills is of great value to the organization.

This section will provide a foundation in the reasoning theory that is used in the analysis of any system. The presentation in this section will rely upon concepts introduced in the previous sections of this chapter, and it will be assumed that the student has mastered those concepts. When specific systems are introduced in later sections, techniques will be covered for troubleshooting those systems. The student should have a good understanding of the basic troubleshooting theory presented in this chapter prior to study of those systems.

To troubleshoot a specific system, the technician first must understand the system and its normal operation. Each system is designed to perform a specific function within certain design parameters. The first step in analyzing a reported malfunction is to determine which of those design parameters is not being performed properly. This requires a thorough understanding of the system and the availability of system specifications for reference. Only then can the technician properly continue the analysis and identify the fault within the system.

Troubleshooting Resources

In addition to the MM and basic measurement instruments, the technician often is provided with additional tools to assist in the troubleshooting of complex systems. These may include any of the following.

Maintenance manuals. As mentioned above, troubleshooting requires an understanding of the specific system and the design specifications for each component within the system. The technician must be able to determine what each component within the system is designed to do (its function) and must be able to determine whether that component is, in fact, performing this function within the design specifications. The primary source for this information is the MMs provided for that system. Obviously, these manuals must be kept current for the existing configuration of the system.

Built-in test equipment (BITE). In some systems, test equipment is built into the system to monitor various parameters during operation and to record events that are not within design tolerance. For example, such equipment sometimes is used to record engine parameters throughout the operating cycle. These data then can be used for troubleshooting as well as for routine monitoring of engine performance for trend analysis. Other BITE is used to perform automatic tests of the system as commanded by the technician. An example of this is the use of test functions within an Electronic Flight Instrument System (EFIS), which the technician can display on the cathode ray tubes normally used to display flight information to the pilots.

Ground-based automatic test equipment (ATE). ATE is system specific equipment that is used to check various functions within the system and to report the results to the technician. Such equipment automatically compares the measured system parameters against the programmed design limits and reports whether each measurement is within acceptable limits.

Validity of automatic test equipment. Note that for either type of computerized automatic testing, BITE, or ATE, the validity of the tests is dependent upon the validity of the normal system parameters, or limits, programmed into the test equipment. Frequently, manufacturers change normal system parameters because of modifications to the system or because of operating experience. It is essential that these changes be programmed into the computerized test equipment.

Logic trees (decision trees). Logic trees graphically depict a type of "if-then" logic. The technician begins with a symptom of the malfunction and then selects a choice derived from observations or tests. Each available choice leads to another set of choices and a choice again is selected that also is derived from observations or tests. This procedure continues until the cause of the malfunction is isolated or until there are no more paths applicable to the existing situation.

Expert systems. A computer-based expert system basically carries out the procedures of a logic tree. Usually, the computer program asks for appropriate input from the technician and branches according to the technician's responses. Each time information is received from the technician, functions that could not be causing the reported results are eliminated until the one function, or a small set of functions, remains which is consistent with the results input by the technician. In other words, within its limitations, the expert program performs very similar to the way an expert maintenance technician would perform the analysis using his or her own logical reasoning. In advanced expert applications, much of the information may be input directly from the malfunctioning system instead of being input by the technician.

Systems training. Troubleshooting procedures related to a specific system usually are taught as part of the training for that system. Critical malfunctions and malfunctions commonly experienced in the field are discussed and procedures for identifying and correcting these malfunctions are taught. Frequently, part-task trainers are used which allow the student to practice troubleshooting of these selected malfunctions.

Limitations of troubleshooting resources. Each of the troubleshooting resources available to the technician provides valuable assistance when correctly applied. However, each resource depends upon its ability to test and analyze the specific version of the system experiencing the malfunction and upon the technician's ability to use that resource to arrive at a correct diagnosis of the malfunction. As valuable as they are, each troubleshooting resource is inherently limited.

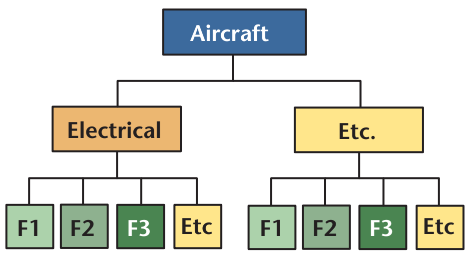


Figure 12-5-1. Function of an aircraft system.

Automatic test equipment and expert systems are expensive to purchase and to upgrade as the aircraft system is modified. Consequently, they frequently are available for only the most complex systems such as avionics and propulsion, if available at all. Logic trees can be developed much less expensively, but still must be kept up to date. Even when one of these resources is available and properly maintained, it still does not cover all possible malfunctions that might occur in the system.

The troubleshooting procedures covered during formal systems training are necessarily limited to the time available and the experience of the instructor. Again, not all possible malfunctions can be covered.

Finally, regardless of the troubleshooting aids available, the technician still must be able to troubleshoot the system when the available resources do not isolate the malfunction. The aviation maintenance technician always is the troubleshooting resource of last resort.

Logical reasoning. Troubleshooting basically is a process of logical reasoning wherein the technician analyzes available information, decides what other information is needed, acquires that information, and analyzes it. The process is continued until all false indications are eliminated and the root cause of the malfunction is identified. The purpose of this section is to teach these logical reasoning skills. This reasoning process is applicable to any specific system and integrates the technician's knowledge of that system in the analysis. Actually, this logical reasoning process is useful in any decision-making situation. Many technicians have commented on how the learning of this skill has helped them in other situations not related to aircraft maintenance. However, the emphasis in this section will be upon troubleshooting of aircraft systems only.

Basic Concepts

Functions. The most basic element in troubleshooting theory is the function. Each part, or component, within an aircraft system is designed and placed within the systems to do a specific thing, or, in other words, to perform a specific function. As depicted in Figure 12-5-1, each component contributes to the overall function of the system. A system is a network of these functions, which work together to perform the overall system function. The aircraft, in turn, is a network of systems, each of which performs a higher-level function to provide the overall function of the aircraft. In troubleshooting, one begins at the top level (the overall aircraft function) to determine which system is not performing its overall function as specified. The malfunctioning system is analyzed to identify the specific component level function that is causing the fault. Then the faulty component is either repaired or replaced and the system is tested to ensure that it now performs properly. Regardless of the level of analysis, each function receives an input, performs the specific function it was designed to do, and provides an output to other functions as shown in Figure 12-5-2. If the input to the function is within design limits, but the output is not within design limits, a malfunction (a fault) has occurred. The technician must determine the cause of this fault.

Sufficiency. The results of tests usually are in numerical form, which indicates a specific voltage, pressure, temperature, etc. In troubleshooting, these quantities are meaningful only when considered in relationship to the design requirements of the functions being analyzed. As indicated in Figure 12-5-3, a function's output may, or may not, be a sufficient output. For example, an output of 1,234 p.s.i. hydraulic pressure may, or may not, be sufficient to retract the landing gear properly. A sufficient input or output is defined as "an input or output that is within the design specification for the related function." This definition is of critical importance to the technician, who always must be concerned with how the system is designed to work and not be misled by how the operator thinks the system should work.

Functional networks. Every system consists of a network of lower level functions, as illustrated in Figure 12-5-4. In a normal system, each function receives sufficient input and provides a sufficient output as it is designed to do. However, an important piece of information is missing in Figure 12-5-4. One cannot tell from inspection which connection provides the input to a function and which connection from the function provides the output. Clearly, there must be paths within the network such that the output from one function affects the input to another function, etc. Furthermore, when there are two or more inputs to a function, Figure 12-5-4 does not indicate whether all these inputs must be sufficient to obtain a sufficient output or if only one of the inputs is sufficient.

Unfortunately, wiring manuals and the schematics in MMs frequently do not indicate the direction of these paths and do not indicate whether all inputs must be sufficient to obtain a sufficient output. In such cases, the troubleshooter must know the system well enough to determine this information.

Paths of influence. Within a network of functions, the output from one function provides the input to the next function, etc., and this provides a process flow throughout the network. Since each output influences the behavior of the next function downstream of it, these paths are known in troubleshooting as "paths of influence." This is illustrated in Figure 12-5-5.

In Figure 12-5-5, a malfunction has occurred in the output from function F5. Assume that the system design requires that both inputs to F5 must be sufficient to obtain a sufficient output. The troubleshooter who understands the paths of influence within this system will quickly realize two things before even beginning to test:

- Functions F6 and F7 are not receiving sufficient inputs. No useful information can be obtained by testing their outputs.
- Either function F5 has failed or there is a malfunction upstream of F5. This fault may

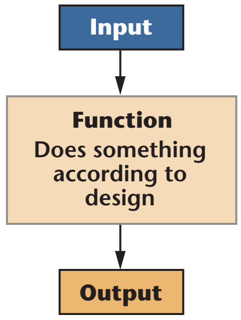


Figure 12-5-2. Input analysis.

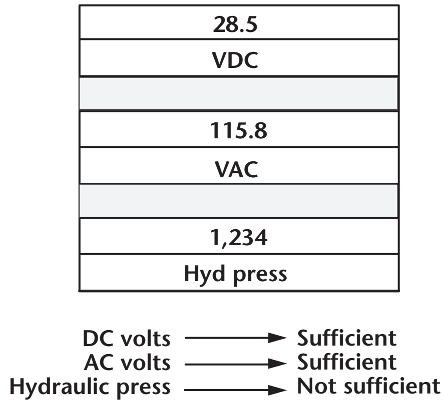


Figure 12-5-3. Sufficient, not sufficient functions.

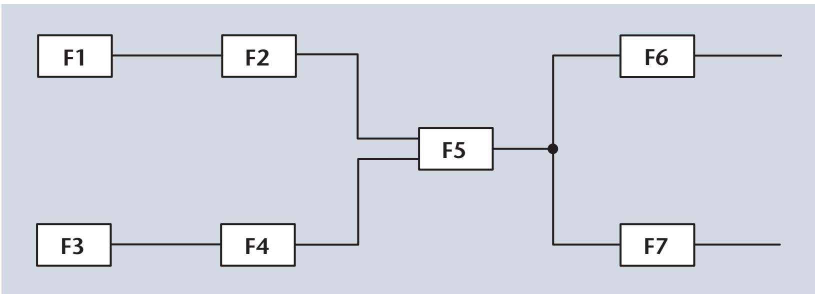


Figure 12-5-4. Missing information, functional network.

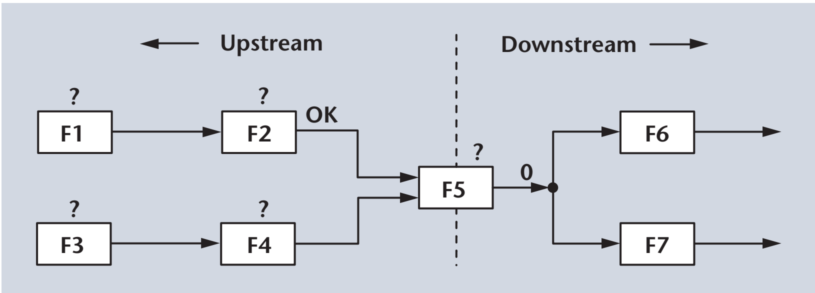


Figure 12-5-5. Malfunction in output, example.

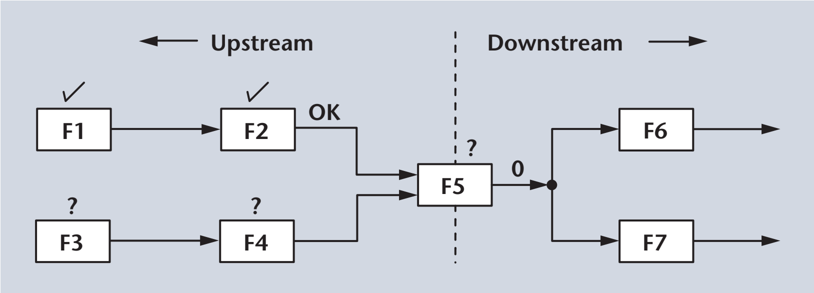


Figure 12-5-6. Determining fault, example.

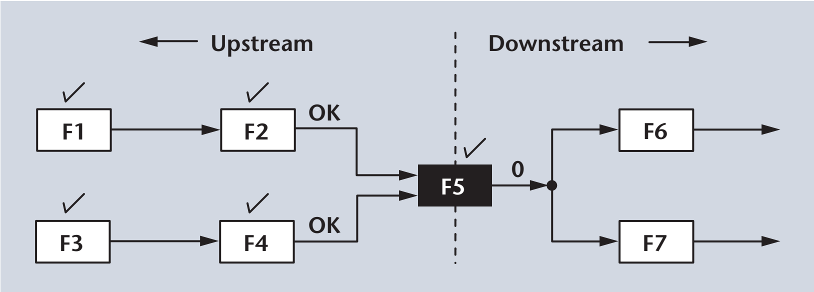


Figure 12-5-7. F5 failure, example.

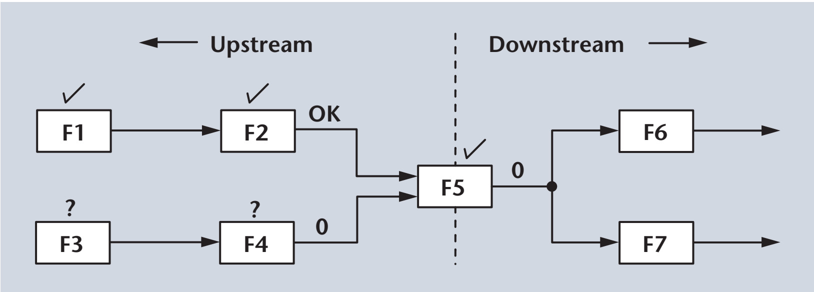


Figure 12-5-8. F4 is not sufficient, example.

be in the branch containing F1 and F2, or it may be in the branch containing F3 and F4. The technician might consider checking the output from F2 or from F4 as the first test, thus eliminating one of the branches from further testing see Figure 12-5-6.

NOTE: To simplify the explanation of concepts and examples of these concepts, only single failures will be considered hereafter in this chapter.

In Figure 12-5-6, the output from F2 has been tested and found to be sufficient. This information doesn't provide any information about F5, but does indicate that neither F1 nor F2 are causing the fault. These functions can be eliminated from further consideration. The troubleshooter now knows that only F3, F4, or F5 can be causing the fault.

Now the output from F4 is tested and two possibilities will be considered. First, consider the case where the output from F4 is sufficient, as shown in Figure 12-5-7. The troubleshooter now knows that all required inputs to F5 are sufficient and that its output is not sufficient. There is only one possible conclusion: F5 has failed and must be repaired or replaced.

Now consider the case where the output from F4 is not sufficient, as shown in Figure 12-5-8. If one assumes a single failure only, then the fault is in either F3 or F4. A test of the output from F3 will positively identify the fault.

Critical path. The student should note how, in the preceding example, testing began at the original symptom (a point of known failed output) and worked upstream from there to identify the actual malfunction. In general, the troubleshooter always can find a malfunction by beginning at a known symptom of failure and working upstream to the actual malfunction. In other words, a critical path always exists between the failed function and the observed symptom of failure. Multiple paths often exist, and the technician must try to isolate the critical path as quickly as possible and with a minimum amount of testing. The examples in this section will follow that principle.

Logic of functions. An aircraft system contains components that are designed to perform many different physical functions. Regardless of the physical characteristics of these components, the troubleshooter analyzes each function in terms of its sufficiency to determine whether it is, or is not, performing according to design. If the output from the function is not sufficient, the troubleshooter cannot assume immediately that the function has failed. First, the troubleshooter must determine that the input to the function is, or is not, sufficient. For troubleshooting, each function can be considered to be a binary function. First, analysis of the input is binary: either the input is, or is not, sufficient. Likewise, analysis of the output is binary: either the output is, or is not, sufficient.

To determine whether the inputs and outputs are sufficient, the technician must not only know the physical design requirements of the function, but also must know the logic of the function. For example, for one specific function with two inputs, it may require that both inputs be sufficient in order to obtain a sufficient output. For another function, only one sufficient input may be required. In another function, such as a warning system, a sufficient input will cause

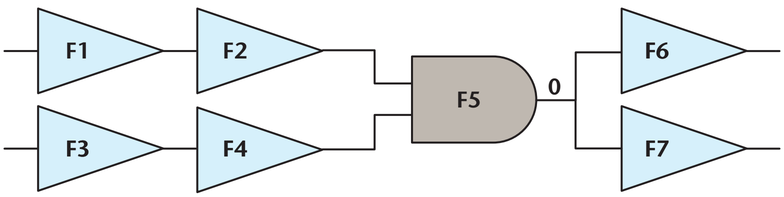


Figure 12-5-9. Use of buffer or yes symbols.

the function to have a zero output. An output from the function — perhaps to turn on a warning light — will occur only when the input in not sufficient.

For troubleshooting analysis, each function can be depicted by a standard logic symbol as discussed earlier in this chapter. When binary logic symbols are used to depict each function, the well-trained technician can immediately tell what input is required when there are multiple inputs to a function and can immediately understand the logical behavior of the function. Fortunately, some aircraft MMs display systems as networks of logic functions. In other cases, the technician must use his or her own knowledge of the system and knowledge of binary logic to visualize the system in this manner.

Logical Analysis of Systems

Use of logic symbols. The system shown in Figure 12-5-9 is the same as the previous system. However, the functions now are presented as logic symbols consisting of six BUFFER (or YES) symbols and one AND symbol which implies that both inputs to F5 must be sufficient to obtain a sufficient output. The initial inputs to F1 and F2 are sufficient as indicated by the "1" or "high" values.

For the remainder of this section, systems will be represented by logic symbols, which represent the logical function of each component, with one exception. Each connection between components, such as a wire, tube, hose, mechanical link, etc., actually performs a logical Buffer (or YES) function. However, for clarity, these will be presented as lines that connect the other components.

Logic symbols will be used for the following reasons:

- The logic of the system can be understood without prior knowledge of the actual system.
- This method reinforces the use of logical analysis during troubleshooting, which is the main objective of the section.
- The student will become much more proficient in the interpretation of logic symbols in general. This will be especially useful when studying or analyzing purely binary systems such as those found in avionics, control systems, warning systems, and computers.

Analysis of simple systems. Figure 12-5-10A depicts a simple system consisting of seven functions. Each function performs a logical AND operation. This means that both inputs to each function must be sufficient to obtain a sufficient

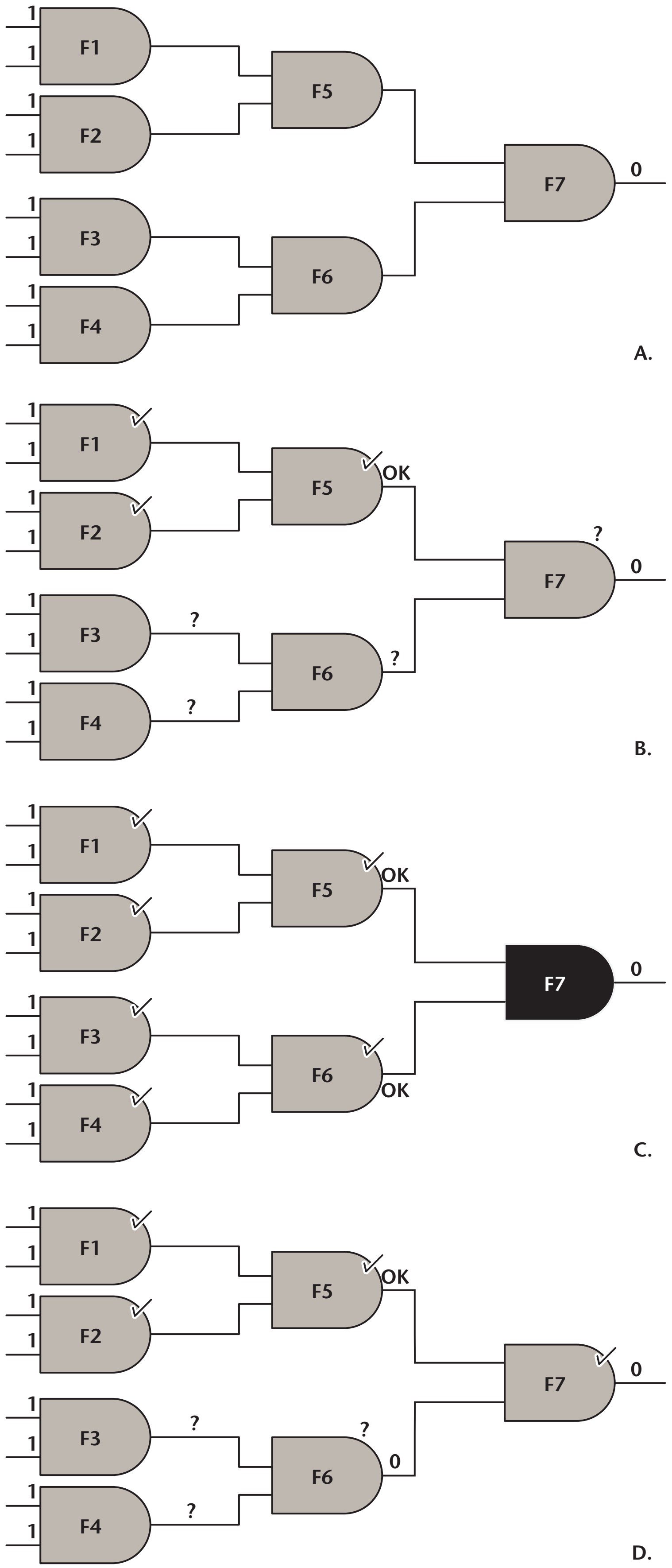


Figure 12-5-10. Simple system with seven functions.

output. The initial inputs to F1, F2, F3, and F4 are sufficient as indicated by the "1" values.

The final output, from F7 is not sufficient. Quite a bit of analysis can be done before any tests are made. First, since functions F1 through F6 all are on paths of influence to F7, a fault in any one of these functions will cause a failed output from F7. Since we are assuming a single failure, one test of the output from either F5 or F6 will immediately eliminate three functions from further suspicion. For example, a test finds that the output from F5 is sufficient. As depicted in Figure 12-5-10B, the troubleshooter can infer from that information that neither F1, F2, nor F5 is causing the fault. Those functions should be eliminated from further consideration.

A test of the output from F6 is made. If its output is sufficient, as indicated in Figure 12-5-10C, then clearly the fault is in F7 and the analysis has been completed with only two tests required.

If the output from F6 is not sufficient, as indicated in Figure 12-5-10D, then a test of the output of F3 or F4, or both, will be required to completely isolate the fault. As an exercise in logical reasoning, the student should work through each of these possibilities by first assuming a sufficient output from both F3 and F4, and then assuming an insufficient output from either F3 or F4.

In Figure 12-5-10, F7 now is represented by an OR logical operator, which means that it only requires one sufficient input from either F5 or from F6. All the other functions still perform AND logical operations. In this case, the fault can be determined by logical reasoning with no tests required. The student should analyze the system until convinced that a fault in function F7 is the only condition that could be causing the failed output from F7.

Changing configuration. Frequently, valuable information about a fault can be obtained by simply changing the configuration of the system. For example, the source of power might be switched from the Left Essential Bus to the Right Essential Bus. If the fault disappeared, then obviously the fault is in the power source and not in the system being analyzed. Sometimes, a fault occurs only when the aircraft is in flight and not when it is on the ground. In such a case, the technician may decide to put the aircraft on jacks to simulate the in-flight configuration while troubleshooting.

Figures 12-5-11A and B represent a slightly more complex system. When switch S1 is in the "low"

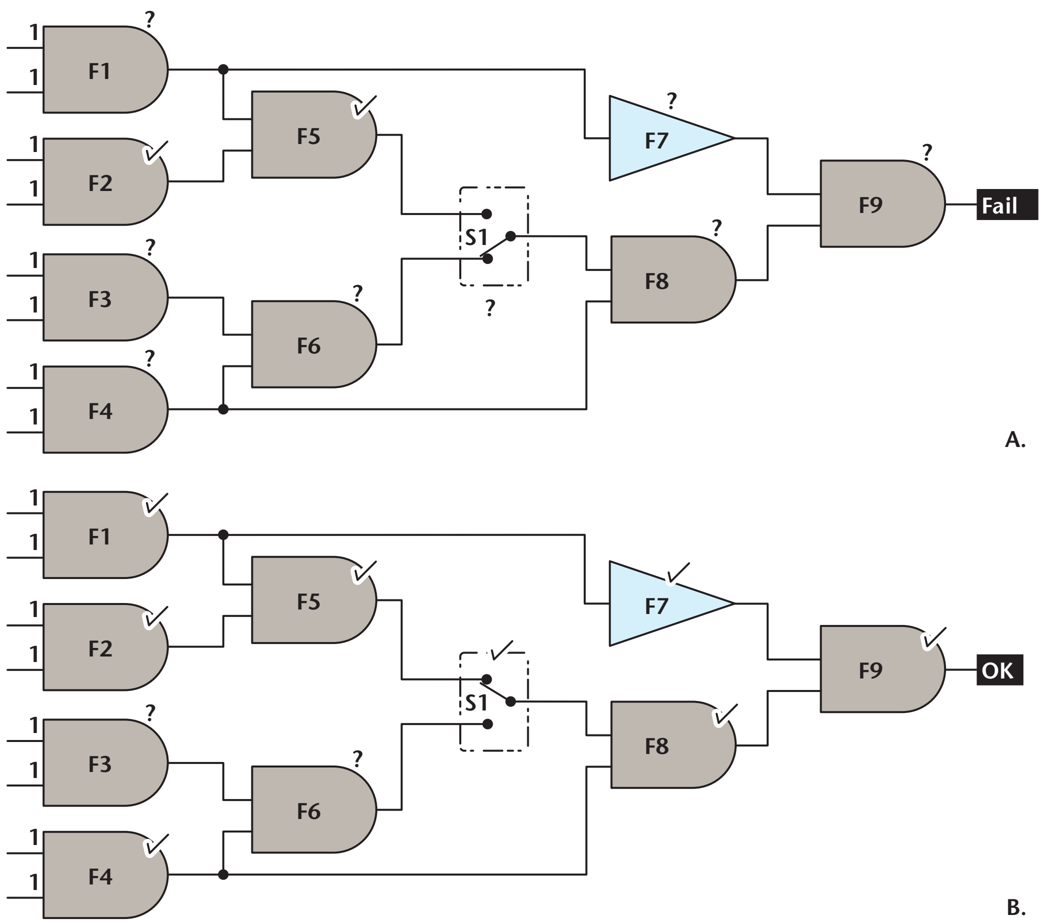


Figure 12-5-11. Switch movement.

position, as shown in Figure 12-5-11A, the annunciator light indicates a fault. F9 is a logical AND function, which means that all inputs into it must be sufficient in order to obtain a sufficient output. In the configuration shown in Figure 12-5-11A, every function except F2 and F5 (and possibly the upper half of S-1) is in a path that influences the inputs to F9. Any one of these functions could be causing the fault. Only F2 and F5 can be eliminated from further consideration at this time.

When switch S1 is moved to the "high" position, as shown in Figure 12-5-11B, the annunciator light indicates that the output from F9 is sufficient. This means that all functions in paths of influence to F9 necessarily are operating properly. The technician now logically reasons that only F3, F6, or possibly the lower half of switch S1 is malfunctioning. A maximum of two tests are needed to completely identify the fault.

This example illustrates a valuable principle of troubleshooting. Prior to beginning any testing at all, an expert troubleshooter obtains all readily available information and uses this information to analyze what could and what could not be causing the malfunction. Only then does he or she begin testing. No time is wasted testing functions that could not possibly be causing the malfunction.

Systems Containing XOR Functions

As discussed in the chapter on binary logic, an EXCLUSIVE OR (XOR) function will have a High output only if one input is High and the other input is Low, as depicted in the truth table shown in Figure 12-5-12A.

The system shown in Figure 12-5-12A contains two XOR functions in addition to the five AND functions. During normal operation, the two High inputs to F5 result in a Low output. Function F7 receives one Low input from F5 and one High input from F6, which produces the desired High output.

In Figure 12-5-12B, a fault has occurred and the output is Low. Any fault, except for a failure of F5 to a Low output, could cause this Low output from F7.

As shown in Figure 12-5-12C, a test indicates that the output from F5 is High. The troubleshooter reasons that F5 must be operating properly and either F1 or F2 has failed to a Low output. A test of F1 or F2 will indicate which function has failed.

Figure 12-5-12D represents a new situation. A test of the output of F6 indicates that it is Low. A test of F3, and possibly F4, will need to be made to isolate the fault.

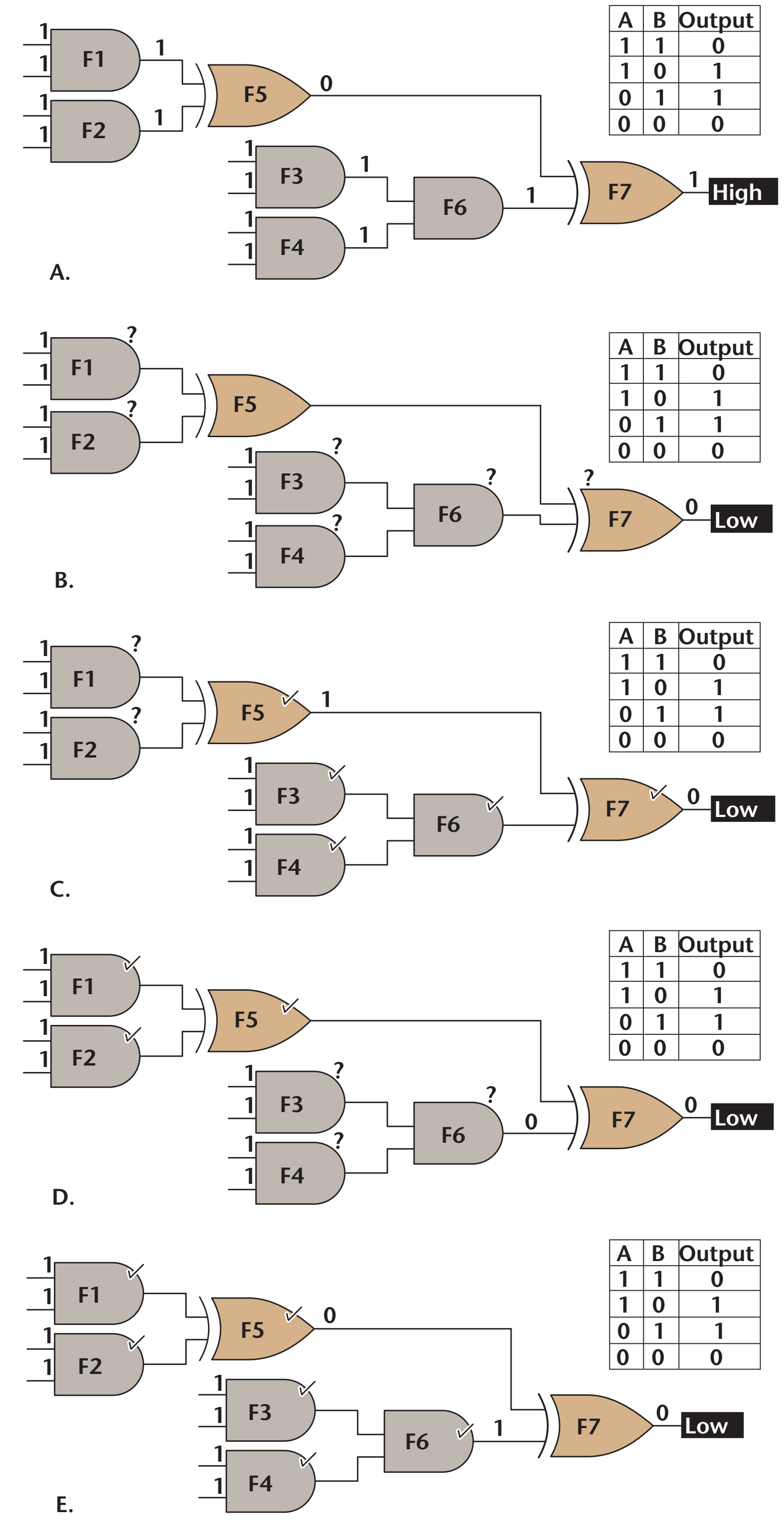


Figure 12-5-12. Systems containing XOR functions.

Figure 12-5-12E represents a third possible situation. Tests indicate that the output from F5 is Low and the output from F6 is High, which is normal. Since F7 is receiving one High and one Low input, the output should be High. Clearly, F7 has failed in this case.

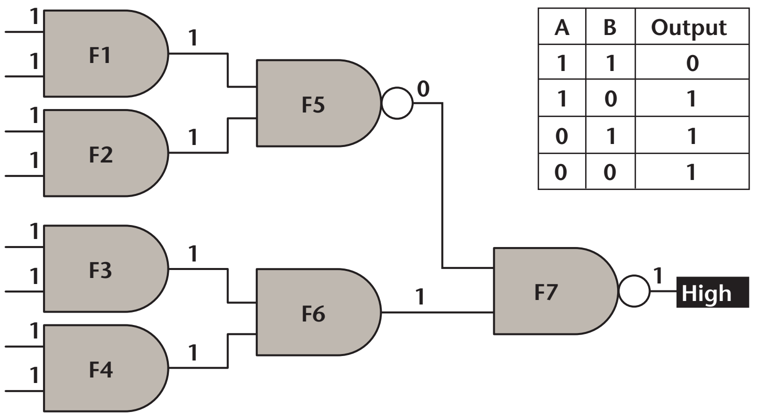


Figure 12-5-13. System with inverse function.

Systems Containing Inverse Functions

Figure 12-5-13 represents a system consisting of five functions with AND logical operators and two functions with NAND logical operators. As indicated in the truth table shown in Figure 12-5-13, the NAND operator is the inverse of the AND operator with the following rule: the output from a NAND operation is Low if, and only if, both inputs are High; otherwise the output is High. As an exercise, the student should confirm that a failure of F5 or F6 to a Low output would not cause a Low output from F7. Then the student should confirm that a Low output from F7 could be caused only by a failure of F1, F2, or F7 itself to a Low output.

Choosing Where to Test

Figure 12-5-14A, represents a larger system consisting entirely of functions with AND logical operators. The output from F15 is not sufficient. All of the other functions are in paths to F15. Since all inputs to an AND function must be sufficient (High) to obtain a High output, the failed (Low) output from F15 could be caused by a failure of any one of the functions.

Test where the most information can be obtained. A test of the output of either F13 or F14 will eliminate half of the functions upstream of F15 from further consideration. No other test can provide that much information. In Figure 12-5-14B, a test of the output from F13 has been made and the output is sufficient. As indicated, Functions F1, F2, F3, F4, F9, F10, and F13 must be operating satisfactorily. One of the remaining functions must be causing the fault.

If the output from F13 had not been sufficient, then the fault would have been caused by F13 or a function upstream of it. In either case, this one test would eliminate about half of the functions from further consideration.

With the information gained from testing F13, as shown in Figure 12-5-14B, a test of the output of F14 now will provide the most information. If the output from F14 is sufficient (High), then the failure must be caused by a fault in function F15. If the output from F4 is not sufficient (Low), as shown in Figure 12-5-14C, then F14 or a function upstream of it is causing the fault, as indicated in Figure 12-5-14C. A test of the output of F11 or F12 would be the most appropriate next step.

As an exercise, work through the tests you would make and the expected results for each test, to find a fault in function F8.

The objective of this section has been to provide the student with a solid foundation in the reasoning theory that is used in the analysis and troubleshooting of any aircraft system. The student now should have a good understanding of the basic concepts of functions, sufficiency, functional networks, paths of influence, and critical paths, and be able to apply those concepts in the logical analysis of aircraft systems. As the student progresses through the course, there will be many opportunities to practice the application of these concepts to specific systems.

The aircraft maintenance technician often has many resources to assist in troubleshooting, ranging from the systems MMs and wiring diagrams to expensive automatic test equipment. All such resources, when available, provide valuable assistance to the technician, but they all have limitations. When such resources fail to identify the fault, the technician still must analyze the system, find the fault, recommend the proper repair or replacement, and then verify that the corrective action did, in fact, correct the malfunction. The aircraft maintenance technician always is the troubleshooting resource of last resort.

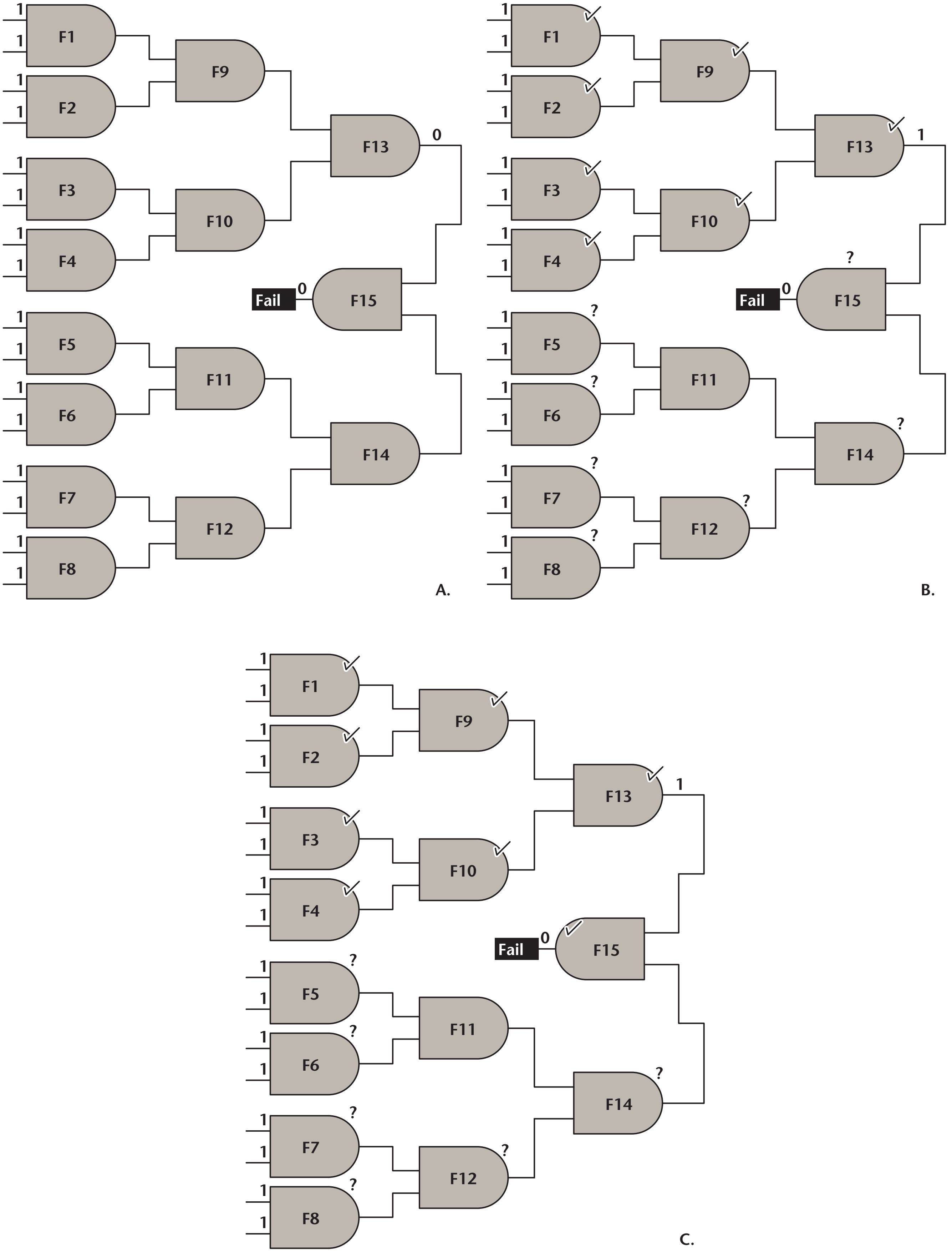


Figure 12-5-14. Choosing where to test.

13

Safety and Ground Handling

Section 1

Shop Safety

Aircraft maintenance technicians devote a portion of their aviation career to ground handling aircraft and working with ground-support equipment. The complexity of support equipment and the hazards involved in the ground handling of expensive aircraft require that maintenance technicians possess a detailed knowledge of safe procedures to be used in aircraft servicing, taxiing, and run-up, and in the use of ground-support equipment. The information provided in this is intended as a general guide for working around all types of aircraft.

Good housekeeping in hangars, in shops, and on the flightline is essential to safety and efficient maintenance. The highest standards of orderly work arrangements and cleanliness should be observed during the maintenance of aircraft.

Where continuous work shifts are established, the outgoing shift should remove and properly store personal tools, rollaway boxes, all workstands, maintenance stands, hoses, electrical cords, hoists, crates, and boxes that are superfluous to the work to be accomplished.

Signs should be posted to indicate dangerous equipment or hazardous conditions. Signs also provide information on the location of first-aid, fire equipment, exits, and other information.

Safety lanes, pedestrian walkways, or fire lanes should be painted around the perimeter inside the hangars. This should be done as a safety measure to prevent accidents and to keep pedestrian traffic out of work areas.

Learning Objectives

REVIEW

- Fire classes and safety considerations and documentation
- Methods of moving aircraft on the ground

DESCRIBE

- Shop safety standard practices
- Flightline safety factors
- Aircraft fuel varieties, fueling equipment and procedures
- Jacking and hoisting procedures
- Types of ground servicing equipment

EXPLAIN

- Tiedown procedures for various aircraft
- Engine starting procedures for reciprocating and turbine engines

Left. A lineman guides a corporate jet into a parking place. Notice the hearing protectors, which are always necessary on the flight line.

Photo courtesy of National Business Aviation Association

GLASS BEADS
PART 6700

OSHA regulations require that a Material Safety Data Sheet be available for all users. Material Safety Data Sheets are included with each box of our abrasive. Included with most Skat Blast Cabinets is a small supply of Glass Beads for initial start-up. This is the Material Safety Data Sheet for our Part No. 6700 Glass Beads.

WARNING Glass Beads, if spilled on the floor, are as slippery as ice. Sweep up spills promptly.

Occupational Safety and Health Administration

Material Safety Data Sheet

PART NO. 6700
GLASS BEADS
Revised 9-14-98

SECTION I

DISTRIBUTOR NAME: **Distributor---Skat Blast, Inc.**	EMERGENCY PHONE NO. **(330) 533-9477**
ADDRESS, (Number, Street, City, State and Zip Code) **7077 State Rt. 446, Canfield, OH 44406**	
CHEMICAL NAME AND SYNONYMS **Glass (CAS Number 65997-17-3)**	TRADE NAME AND SYNONYMS **GLASS BEADS**
CHEMICAL FAMILY **GLASS, SODA-LIME TYPE**	FORMULA **Sodium Aluminum Silicate base Glass**

SECTION II - HAZARDOUS INGREDIENTS

	OSHA-PEL	ACGIH-TLV	ALLOYS AND METALLIC COATINGS
NUISANCE DUST	15mg/m^3	10mg/m^3	N/A
NUISANCE DUST - RESPIRABLE	5mg/m^3	5mg/m^3	

CONTAINS NO FREE SILICA - All components are amorphous and non-crystalline; none are SARA Title III reportable.
NUISANCE DUST - to the best of our knowledge, this material is non-hazardous as per OSHA 29 CFR 1910.1200.

SECTION III - PHYSICAL DATA

BOILING POINT (C) N/A	MELTING POINT (C) Above 1100°F	SPECIFIC GRAVITY (@ 60 degrees F)	2.4-2.6g/cm^3
VAPOR PRESSURE (mm Hg)	N/A	PERCENT SOLID BY WEIGHT	N/A
VAPOR DENSITY (Air = 1)	N/A	EVAPORATION RATE	N/A
SOLUBILITY IN WATER	None	APPEARANCE AND COLOR	White, odorless, tasteless powder.

SECTION IV - FIRE AND EXPLOSION HAZARD DATA

Flash Point (Method Used): None. Flammable Limits: None. Extinguishing Media: Does not burn. Water - avoid creating dust.
Materials to avoid - (Incapability) Concentrated Hydrofluoric Acid, fluosilicic, phosphoric acids, and hot, strong alkaline solutions.

SECTION V - HEALTH HAZARD DATA

ROUTES OF ENTRY Inhalation, Ingestion	CARCINOGENICITY - This product is not listed as a potential carcinogen in either the NIP, IARC, or OSHA.

HEALTH HAZARD - Repeated or prolonged inhalation of dust in excess of permissible exposure limits may result in irritation to the respiratory tract.
OVEREXPOSURE - Can aggravate existing respiratory conditions and eye irritation.

EMERGENCY AND FIRST AID PROCEDURE:
Eye Contact: Flush with running water for 15 min. If irritation or redness persists, see a physician. Skin Contact: Wash area well with soap and water. Ingestion: Seek medical help if large quantities of material have been ingested.

SECTION VI - REACTIVITY DATA

STABILITY **Stable. Hazardous Polymerization - Will not occur**	CONDITIONS TO AVOID **Excessive dust, slippery if spilled**

HAZARDOUS DECOMPOSITION PRODUCTS
None Glass Beads will break down into progressively smaller particles during normal use.

SECTION VII - SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED. Considered as non-hazardous per EPA 29CFR1910.1200.
Sweep from floor to prevent slipping hazard. Wear NIOSH-approved respirator. If respiratory aggravation, go to a well-ventilated area.

WASTE DISPOSAL METHOD
Collected dust from blast cleaning or shot peening operations always contain contaminates from the surface of the parts being processed; and, therefore, the dust may be classed as a hazardous waste and, as such, must be disposed of according to appropriate Local, State, or Federal regulations. The RCRA status of UNUSED material is non-hazardous, according to the list of CERCLA chemicals.

SECTION VIII - SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (SPECIFY TYPE) Use NIOSH/OSHA-approved respiratory equipment. Positive pressure air-supplied type recommended. If beads or dust cause eye irritation, flush eye(s) with water or eye wash.

VENTILATION N/A	LOCAL EXHAUST Follow OSHA standards; use adequate dust collecting system to remove suspended particulate from equipment and ambient environment.	
	MECHANICAL (GENERAL) **As required for nuisance dust.**	OTHER **Provide eyewash station in the area.**
	PROTECTIVE GLOVES **As required per job.**	EYE PROTECTION **Normal for dust—use safety goggles.**
	OTHER PROTECTIVE EQUIPMENT **If blasting, use appropriate protective clothing, air-supplied hood/respirator & other safety equipment.**	

SECTION IX - SPECIAL PRECAUTIONS

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING
Observe maximum floor loading and stacking limitations due to density of product.

OTHER PRECAUTIONS
Keep dry. Store material away from incompatible materials. Avoid generating dust.
The company has no control over this product or its use after it leaves our facility. The company assumes no liability for loss or damage from the proper or improper use of this product. The information presented here has been compiled from sources considered to be reliable and accurate to the best of our knowledge and belief, but is not guaranteed to be so. Revision Date, September 14, 1998. Rev 3/28/00

Figure 13-1-1. This MSDS represents the information for the basic product.

Safety is everyone's business, and communication is key to ensuring everyone's safety. Technicians and supervisors should watch for their own safety and for the safety of others working around them. If someone else is conducting themselves in an unsafe manner, communicate with them and remind them of their safety and that of others around them.

Material Safety Data Sheets

It is every employer's responsibility to teach employees about the *Hazard Communications Standard*. The Hazard Communications Standard (HCS) is a uniform standard to communicate workplace hazards. It clearly spells out what specific information has to be communicated and how it must be communicated. The Hazard Communication Standard is an *Occupational Safety and Health Administration* (OSHA) requirement to cover handling of workplace chemicals. It addresses both health and safety issues. The standard is a *Right to Know* requirement for potential chemical hazards. It says that everyone handling chemicals needs to know how to protect themselves. This is a federal standard however; there may also be state and local Right to Know laws that must be followed as well.

We are often exposed to chemicals. Improper handling of some of these chemicals is dangerous and could result in illness, injury, or incapacitation. The effects may be either external, like burns and rashes, or internal, such as nausea or organ damage. Chemicals generally enter the body through the skin, nose, mouth, or eyes.

The *Hazard Communication Standard* requires employers to develop, implement, and continuously maintain a documented program for the instruction of employees. The written program has to list all the hazardous chemicals used in each specific work area, and explain how to handle them. There has to be information on how to read and understand *Material Safety Data Sheets* (MSDS) and chemical labels. The written methods program must include both how to observe and how to detect a release or presence of hazardous chemicals in the workplace. The last element of the written program is to provide for training of new employees and a means to inform nonemployees—either visitors or vendors—about the specific hazardous chemicals handled in each work area.

When any chemical is made or distributed, its potential hazards must be determined. Manufacturers, importers, and distributors are required by law to assess the extent of this potential hazard and make this information easily accessible through MSDS. For each chemical used in the workplace, it is the employer's task to make readily available the MSDS and to tell everyone where the MSDS are in your facility. Anyone using a chemical also has to take responsibility for knowing how to read labels, understanding MSDS, handling chemicals with all necessary precautions, and knowing what to do if a particular chemical is spilled or comes into contact with someone's skin. An MSDS tells how the chemical would enter the body and gives *emergency first aid procedures*.

There is no specific format for the MSDS, but it serves as the vehicle to inform everyone of safety procedures, emergency response options, chemical components, and dangers. The MSDS will generally have the chemical name, its trade name, and often even the formula. Addresses and emergency numbers are provided. A sample MSDS is shown in Figure 13-1-1.

Physical data. A material's physical data listing could include percentage of volatile components, odor, appearance, boiling point, specific gravity, vapor pressure, density, evaporation rate, and solubility in water. Also included is information regarding the stability of the chemical, how it reacts and it's extent of reaction with other chemicals and compounds, along with ways to prevent an unexpected and unwanted chemical reaction.

MSDSs also include information on fire prevention and extinguishing.

Explosion and fire data. This provides information on which fire extinguishers to use and their media, the temperature at which the chemical ignites (flashpoint), any unusual fire hazards and special fire-fighting procedures, any unusual or special dangers, and chemical flammability limits by volume. Any *spill or leak procedure* or process will be identified. All equipment needed in clean-up and any special precautions, including methods for disposal, will be clearly defined. Also, any *special precautions for handling* will be listed. Safe handling of hazardous chemicals may require protective clothing, gloves, respirators, eye protection, and ventilation requirements. Some chemicals require *special storage precautions*, like refrigeration and explosion-proof cabinets.

The *Hazard Communication Standard* also requires that all containers that are used in a work area be labeled with special precautions identified with either words or descriptive symbols. The one exception is a portable container for immediate use by the person transferring the chemical. Everyone must have training in reading the labels and understanding what they mean. The label should identify the chemical, hazard severity, health hazards, and any needed protective clothing or equipment. The most common label is illustrated in Figure 13-1-2. In some areas the sign must be placed on the entry doors to indicate what is located inside the building.

Understanding the meaning of labels can prevent serious accidents. Investigate all chemicals that lack labels. Always follow the directions and precautions to ensure safe handling of all chemicals. Don't mix chemicals that you have not positively identified. The end result may be a big, unpleasant surprise. Following instructions and warnings will prevent accidents that could ruin your day.

Electrical Safety

Physiological safety. Working on or with electrical equipment poses certain physiological safety hazards. It is known that when electricity is applied to the human body, it can create severe burns in the areas where it enters and exits the body. In addition, the nervous system is affected and can be damaged or destroyed.

NFPA

- This label is for emergency response and fire fighters.
- Hazard rating is from 0 (no hazard) to 4 (extreme).

Flammability (flash points)
0 = Will not burn
1 = Above 200°F (93°C)
2 = Between 100 - 200°F (38°-93°C)
3 = Below 100°F (38°C)
4 = Flash Point Below 73°F (23°C)

Specific hazard
ACID - acid
ALK - alkali
COR - corrosive
OX - oxidizer
P - polymerization
☢ - radioactive
W̶ - use no water

Health hazard
0 = Normal material
1 = Slight hazard
2 = Moderately hazardous
3 = Extremely hazardous
4 = Deadly

Reactivity
0 = Stable
1 = Unstable if heated
2 = Violent chemical change
3 = Shock or heat may detonate
4 = Rapidly capable of detonation or explosion

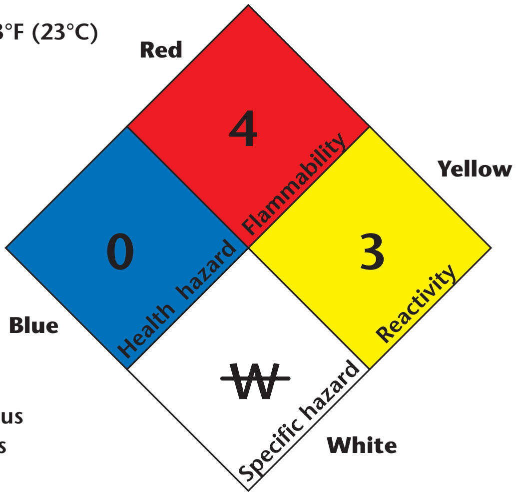


Figure 13-1-2. The hazard communication label illustrated is used on all commercial items.

To safely deal with electricity, the technician must have knowledge of the principles of electricity and a healthy respect for its capability to do both work and damage.

Wearing or using proper safety equipment can give a psychological reassurance, while at the same time physically protecting the user. Rubber gloves, safety glasses, rubber or grounded safety mats, and other safety equipment can all be used to contribute to the physiological safety of the technician working on or with electrical equipment.

Two factors that affect safety when working with or around electricity are fear and overconfidence. While a certain amount of fear is healthy and a certain level of confidence is necessary, extremes of either can be deadly.

Fear is often born of a lack of knowledge. Those who try to work on electrical equipment with no knowledge of its principles or a lack of confidence in their work, are often fearful of it. Overconfidence leads to risk-taking. The technician who does not respect electricity's capabilities will, sooner or later, become a victim of electricity's awesome power.

Electrical fire safety. Anytime current flows, whether during generation or transmission, a by-product of that flow is heat. The greater the current flow, the greater the amount of heat created. When this heat becomes too great, protective coatings on wiring and other electrical devices can melt, causing shorting, which leads to more current flow and greater heat. This heat can become so great that metals can melt, liquids vaporize, and flammable substances ignite.

The single most important factor in preventing electrical fires is to keep the area around electrical work or electrical equipment clean, uncluttered, and free of all unnecessary flammable substances.

Ensure that all power cords, wires, and lines are free of kinks and bends, which can damage the wire. When several wires inside a power cord are broken, it causes the current passing through the remaining wires to increase. This generates more heat than the insulation coatings on the wire are designed to withstand, and can lead to a fire.

Compressed Gas Safety

Compressed air, like electricity, is an excellent tool, as long as it is kept under control.

The following DOs and DON'Ts apply when working with or around compressed gases:

- Air hoses should be inspected frequently for breaks and worn spots. Unsafe hose should be replaced immediately.
- All connections should be kept in a *no-leak condition.*
- In-line oilers, if installed, should be maintained in operating condition.
- The system should have water sumps installed and should be drained at regular intervals.
- Air used for paint spraying should be filtered to remove oil and water.
- Never use compressed air to clean hands or clothing. Pressure can force debris into the flesh, leading to infection.
- Never horseplay with compressed air.
- Air hoses should be straightened, coiled, and properly stored when not in use.

Many accidents involving compressed gases occur during aircraft tire mounting. To prevent possible personal injury, tire dollies and other appropriate lifting and mounting devices should be used in mounting or removing heavy aircraft tires.

- When inflating tires on any type of aircraft wheels, tire cage guards should always be used. Because of possible personal injury, extreme caution is required to avoid overinflation of high-pressure tires. Pressure regulators should be used on high-pressure air bottles to eliminate the possibility of overinflation of tires.
- Tire cages need not be used when adjusting pressure in tires installed on aircraft.

Machine Tool Safety

Hazards in a shop's operation increase when the operation of lathes, drill presses, grinders, and other types of machines are used. Each machine has its own set of safety practices. The following precautions should be followed to avoid injury:

Drill press. The drill press can be used to bore and ream holes, to do facing, milling, and other similar types of operations. Following a few precautions can reduce the chance of injury.

- Wear eye protection.
- Clamp the work securely.
- Set the proper r.p.m. for the material used.
- Do not allow the spindle to feed beyond its limit of travel while drilling.
- Stop the machine before adjusting work or attempting to remove jammed work.
- Clean the area when finished.
- Never leave the chuck key in the chuck after tightening/loosening a drill.

Engine lathe. Lathes are used in turning work of a cylindrical nature. This work may be performed on the inside or outside of the cylinder. The work is secured in the chuck to provide the rotary motion, and the forming is done by contact with a securely mounted tool. Following the precautions listed below will reduce the chance of injury.

- Wear eye protection.
- Use sharp cutting tools.
- Allow the chuck to stop on its own. Do not attempt to stop the chuck by hand pressure.
- Examine tools and work for cracks or defects before starting the work.
- Do not set tools on the lathe. Tools may be caught by the work and thrown.
- Stop the lathe before measuring the work.
- Never leave the chuck wrench in the chuck.

Milling machine. Mills are used to shape or dress, cut gear teeth, slots, or key ways, and to perform similar work. The following precautions can reduce the chance of injury:

- Wear eye protection.
- Clean the work bed prior to work.
- Secure the work to the bed to prevent movement during milling.
- Select the proper tools for the job.
- Do not change the feed speed while working.
- Lower the table before moving under or away from the work.
- Make sure all clamps and bolts will pass under the arbor.

Grinders. These are used to sharpen tools, dress metal, and perform other operations involving the removal of small amounts of metal. These precautions will reduce the chance of injury:

- Wear eye protection, even if the grinder has a shield.
- Inspect the grinding wheel for defects prior to use.
- Do not force grinding wheels onto the spindle. They fit snugly but do not require force to install. Also, do not put any side pressure on a wheel, or it can explode.

- Check the wheel flanges and compression washer. They should be one-third the diameter of the wheel.
- Do not stand in the arc of the grinding wheel while operating, in case the wheel explodes.
- Always keep the blade guard adjusted properly.

Welding. Welding should only be performed in designated areas. Any part to be welded should be removed from the aircraft, if possible. Repair should then be accomplished in the welding shop under a controlled environment.

A welding shop should be equipped with proper tables, ventilation, tool storage, and fire prevention and extinguishing equipment. Welding on an aircraft should be performed outside, if possible. If welding in the hangar is necessary, these precautions should be observed:

- During welding operations, there should be no open fuel tanks, and no work on fuel systems should be in progress.
- No painting in progress.
- No aircraft within 35 ft. of the welding operation.
- Immaculate housekeeping should prevail around the welding area.
- Only qualified welders should be permitted to do the work.
- The welding area should be roped off and placarded.
- Fire extinguishing equipment with a minimum rating of 20B should be in the immediate area, with 80B rated equipment as a backup. These ratings will be explained later in this .
- There should be trained fire-watch personnel in the area around the welding operation.
- Aircraft being welded should be in towable condition, with a tug attached, and the aircraft parking brakes released. A qualified operator should be on the tug, and mechanics available to assist in the towing operation should it become necessary to tow the aircraft. If the aircraft is in the hanger, the hangar doors should be opened.

Lockout/Tagout

Lockout/tagout refers to specific practices and procedures to safeguard employees from the unexpected startup of machinery and equipment during service or maintenance activities. This process requires, in part, that a designated individual turn off and disconnect the machinery or equipment from its energy source before performing service or maintenance.

Lockout devices hold energy-isolation devices in a safe or "off" position. They provide protection by preventing machines or equipment from becoming energized, because they are positive restraints that no one can remove without a key or other unlocking mechanism or through extraordinary means, such as bolt cutters.

Tagout devices, by contrast, are prominent warning devices that an authorized employee fastens to energy-isolating devices to warn employees not to re-energize the machine while he or she services or maintains it.

Tagout devices are easier to remove and, by themselves, provide less protection than do lockout devices.

Employees can be seriously or fatally injured if machinery they service or maintain unexpectedly energizes, starts up, or releases stored energy.

OSHA's standard on the Control of Hazardous Energy (Lockout/Tagout), spells out the steps employers must take to prevent accidents associated with hazardous energy. The standard addresses, practices, and procedures necessary to disable machinery and prevent the release of potentially hazardous energy while maintenance or service activities are performed.

Section 2

Fire Protection

Fire Safety

Work on and around aircraft and their components requires the use of electrical tools and equipment, spark-producing tools and equipment, heat-producing tools and equipment, and flammable and explosive liquids and gases. As a result, a high potential exists for fire to occur, and measures must be taken to prevent such an occurrence. Should one occur, extinguish it.

Spontaneous combustion. *Spontaneous combustion* occurs when a slow buildup of heat in flammable materials eventually erupts into a fire. It might occur in rags or waste that has been saturated with flammable materials. The following practices will aid in prevention of spontaneous combustion:

- Dispose of flammable wastes in closed, airtight metal containers and empty the containers regularly.
- Keep flammable waste that can't be put in containers in a cool, dry, well-ventilated area. Dispose of them frequently.

Chemicals. Chemicals that are not a fire hazard by themselves may become flammable when mixed with an incompatible substance —air, water, heat, or another chemical. This is known as *reactivity*.

The key to fire safety is knowledge of what causes fire, how to prevent it, and how to put it out. This knowledge must be instilled in each technician, emphasized by his or her supervisors through sound safety programs, and occasionally practiced. Airport fire departments or local fire departments can normally be called upon to assist in training personnel and helping to establish fire safety programs for the hangar, shops and flightline.

Requirements of Fire

Three things are required for a fire:

- Fuel - Something that will, in the presence of heat, combine with oxygen, thereby releasing more heat and, as a result, reducing itself to other chemical compounds.
- Heat - Heat can be considered the catalyst that accelerates the combining of oxygen with fuel, in turn releasing more heat.
- Oxygen - The element that combines chemically with another substance through the process of oxidation.

Rapid oxidation, accompanied by a noticeable release of heat and light, is called *combustion, or burning* (Figure 13-2-1). Remove any one of these things and the fire goes out.

Classification of Fire

The National Fire Protection Association (NFPA), for commercial purposes, has classified fires into four basic types: *Class A, Class B, Class C,* and *Class D.*

- **Class A**. Class A fires are fires in ordinary combustible materials such as wood, cloth, paper, upholstery materials, etc.
- **Class B**. Class B fires are fires in flammable petroleum products or other flammable or combustible liquids, greases, solvents, paints, etc.
- **Class C**. Class C fires are fires involving energized electrical wiring and equipment.

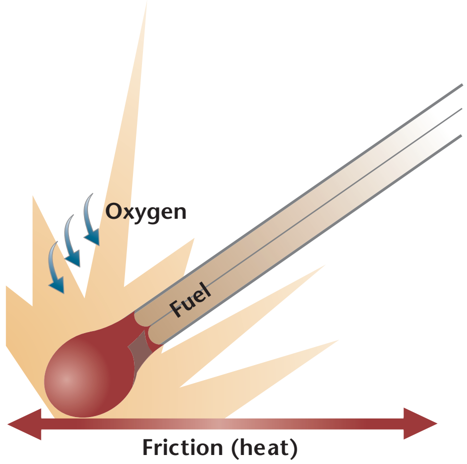


Figure 13-2-1. To start a fire, it takes three things: fuel, oxygen, and heat.

- **Class D**. A fourth class of fire with which the technician should be familiar, the Class D fire, is defined as *fire in flammable metal*. Class D fires are considered by the National Fire Protection Association to be a basic type or category of fire. Usually, Class D fires involve magnesium in the shop or in aircraft wheels and brakes, or are the result of improper or poorly conducted welding operations.

Any one of these types of fires can occur during maintenance of or operations on or around aircraft. There is a particular type of extinguisher that is most effective for each type of fire.

Types of Fire Extinguishers

Water extinguishers. These are the best type to use on Class A fires. The water has two effects on the fire, in that it can deprive the fire of oxygen and, at the same time, cool the temperature of the material being burned. (Table 13-2-1).

Because they can only safely be used on one type of fire, water fire extinguishers have disappeared from any commercial establishment. When working with Class A material, having a firehose available is always a good idea. However, never use a water hose on the following types of fires:

- Since most petroleum products float on water, water-type fire extinguishers are not recommended for Class B fires.
- Extreme caution must be used when fighting Class C electrical fires with water-type extinguishers. Not only must all electrical power be removed or shut off to the burning area, but residual electricity in capacitors, coils, etc., must be considered to

prevent severe injury and possibly death from electrical shock.

- Never use water-type fire extinguishers on Class D fires. Because metals burn at extremely high temperatures, the cooling effect of water causes an explosive expansion of the metal.

Carbon dioxide extinguishers. Carbon dioxide (CO_2) extinguishers can be used for Class A, Class B, and Class C fires, extinguishing the fire by depriving it of oxygen (Figure 13-2-2). Additionally, like water-type extinguishers, CO_2 cools the burning material. There are also some places not to use a CO_2 extinguisher.

- Never use CO_2 on Class D fires. As with water extinguishers, the cooling effect of CO_2 can cause an explosive expansion of the metal.
- When used, all parts of the CO_2 fire extinguisher can become extremely cold and will remain so for a short time after operation. Wear protective equipment or take other precautions to prevent cold injury (such as frostbite) from occurring.
- Extreme caution must be used when operating CO_2 fire extinguishers in closed or confined areas. Not only can the fire be deprived of oxygen, so too can the operators.
- CO_2 fire extinguishers generally use the self-expelling method of operation. This means that the CO_2 has sufficient pressure at normal operating pressure to expel itself. This pressure is held inside the container by some type of seal or frangible disk, which is broken or punctured by a firing mechanism, usually a pin. This means that once the seal or disk is broken, pressure in the container is released, and the fire extinguisher is spent, requiring replacement (Table 13-2-1).
- Using CO_2 on Class A fires may disperse the burning materials and spread the fire.

Halogenated hydrocarbon extinguishers. While most effective on Class B and C fires, halogenated hydrocarbon (commonly called freon) extinguishers can be used on Class A and D fires. Halogenated hydrocarbon names start with the word *Halon* and end with a number.

- Carbon tetrachloride (*Halon 104*), chemical formula CCl_4, has an Underwriters' Laboratory (UL) toxicity rating of 3. As such, it is extremely toxic (Table 13-2-2). Hydrochloric acid vapor, chlorine, and phosgene gas are produced whenever carbon tetrachloride is used on ordinary fires. The amount of phosgene gas is increased whenever carbon tetrachloride

Figure 13-2-2. CO_2 fire extinguishers can be used on Class A, B, and C fires without creating contamination from the extinguishing medium.

Extinguishing materials	Class A fire	Class B fire	Class C fire	Class D fire	Self-generating	Self-expelling	Cartridge of N_2 cylinder	Stored pressure	Pump	Hand
Water and antifreeze	X						X	X	X	X
Soda-acid (water)	X				X					
Wetting agent	X						X			
Foam	X	X			X					
Loaded stream	X	X*					X	X		
Multipurpose dry chemical	X*	X	X				X	X		
Carbon dioxide		X*	X			X				
Dry chemical		X	X	X			X	X		
Bromotrifluoromethane-Halon 1301		X	X			X				
Bromochlorodifluormethane-Halon 1211		X	X					X		
Dry powder (metal fires)	X	X	X	X			X			X

*Smaller sizes of these extinguishers are not recognized for use on these classes of fires.

Table 13-2-1. Extinguisher operations and methods of expelling.

is brought in direct contact with hot metal, certain chemicals or continuing electrical arcs. It is not approved for any fire extinguishing use. Old containers of Halon 104 found in or around shops or hangars should be disposed of in accordance with Environmental Protection Agency (EPA) regulations and local laws and ordinances.

- Methyl bromide (*Halon 1001*), chemical formula CH_3Br, is a liquefied gas with a UL toxicity rating of 2. Effective but very toxic, it is corrosive to aluminum alloys, magnesium, and zinc. Halon 1001 is not recommended for aircraft use.
- Chlorobromomethane (*Halon 1011*), chemical formula CH_2ClBr, is a liquefied gas with a UL toxicity rating of 3. Like methyl bromide, Halon 1011 is not recommended for aircraft use (Table 13-2-2).
- Dibromodifluoromethane (*Halon 1202*), chemical formula CBr_2F_2, has a UL toxicity rating of 4. Halon 1202 is not recommended for aircraft use (Table 13-2-2).
- Bromochlorodifluoromethane (*Halon 1211*), chemical formula $CBrClF_2$, is a liquefied gas with a UL toxicity rating of 5. It is colorless, noncorrosive, and evaporates rapidly, leaving no residue whatsoever. It does not freeze or cause cold burns, and it will not harm fabrics, metals, or other materials it contacts. Halon 1211 acts rapidly on fires by producing a heavy blanketing mist that eliminates oxygen from the fire source. More importantly, it interferes chemically with the combustion process of the fire. It has outstanding properties in preventing reflash after the fire has been extinguished.
- Bromotrifluoromethane (*Halon 1301*), chemical formula CF_3Br, is a liquefied gas with a UL toxicity rating of 6. It has all the characteristics of Halon 1211. The significant difference between the two is that Halon 1211 forms a spray similar to CO_2, while Halon 1301 has a vapor spray that is more difficult to direct (Table 13-2-2).

NOTE: The Environmental Protection Agency (EPA) has restricted Halon to its 1986 production level because of its effect on the ozone layer.

Dry chemical extinguishers. These are most effective on Class B and Class C fires, and are the best for use on Class D fires (Figure 13-2-3).

Dry powder extinguishers. Different from dry chemical extinguishers, dry powder units are best on class D fires of burning metals.

NOTE: Dry chemical is not recommended for internal aircraft use as a fire extinguisher, because chemical residues and dust left by their use is often difficult to clean up and can cause damage to electronics or other delicate equipment. Use CO_2 instead.

Dry powder extinguishers are the best for extinguishing general shop fires, and especially for burning liquids.

Extinguisher operation. Before using the extinguisher, make sure your back is to an exit. Stand at least 6-8 ft. from the fire. Use the acronym P.A.S.S. (Pull, Aim, Squeeze, Sweep).

- PULL the pin: Hold the extinguisher with the nozzle pointing away from you and pull out the pin located below the handle. This unlocks the operating lever and allows you to discharge the extinguisher.
- AIM low: Aim the nozzle at the base of the fire.

Figure 13-2-3. Because dry chemical fire extinguishers may be used on Class B, C, and D fires, they are commonly carried on mobile equipment.

Group	Definition	Examples
6 (least toxic)	Gases or vapor which in concentrations up to at least 20% by volume for durations of exposure of the order of 2 hours do not appear to produce injury.	Bromotrifluoromethane (Halon 1301)
5a	Gases or vapors much less toxic than group 4 but more toxic than group 6.	Carbon dioxide, Bromochlorodifluoromethane (Halon 211)
4	Gases or vapors which in concentrations of the order of 2 to 2 1/2% for durations of exposure of the order of 1 hour are lethal or produce serious injury.	Dibromodifluoromethane (Halon 1202)
3	Gases or vapors which in concentrations of the order of 2 to 2 1/2% for durations of exposure of the order of 1 hour are lethal or produce serious injury.	Chlorobromomethane (Halon 1011), Carbon tetrachloride (Halon 104)
2	Gases or vapors which in concentrations of the order of 1/2 to 1% for durations of exposure of the order of 1/2 hour are lethal or produce serious injury.	Methyl bromide (Halon 1001)

Table 13-2-2 Toxicity table.

Figure 13-2-4. An airport fire crew undergoes training.

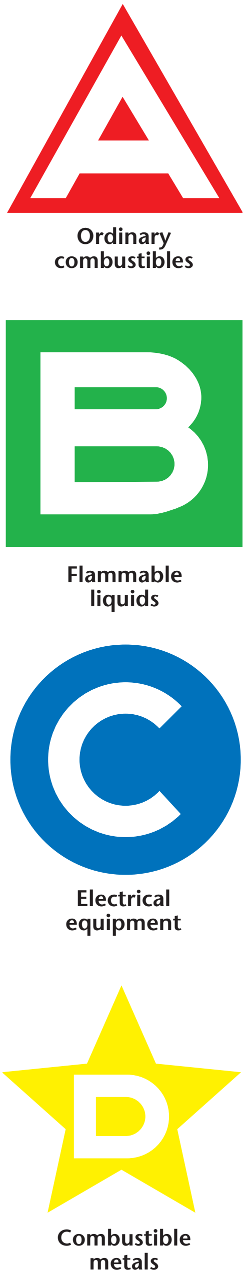


Figure 13-2-5. Fire extinguisher types are identified by standard symbols. The major symbol shows the fire class.

- SQUEEZE the lever: Squeeze slowly and evenly to release the extinguisher.

- SWEEP back and forth over the burning material: Make certain the entire surface area is being targeted. Keep watching the fire to ensure that it does not reignite.

NOTE: Make sure you don't blow burning papers out of wastebasket fires. Don't attempt to fight a fire that is too big—call the fire department (Figure 13-2-4).

Checking Fire Extinguishers

Fire extinguishers should be checked periodically. OSHA and fire regulations require it.

Airport or local fire departments can usually help maintain fire extinguishers. In addition, they can be helpful in answering questions and assisting in repairs to or replacement of fire extinguishers. Most businesses buy or rent extinguishers from a company specializing in fire equipment. Most provide an annual inspection service that not only maintains the extinguishers themselves, but also provides documentation in the form of equipment tags which state a record of the service.

Identifying Fire Extinguishers

Classification of Portable Fire Extinguishers

Portable fire extinguishers are classified to indicate their ability to handle specific classes and sizes of fires. Labels on extinguishers indicate the class and relative size of fire that they can be expected to handle. The following symbols are illustrated in Figure 13-2-5.

Class A. Class A extinguishers are used on fires involving ordinary combustibles, such as wood, cloth, and paper.

Class B. Class B extinguishers are used on fires involving liquids, greases, and gases.

Class C. Class C extinguishers are used on fires involving energized electrical equipment.

Class D. Class D extinguishers are used on fires involving metals such as magnesium, titanium, zirconium, sodium, and potassium.

Fire Extinguisher Marking

The OSHA-recommended marking system that indicates the extinguisher suitability according to class of fire is a pictorial concept that combines the uses and non-uses of extinguishers on a single label. This system is illustrated in Figure 13-2-6.

- The first row of symbols illustrated is from a label for use on a Class A extinguisher. The symbol at the left (which depicts a Class A fire) is blue. Since the extinguisher is not recommended for use on Class B or C fires, the remaining two symbols (which depict Class B/C fires) are black with a red line through them.

- The second set (row) of symbols illustrated is from a label for use on a Class A/B extinguisher. The two left symbols are blue. Since the extinguisher is not recommended for use on Class C fires, the symbol on the far right (which depicts a Class C fire) is black with a red line through it.

- The third set of symbols is from a label for use on Class B/C extinguishers. The two right symbols are blue. Since the extinguisher is not recommended for use on Class A fires, this symbol is black with a red line through it.
- The fourth set of symbols is a label for use on Class A/B/C extinguishers. All symbols on this label are blue.

Letter-shaped symbol markings are also used to indicate extinguisher suitability according to class of fire (Figure 13-2-5).

- Extinguishers suitable for Class A fires should be identified by a triangle containing the letter "A." If colored, the triangle should be green.
- Extinguishers suitable for Class B fires should be identified by a square containing the letter "B." If colored, the square will be colored red.
- Extinguishers suitable for Class C fires should be identified by a circle containing the letter "C." If colored, the circle should be colored blue.
- Extinguishers suitable for fires involving metals should be identified by a five-pointed star containing the letter "D." If colored, the star should be colored yellow.

Extinguishers suitable for more than one class of fire should be identified by multiple symbols placed in a horizontal sequence.

Numerical rating. Class A and Class B extinguishers carry a numerical rating to indicate how large a fire an experienced person can put out with the extinguisher. The ratings are based on reproducible physical tests conducted by Underwriters' Laboratories, Inc. Class C extinguishers have only a letter rating because there is no readily measurable quantity for Class C fires, which are essentially Class A or B fires involving energized electrical equipment. Class D extinguishers, likewise, do not have a numerical rating. Their effectiveness is described on the faceplate.

Class A ratings. An extinguisher for Class A fires could have any one of the following ratings: 1-A, 2-A, 3-A, 4-A, 6-A, 10-A, 20-A, 30-A, and 40-A. A 4-A extinguisher should extinguish about twice as much fire as a 2-A extinguisher.

Class B ratings. An extinguisher for Class B fires could have any one of the following ratings: 1-B, 2-B, 5-B, 10-B, 20-B, 30-B, 40-B, and on up to 640-B.

Figure 13-2-6. OSHA labels show how to define which extinguisher will work for what type of fire.

Class C ratings. Extinguishers rated for Class C fires are tested only for electrical conductivity. However, no extinguisher gets a Class C rating without a Class A and/or Class B rating.

Class D ratings. Class D extinguishers are tested on metal fires. The agent used depends on the metal for which the extinguisher was designed. Check the extinguisher faceplate for the unit's effectiveness on specific metals.

Section 3

Safety on the Flightline

The flightline is a place of dangerous activity. Technicians who work on the flightline must constantly be aware of what is going on around them.

Hearing Protection

The noise on a flightline comes from many places. The aircraft are only one source of noise. There are ground power units (GPUs), fuel trucks, baggage-handling equipment, etc. Each has its own frequency of sound. All ramp or flightline noise can cause serious hearing loss.

Types of protection available. There are many types of hearing protection available. Hearing protection can be external or internal. The external protection is the earmuff/headphone type. The internal type fits into the auditory canal. Both types will reduce the sound level reaching the eardrum and reduce the chances of hearing loss (Figure 13-3-1).

Figure 13-3-1. Three of the most popular types of hearing protectors.

Hearing protection should also be used when working with pneumatic drills, rivet guns, or

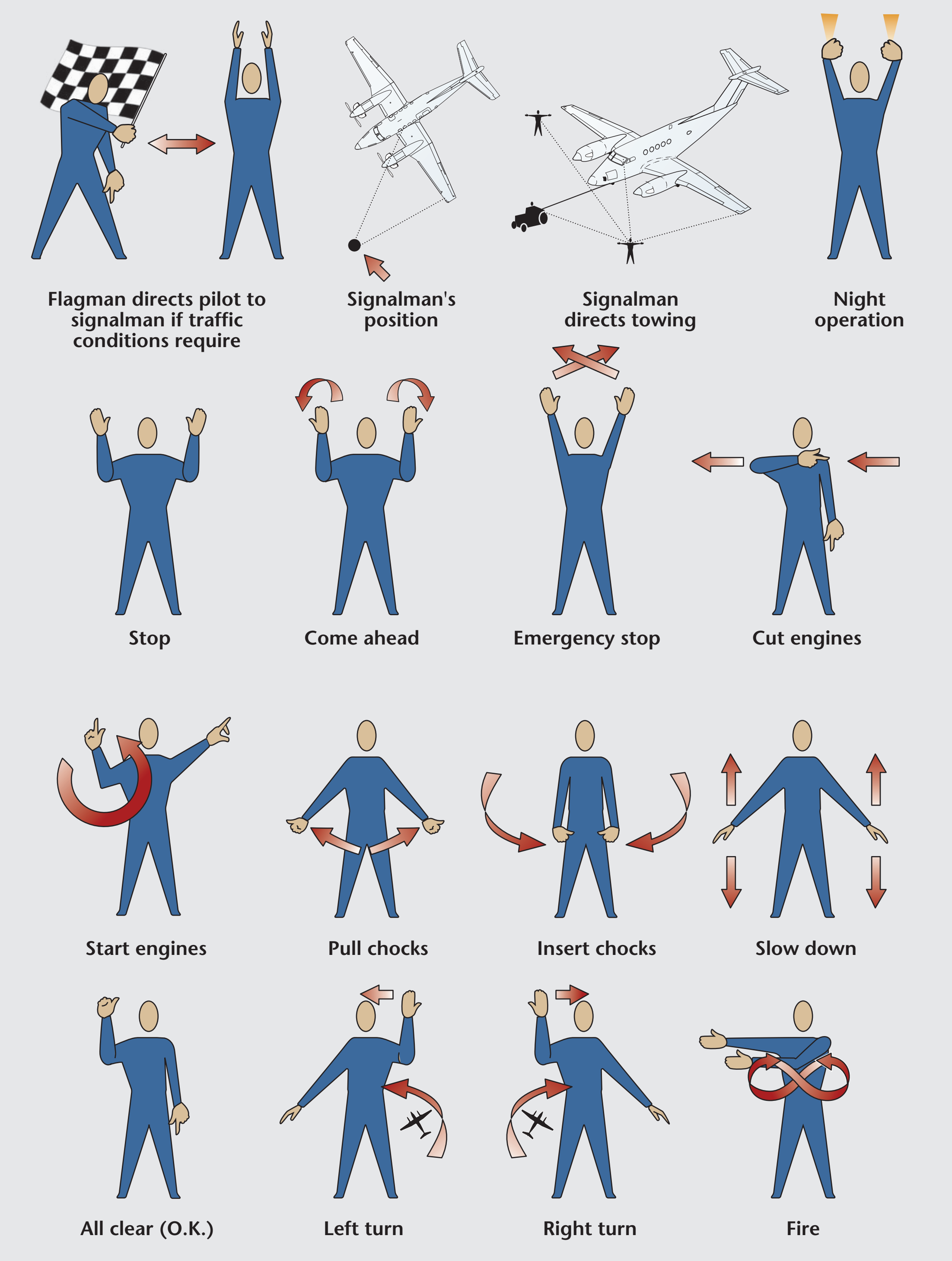


Figure 13-3-2. A standard set of aircraft hand signals.

other loud or noisy tools or machinery. Because of their high frequency, even short duration exposure to these sounds can cause a hearing loss. And continued exposure WILL cause hearing loss.

Foreign Object Damage (FOD)

Foreign Object Damage (FOD) is any damage to aircraft, personnel, or equipment caused by any loose object. These loose objects can be anything from broken runway concrete to rags, safety wire, and tools; and, in rare instances, mechanics.

FOD can be controlled by good housekeeping practices, a tool-control program, and by providing convenient receptacles for used hardware, rags, and other consumables.

The modern jet engine can create a low-pressure area in front of the engine that will cause

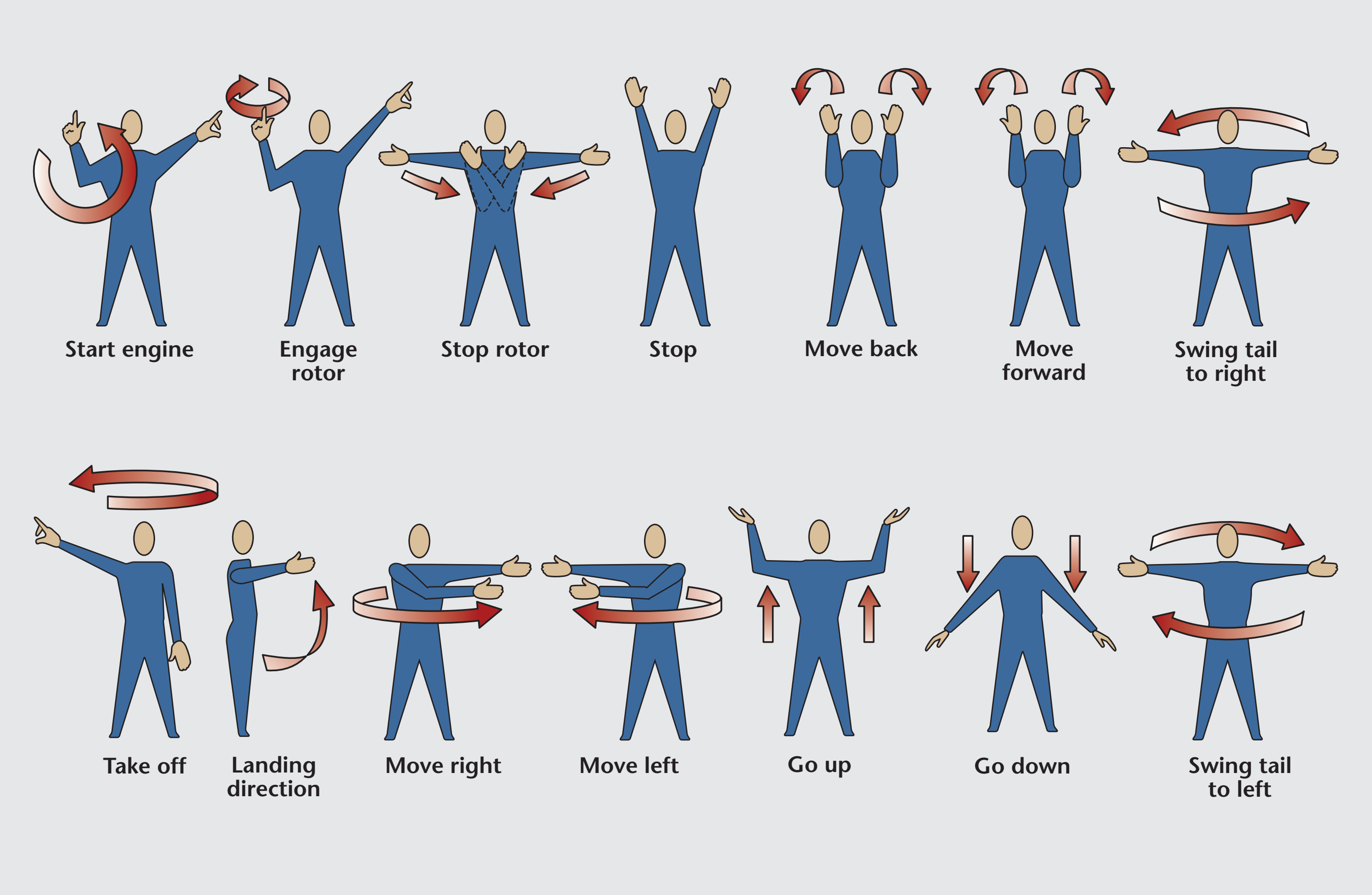


Figure 13-3-3. A standard set of helicopter hand signals.

any loose object to be drawn into the engine. The exhaust of these engines can propel loose objects great distances with enough force to damage anything hit.

The importance of an FOD program cannot be overstressed when considering the cost of engines, components, or the cost of a human life.

Safety Around Helicopters

Every type of helicopter has its own important differences. These differences must be learned to avoid damaging the helicopter or injuring the mechanic.

When approaching a helicopter while the blades are turning, observe the rotor head and blades to see if they are level. This will allow the maximum clearance while you approach the helicopter.

- Approach the helicopter in view of the pilot.
- Never approach a helicopter carrying anything with a vertical height that could be hit by the blades. This could cause damage to the blades or injury to you.
- Never approach a helicopter directly from the front. The blades/rotor head is designed for the greatest amount of "down traveler" in the front.
- Never approach a single-rotor helicopter from the rear. The tail rotor is invisible when operating.
- Never go from one side of the helicopter to the other by going around the tail. Always go around the nose of the helicopter.

When securing the rotor on some helicopters with elastomeric bearings, check the maintenance manual (MM) for the proper method. Using the wrong method could damage the bearings.

Hand Signals

Because of the difficulty in seeing from the cockpit and not being able to hear instructions from ground personnel, a standard set of hand signals has evolved. They are shown in Figure 13-3-2, Figure 13-3-3, and Figure 13-3-4. It will pay you to learn the most common ones and not improvise and make up your own. If you don't use the standard signals, no one else will know what you are doing. Some of the signals will be rarely used; the obvious ones will be used frequently.

Figure 13-3-4. Ground handling personnel directing a helicopter approach.

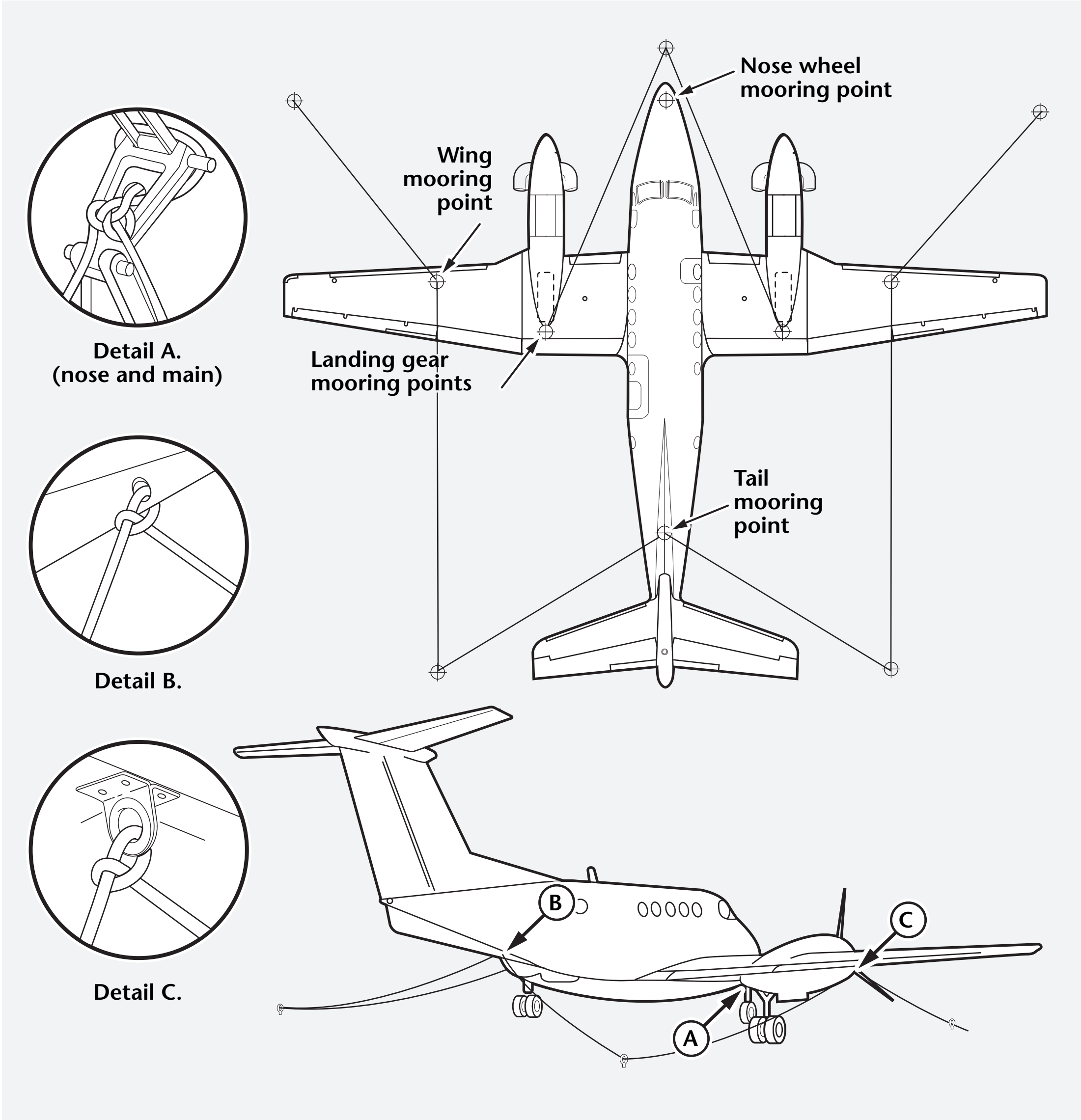
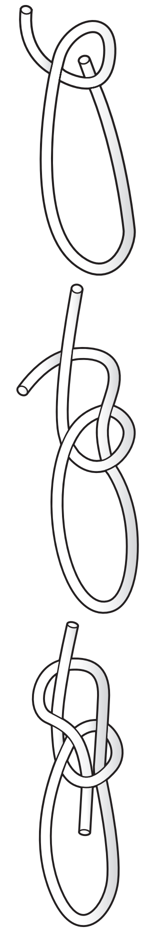
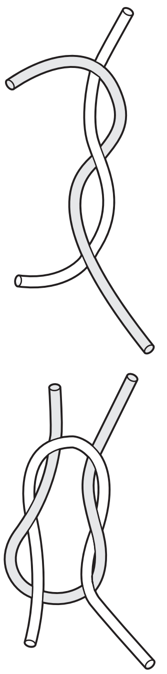


Figure 13-4-1. The manufacturer-recommended tiedown method for a Beechcraft King Air 200.



Tying a bowline knot



Tying a square knot

Figure 13-4-2. The most popular knot to use for tiedowns is the bowline.

Section 4

Tiedown Procedures

Preparation of Aircraft

Aircraft should be tied down after each flight to prevent damage from sudden storms. The direction in which aircraft are to be parked and tied down should be determined by prevailing winds or forecast wind direction.

Aircraft should be headed, as nearly as possible, into the wind, depending on the locations of the parking area's fixed tiedown points. Spacing of tiedowns should allow for ample wingtip clearance as illustrated in Figure 13-4-1. After the aircraft is properly located, lock the nosewheel or the tailwheel in the fore and aft position.

Land Planes

Securing light aircraft. Light aircraft are most often secured with ropes tied only at the aircraft tiedown rings. Rope should never be tied to a lift strut, since this practice can bend a strut if the rope slips to a point where there is no slack. Manila rope shrinks when wet, so about 1 inch of slack should be provided for movement. For this reason, nylon or Dacron® ropes are preferred for tying down aircraft to the manila because they are stronger and do not shrink when wet. Too much slack will allow the aircraft to jerk against the ropes. Tight tiedown ropes put inverted flight stresses on the aircraft, many of which are not designed to take such loads.

A tiedown rope holds no better than the knot. Antislip knots such as the *bowline* are quickly tied and are easy to untie (Figure 13-4-2). Learn how to tie a bowline knot. Aircraft not equipped with tiedown fittings should be secured in accordance with the manufacturer's instructions. Ropes should not be tied to outer ends of struts on high-wing monoplanes, and suitable rings should be provided where structural conditions permit, if the manufacturer has not already provided them.

For many reasons, most permanent tiedowns on airport parking areas use chains (Figure 13-4-3). They should be connected without excess slack, but not under tension. Too much slack and a high wind will make the airplane jerk against the slack. Chain makes the best tiedown because there is seldom a problem with deterioration, there are no shrinkage or slack requirements, and they are strong. Also, in the long run, chain costs less.

Securing heavy aircraft. The normal tiedown procedure for heavy aircraft can be accomplished with rope or cable tiedown. The number of such tiedowns should be governed by anticipated weather conditions.

Most heavy aircraft are equipped with surface-control locks, which should be engaged or installed when the aircraft is secured. Since the method of locking controls vary on different types of aircraft, check the manufacturer's instructions for proper installation or engaging procedures. If high winds are anticipated, control-surface battens can also be installed to prevent damage. The normal tiedown procedure for heavy aircraft should generally include the following:

- Head airplane into prevailing winds whenever possible.
- Install control locks, all covers, and guards.
- Chock all wheels fore and aft.

Figure 13-4-3. Properly connected, chain makes the best tiedown lead.

- Attach tiedown reels to airplane tiedown loops and to tiedown anchors or tiedown stakes. Use tiedown stakes for temporary tiedown only. If tiedown reels are not available, 1/4 inch wire cable or 1-1/2 inch manila line may be used.

Other Types of Aircraft

Seaplane mooring. Seaplanes can be moored to a buoy, weather permitting, or tied to a dock. Weather causes wave action, and waves will cause the seaplane to bob and roll. This bobbing and rolling while tied to a dock can cause damage.

When warning of an impending storm is received and it is not possible to fly the aircraft out of the storm area, some compartments of the seaplane can be flooded, partially sinking the aircraft. In addition, the aircraft should be tied down securely to anchors. Seaplanes tied down on land have been saved from high-wind damage by filling the floats with water, in addition to tying the aircraft down in the usual manner.

During heavy weather, if possible, remove the seaplane from the water and tie down in the same manner as a land plane. If this is not possible, the seaplane could be anchored in a sheltered area away from wind and waves.

Ski-equipped airplanes. Ski planes are tied down, if the securing means are available, in the same manner as land planes.

Ski-equipped airplanes can be secured on ice or in snow by using a device called a deadman. A deadman (Figure 13-4-4) is any item at hand (such as a piece of pipe, log, etc.) that a rope can be attached to and buried in a snow or ice

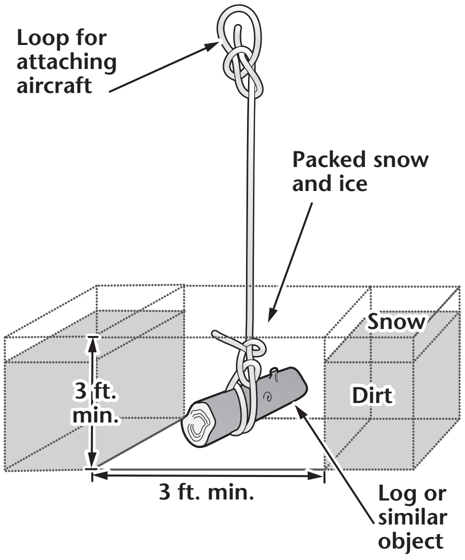


Figure 13-4-4. When tying down a ski-equipped airplane at an off-airport site, it is preferable to use earth anchors.

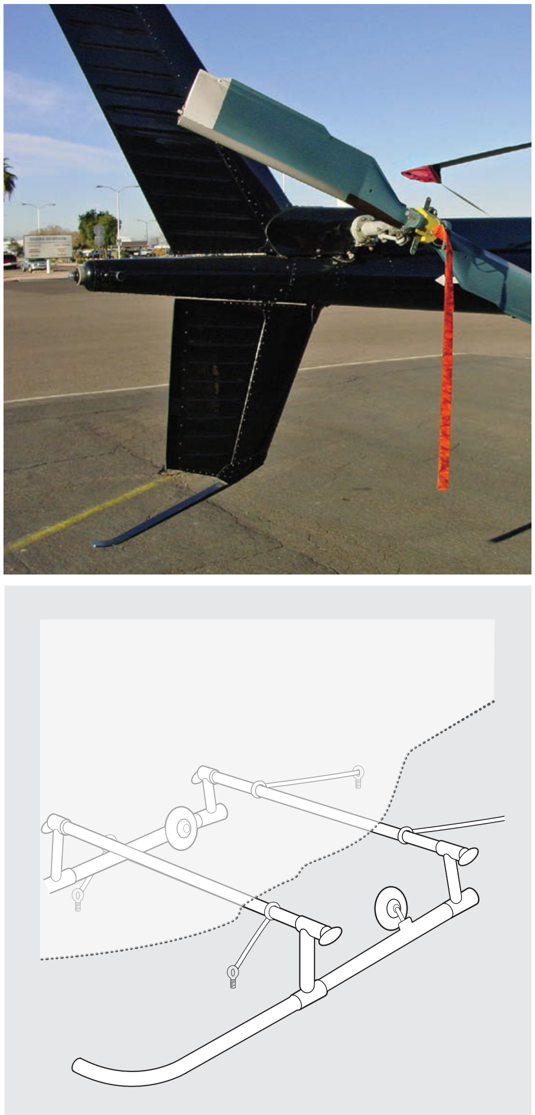


Figure 13-4-5. The photo shows a helicopter's rotor tied to the tail, while the bottom illustration demonstrates one method of securing a helicopter's landing skid to the ground.

trench. Using caution to keep the free end of the rope dry and unfrozen, snow is packed in the trench. If water is available, pour water into the trench; when it is frozen, tie down the aircraft with the free end of the rope.

While a deadman can be used in warm weather, the hole must be deeper. In frozen ground, the hole can be refilled with the dirt removed and a bucket of water poured over it. Refreezing will anchor it solid.

Operators of ski-equipped aircraft sometimes pack soft snow around the skis, pour water on the snow, and permit the skis to freeze to the ice. This, in addition to the usual tiedown procedures, aids in preventing damage from windstorms. Caution must be used when moving an aircraft that has been secured in this manner to ensure that a ski is not still frozen to the ground. Otherwise, damage to the aircraft or skis can occur.

Helicopters. Like other aircraft, helicopters are secured to prevent structural damage, which can occur from high-velocity surface winds.

Helicopters should be secured in hangars when possible. Otherwise, they should be tied down securely. Helicopters that are tied down can usually sustain winds up to approximately 65 m.p.h. If at all possible, helicopters should be evacuated to a safe area if tornadoes or hurricanes are anticipated.

For added protection, helicopters should be moved to a clear area so that they will not be damaged by flying objects or falling limbs from surrounding trees.

If high winds are anticipated with the helicopter parked in the open, the main rotor blades should be tied down. Detailed instructions for securing and mooring each type of helicopter can be found in the applicable MM. Methods of securing helicopters will vary with weather conditions, the length of time the aircraft is expected to remain on the ground, location, and characteristics of the aircraft. Wheel chocks, control locks, rope tiedowns, mooring covers, tip socks, tiedown assemblies, parking brakes, and rotor brakes are used to secure helicopters.

Typical mooring procedures are as follows:

- Face the helicopter in the direction from which the highest forecasted wind or gusts are anticipated.
- Spot the helicopter slightly more than one rotor-span distance from other aircraft.
- Place wheel chocks ahead of and behind all wheels (where applicable). On helicopters equipped with skids, retract the ground-handling wheels, lower the helicopter to rest on the skids, and install wheel position lockpins or remove the ground-handling wheels. Ground-handling wheels should be secured inside the aircraft or inside the hangar or storage buildings. Do not leave them unsecured on the flightline.
- Align blades and install tiedown assemblies as prescribed by the manufacturer of the helicopter. An example can be seen in Figure 13-4-5. Tie straps snugly without strain, and during wet weather provide some slack to avoid the possibility of the straps shrinking, causing undue stresses on the aircraft and/or its rotor system(s).
- Fasten the tiedown ropes or cables to the forward and aft landing-gear cross tubes and secure to ground stakes or tiedown rings.

Section 5

Jacking and Hoisting

The aviation technician must be familiar with the jacking of aircraft in order to perform maintenance and inspection. Since jacking procedures and safety precautions vary for different types of aircraft, only general jacking procedures and precautions are discussed in this section. Consult the applicable aircraft manufacturer's maintenance instructions for specific jacking procedures.

> **CAUTION:** Extensive aircraft damage and serious personal injury have resulted from careless or improper jacking or hoisting procedures. As an added safety measure, all equipment should be inspected prior to use to determine the specific lifting capacity, proper functioning of safety devices, condition of pins and locks, and general serviceability.

Before hoisting or raising an aircraft on jacks, all workstands and other nonessential equipment should be removed from under or near the aircraft. No one should remain in the aircraft while it is being raised or lowered, unless MM procedures require such practice for observing leveling instruments in the aircraft.

Jacking

The *jacking* of an aircraft starts with the selection of the proper capacity and type of jack. The selection of a jack with just enough capacity to do the job will cause the jack to support close to its maximum capacity. This does not leave the technician, who is under the aircraft, a safety margin.

Check the selected jacks for proper servicing, leaks, or deteriorated hoses or fittings. Open the vent and operate the jack so the ram is fully extended, then release the pressure and let the ram completely down. This checks the jack through a complete operating cycle and indicates if there are any problems with the jack.

Check the maintenance and service manuals of the aircraft for the proper methods to use and for any special precautions to take before or while jacking the aircraft.

The following general precautions should be observed when raising an aircraft on jacks:

- Jack up the aircraft inside the hangar, if possible.
- Jack on a level surface.
- Check maintenance/service manuals for precautions.
- Operate jacks slowly, and raise the aircraft evenly.
- Use the jack's safety/lock features.
- Check before jacking to see that the aircraft will not be raised into anything.
- Before lowering the aircraft, check to see if anything has been left or moved under the aircraft.

After lowering the aircraft, remove the jacks. Use extreme caution during jack removal, because if the aircraft has oleo/shock struts, they may bind, giving the impression that the aircraft is firmly back on the ground. The binding struts can often support the weight of the aircraft for quite some time or, more often, until some change or movement of the aircraft causes them to break free. When the struts do break free, the aircraft may drop the distance of the strut travel, which can be several inches. This drop can occur either after or during jack removal.

Single-wheel jacking for brake or tire servicing is conducted using a low, single-base jack similar to the one shown in Figure 13-5-1. Before the wheel is raised, the remaining wheels must be chocked fore and aft to prevent movement of the aircraft. If the aircraft is equipped with a tailwheel, it must be locked. The wheel should

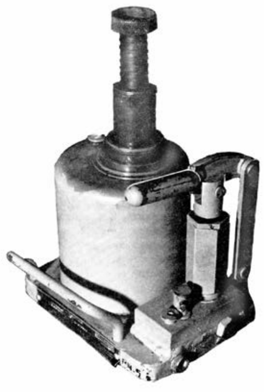


Figure 13-5-1. A low single-base jack is best for raising a single-gear leg.

Figure 13-5-2. Many aircraft with an oleo-type strut have jack pads that insert into the hollow axle.

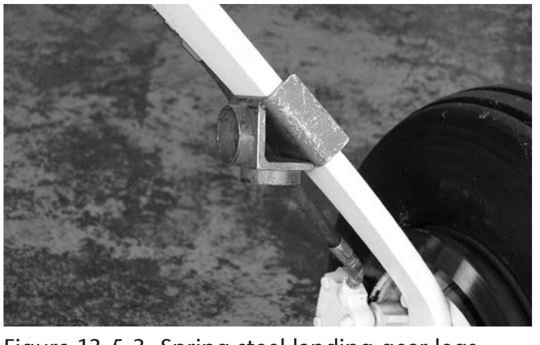


Figure 13-5-3. Spring steel landing gear legs must have special adaptors to allow jacking.

Figure 13-5-4. Tripod jacks are used to lift complete aircraft when gear retraction tests are required.

be raised only high enough to clear the surface, except when changing a flat tire. Remember that the inflated tire to be installed will require more room than the flat tire needs to be removed. Figure 13-5-2 shows an oleo-type strut that has jack pads that insert into the hollow axle. Figure 13-5-3 shows a jack pad for a spring-steel landing gear leg.

Gear-retraction tests. For retraction tests and landing-gear service, the entire aircraft must be jacked. Prior to jacking the aircraft, an overall survey of the complete situation should be made to determine if any hazards to the aircraft or personnel exist.

Tripod jacks of the appropriate size for the aircraft being jacked should be placed under the aircraft jacking points and perfectly centered to prevent them from cocking while the aircraft is being raised. Figure 13-5-4 shows an example of tripod jacks in use. The legs of the jacks should be checked to see that they will not interfere with the operations to be performed after the aircraft is jacked, such as retracting the landing gear.

At least three places or points are provided on aircraft for jacking purposes. A fourth jacking point on some aircraft is used to stabilize the aircraft while it is being jacked at the other three points. The two main places are on the wings, with a smaller one on the fuselage near either the tail or the nose, depending on the landing gear design.

Figure 13-5-5. Two types of jack pads.

Most aircraft have jack pads located at the jack points. Others have removable jack pads that are inserted into receptacles bolted in place prior to jacking. The correct jack pad should be used in all cases. The function of the jack pad is to ensure that the aircraft load is properly distributed at the jack point and to provide a convex bearing surface to mate with the concave jack stem. Figure 13-5-5 illustrates two types of jack pads.

Prior to jacking, determine that the aircraft configuration will permit jacking. Certain equipment or fuel may need to be removed to prevent serious structural damage during jacking. If any other work is in progress on the aircraft, ascertain if any critical panels have been removed. On some aircraft, stress panels or plates must be installed to avoid structural damage when the aircraft is jacked.

Extend the jacks until they contact the jack pads. A final check for alignment of the jacks should be made before the aircraft is raised, since most accidents that occur during jacking are the result of improperly aligned jacks.

When jacking an aircraft, one trained person should be stationed at each jack. The jacks should be operated simultaneously to keep the aircraft as level as possible and to avoid overloading any of the jacks. This can be accomplished by having the crew leader stand in front of the aircraft and give instructions to the personnel operating the jacks.

Since the piston on many jacks can be raised beyond the safety point, a jack should never be raised any higher than is necessary to accomplish the job. The area around the aircraft should be secured while the aircraft is on jacks. This is often accomplished by roping off the area. Climbing on the aircraft should be held to an absolute minimum, and persons who are required to go aboard should make no violent movements. Any cradles or necessary supports should be placed under the fuselage or wings of the aircraft at the earliest possible time, particularly if the aircraft is to remain jacked for any length of time.

On jacks equipped with a collet-type locking device, the collet should be kept within two threads of the lift-tube cylinder during raising, and screwed down firmly to the cylinder to prevent settling when jacking is completed.

Before releasing jack pressure and lowering the aircraft, make certain that all cribbing, workstands, equipment, and persons are clear of the aircraft; that the landing gear is down and locked; and that all ground-locking devices are properly installed.

Hoisting. General hoisting procedures for aircraft are similar to the general procedures for jacking. Slings, clevis assemblies and other equipment should be thoroughly checked for defects before their use. The areas above, below, and around the aircraft should be clear of equipment, personnel, and anything that could damage or be damaged by the aircraft should contact be made.

No one should be in or on an aircraft being hoisted. Personnel not trained in hoisting and not involved in the hoisting operation should be kept clear of the area.

Follow the manufacturer's detailed instructions for hoisting. Each aircraft is hoisted in a different way, and it is therefore impossible to describe one all-encompassing way to hoist aircraft.

Hoisting is an extremely dangerous operation that can result in the damage or destruction of the aircraft. Serious injury or death to the personnel involved in the operation is possible if the procedures recommended by the manufacturer are not carefully followed.

Air bags. Large aircraft can be difficult, if not impossible, to hoist. Most larger airports, especially those with on-site fire departments or rescue squads, use a system of inflatable air bags to lift an airplane. The bags are placed under the appropriate sections of the wings and/or fuselage, then inflated. As the pressure inside the bags builds, the airplane is safely lifted to the required height. The aircraft can then be placed on a low trailer, or if it had a gear-up landing, the gear can be lowered.

Section 6

Ground Movement of Aircraft

Movement of large aircraft on an airport and about the flightline and hangar is usually accomplished by towing with a tow tractor (sometimes called a *mule* or *tug*). Figure 13-6-1 shows a typical tow tractor.

There are several designs of small aircraft movers, such as the one shown in Figure 13-6-2, that can be operated by one person. These are principally for short-term use, such as taking an airplane in or out of a tee hangar. Normally, the pavement is striped with center lines to assist in getting the airplane centered in the hangar. Even then, you must be fairly cautious not to create some hangar rash by damaging a wingtip or tail surface.

Figure 13-6-1 A typical tow tractor.

Figure 13-6-2. Small-aircraft movers.

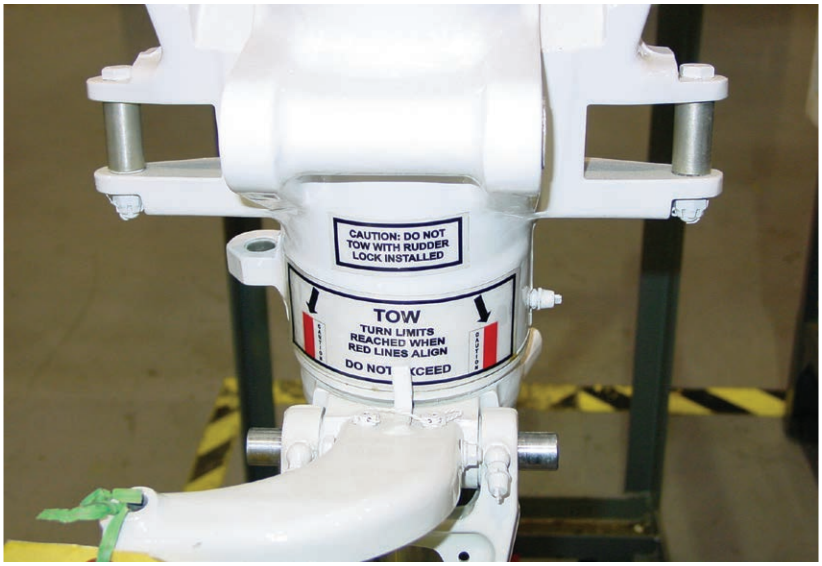


Figure 13-6-3. Tow limits are clearly marked on this King Air nose-gear strut.

Movement of small aircraft is most often accomplished by hand, by pushing on certain areas of the aircraft surface. Aircraft may also be taxied about the flightline, but this is usually only done by qualified persons.

Turning radius. Each airplane has a certain number of degrees the nose wheel may be turned without damaging the nose-wheel strut. They are normally marked where the tug operator can watch them (Figure 13-6-3.) Exceeding the tow limits will damage the structure of the aircraft.

Taxiing

As a general rule, only rated pilots and qualified airframe and powerplant technicians are authorized to start, run-up, and taxi aircraft. Many airports require contacting ground control by radio before the airplane can be moved. All taxiing operations should be performed in accordance with applicable airport regulations.

Tower light signals. Any FAA control tower can use a light gun to direct traffic. When moving an airplane on the ground, the tower can guide you with the three-colored signal light. Table 13-6-1 shows the possible light signals from the towers, along with their meanings.

To be qualified to taxi aircraft, the technician who is not also a pilot should first become familiar with the contents of the Airman's Information Manual and the operator's manual(s) of the aircraft that are to be taxied. Then the technician should be checked-out by a certified flight instructor (CFI).

CAUTION: Before taxiing any airplane, first check the brakes.

Taxiing in the wind. There is always the danger of a wind gust getting under a surface and flipping a small airplane. You can minimize the risk by moving the control surfaces. When going downwind, shove the control forward; pressure on top of the elevators helps keep the tail down. Going upwind, keep the controls in neutral with a nosewheel airplane, back with a tailwheel airplane. When going downwind, move the aileron control away from the wind. In a headwind, move the aileron control toward the wind.

CAUTION: Taxiing a tail wheel aircraft requires extra care since the fuselage will try to weathervane in a cross wind condition and can lead to a serious accident.

Towing

Towing aircraft can be a hazardous operation, causing damage to the aircraft and injury to personnel if done recklessly or carelessly. While the following paragraphs outline the general procedure for towing aircraft, specific instructions for each model of aircraft are detailed in the manufacturer's maintenance instructions, and should be carefully followed.

Operator training. Operators of equipment used to tow aircraft should be trained and, if required by local law or ordinance, licensed. Inexperienced operators should be closely

Light signals		
Color and type of signal	On the ground	In flight
Steady green	Cleared for takeoff	Cleared to land
Flashing green	Cleared to taxi	Return for landing
Steady red	Stop	Give way, continue circling
Flashing red	Taxi clear of the runway	Do not land
Flashing white	Return to airport starting point	Not used
Alternating red and green	Use caution	Use extreme caution

Table 13-6-1. FAA control tower light signals.

supervised. The towing vehicle driver is responsible for operating the vehicle in a safe manner and obeying emergency stop instructions given by any team member.

In addition to the operator of towing equipment, one qualified person must be in the cockpit to operate the brakes in case the tow bar should fail or become unhooked. The aircraft can then be stopped, preventing possible damage. This person should be familiar with the operation of the aircraft braking system and other aircraft systems that must be activated or operated during towing, such as nosewheel steering disable, setting of flight controls, etc.

Wingwalkers. Additional personnel should be assigned by the person in charge, and should be positioned to observe wingtips and tails, rotor blades, empennage, etc., for clearance of obstacles, structures, and other aircraft. In addition to being in a position to see tips and tails, these *wingwalkers* should also be able to see and communicate with the driver of the towing vehicle or other person in charge of the towing operation.

The person in charge of the towing operation should verify that, on aircraft with a steerable nosewheel, the locking scissors are set to full-swivel for towing. The locking device must be reset after the tow bar has been removed from the aircraft. Persons stationed in the aircraft should not attempt to steer or turn the nosewheel when the tow bar is attached to the aircraft.

When stopping either a nosewheel or tailwheel airplane, always leave them pointed straight ahead with the steering system engaged.

Safety during towing. The speed of the towing operation should, as a general rule of thumb, be no greater than a comfortable walking speed for the wingwalkers.

Extreme caution should be exercised during towing, especially inside hangars and in congested areas where contact with other aircraft or structures is most likely.

No one should be permitted to either walk or ride between the nosewheel of an aircraft and the towing vehicle, nor ride on the outside of a moving aircraft or on the towing vehicle. In the interest of safety, no attempt to board or leave a moving aircraft or towing vehicle should be permitted.

Chocks should be immediately available in case of an emergency during a towing operation.

Sudden starting and stopping should be avoided when moving aircraft. For added safety,

Figure 13-7-1. Benchtop-size APU supplies filtered DC to the airplane's ground power plug.

aircraft brakes must never be applied during towing except in emergencies, and then only upon command by the team leader.

After towing, ensure the following to complete the operation:

- Wheel chocks should be placed fore and aft of the main landing gear of the parked aircraft.
- Internal or external control locks (gust locks or blocks) should be installed.
- Aircraft parked inside hangars should be immediately statically grounded.
- Aircraft parked outside (except those being prepared for flight) should be tied down in accordance with manufacturer's specifications and local policy.

Section 7

Ground-Servicing Equipment

Auxiliary Power Equipment

Ground-support electrical auxiliary power units. Ground power units (GPU) vary widely in size and type. However, they can be generally classified as either towed or self-propelled.

The towed power units vary in size and range of available power. The smallest units may simply be high-capacity batteries used to start light aircraft. These units are normally mounted on wheels or skids and are equipped with an extra-long electrical line terminated in a suitable plug-in adapter. Some small units are portable power units that supply filtered DC to the airplane's ground-power plug (Figure 13-7-1).

Larger units are equipped with engine-driven generators. Providing a wider range of output power, these power units are normally designed to supply constant-current, variable-voltage DC electrical power for starting jet aircraft engines, and constant-voltage DC for starting reciprocating aircraft engines. Normally somewhat top-heavy, large towed power units should be towed at restricted speeds, and sharp turns should be avoided.

When using a ground electrical power unit, it is important to position the unit to prevent collision with the aircraft being serviced or others nearby, in the event the brakes on the unit fail. It should be parked so that the service cable is extended to nearly its full length away from the aircraft being serviced, but not so far that the cable is stretched or undue stress is placed on the aircraft's electrical receptacle.

Hydraulic power units. Portable hydraulic test stands, or mules, (Figure 13-7-2) are manufactured in many size and cost ranges. Some have a limited range of operation, while others can be used to perform all the system tests that fixed shop test stands are designed for.

Because they operate at pressures of 3,000 p.s.i. or more, extreme caution must be taken when using hydraulic power units. At 3,000 p.s.i., a small stream from a leak can cut like a sharp knife. Therefore, lines used with the system should be inspected for cuts, frays, or any other damage and kept free of kinks and twists. When not in use, hydraulic power unit lines should be stored (preferably wound on a reel) and kept clean, dry, and free of contaminants.

Figure 13-7-2. Portable hydraulic test stand.

Oxygen Servicing Equipment

Oxygen used on aircraft is available in three types: gaseous, liquid, and solid. The type to use on any specific aircraft depends on the type of equipment in the aircraft. Gaseous oxygen is stored in large steel cylinders. Solid oxygen is produced by an *oxygen generator*, which consists of a chemical compound that, when ignited by a percussion cap, burns and releases pure oxygen gas. An oxygen generator is used on airline equipment as an emergency oxygen supply. Because an oxygen generator is classified as a pyrotechnic device, it has special handling requirements. Understand all handling and storage procedures for solid-oxygen generators before any servicing is attempted. Liquid oxygen (LOX) is stored and converted into a usable gas in a liquid oxygen converter. It is used principally in military airplanes.

Before servicing any aircraft, consult the specific aircraft MM to determine the proper type of servicing equipment to be used.

Two personnel are required to service an aircraft with gaseous oxygen. One person should be stationed at the control valves of the servicing equipment, and one person should be stationed where they can observe the pressure in the aircraft system. Communication between the two people is required in case of an emergency. Figure 13-7-3 shows a typical gaseous oxygen service cart.

Aircraft should not be serviced with oxygen during fueling, de-fueling, or other maintenance work that could provide a source of ignition. Oxygen servicing of aircraft should be accomplished outside hangars.

Gaseous oxygen is chemically stable and is non-flammable. However, combustible materials ignite more rapidly and burn with greater intensity in an oxygen-rich atmosphere. In addition, oxygen combines with oil, grease, or bituminous material to form a highly explosive mixture that is sensitive to compression or impact. Physical damage to, or failure of, oxygen containers, valves, or plumbing can result in an explosive rupture. It is imperative that the highest standard of housekeeping is observed in handling oxygen and that only qualified and authorized persons be permitted to service aircraft gaseous oxygen systems.

In addition to aggravating the fire hazard, because of its low temperature (it boils at -297°F (-183°C)), liquid oxygen causes severe burns (frostbite) if it comes in contact with the skin.

Figure 13-7-3. O_2 service cart.

Types of oxygen. Oxygen is commercially available in three general types: aviator's breathing, industrial, and medical.

Only oxygen marked *Aviator's Breathing Oxygen*, which meets Federal Specification BB-0-925A, Grade A, or its equivalent should be used in aircraft breathing-oxygen systems.

Industrial oxygen may contain impurities that could cause the pilot, crew and/or passengers to become sick.

Medical oxygen, although pure, contains water, which can freeze in the cold temperatures found at the altitudes where in-flight oxygen is necessary. It must not be used in aircraft systems.

Many gaseous oxygen suppliers only handle aviator's breathing oxygen. It simplifies their production, storage, and delivery of bottled oxygen. You do, however, need to be sure the bottles are labeled correctly. If you use a bottle labeled *medical oxygen*, even though it is the same quality as aviator's breathing oxygen, you could be violating a FAR.

Section 8

Aircraft Fueling

Types of Fuel

Two types of aviation fuel in general use are: aviation gasoline, also known as *AVGAS*, and turbine fuel, also known as *jet fuel*.

Aviation gasoline (AVGAS). AVGAS is used in reciprocating engine aircraft. Currently there are three grades of fuel: 80/87, 100/130, and 100LL (Low Lead). A fourth grade, 115/145, was in limited use in large reciprocating engine aircraft but is no longer available.

The two numbers indicate the lean mixture and rich mixture octane-rating numbers of the specific fuel. In other words, with 80/87 aviation gasoline, the 80 is the lean-mixture rating and 87 is the rich-mixture rating number. To avoid confusing the types of AVGAS, it is generally identified as grade 80, 100, 100LL, or 115. AVGAS can also be identified by a color code (Table 13-8-1). The color of the fuel should match the color band on piping and fueling equipment. For practical purposes, 100LL is the current fuel of choice. Often, that is all that is available.

Common additives to aviation gasoline are tetraethyl lead and ethylene dibromide. Tetraethyl lead is added to aviation gasoline to improve the gasoline's performance in the engine. Ethylene dibromide is mixed with the gasoline to help scavenge lead residue in the combustion chambers.

Jet fuel. Turbine fuel/jet fuel is used to power turbofan and turboshaft engines. Even though gasoline and kerosene can be used as jet fuel, kerosene is the preferred choice because it has a higher heat energy value per unit volume than gasoline. Three types of jet fuel generally used in civilian aviation are Jet A and Jet A-1, which are made from kerosene, and Jet B, which is a blend of kerosene and aviation gasoline. While jet fuel is identified by the color black on piping and fueling equipment, the actual color of jet fuel can be clear or straw-colored.

Misfueling. *AVGAS and jet fuel should never be mixed.* Adding jet fuel to AVGAS will cause a decrease in the power developed by the engine and could cause damage to the engine and loss of life. Adding AVGAS to jet fuel will cause lead deposits in the turbine engine and can lead to reduced service life.

Fire hazards. The volatility of aviation fuels creates a fire hazard that has plagued aviators and aviation engine designers since the beginning of powered flight. Volatility is the ability

Fuel grade color code	
Color	**Grade**
Red	80
Green	100
Blue	100LL
Purple	115

Table 13-8-1. Aircraft fuel is identified by its color. The colored die helps eliminate misfueling.

of a liquid to change into a gas at a relatively low temperature. In its liquid state, aviation fuel will not burn. It is, therefore, the vapors, or gaseous state to which the liquid fuel changes, that is not only useful in powering the aircraft, but also a fire hazard.

Static electricity is a by-product of one substance rubbing against another. Fuel flowing through a fuel line causes a certain amount of static electricity. The greatest static electricity concern around aircraft is that during flight, the aircraft moving through the air causes static electricity to build in the airframe. If that static electricity is not dissipated prior to refueling, the static electricity in the airframe will try to return to ground through the fuel line. The spark caused by the static electricity can ignite any vaporized fuel.

Fuel Contamination

Contamination is anything in the fuel that is not supposed to be there. The types of contamination found in aviation fuel include water, solids, and microbial growths.

Contamination control. The control of contamination in aviation fuel is extremely important, since contamination can lead to engine failure and the loss of life.

The best method of controlling contamination is to prevent its introduction into the fuel system. Some forms of contamination will still occur inside the fuel system. Either way, the filter, separators, and screens should remove most of the contamination.

Most FBOs have fuel handling procedures in place that minimize contamination. The standards are very exacting, and specific procedures, including filter checks and filter changes, need to be followed carefully.

Water in Fuel

Water in aviation fuels will generally take two forms, *dissolved* (vapor) and *free*.

Dissolved water. The dissolved water is not a major problem until, as the temperature lowers, it becomes free water. This then poses the problem of ice crystals forming, clogging filters and other small orifices.

Free water. Free water can appear as *water slugs or entrained water*. Water slugs are concentrations of water. This is the water that is drained after fueling an aircraft or truck.

Entrained water. Entrained water is suspended water droplets. The droplets themselves may not be visible to the eye, but will give the fuel a cloudy look. The entrained water will settle out in time.

Solid Contaminants

Solid contaminants are insoluble in fuel. The more common types of contaminants are rust,

Figure 13-8-1. Pressure fueling system in use.

dirt, sand, gasket material, lint, and rags. The close tolerances of fuel controls and other fuel-related mechanisms can be damaged by particles as small as one-twentieth the diameter of a human hair.

Microbiological Growths

Microbiological growths are a problem in jet fuel. There are a number of varieties of micro-organisms that can live in the free water in jet fuel. Some variations of these organisms are airborne, others live in the soil. The aircraft fuel system becomes susceptible to the introduction of these organisms each time the aircraft is fueled.

The most favorable conditions for the growth of micro-organisms in the fuel are warm temperatures and the presence of iron oxide and mineral salts in the water. The effects of micro-organisms are:

- The formation of slime or sludge that can foul filters, separators, or fuel controls.
- Emulsification of the fuel.
- Creation of corrosive compounds and offensive odors.

The best way to prevent microbial growth is to keep the fuel dry.

Fueling Equipment

Aircraft fueling equipment normally takes on one of two forms: fuel trucks or hydrant systems.

Fuel trucks. Fuel truck types are determined more by their tank capacity than anything else. An AVGAS truck that may dispense 50 to 200 gallons at one refueling is generally a small, two-axle, gasoline-powered vehicle. Turbine and jet airplanes typically carry more fuel, therefore a fuel truck for a bigger craft must carry a larger tank, which means the truck itself is bigger, usually three axles, to reduce the weight distribution on the ramp pavement.

The dispensing equipment on each truck can be a complex mixture of valves, pipes, and filters. They normally require a thorough checkout before any new operator can be put in charge. How fuel is handled in a truck operation is part of the total fuel-quality program. Each FBO will have its own operating procedures and maintenance schedule.

Hydrant systems. Hydrant systems are normally used in airline-type operations where the total fuel delivered at each refueling is

Figure 13-8-2. Over-the-wing fueling.

quite large. So large, in fact, that bulk fuel is stored remotely and the hydrant is supplied by underground pipelines. Almost exclusively, they are equipped with pressure-point refueling connectors. No pressure refueling system can be operated without both the knowledge and experience of operating both the aircraft and the hydrant systems.

Fueling Procedures

The proper fueling of an aircraft is the responsibility of the owner/operator. This does not, however, relieve the person doing the fueling of the responsibility to use the correct type of fuel and safe fueling procedures. These procedures are illustrated in Figure 13-8-1 and Figure 13-8-2.

Prior to fueling, the person fueling should check the following:

- All aircraft electrical systems and electronic devices, including radar, should be turned off.
- Nothing should be carried in the shirt pockets. These items could fall into the fuel tanks.
- No flame-producing devices should be carried by anyone engaged in the fueling operation. A moment of carelessness could cause an accident.
- Ensure that the proper type and grade of fuel is used. Do not mix AVGAS and jet fuel. With the current size of the fuel nozzles, it is possible to put AVGAS in a jet, however, the jet-fuel nozzle will not fit in a reciprocating engine airplane.
- Ensure that all the sumps are drained.
- Wear eye protection.

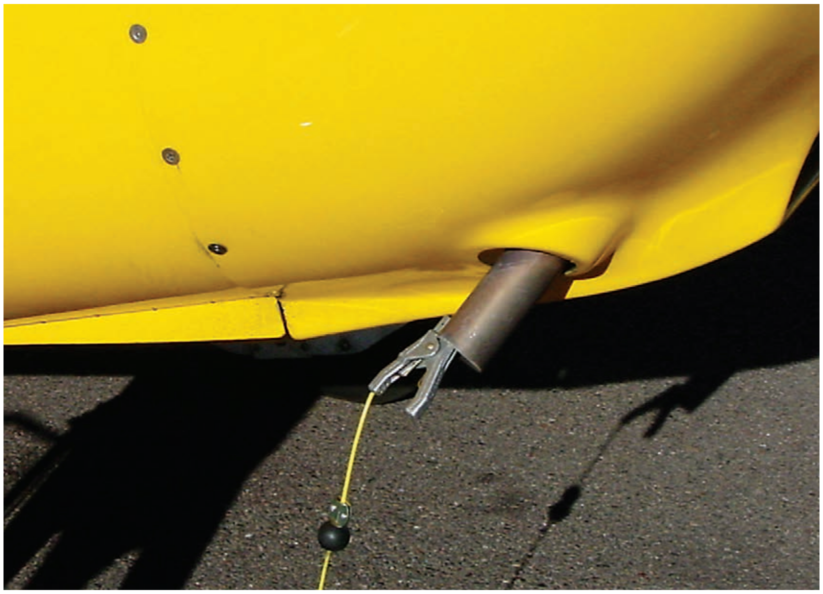


Figure 13-8-3. Do not use the engine exhaust or propeller as grounding points.

- Wear protective clothing. Although generally not as critical as eye protection, other forms of protection such as rubber gloves, aprons, etc., can protect the skin from the affects of spilled or splashed fuel.
- Do not fuel aircraft if there is danger of other aircraft in the vicinity blowing dirt in the direction of the aircraft being fueled. Blown dirt, dust or other contaminants can enter an open fuel tank, contaminating the entire contents of the tank.
- Do not fuel an aircraft when there is lightning within five miles.
- Do not fuel an aircraft within 500 feet of an operating ground radar.

When using mobile fueling equipment:

- Approach the aircraft with caution, positioning the fuel truck so that if it is necessary to depart quickly, no backing will be needed.
- Set the handbrake of the fuel truck and chock the wheels to prevent rolling.
- Ground the aircraft, then ground the truck. Next, ground or bond them together by running a connecting wire between the aircraft and the fuel truck. This can be done by three separate ground wires or by a Y cable from the fuel truck.
- Ensure that the grounds are in contact with bare metal or are in the proper grounding points on the aircraft. Do not use the engine exhaust or propeller as grounding points (Figure 13-8-3). Damage can result to the propeller, and there is no way of quickly ensuring a positive bond between the engine and the airframe.
- Ground the nozzle to the aircraft, then open the fuel tank.
- Protect the wing and any other item on the aircraft from damage caused by spilled fuel or careless handling of the nozzle, hose, or grounding wires.
- Check the fuel cap for proper installation and security before leaving the aircraft.
- Remove the grounding wires in the reverse order. If the aircraft is not going to be flown or moved soon, the aircraft ground wire can be left attached.

When fueling from pits or cabinets, follow the same procedures as when using a truck. Pits or cabinets are usually designed with permanent grounding, eliminating the need to ground the equipment. However, the aircraft still must be grounded, and then the equipment must be grounded to the aircraft as it was with mobile equipment.

De-fueling

De-fueling procedures will differ with different types of aircraft. Before de-fueling an aircraft, check the maintenance/service manual for specific procedures and cautions to be taken.

De-fueling can be accomplished by gravity or by pumping the fuel out of the tanks. When the gravity method is used, it is necessary to have a method of collecting the fuel. When the pumping method is used, care must be taken not to damage the tanks, and the removed fuel should not be mixed with good fuel.

Some precautions to be taken when de-fueling:

- Ground aircraft and de-fueling equipment.
- Turn off electrical and electronic equipment.
- Have the correct type of fire extinguisher available.
- Wear eye protection.
- Do not de-fuel inside the hangar.
- Be sure of the type of fuel being de-fueled from the aircraft to prevent contamination and to ensure proper disposal.

Section 9

Engine Starting Procedures

The following instructions cover the starting procedures for reciprocating, turboprop, and turbofan engines. These procedures are presented only as a general guide for familiarization with typical procedures and methods. Detailed instructions for starting a specific type of engine can be found in the manufacturer's instruction manuals. In addition, there are some pretty specific insurance company requirements on the training required by maintenance personnel before they can do run-ups.

At the very least, a thorough checkout by a certified fight instructor is a must. In the case of complex airplanes, a checkout for run-ups could be a multiple-day certification course. Frequently, a person certified to taxi a specific airplane may have to observe a student for several hours before the student can taxi solo.

The following procedures apply before starting any aircraft engine:

- Position the aircraft to head into the prevailing winds to ensure adequate airflow over the engine for cooling purposes.
- Ensure that all intake, exhaust, propeller rotation, and propeller wash areas are clear of personnel, equipment, and any object that could be drawn into or thrown by the engine or propeller.
- Be sure to remove intake covers, landing gear pins, pitot covers, ADA probe covers, and all other "red" gear.
- Make certain the tow bar is disconnected and removed from the propeller arc.
- If external electrical power is used for starting, make sure that it can be removed safely.
- During any and all starting procedures, a *fire guard*, equipped with a suitable fire extinguisher, should be stationed adjacent to the outboard side of the engine, in view of the pilot, where the engine and aircraft can be observed for indications of starting problems. If an engine fire does develop during the starting procedure, continue cranking to start the engine and blow out the fire. If the engine does not start and the fire continues to burn, discontinue the start attempt and the fire guard should extinguish the fire using a carbon monoxide extinguisher. The fire guard should be familiar with aircraft starting procedures and fire extinguisher operation.
- Once the engine is running, always test brakes prior to taxiing the aircraft. If the brakes do not work satisfactorily shut the engine down.

Reciprocating Engines

While the following procedures are typical of those used to start reciprocating engines, there are wide variations in the procedures for the many reciprocating engines. No attempt should be made to use the methods presented here for actually starting an engine. Instead, always refer to the procedures contained in the applicable manufacturer's instructions.

- Conduct a thorough preflight inspection.
- Fasten seatbelt and shoulder harness.
- Ensure that the cowl flaps (if installed) are fully open, landing gear lever is down (if retractable) and that all avionics, electrical equipment and radar (if so equipped) are turned off.
- All cockpit switches are off, safe, normal.
- Turn the master switch on. Anti-collision or navigation lights may be turned on at this time as an indication that the engine is about to be started.
- Ensure that fuel selector valves are positioned to provide fuel. Follow the manufacturer's recommendations and checklists to establish fuel for the start. Fuel pump operation, priming, and various other fuel scheduling operations normally take place at this point in the start procedures.
- Set the mixture lever to rich, propeller lever to high r.p.m. and the throttle to the recommended position.
- Clear the propeller area and activate the starter switch. As the engine begins to fire, advance the throttle slowly to the recommended position.
- Ensure that oil pressure is established as recommended by the manufacturer, and that voltage lights or ammeters indicate appropriately. If oil pressure remains at zero or is lower than the manufacturer's recommendation after approximately 30 seconds, shut down the engine and determine the cause.
- If an engine is flooded due to a non-start event, clear the engine of excessive fuel by the following: place the mixture control in the fuel shut-off position to shut off all fuel flow to the cylinder; turn the ignition off, open the throttle, and crank the engine with the starter or by hand until the

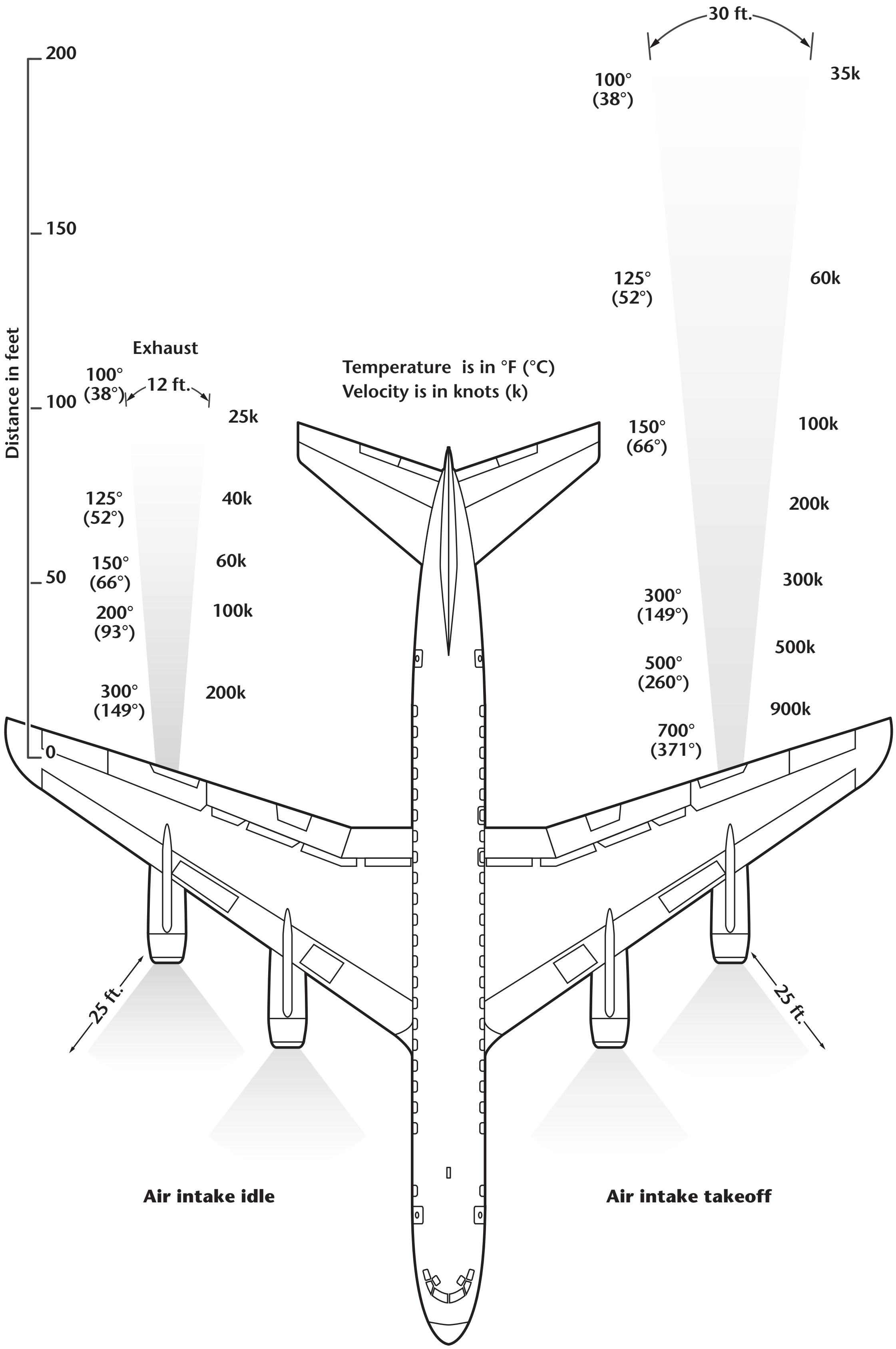


Figure 13-9-1. The turbine engine intake and exhaust hazard areas.

excessive fuel change in the cylinders has been cleared; repeat the starting procdure.

- Follow manufacturer's checklists for after-start procedures and shutdown procedures.
- Manufacturers publish emergency operations checklists, with which the operator hould be familiar before starting the engine.

Turbine Engines

Preflight operations for turbine-powered aircraft, like the reciprocating-engine aircraft, should begin with a thorough preflight examination of the aircraft.

- Before starting, all protective covers and air-inlet duct covers should be removed.
- The aircraft should be headed into the wind to obtain better cooling, faster starting, and smoother engine performance. It is especially important that the aircraft be headed into the wind if the engine is to be trimmed.
- The run-up area around the aircraft should be cleared of both personnel and loose equipment. The turbine engine intake and exhaust hazard areas are illustrated in Figure 13-9-1. Care should also be taken to ensure that the run-up area is clear of all items such as nuts, bolts, rocks, rags, or other loose items or debris.

While typical of those used to start many turbine engines, there are wide variations in the procedures for the many turbine engines. As with reciprocating engines, no attempt should be made to use the methods presented here for actually starting an engine. Instead, always refer to the procedures contained in the applicable manufacturer's instructions.

Most turbine engines can be started by either air-turbine or combustion-type starters. Air-turbine starters use compressed air from an external source. This source may be a ground cart unit or air bled from another engine on the aircraft that is in operation. Combustion starters are small, gas-turbine engines that obtain power from expanding gases generated in the starter's combustion chamber. These hot gases are produced by the burning of fuel and air, or, in some cases, a slow-burning solid or liquid monopropellant specially compounded for such starter units.

Fuel is turned on either by moving the power-lever to *idle* position or by opening a fuel shutoff valve. If an air-turbine starter is used, the engine should start, or *light off*, within approximately 20 seconds after the fuel is turned-on. This is a time interval that, if exceeded, indicates a malfunction has occurred and the start should be discontinued. After the cause of the trouble has been removed, another start may be made. If a combustion starter is used, the 20-second interval need not be observed, since starter operation will discontinue automatically after a predetermined time interval. The following procedures are useful only as a general guide, and are included to show the sequence of events in starting a turbine engine:

- Move power lever to the OFF position, unless the engine is equipped with thrust reverser. If the engine is so equipped, place the power lever in the idle position.
- Turn on electrical power to the engine.
- Turn the fuel system shut-off switch to FUEL ON position.
- Turn the fuel-boost pump switch on.
- The fuel-inlet pressure indicator should have an appropriate reading to ensure fuel is being adequately delivered to the engine's fuel-pump inlet.
- Turn the engine starter switch on. When the engine begins to rotate, check for an oil pressure rise.
- Turn the ignition switch on after engine begins to rotate.
- Move throttle to the idle position or *detent* if engine is not equipped with thrust reverser.
- Engine start (light-off) is indicated by a rise in exhaust-gas temperature.
- After the engine stabilizes at idle, ensure that none of the engine limits are exceeded.
- Turn the engine starter switch off after the start is complete.
- Turn the ignition switch off.

Hot starts occur when the engine starts but the exhaust-gas temperature exceeds specified limits. This is usually caused by an excessively rich fuel/air mixture entering the combustion chamber. The fuel to the engine should be shut off immediately, while continuing to motor the starter. If possible, continue to monitor the start until the engine cools down.

False starts, or hung starts, occur when the engine starts normally but the r.p.m. remains at some low value rather than increasing to the normal starting r.p.m. This is often the result of insufficient power to the starter, or the starter cutting off before the engine begins to self-accelerate. In any case, the engine should be shut down.


Micron 780

14

Maintenance Documentation

Section 1

Federal Aviation Regulations

Learning Objectives

REVIEW

- Types of Federal Aviation Regulations important to AMTs
- Manufacturer maintenance manuals commonly used by AMTs
- Typical maintenance forms and records and their purposes

The Federal Aviation Regulations (FAR) are part of the *Code of Federal Regulations (CFR), Title 14*; as such, they are the laws governing aeronautics. The Federal Aviation Act of 1958 charges the FAA with the responsibility of fostering and promoting civil aviation. The safe and orderly conduct of all civil flight operations, and the continued surveillance of all flight and maintenance activities pertaining to civil aircraft, are among the primary functions of the FAA.

Flight operating regulations and maintenance regulations developed by the FAA are published in the Federal Register and become law. They are then reprinted by the FAA and made available to the aviation community. The FAA is also tasked with enforcing compliance with its regulations. There are many different ways this compliance is achieved, but the most common is by a *certificate action*. A certificate action can be placed against any certified agency, including an individual. In essence, if you are cited by the FAA for violating a FAR, they may remove your certificate. There is a FAA process by which you may request a hearing to determine if you're innocent of the violation. It might be prudent to read *FAR Part 13 - Investigative and Enforcement Procedures*.

The following list gives a brief description of some of the FARs of which the aviation maintenance technician should have a thorough working knowledge in order to properly perform their duties and functions:

Left. Thousands of aircraft industry publications and FAA regulations have been transferred to the microfiche system for use by repair stations, inspectors and technicians.

FAR Part 1. Definitions and Abbreviations. This part contains the official meaning of terms and abbreviations used for interpreting the FARs.

FAR Part 21. Certification Procedures for Products and Parts. This part describes the Administrative procedures for obtaining FAA approval of products and parts.

FAR Part 23. Airworthiness Standards: Normal, Utility, and Acrobatic Category Aircraft. This part prescribes the Technical Standards which an aircraft or part must meet before the aircraft is approved for type certification.

Code of Federal Regulations

Title 14—Aeronautics and Space

CHAPTER I—FEDERAL AVIATION ADMINISTRATION, DEPARTMENT OF TRANSPORTATION

PART 43—MAINTENANCE, PREVENTIVE MAINTENANCE, REBUILDING, AND ALTERATION

43.1	Applicability.
43.2	Records of overhaul and rebuilding.
43.3	Persons authorized to perform maintenance, preventive maintenance, rebuilding, and alterations.
43.5	Approval for return to service after maintenance, preventive maintenance, rebuilding, or alteration.
43.7	Persons authorized to approve aircraft, airframes, aircraft engines, propellers, appliances, or component parts for return to service after maintenance, preventive maintenance, rebuilding, or alteration.
43.9	Content, form, and disposition of maintenance, preventive maintenance, rebuilding, and alteration records (except inspections performed in accordance with part 91, part 123, part 125, 135.411(a)(1), and 135.419 of this chapter).
43.10	Disposition of life-limited aircraft parts.
43.11	Content, form, and disposition of records for inspections conducted under parts 91 and 125 and 135.411(a)(1) and 135.419 of this chapter.
43.12	Maintenance records: Falsification, reproduction, or alteration.
43.13	Performance rules (general).
43.15	Additional performance rules for inspections.
43.16	Airworthiness Limitations.
43.17	Maintenance, preventive maintenance, and alterations performed on U.S. aeronautical products by certain Canadian persons.
APP.	Appendix A to Part 43 --Major Alterations, Major Repairs, and Preventive Maintenance
APP.	Appendix B to Part 43 --Recording of Major Repairs and Major Alterations
APP.	Appendix D to Part 43 --Scope and Detail of Items (as Applicable to the Particular Aircraft) To Be Included in Annual and 100-Hour Inspections
APP.	Appendix E to Part 43 --Altimeter System Test and Inspection
APP.	Appendix F to Part 43 --ATC Transponder Tests and Inspections

Figure 14-1-1. Federal Regulations are available in several different forms: they can be purchased in a Title 14 bound volume, purchased in single copies, downloaded from the Internet, or purchased in bound volumes from a commercial supplier.

FAR Part 27. Airworthiness Standards: Normal Category Rotorcraft. This part prescribes the technical standards to which a normal category rotorcraft must meet prior to type certification.

FAR Part 39. Airworthiness Directives. This part describes the *Airworthiness Directives* program and how they are given FAR status.

FAR Part 43. Maintenance, Preventive Maintenance, Rebuilding, and Alterations. This part deals with the administrative procedures, scope, and details of recording maintenance performed on type certificated aircraft.

FAR Part 45. Identification and Registration Marks. This part contains information regarding the size and location of identifying marks and registration numbers on aircraft and replacement and modification parts.

FAR Part 65. Certification: Airmen other than Flight Crew members. This part contains the eligibility requirements, privileges, and limitations for maintenance technicians, inspectors, and repairmen.

FAR Part 91. General Operating and Flight Rules. This part applies to the owner or lessee of the aircraft. Subpart c of this FAR applies to maintenance and describes the aircraft owners responsibility to maintain their aircraft in an airworthy condition.

FAR Part 121. Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft. This part is most often used by the large commercial airlines operating large multiengine, turbine-powered aircraft in passenger service.

FAR Part 125. Certification and Operations: Airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more. This part, like Part 121, is most often used by the large commercial airlines operating large multiengine, turbine-powered aircraft in passenger service.

FAR Part 127. Certification and Operations of Scheduled Air Carriers with Helicopters. Similar in content and wording to Part 125, except that it applies to rotorcraft instead of fixed-wing aircraft.

FAR Part 135. Air Taxi Operators and Commercial Operators. This part applies to small commuter airlines operating smaller aircraft with less than 20-passenger capacity, or to nonscheduled air taxi service providing charter flights.

FAR Part 137. Agricultural Aircraft Operators. This part covers the aerial application of insecticides, seeding operations, and fertilizer applications.

FAR Part 145. Repair Stations. This part covers the certification, operation, and limitations of repair stations.

FAR Part 147. Aviation Maintenance Technician (AMT) Schools. Part 147 covers the requirement for establishing and conducting an AMT training facility. It is the FAR under which your school operates.

FAR Part 183. Representatives of the Administrator. This part describes the requirements for designating private persons to act as representatives of the Administrator in examining, inspecting, and testing persons and aircraft for the purpose of issuing airman and aircraft certificates. Aviation medical examiners, *designated mechanic examiners*, pilot examiners, and *designated aircraft maintenance examiners* are just a few of the people who are designated under the provisions of this part.

A sample of a downloaded FAR hard copy is illustrated in Figure 14-1-1.

Special Federal Aviation Regulations

Special Federal Aviation Regulations (SFARs) are temporary regulations. They are used to address an emergency issue that needs longer term study, solve a problem specific to a certain locality or address temporary safety concerns.

Special Federal Aviation Regulations are published in the same volumes as the Federal Aviation Regulations. Special Federal Aviation Regulations, and the volumes of the Federal Aviation Regulations in which they are published, do not have a numerical sequential link. For example, SFAR 29-4 is published in FAR Part 91, usually at the beginning of the regulation.

Because the FAA does not currently have a readily accessible database of Special Federal Aviation Regulations, one method of finding Special Federal Aviation Regulations is to access the Code of Regulations website at the National Archives and Records Administration (ecfr.gpoaccess.gov). As with all federal regulations, you must take the time to do the research.

SFARs do not typically apply to normal maintenance operations. However, they still need to be researched, just in case.

Advisory Circulars (ACs). ACs are issued by the FAA to inform the aviation community of subjects which are not normally regulatory in nature. ACs are issued to provide guidance and information in their designated subject areas; however, they are not binding unless incorporated into a regulation. ACs may be informative, explanatory, or technical in content. ACs are issued in a numbered subject area corresponding to the FARs.

AC 43.13-1B — Change 1. The AC covering inspection and repair of aircraft, *AC 43.13-1B Acceptable Methods, Techniques, and Practices*, is a valuable guide for an airframe and powerplant technician performing maintenance or repairs on general aviation aircraft. It is likely to be one of your required textbooks. Forty-Three Thirteen, as it is commonly referred to, provides maintenance and repair information for airplanes that do not have a structural repair manual. It is also used, for reference, by many small aircraft manufacturers. They use it as a reference because it is virtually the only AC that is actually *FAA-approved material* under certain conditions. Most of the others are only *advisory*, and state so in the forward.

Being “approved material” means that a repair can be accomplished using the examples in AC 43.13-1B without going through a *Designated Engineering Representative* (DER) to gain approval materials. Only an FAA Form 337 and an inspection by an A&P with an *Inspection Authorization* (IA) is required. While this may seem like a quick and easy way to get approvals for repairs, there are some problems associated with the process. One is that the repairs listed in AC 43.13-1B are fairly specific and, in many cases, are difficult to apply to the particular job you are trying to accomplish. Another problem arises when the particular airplane you are working on has a repair manual (for older aircraft, they may be difficult to find). If it does, you must follow those examples instead of the AC.

There is another facet to 43.13. By the nature of the material it contains, it has also become a reference for many standard practices. An example that can apply to any airplane is how to check a tachometer for accuracy, and the authority for requiring the check is included in AC 43.13-1B paragraph 8-40.

Other ACs. There are many subjects which the FAA may cover by the use of ACs. Figure 14-1-2 shows the first page of an AC. A few examples are listed below:

- **AC 00-2.** Advisory Circular Checklist
- **AC 00-33.** Nickel-Cadmium Battery Operational, Maintenance, and Overhaul Practices
- **AC 20-66.** Vibration Evaluation of Aircraft Propellers

- **AC 20-77.** Use of Manufacturers' Maintenance Manuals (MM)
- **AC 39-7.** Airworthiness Directives
- **AC 43-3.** Non-Destructive Testing in Aircraft
- **AC 43-9.** Maintenance Records
- **AC 43-12.** Preventive Maintenance
- **AC 43-16.** General Aviation Airworthiness Alerts

Type Certificate Data Sheets, Aircraft Specifications, and Aircraft Listings

Type certificate data sheet. When a manufacturer wants to produce an aircraft, they must first obtain a Type Certificate. Basically, the manufacturer must state how they are going to design an airplane that meets the required FARs. If the applicant submits the type design, test reports and computations necessary to show that the product to be certificated meets the airworthiness requirements of FAR Part 23 — and if the product meets the applicable aircraft noise requirements of the FARs — a Type Certificate Data Sheet (TCDS) may be issued for an aircraft, powerplant, propeller, or component (Figure 14-1-3).

Once the design is approved and a Type Certificate issued, the manufacturer must then set out to obtain a production certificate. A production certificate says, in effect, "this is how we plan to build the airplane, and these are the inspection procedures we plan to follow to make sure the manufactured airplane matches the Type Certificate." A production certificate may not be deviated from during the course of an airplane's life cycle.

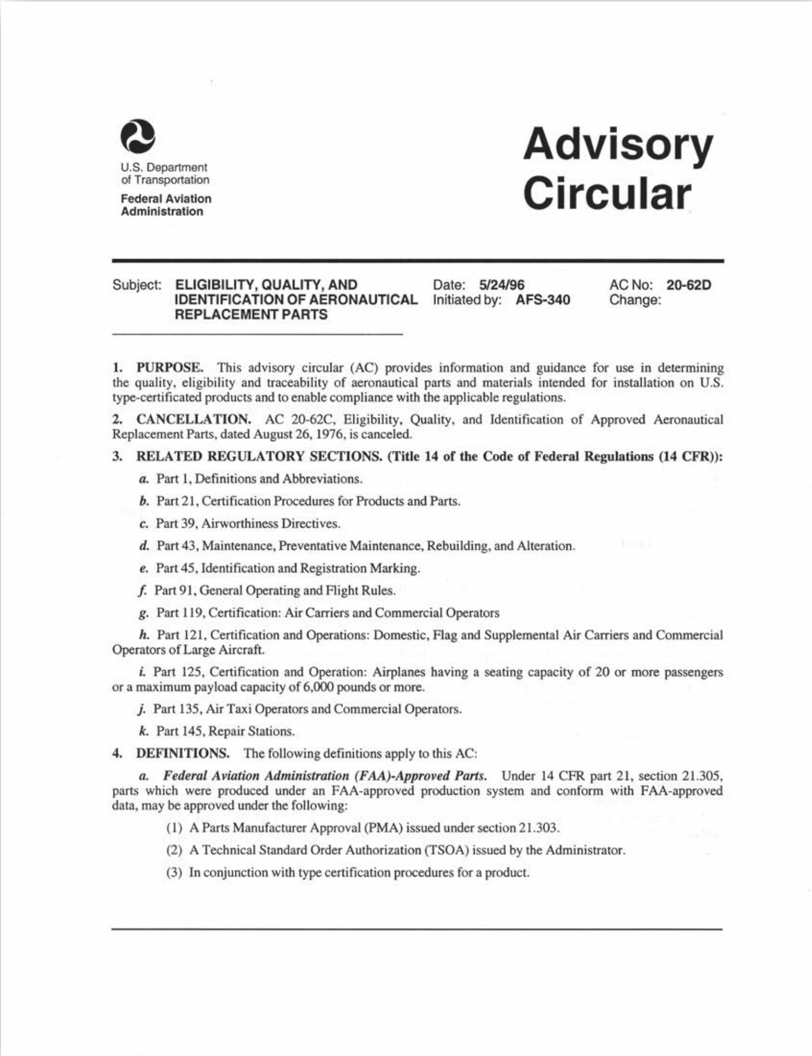
Aircraft manufactured by a production certificate holder, in conformity with the applicable Type Certificate data sheet, can be issued an airworthiness certificate. This certificate is unique to each individual aircraft and stays with that aircraft when it changes ownership.

Any deviation from the specifications and data contained in the data sheets must be documented by *FAA Form 337* (Major Repair or Alteration), an *FAA Form 8110-2* (Supplemental Type Certificate), or by compliance with an *Airworthiness Directive* (AD) like the one shown in Figure 14-1-4. These modifications or deviations from the data sheets must be documented and approved by the FAA.

TCDSs are only issued for airframes, engines, and propellers. Type Certificate (TC) data sheets are numbered in the upper right hand corner of each page. This number is the same as the TC number assigned to the manufacturer. The name of the certificate holder, with the model numbers, appears below the TC number. The issue date and revision number are also included and enclosed in a box in the upper right hand corner of the first page of the data sheet.

The items which may be found in a Type Certificate Data Sheet (TCDS) include:

- Configuration designations: 2 PCLM and 2 PCSM. 2PCLM is read "two place, closed land monoplane." This indicates the plane seats two people, has an enclosed cockpit, can be operated from the solid part of the earth's surface, and has only one wing.
  2 PCSM– is read "two place, closed sea monoplane."



U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: **ELIGIBILITY, QUALITY, AND IDENTIFICATION OF AERONAUTICAL REPLACEMENT PARTS** Date: **5/24/96** Initiated by: **AFS-340** AC No: **20-62D** Change:

1. PURPOSE. This advisory circular (AC) provides information and guidance for use in determining the quality, eligibility and traceability of aeronautical parts and materials intended for installation on U.S. type-certificated products and to enable compliance with the applicable regulations.

2. CANCELLATION. AC 20-62C, Eligibility, Quality, and Identification of Approved Aeronautical Replacement Parts, dated August 26, 1976, is canceled.

3. RELATED REGULATORY SECTIONS. (Title 14 of the Code of Federal Regulations (14 CFR)):

a. Part 1, Definitions and Abbreviations.

b. Part 21, Certification Procedures for Products and Parts.

c. Part 39, Airworthiness Directives.

d. Part 43, Maintenance, Preventative Maintenance, Rebuilding, and Alteration.

e. Part 45, Identification and Registration Marking.

f. Part 91, General Operating and Flight Rules.

g. Part 119, Certification: Air Carriers and Commercial Operators

h. Part 121, Certification and Operations: Domestic, Flag and Supplemental Air Carriers and Commercial Operators of Large Aircraft.

i. Part 125, Certification and Operation: Airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more.

j. Part 135, Air Taxi Operators and Commercial Operators.

k. Part 145, Repair Stations.

4. DEFINITIONS. The following definitions apply to this AC:

a. ***Federal Aviation Administration (FAA)-Approved Parts.*** Under 14 CFR part 21, section 21.305, parts which were produced under an FAA-approved production system and conform with FAA-approved data, may be approved under the following:

(1) A Parts Manufacturer Approval (PMA) issued under section 21.303.

(2) A Technical Standard Order Authorization (TSOA) issued by the Administrator.

(3) In conjunction with type certification procedures for a product.

Figure 14-1-2. ACs are convenient methods for dissemination of information that is "advisory." It is very beneficial to go through the list of Advisory Circulars and read all that pertain to maintenance.

- The type and model number of the engine approved for this model aircraft.
- Minimum fuel grade for this engine.
- Maximum approved r.p.m. and horsepower rating of the engine.
- Propellers approved for use, the r.p.m. limits and any other operating restrictions
- Airspeed limits in both m.p.h. and knots.
- Center-of-gravity range (CGR) in inches from datum. The CGR may be given in percent MAC for transport category aircraft.
- Empty-weight center-of-gravity range may be given, if it has been established by the manufacturer. Usually the word "None" will be listed under this category.
- Location of the datum.
- Means for leveling the aircraft.
- All maximum weights and their locations.
- Oil and fuel capacity and fuel tank arms.
- Control-surface movements.
- Required equipment (not be construed to be the same as the minimum equipment list required under FAR Section 135.179 for air taxi and commercial operators).
- Any additional equipment found necessary for certification of the aircraft.
- Information concerning placards which must be displayed in full view of the pilot.

NOTE: The Specifications and the TCDS list all placards that must be displayed in the pilots' compartment. These placards are required items, and most will have a manufacturers' part number assigned.

TCDSs are available from The Government Printing Office as unbound paper copies in six volumes. They can be purchased as a subscription, although most TCDSs are available as a download from the FAA website. Because of the cost and the actual size of the printed copies, it might be better to go the electronic route.

Aircraft specifications. Prior to about 1965, the *Civil Aeronautics Administration* (CAA) issued *Aircraft Specifications* for each aircraft certificated under the old *CAR Part 03* of the Civil Air Regulations. The major difference between the Aircraft Specifications and TCDS was the inclusion of an equipment list in the Aircraft Specifications. The cost of printing and constant revision of the information made this practice prohibitive. Many of the older aircraft models required as many as sixty pages of the specifications to list the required or approved equipment for the aircraft, engine, or propeller. The specifications were phased out over a two- or three-year period around 1965, and the equipment list for new model aircraft (type certificated under FAR Part 23) is now delivered to the owner of the aircraft at the time of original delivery, and it remains with the aircraft records when the aircraft is sold or disposed of. Several aircraft manufacturers now print the equipment list in the *Pilots' Operating Handbook* (POH) for easy accessibility by maintenance technicians.

Aircraft, engine, and propeller listings. The aircraft listings section is often referred to as *antique listings*. When there are 50 or less of a particular type and model aircraft shown on the FAA Aircraft Registry, the Type Certificate Data Sheets for these aircraft, engines, and propellers are transferred to *Volume VI, Aircraft Listing* section, where they are still available for reference if needed.

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

A21EA
Revision No. 15
Canadair
CL-600-1A11(CL-600)
CL-600-2A12(CL-601)
CL-600-2B16(CL-601-3A) & (CL-601-3R) & (CL-604)
CL-600-2B19 (Regional Jet Series 100 & 440)
CL-600-2C10 (Regional Jet Series 700 & 701)
CL-600-2D24 (Regional Jet Series 900)
October 25, 2002

TYPE CERTIFICATE DATA SHEET NO. A21EA

This data sheet which is part of Type Certificate No. A21EA, prescribes conditions and limitations under which the product for which the Type Certificate was issued meets the airworthiness requirements of the Federal Aviation Regulations.

Type Certificate Holder: Bombardier Inc.
P.O. Box 6087, Station Centre-Ville
Montreal, Quebec, Canada H3C 3G9

I - Model CL-600-1A11 (Transport Category), Approved November 7, 1980, by the FAA and August 10, 1980, by the Canadian Department of Transport (DOT).

Engines: Two AVCO Lycoming ALF-502L or ALF-502L-2

Fuel

Type	Specifications: Canada	U.S.A.	U.K.
Jet A	CAN2-3.23-M81	ASTM D1655	D. Eng RD2494
Jet A-1	CAN2-3.23-M81	ASTM D1655	D. Eng RD2494
Grade JP-5	-	MIL-T-5624	D. Eng RD2452
Grade JP-8	-	MIL-T-83133A	D. Eng RD2453
Jet B	CAN2-3.22-M80	ASTM D1655	D. Eng RD2486
JP-4	CAN2-3.22-M80	MIL-T-5624	D. Eng RD2486

Jet A and Jet A-1 fuels must contain an approved anti-icing additive unless Canadair Modification Summary 600-702 and Lycoming Service Bulletin ALF-502-79-0007 are incorporated.

Oil: Engine, APU, Generator Adapter:
MIL-L-7808 (Type I) or MIL-L-23699 (Type II) or other approved oils as identified in the Maintenance Manual (refer to Approved Publications).

Engine Limits

	SL Static Thrust(lb.)	Compressor RPM LP %N1	HP %N2	Interturbine Temperature °C	°F
Takeoff (5 minutes)	7500	96.0	98.2	904	1660
Maximum Continuous	7100	96.0	96.4	877	1610
*Starting maximum				823	1513

Maximum Oil Temperature: Normal 143°C(290°F)
**Transient 170°C(338°F)

*Time limit 10 seconds above 793°C(1460°F)
**Permitted during power reduction. Normal temperature must be achieved within two minutes of achieving steady state operation.

Page No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Rev. No.	15	7	6	7	10	7	7	7	10	7	7	7	10	11	11	15
Page No.	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Rev. No.	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15

Figure 14-1-3. This is the front page of a 32 page TCDS. No aircraft may deviate from its type certificate without having the appropriate paperwork to authorize that deviation.

The aircraft listing section also includes engine and propeller information for which type approvals have expired, or for which the manufacturer no longer holds a production certificate.

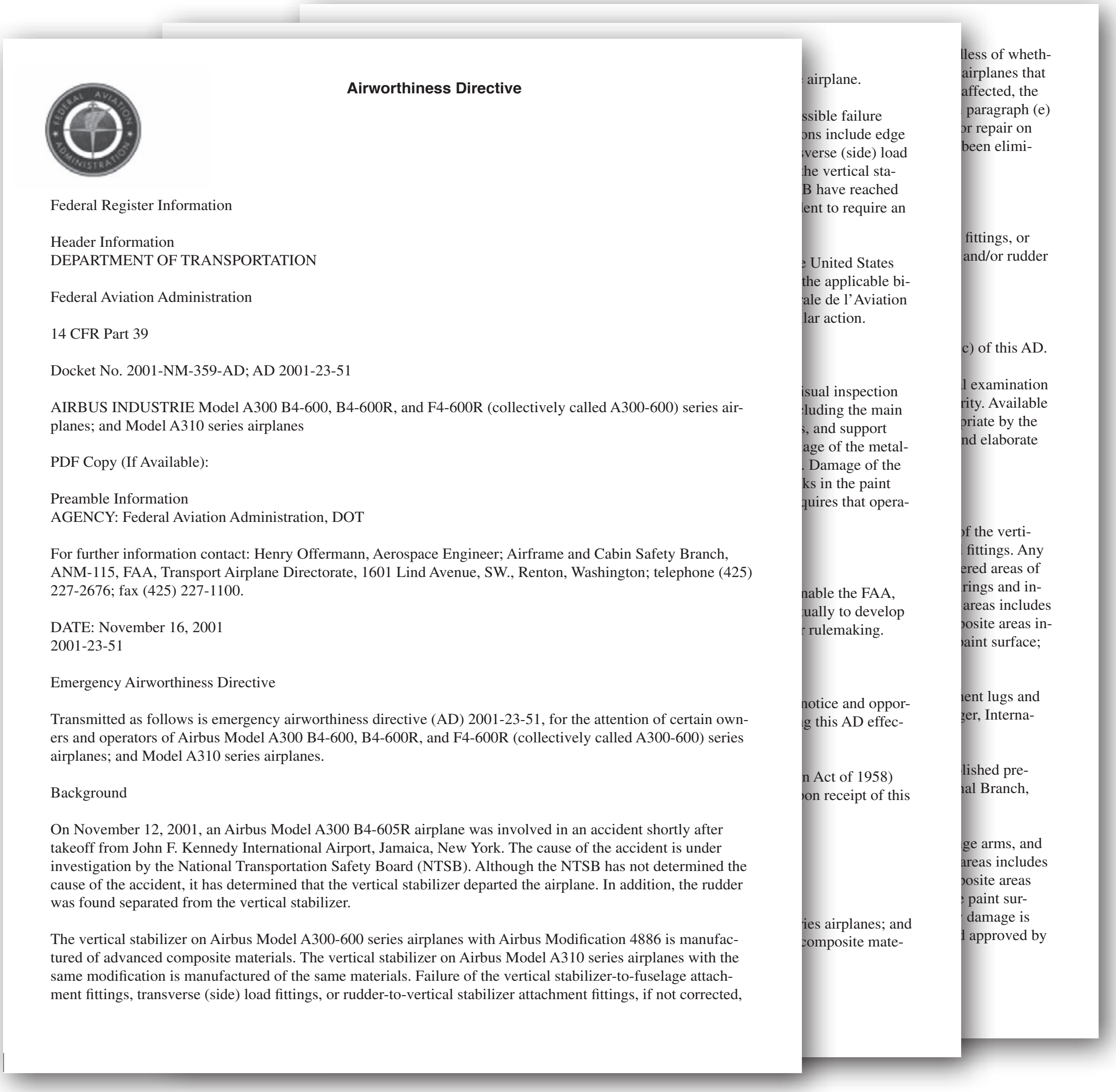
Supplemental Type Certificates

The Type Certificate Data Sheet defines the aircraft's original FAA approved configuration. A Supplemental Type Certificate (STC) is a document issued by the Federal Aviation Administration approving a product (aircraft, engine, or propeller) modification. A STC is issued to an individual or organization desiring to modify an aircraft to a configuration different than specified in the original Type Certificate. It is NOT issued to the original Type Certificate holder. The STC may be issued as a result of an engine change, a performance modification, or the modification or installation of different equipment than that used in the original design.

The STC defines the product design change, states how the modification affects the existing type design, and lists serial number effectivity. It also identifies the certification basis, listing specific regulatory compliance for the design change. Information contained in the certification basis is helpful for those applicants proposing subsequent product modifications and evaluating certification basis compatibility with other STC modifications. Other individuals or organizations desiring to make the same modifications can either obtain permission from the STC holder, or they can request a similar STC from the FAA.

Replacement and Repair Parts Certification

Replacement and repair parts supplied by the original Type Certificate holder are required to meet original FAA approved type certificate and production certificate standards. Parts are also available from third party suppliers. These parts must also meet FAA standards; there are



Airworthiness Directive

Federal Register Information

Header Information
DEPARTMENT OF TRANSPORTATION

Federal Aviation Administration

14 CFR Part 39

Docket No. 2001-NM-359-AD; AD 2001-23-51

AIRBUS INDUSTRIE Model A300 B4-600, B4-600R, and F4-600R (collectively called A300-600) series airplanes; and Model A310 series airplanes

PDF Copy (If Available):

Preamble Information
AGENCY: Federal Aviation Administration, DOT

For further information contact: Henry Offermann, Aerospace Engineer; Airframe and Cabin Safety Branch, ANM-115, FAA, Transport Airplane Directorate, 1601 Lind Avenue, SW., Renton, Washington; telephone (425) 227-2676; fax (425) 227-1100.

DATE: November 16, 2001
2001-23-51

Emergency Airworthiness Directive

Transmitted as follows is emergency airworthiness directive (AD) 2001-23-51, for the attention of certain owners and operators of Airbus Model A300 B4-600, B4-600R, and F4-600R (collectively called A300-600) series airplanes; and Model A310 series airplanes.

Background

On November 12, 2001, an Airbus Model A300 B4-605R airplane was involved in an accident shortly after takeoff from John F. Kennedy International Airport, Jamaica, New York. The cause of the accident is under investigation by the National Transportation Safety Board (NTSB). Although the NTSB has not determined the cause of the accident, it has determined that the vertical stabilizer departed the airplane. In addition, the rudder was found separated from the vertical stabilizer.

The vertical stabilizer on Airbus Model A300-600 series airplanes with Airbus Modification 4886 is manufactured of advanced composite materials. The vertical stabilizer on Airbus Model A310 series airplanes with the same modification is manufactured of the same materials. Failure of the vertical stabilizer-to-fuselage attachment fittings, transverse (side) load fittings, or rudder-to-vertical stabilizer attachment fittings, if not corrected,

Figure 14-1-4. AD 01-23-51 is a sample of a three-page AD downloaded from the FAA website.

four common methods by which these standards can be met. The first is the Technical Standard Order (TSO) authorization. These are issued for parts, such as aircraft instruments, tires, cabin furnishings, and similar items, that can be used on multiple aircraft types. The TSO is issued under CFR 147 Part 21 and may limit the item to certain categories or types of aircraft.

A second common method is the Parts Manufacturing Approval (PMA). This is typically issued to someone other than the Type Certificate holder who desires to manufacture parts for specific aircraft applications. These parts are usually intended as a less costly alternative to the OEM (define?) parts. In some cases, these items are manufactured by a competitor, as is the case with most PMA engine parts. In other cases, they are issued to a component supplier to the OEM. This allows the component supplier to directly sell parts— whether it be wheels and brakes, deicing components, motors, or similar items—to the operator or maintainer. These parts are produced under an FAA approved manufacturing and quality control system.

The third method is through an STC. The holder of an STC is permitted to manufacture and supply parts for that STC in accordance with the terms of the STC.

The fourth method is by using owner-produced parts. The FAA permits owners, with certain restrictions, to manufacture parts for their own aircraft. They must meet the certification criteria for the original part.

Aircraft Safety Alerts

One of the FAA's mandates is aviation safety. The FAA issues a number of types of safety alerts. Some of these are mandatory, others are recommended or are informational in nature. The different types of safety alerts are:

- Airworthiness Directives (AD)
- Special Airworthiness Information bulletins (SAIB)
- Maintenance Alerts
- Service Difficulty Reports (SDR)
- Unapproved Parts Notification

Airworthiness Directives (ADs)

Airworthiness Directives (AD) are issued by the FAA in accordance with FAR Part 39. ADs affect aviation safety, and no person may operate an aircraft to which an AD applies, except in accordance with the requirements of the AD. That means that you MUST comply with an AD in whatever manner is listed in the AD itself. While it may sound simple to do as the AD says, it sometimes isn't. It can frequently take more than a small amount of research to determine specific applicability (Figure 14-1-4). Airworthinness Directives are legally enforceable rules issued by the FAA in accordance with 14 CFR Part 39 to correct an unsafe condition in a product. In 14 CFR Part 39, a product is defined as an aircraft, aircraft engine, propeller, or appliance.

ADs are unofficially divided into groups by their compliance methods:

- One-time inspection
- One-time inspection with replacement
- Recurrent inspection
- Before further flight

Each of the four methods has its own unique handling. The action required by an AD may take the form of an inspection, part(s) replacement, design modification, or change in operation procedure.

AD numbering system. ADs are issued every two weeks and are identified by a six-digit number. The first two digits designate the year of the issue, the middle two digits identify the bi-weekly listing in which the AD was published, and the last two digits identify the position of publication in the bi-weekly listings.

In Figure 14-1-4, the AD is numbered AD 01-23-51. To understand the system, it may be easier to reverse the number thusly: 51 = the fifty-first AD issued during that bi-weekly session, the 23rd such session (out of 26 in a year); 01 stands for the year it came out: 2001.

Having said that, ADs obtained from the FAA web site are numbered a bit differently. They contain the full year instead of the last two digits.

When inspecting a general aviation airplane, it is required that a summary sheet be compiled. It should list all ADs that apply to the specific airplane and its equipment. This list also makes a good way to check AD compliance. AD summaries are generally kept attached to the log book. Compliance with an AD is the owner's responsibility.

Special Airworthiness Information Bulletins (SAIB)

A Special Airworthiness Information Bulletin (SAIB) is an information tool that alerts, edu-

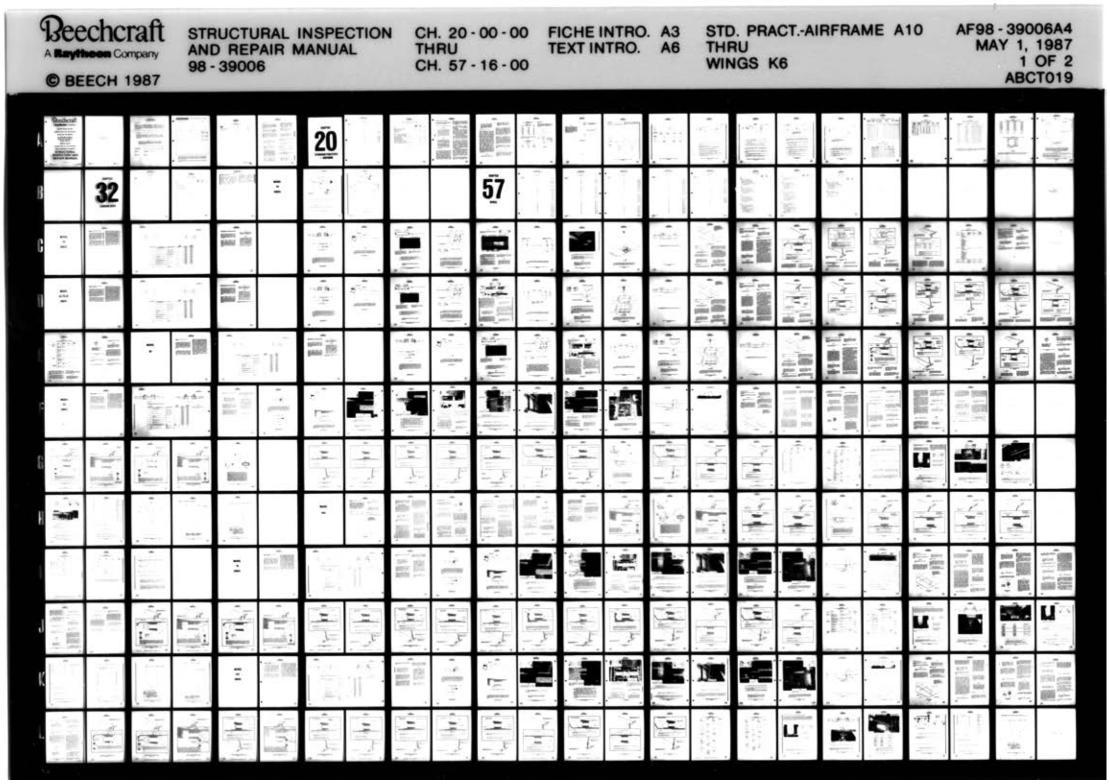


Figure 14-2-1. A full-size representation of a sheet of microfiche.

cates, and makes recommendations to the aviation community. SAIBs contain non-regulatory information and guidance that does not meet the criteria for an Airworthiness Directive (AD). Guidance on when to use an SAIB, and how to develop and issue an SAIB is provided in Order 8110.100A.

Maintenance Alerts

The Aviation Maintenance Alerts provide a way to share information on aviation service experiences. This leads to improved aeronautical product durability, reliability, and safety. The FAA uses information submitted by aircraft operators and maintainers to prepare the alerts. This information is compiled and released on a monthly basis.

Service Difficulty Reports (SDR)

The Service Difficulty Report system is a mechanism for disseminating potential maintenance issues to the aviation community. Service Difficulty Reports (SDR) consist of maintenance incidents collected by the FAA for the purpose of tracking repair problems with private, commercial, and military aircraft and aircraft componentry. The system allows aircraft operators and maintainers to report issues they have encountered in the field. This information is entered into a central, searchable database. Maintenance technicians can use it to research a problem and see if it has occurred elsewhere. The FAA and aircraft manufacturers can use it to determine if there are recurring maintenance or safety issues that need to be addressed. The data is reported by tail number and aircraft serial number, so it is also possible to trace the maintenance history of a particular airplane with this database.

Unapproved Parts Notification

When the FAA becomes aware of instances of non-aircraft parts entering the aircraft parts system or of improper maintenance or repairs conducted on aircraft parts, they publish an Unapproved Parts Notification. The most commonly occurring instances are:

- Manufacturing aircraft parts without an FAA approval
- Conducting maintenance or repairs without the appropriate certifications
- Not following FAA approved procedures for maintenance or repairs

Parts manufactured or repaired under these circumstances do not meet the FAA standards for approved parts. The notification system is intended to inform the public about those cases.

Section 2

Manufacturers' Maintenance Manuals

Maintenance is defined in 14 CFR Part 1.1 as: inspection, overhaul, repair, preservation, and the replacemnt of parts. By federal regulation, each current aircraft manufacturer must provide all the manuals necessary to service, operate, maintain, repair, and overhaul each product that they manufacture. Each sub-contractor that supplies assemblies to that manufacturer must also have those same types of manuals available. The price of manuals varies significantly. Some small manuals for high-production parts cost just a few dollars. For large, complex airplanes, these same types of manuals can run several hundred dollars each. Hard-to-find manuals for out-of-production airplanes can cost more than a thousand dollars per copy.

While all the FARs in book form might use six or eight feet of shelf space, all the manuals required by a large general aviation shop, in hard copy, might cover forty to fifty feet of shelf space. Within this wall of books would be many of the following:

- Service manuals
- Maintenance manuals
- Parts manuals
- Overhaul manuals
- Standard procedures manual
- Structural repair manuals
- Operations manuals
- Inspection manuals (by type of inspection)
- Component service manuals
- Component overhaul manuals
- Component parts manuals
- Electrical system manuals
- Troubleshooting manuals

Now, imagine this list of manuals existing for each different model of each manufacturers airplane. In addition, each engine model will have its own set of manuals, as will each engine accessory.

In the case of transport category airplanes, one model airplane by one manufacturer could produce as much as 20 linear feet of manuals. Boeing 767 component overhaul manuals alone occupy 8 feet of shelving.

This discussion on the sheer volume of material has a point: You don't have to read it all. What you do have to read is the material that covers what it is you are doing today. Once you have read it and understand what it is telling you, you may not have to read it again (though refreshing your memory from time to time is a good idea). What you do have to do is to keep the material available. For the FAA's purposes, that means at the least having it in the same building with you.

Work cards. From all the previous information, it is clear that finding specific information could pose a challenge. It is not possible to start at one end of the bookcase and go through each volume looking for specific directions. That is why airline shops use a work-card system. The card contains not only the job description, but enough information from the proper manual to allow completion of the project. If it doesn't, or if you don't understand the card, then you must look up the material you need. This is where the ATA 100 system is a major benefit. You can find what you need fairly quickly.

Just think it out beforehand so you will be looking for what you need in the place it really is.

The constant revision of maintenance publications and the increasing scope of the printed page requires several full-time personnel who do nothing but try to keep up with the filing and storage of these documents.

Aerofiche. This problem was originally addressed by large aircraft manufacturers who produced maintenance and overhaul data on microfilm. The microfilm was available in rolls and used a special machine to read it. The reader machines had a search feature that made finding information relatively quick. In a shop where all work was done on a single type of airplane, microfilm was hard to beat. However, the system did have some drawbacks: the readers were expensive, and the entire roll of microfilm had to be replaced when any information was updated. Especially troublesome was changing from one type airplane to another. Even at that, microfilm worked and many large airplane shops still use it.

An outgrowth of the microfilm system was Aerofiche. Instead of using roll film, a film card is used. The standard microfiche card uses 24 columns by 12 rows of pictures on a transparent film approximately 4-1/8 inches high by 5-7/8 inches wide (Figure 14-2-1). One microfiche card will accommodate 288 pages of information.

Information retrieval is from a microfiche reader, or reader/printer. The reader has a lens that is 40x, or 40 power, for enlarging the pages and making the information easy to read. Reader/printer models allow for printing single pages and taking them to the job.

Thousands of aircraft industry publications and FAA regulations have been transferred to the microfiche system for use by aircraft repair stations, inspectors, and individual technicians.

Some of the features of the microfiche system which are available from the FAA, aircraft manufacturers, and private companies are:

- Numerical indexing and dating for control and management
- Bi-weekly updates are standard procedures of most microfiche publishers
- All regulatory data, such as TCDS, supplemental TC information and all ACs
- ADs and manufacturers' service bulletins and letters are collated and indexed by aircraft type
- All Federal Regulations are kept current by subscription
- All powerplant service, repair, and overhaul manuals

MAINTENANCE MANUAL CHAPTER NUMBERS

AIRCRAFT GENERAL	
Time Limits/ Maintenance Checks	5
Dimensions & Charts	6
Lifting & Shoring	7
Leveling & Weighing	8
Towing & Taxiing	9
Parking & Mooring	10
Required Placards	11
Servicing	12
Standard Practices - Airframe	20
AIRPLANE SYSTEMS	
Air Conditioning	21
Auto Flight	22
Communication	23
Electrical Power	24
Equipment and Furnishings	25
Fire Protection	26
Flight Controls	27
Fuel	28
Hydraulic Power	29
Ice & Rain Protection	30
Instruments	31
Landing Gear	32
Lights	33
Navigation	34
Oxygen	35
Pneumatic	36
Water/ Waste	38
Airborne Auxiliary Power	49
STRUCTURES	
Structures - General	51
Doors	52
Fuselage	53
Nacelles/Pylons	54
Stabilizers	55
Windows	56
Wings	57
POWERPLANT	
Standard Practices - Engine	70
Power Plant	71
Engine	72
Engine Fuel & Control	73
Ignition	74
Air	75
Engine Controls	76
Engine Indicating	77
Exhaust	78
Oil	79
Starting	80
Water Injection	82
CHARTS	
Charts	91

ATA SPECIFICATION 100
MAINTENANCE INFORMATION SYSTEM

Application of Standard Maintenance Manual Numbering System
The "Chapter-Section" Number: The numbering system used in the Maintenance Manual consists of a three element number separated by dashes:

First and second digits	-	System/Chapter
Third digit	-	Sub-System/ Section
Fourth digit	-	Sub-Sub-System
Fith and sixth digits	-	Unit/Subject

The following example illustrates and describes use of each element of the number:

Typical Chapter - Section - Subject

52-34-01

This number designates Chapter 52, the title of which is "Doors." (Designated by ATA 100 Spec.)

This number designates the section breakdown of material in Chapter 52. In this case, 3X represents "Cargo" doors. (Designated by ATA 100 Spec.)

This number designates a specific sub-subsytem within "Cargo" doors. In this case, -34 represents "Cargo" Doors (Designated by ATA 100 Spec.)

This number designates a specific component. In this case, -01 represents the rotary actuator. (Assigned by the manufacturer)

Page Number Blocks

SUBJECT	PAGE BLOCK
Description and	1-100
Operation	101-200
Trouble Shooting	301-400
Servicing	401-500
Removal/ Installation	501-600
Adjustment/ Test	601-700
Inspection/ Check	701-800
Cleaning/ Painting	801-900

Figure 14-2-2. The ATA 100 numbering system takes a little getting used to. Once fully understood, finding information becomes much simpler.

Many commercial services have a subscription program whereby they send monthly updates. Fiche libraries are kept current simply by replacing the old fiche with the new one.

The FAA regulations state that a shop must have all of the current information in order to do repair and maintenance. Microfiche is an excellent way to keep current without investing large amounts time in the updating process.

Microfiche is available in libraries, which allow a service facility to buy information on an as-needed basis. As needs grow, the facility can simply add the appropriate library.

Computerized Maintenance Manuals. Laptops or computer workstations are now common in the maintenance hanger. These computers access electronic versions of the maintenance and parts manuals for the aircraft. While the programs that are used differ from manufacturer to manufacturer, the information is organized the same way as in printed manuals.

The advantages to using computers are many:

- The most current information is always available.
- The technician can printout any page or the diagram needed.
- For many aircraft, all the information can be contained on a few compact disks (CDs) or on a hard drive, instead of hundreds of pages of printed material.

NOTE: Printouts should be disposed of after use to ensure that the most current information will be used in the future.

Many manufacturers incorporate programs that allow the user to make maintenance entries to the aircraft historical records. These programs can also track the usage of time-critical parts and recommended overhaul times.

Some aftermarket companies have maintenance tracking and scheduling programs that integrate with the various aircraft used by a company. These programs prove vital to cost-effective operations.

Manufacturers allow access to their manuals and databases through the internet. This means that the data is always up-to-date with the latest standards. Information can be input that helps in diagnosing and troubleshooting out of the ordinary problems on an aircraft. Access is usually restricted to paid subscribers.

ATA Specification 100. The *Air Transport Association of America* (ATA) issued the specifications for Manufacturers' Technical Data on June 1, 1956. From then until March 2003, the ATA 100 maintenance information numbering system prevailed. In April 2003, the ATA 100 Specification was replaced by another specification, called ATA iSPEC 2200. iSPEC 2200 consists of *ATA Spec 100 Manufacturers' Technical Data* and *ATA Spec 2100 Digital Data Standards for Aircraft Support*. The combined edition is called *ATA Specification iSpec 2200 Information Standards for Aviation Maintenance*.

Because ATA 100 has been used by most major manufacturers for more than 40 years, it will continue to be with us for some time. When manufacturers will start using iSpec 2200 remains to be seen, as does exactly what the new system will look like.

The ATA Specification 100 has the aircraft divided into systems; i.e. electrical, which covers the basic electrical system (ATA 2400). Numbering in each major system provides an arrangement for breaking the system down into several sub-systems. Late model aircraft, both over and under the 12,500 lbs gross weight dividing line, have their parts manuals and MMs arranged according to the ATA coded system (Figure 14-2-2).

Section 3

Maintenance Forms and Records

Permanent Records

Permanent records are those records which must be retained by the owner of the aircraft and transferred with the aircraft when it is sold. They are the responsibility of the aircraft owner. Federal Aviation Regulation (FAR) Section 91.417 lists six types of records in this category, as follows:

- The total time in service of the airframe, each engine and each propeller.
- The current status of life-limited parts of each airframe, engine, propeller, rotor, and appliance.
- The time since last overhaul of all items on the aircraft which are required to be overhauled on a time-specific basis.
- The current inspection status of the aircraft and time since last inspection.
- The current status of applicable Airworthiness Directives (ADs), including

AD Number and Amendment Number	Date Received	Subject	Compliance Due Date Hours/Other	Date of Compliance	Airframe Total Time-in-Service at Compliance	One-Time	Recurring	Next Compliance Due Date Hours/Other	Authorized Signature, Certificate, Type and Number	Remarks

• Aircraft, Engine, Propeller, Rotor, or Appliance: Make __________ Model __________ S.N. __________ N__________

Figure 14-3-1. A list of AD notes and method(s) of compliance is required to be placed in the rear of the log book. This illustration is a sample of the FAA suggested form and format.

(for each) the method of compliance, the AD number and revision date, and the time and date when the next action is required, if any.

- Copies of any FAA Forms 337, Major Repair and Alteration, for each major alteration to the airframe and currently installed engines, rotors, propellers, and appliances.
- For aircraft operated under Part 92, records of maintenance, alterations, preventative maintenance, 100-hour inspections, annual, and progressive inspections must be retained for at least one year or until the work is superseded or repeated by the owner or operator of the aircraft.

Aircraft logbooks. The permanent records listed above may be kept by the private individual in the aircraft's airframe, engine, and propeller or rotor logbook.

All of the permanent data is recorded in chronological order, and the logbooks become a record of the history of the aircraft. The information concerning time-in-service, inspection status and time since last inspection may be carried forward with each succeeding entry in the logbooks.

The current status of ADs may be stapled in the rear of the logbook (Figure 14-3-1) and updated and revised at each annual inspection of the aircraft.

A separate logbook is necessary for the airframe, the engine(s), and the propellers installed on the aircraft. In the event an engine is replaced with a different engine and the propeller data has been recorded in the old powerplant log books, the propeller data would be lost and total *time-in-service* for the propellers may be difficult to establish.

Logbook entries. During your aviation career, you will make hundreds of logbook entries. What should be in these entries has been fairly well established. The desired wording and its applicability is stated in FAR 43.11. Because FAR 43.11 will become a part of every technician's life, it is quoted in its entirety:

> § 43.11 Content, form, and disposition of records for inspections conducted under parts 91 and 125 and §§135.411(a)(1) and 135.419 of this chapter.
>
> (a) Maintenance record entries. The person approving or disapproving for return to service an aircraft, airframe, aircraft engine, propeller, appliance, or component part after any inspection performed in accordance with part 91, 125, §135.411(a)(1), or §135.419 shall make an entry in the maintenance record of that equipment containing the following information:
>
> (1) The type of inspection and a brief description of the extent of the inspection.
>
> (2) The date of the inspection and aircraft total time in service.
>
> (3) The signature, the certificate number, and kind of certificate held by the person approving or disapproving for return to service the aircraft, airframe, aircraft engine, propeller, appliance, component part, or portions thereof.
>
> (4) Except for progressive inspections, if the aircraft is found to be airworthy and approved for return to service, the following or a similarly worded statement—"I certify that this aircraft has been inspected in accordance with (insert type) inspection and was determined to be in airworthy condition."
>
> (5) Except for progressive inspections, if the aircraft is not approved for return to service because of needed maintenance, noncompliance with applicable specifications, airworthiness directives, or other approved data, the following or a similarly worded statement—"I certify that this aircraft has been inspected in accordance with (insert type) inspection and a list of discrepancies and unairworthy items dated (date) has been provided for the aircraft owner or operator."
>
> (6) For progressive inspections, the following or a similarly worded statement—"I certify that in accordance with a progressive inspection program, a routine

inspection of (identify whether aircraft or components) and a detailed inspection of (identify components) were performed and the (aircraft or components) are (approved or disapproved) for return to service." If disapproved, the entry will further state "and a list of discrepancies and unairworthy items dated (date) has been provided to the aircraft owner or operator."

(7) If an inspection is conducted under an inspection program provided for in part 91, 125, or §135.411(a)(1), the entry must identify the inspection program, that part of the inspection program accomplished, and contain a statement that the inspection was performed in accordance with the inspections and procedures for that particular program.

(b) Listing of discrepancies and placards. If the person performing any inspection required by part 91 or 125 or §135.411(a)(1) of this chapter finds that the aircraft is unairworthy or does not meet the applicable Type Certificate data, airworthiness directives, or other approved data upon which its airworthiness depends, that persons must give the owner or lessee a signed and dated list of those discrepancies. For those items permitted to be inoperative under §91.213(d)(2) of this chapter, that person shall place a placard, that meets the aircraft's airworthiness certification regulations, on each inoperative instrument and the cockpit control of each item of inoperative equipment, marking it "Inoperative," and shall add the items to the signed and dated list of discrepancies given to the owner or lessee.

[Amdt. 43–23, 47 FR 41085, Sept. 16, 1982, as amended by Amdt. 43–30, 53 FR 50195, Dec. 13, 1988; Amdt. 43–36, 61 FR 19501, May 1, 1996; 71 FR 44188, Aug. 4, 2006]

Executive and corporate aircraft. Aircraft operating in this category will in most cases be multi-engine aircraft capable of carrying several passengers at a relatively high speed. Usually, maintenance is performed by the corporation's aircraft maintenance department, and the record-keeping functions may be organized under the supervision of the maintenance record-keeping section.

Most aircraft in these two categories use one of the commercial computer-based record-keeping programs. These programs do an excellent job of maintaining maintenance records. They keep track of all inspections, maintenance, AD notes, and Service Bulletins, for the airplane and its engines. They also keep time-in-service records for a variety of items, including each accessory installed. They also remove and replace records.

Another advantage to these programs is that they will keep track of and issue work cards for each phase inspection. The cards also serve as the data collection point for program entries.

Commercial carriers and air taxi operators. These aircraft are maintained under a different set of regulations, and maintenance records will be maintained in accordance with FAR Parts 121, 127, or 135.

Lost Records. AC43-9C states that when maintenance records are lost or destroyed, they can be reconstructed by determining the aircraft's total time in service.

Temporary Records

Temporary records are those maintenance records which must be retained until the work is repeated or superseded by other work, or for one year after the work is performed. This type of record will include the maintenance and alteration of engines, propellers, rotors, and appliances of an aircraft, and records of its 100-hour, annual, or progressive inspections.

These records must include a description or a reference to data acceptable to the Administrator, of the work performed, the date of completion, and the signature, type of certificate, and certificate number of the person approving the aircraft for return to service.

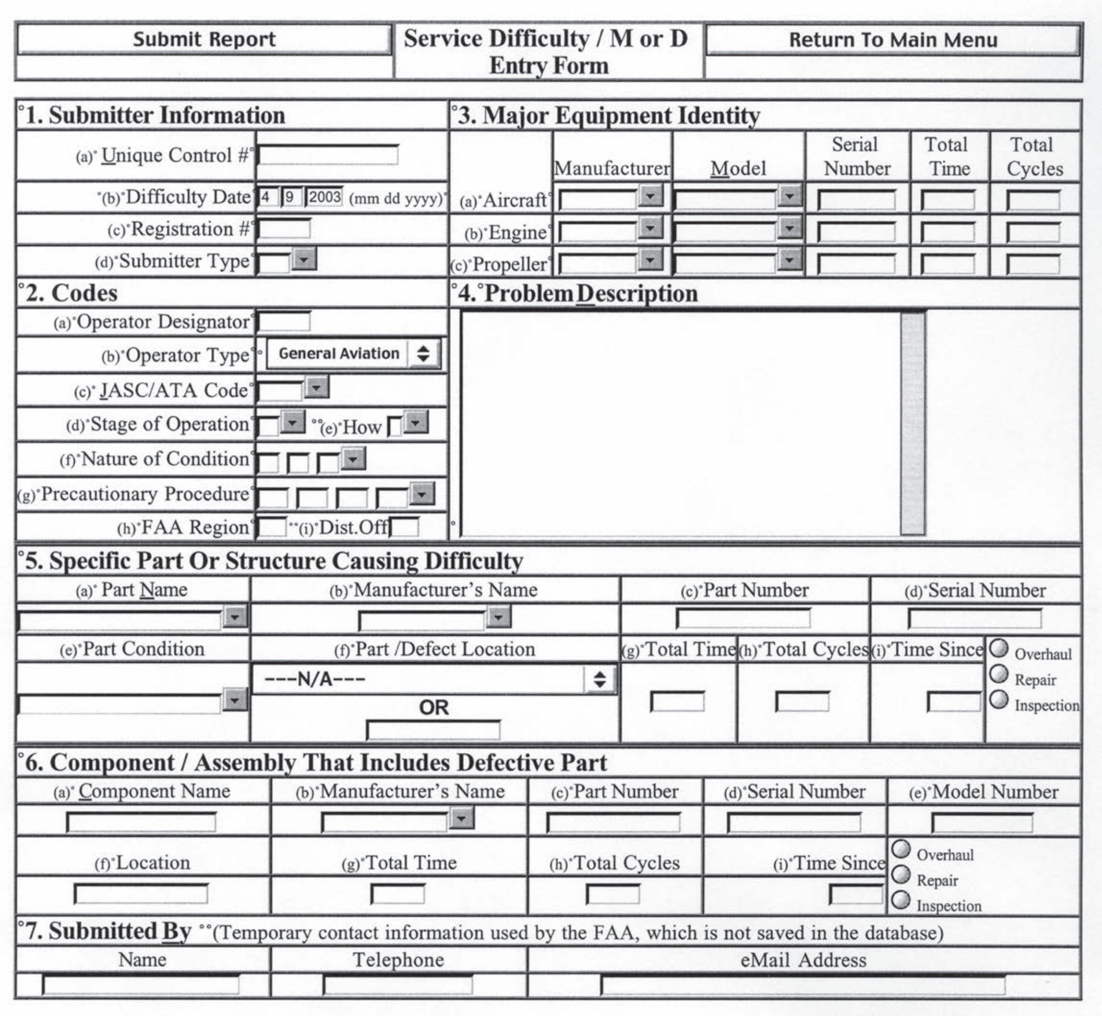
Private owners operating personal aircraft. Records containing information classified as temporary may be entered in the aircraft logbooks at the time the maintenance, alterations, or required inspections were performed.

Removal of these records from the aircraft, powerplant or propeller logbooks is inadvisable. The records should be left intact so as to not destroy the permanent information in the logbooks.

Executive and corporate aircraft. The maintenance, alterations, and inspection records in the temporary classification may be removed from the looseleaf-style log books and destroyed when the work is repeated or superseded, or after one year.

Inspection Forms

FAR Part 43, appendix D, is the authority covering the *scope and detail* of items to be included in the annual and 100-hour inspections of aircraft. The items and systems included in appendix D



Submit Report | Service Difficulty / M or D Entry Form | Return To Main Menu

1. Submitter Information
(a) Unique Control #
(b) Difficulty Date 4 9 2003 (mm dd yyyy)
(c) Registration #
(d) Submitter Type

2. Codes
(a) Operator Designator
(b) Operator Type General Aviation
(c) JASC/ATA Code
(d) Stage of Operation (e) How
(f) Nature of Condition
(g) Precautionary Procedure
(h) FAA Region (i) Dist.Off

3. Major Equipment Identity

	Manufacturer	Model	Serial Number	Total Time	Total Cycles
(a) Aircraft					
(b) Engine					
(c) Propeller					

4. Problem Description

5. Specific Part Or Structure Causing Difficulty
(a) Part Name | (b) Manufacturer's Name | (c) Part Number | (d) Serial Number
(e) Part Condition | (f) Part /Defect Location ---N/A--- OR | (g) Total Time | (h) Total Cycles | (i) Time Since Overhaul / Repair / Inspection

6. Component / Assembly That Includes Defective Part
(a) Component Name | (b) Manufacturer's Name | (c) Part Number | (d) Serial Number | (e) Model Number
(f) Location | (g) Total Time | (h) Total Cycles | (i) Time Since Overhaul / Repair / Inspection

7. Submitted By (Temporary contact information used by the FAA, which is not saved in the database)
Name | Telephone | eMail Address

Figure 14-3-2. This illustration is of a Malfunction or Defect online report form. M or D report forms are also available from a FSDO in prepaid mail-in card form.

are the minimum items which must be covered during annual or 100-hour inspection.

All of the major aircraft manufacturers have expanded the items listed in appendix D and published inspection forms for their aircraft containing additional inspection items, reference to their service bulletins, service letters, and overhaul periods for components installed on the aircraft.

The manufacturers' inspection forms are prepared for each type, model, and series of the aircraft. The single-engine aircraft inspection forms are quite different from their multi-engine inspection forms.

Most manufacturers' inspection forms provide space for identifying the aircraft by its identification and serial numbers, and they provide a space for the person performing the inspection to sign that the work was accomplished.

The use of these inspection forms is permitted by FAR Section 43.15(c), which states that each person performing an annual or 100-hour inspection shall use a checklist while performing the inspection. The checklist may be of the person's own design, one provided by the manufacturer of the equipment being inspected or one obtained from another source. This checklist must include the scope and detail of the items contained in FAR Part 43, appendix D.

FAA Form 8010-4, Malfunction or Defect Report. This form is both a postcard-type report and an online form designed to allow the technician to quickly fill in pertinent information regarding aircraft type, model, and series. Its purpose is to record malfunctions and defects discovered during maintenance.

The form requires no postage and the address of the local FAA office may be stamped on the address side of the form by the local FAA office prior to issue of the forms. All maintenance personnel are encouraged to fill in the information and forward it to the FAA as soon as possible.

The information is processed through the local FAA offices to the Aviation Standards National

Field Office in Oklahoma City, Oklahoma, where significant information is disseminated throughout the aviation maintenance community by AC43-16, General Aviation Airworthiness Alerts.

General Aviation Airworthiness Alerts are published monthly. The information is prepared from Malfunction or Defect Reports submitted by aviation technicians and inspectors who operate civilian aeronautical products.

Malfunction or Defect reports (M or D reports) are important to the continued safe operation of general aviation aircraft. Airworthiness Directives have been issued as a result of the information received through the M or D reporting system (Figure 14-3-2).

FAA Form 337, Major Repair and Alteration. The record of major repairs and alterations of airframes, powerplants, propellers, and appliances is required by FAR Section 43.9(a), which states that these major repairs and major alterations shall be entered on an FAA Form 337 and the form disposed of in accordance with AC 43-9C, by the person performing the work. In the past the owner/operator of an airplane was able to keep a list of all major alterations to an airplane. That rule has been changed so that now any 337 form issued for an alteration becomes part of the maintenance record. Figure 14-3-3 is an example of Form 337.

A copy of FAA Form 337 must be delivered to the aircraft owner for the aircraft records, and a copy must be forwarded to the FAA district office within 48 hours after approval for return to service.

While not a requirement, the inspector should retain a copy for the file, and the technicians submitting the work for approval should have a copy for their file.

The front side of Form 337 contains seven sections, six of which must be filled in by the technician and person/facility approving the form for return to service.

- *Block No. 1.* Aircraft make, model, serial number, and nationality and registration marks.
- *Block No. 2.* Name and address of owner, exactly as it appears on the Certificate of Aircraft Registration.
- *Block No. 3.* For FAA use only. Leave this block blank.
- *Block No. 4.* Unit Identification. Fill in the information for the unit on which the maintenance was performed. If the repair was made to the airframe, an additional entry is not necessary; if the repairs or alterations were made on an engine, propeller, or appliance, enter the make, model, and serial number in the appropriate space.
- *Block No. 5.* Mark the correct type of maintenance in the appropriate column.
- *Block No. 6A.* Enter the name and address of the technician, repair station, or manufacturer performing the work.
- *Block No. 6B.* Mark the appropriate block.
- *Block No. 6C.* Enter the certificate number of the individual who accomplished the work, or the repair station number or manufacturers number, if appropriate.
- *Block No. 6D.* Read the certification statement in block D, then sign and date the form.
- *Block No. 7.* This section must be filled in by a person or repair facility authorized to approve aircraft for return to service after major repairs or alterations. The required blocks must be checked, the form dated, and the certificate number of the person signing block 7 must be entered.
- *Block No. 8.* A full and complete description of the work accomplished is required on this side of the FAA Form 337.

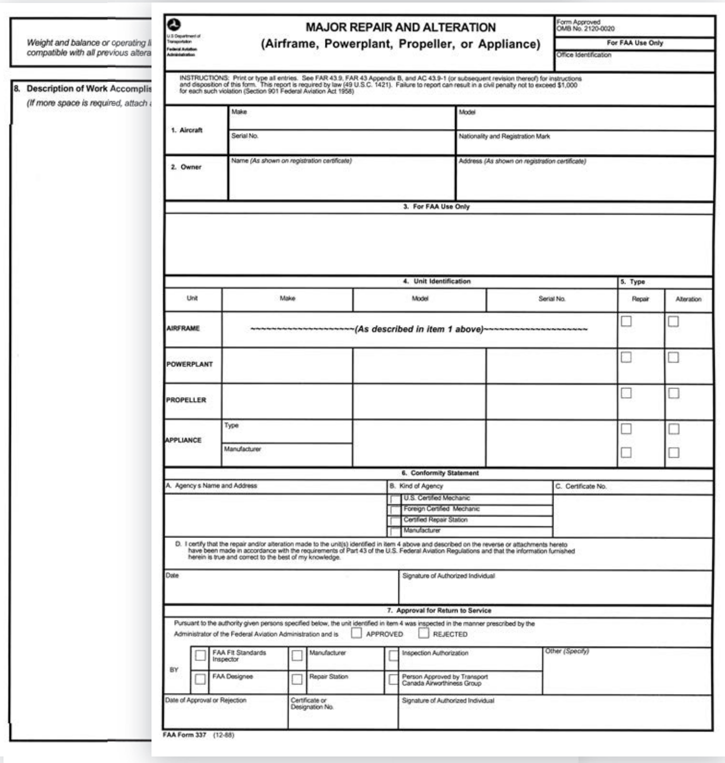


Figure 14-3-3. This is an example of a blank 337 form. It is one of the forms you will use most in repairs and modifications.

1. Include location of the repairs and manufacturers' part numbers for replacement parts used. Photographs, diagrams, and reference to Airworthiness Directives, MMs, and other sources may be used to detail how the work was accomplished. Technical data acceptable to the Administrator must be used for the basis of the repairs.

2. If additional space is needed to describe the alteration or repair, attach sheets bearing the aircraft nationality and registration mark and the completion date of the work. Draw a line after your entries have been made and mark it by the word End to show that nothing else follows.

3. Weight and balance data is not required on FAA Form 337; however, if the repairs or alterations affected the weight and balance of the aircraft, these changes must be recorded in the weight and balance records.

The reverse side of the form contains room for description of the work accomplished.

AC Form 8050-1, Aircraft Registration, and AC Form 8050-2, Aircraft Bill Of Sale. No person may operate an aircraft within the United States that is eligible for registration under Section 501(b) of the Federal Aviation Act of 1958, unless it has been registered by its legal owner.

- An application for a Certificate of Aircraft Registration is made on AC Form 8050-1, which is submitted to the FAA Aircraft Registration Branch with the required fee, and AC Form 8050-2, the original aircraft bill of sale, or other proof of ownership acceptable to the Administrator.

- The pink copy of the application form is retained in the aircraft and is valid until the AC Form 8050-3, Certificate of Aircraft Registration, is received from the FAA, or the application has been denied, but in no case more than 90 days.

The owner of an aircraft that has not been registered under the Federal Aviation Act of 1958 may register it if they submit with their application an AC Form 8050-2 signed by the seller, or other evidence of ownership authorized by FAR Section 47.11.

FAA Form 8120-4, Production Certificate. In order to secure a Production Certificate for aircraft, engines, propellers, or other components, the applicant must comply with the provisions of FAR Part 21, subparts F or G, as applicable.

The applicant must hold a Type Certificate for the product, licensing agreements granting the holder the benefits of the Type Certificate, or a Supplemental Type Certificate.

The manufacturing facilities need not be located within the United States. A system of quality control must be maintained to ensure that the finished product will meet the design provisions of the Type Certificate.

The holder of a Production Certificate must allow the FAA to make any inspections and tests necessary to determine compliance with the applicable regulations.

FAA Form 8100-2, Standard Aircraft Airworthiness Certificate. The manufacturer of an aircraft manufactured under a Production Certificate is entitled to a Standard Airworthiness Certificate. The Administrator may inspect the aircraft to determine its conformity to the Type Certificate.

An applicant for a Standard Airworthiness Certificate for a new aircraft manufactured under a Type Certificate only is entitled to a Standard Airworthiness Certificate after the owner submits a statement of conformity prescribed by FAR Section 21.130, and the Administrator finds, after inspection, that the aircraft conforms to the type design and is in an airworthy condition.

Any registered owner of U.S.-registered aircraft may apply for an Airworthiness Certificate for that aircraft. The Standard Airworthiness Certificate is issued for aircraft type certificated in the normal, utility, acrobatic, or transport category. The owner must present evidence that the aircraft conforms to a type design approved under a Type Certificate number or Supplemental Type Certificate, and to applicable Airworthiness Directives.

If the aircraft has been inspected in accordance with the performance rules for a 100-hour inspection and found airworthy, the FAA may then inspect the aircraft to determine if it conforms to its type design and is in condition for safe operation, and issue the Airworthiness Certificate.

The Standard Airworthiness Certificate is valid until surrendered, suspended, or revoked, as long as the aircraft is registered in the United States and maintenance, preventive maintenance, and alterations are performed in accordance with FAR Part 43 and FAR Part 91.

FAA Form 8130-7, Special Airworthiness Certificate. Special Airworthiness Certificates are issued for restricted, limited, and provisional category aircraft, including special flight permits and experimental aircraft certificates.

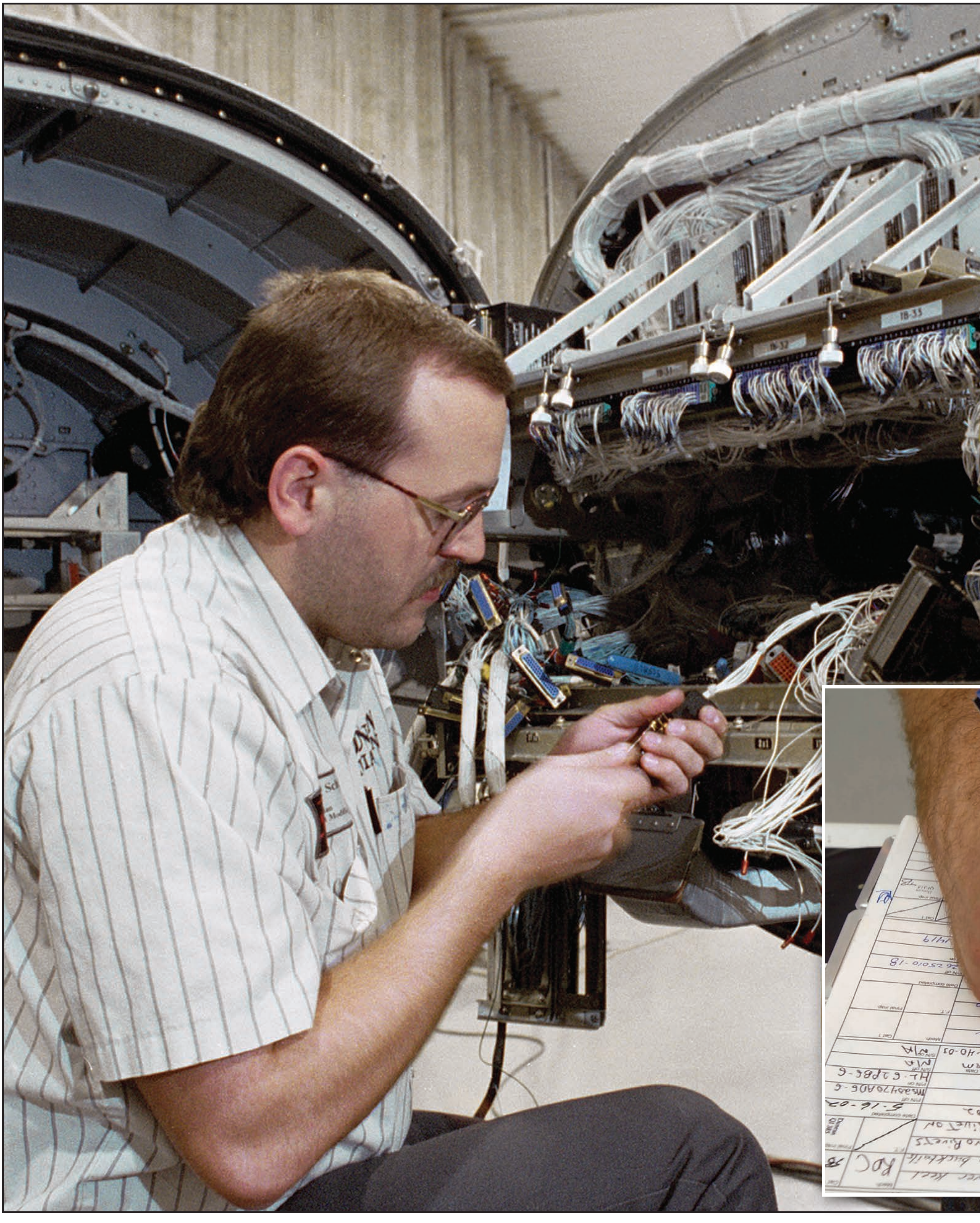
Special flight permits are effective only for the period of time specified on the permit. An experimental certificate for research and development, crew training, etc, is effective for one year unless a shorter period is prescribed by the Administrator.

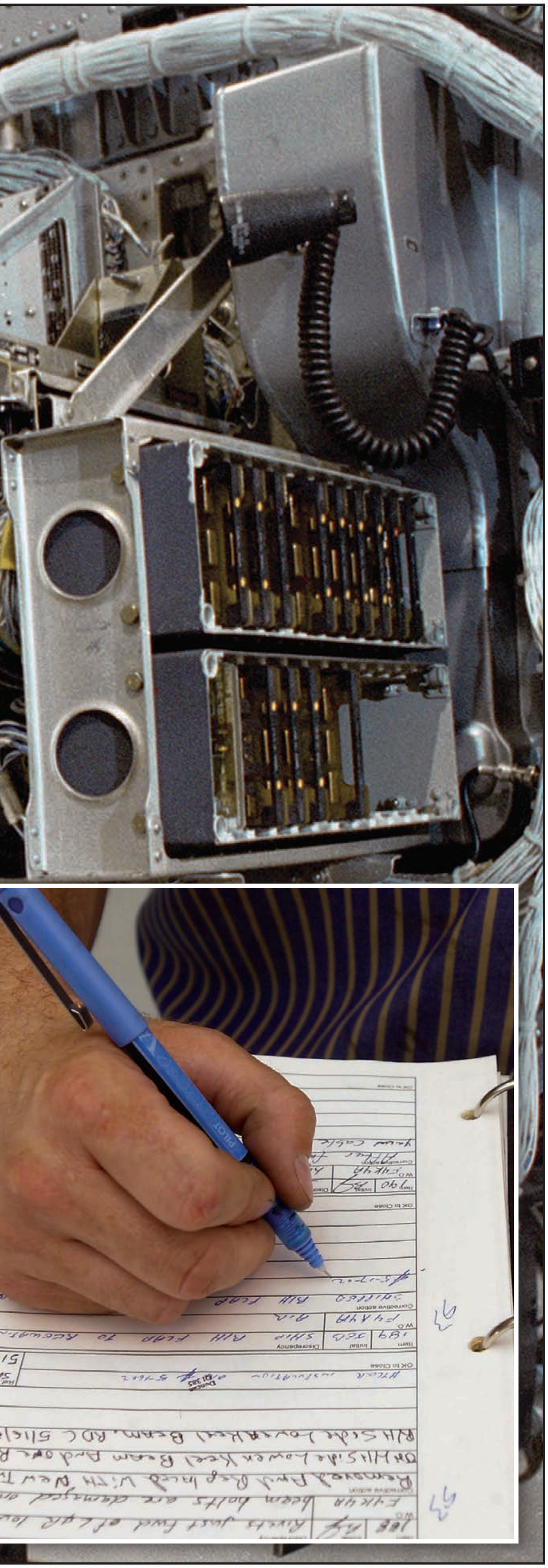
Computers in the maintenance department. The use of computers in the maintenance repair shops and Fixed-Base Operators (FBO) has steadily increased. First used solely as an aid in maintaining a record of Airworthiness Directives and their compliance, they are increasingly used for maintaining historical records, recording replacement intervals of life limited parts, and scheduling of phased inspection intervals.

The software for computers is becoming accessible to the smaller repair shops. Many FBOs are turning to computers for their maintenance departments, and the major aircraft manufacturers are inputting everything about the airplane they manufacture into their computer databases at the time the aircraft is manufactured. Every single part, stock number, and serial number is recorded. The records of the airplane's monthly flight hours, the average length of each flight and all maintenance and repairs performed on the aircraft are maintained in the computer. With this information, the computer can then estimate when the next inspection will be due, which items of equipment or which systems may require special inspections, and the computer can identify which components or parts may need replacement in time to have them on hand when the aircraft is down for the inspection. The computer can save time, improve the efficiency of the maintenance operation and promote safety in general aviation and executive and commercial carrier operations.

Manuals on CD-ROM. The ubiquitous CD has become the preferred method of providing manuals and instructions. They are cheap, hold a tremendous amount of information and are easy to update. With the adoption of Adobe Acrobat® and Adobe's Portable Document Format (PDF), entire libraries are reduced to a handful of CDs. These can be used on screen or printed by just about any computer/printer combination. The double armloads of heavy binders are rapidly becoming a thing of the past.

Computer education. If you do not yet know how to operate a personal computer, chances are you will have to begin learning before your course of study is completed. Classes are available in most communities that have adult education programs or a community college. Most can be taken for little or no money and will be necessary for your continued advancement.





15

Privileges and Responsibilities

Section 1

The Federal Aviation Administration

During the early days of aviation, there was no need for regulation of the airspace. Few people in those early days of the century could have possibly envisioned how large the aviation industry would grow in such a short period of time. The Wright brothers' early experiments in powered flight required that they design, build, maintain, and inspect their own product. The military was the primary consumer of aviation products and established their own systems of operation and maintenance regulations for the new air service.

It wasn't until World War I that this country began to realize the immense potential of aviation, and civil aviation began to grow. In those days, all that was needed to become a civilian pilot was the money to buy a surplus Jenny (Curtiss JN-4) and maybe an hour of instruction in how to land it. Anyone could fly or work on the aircraft and engines if they thought themselves capable of doing the work. There were no regulations or restrictions concerning civil aviation. This lack of regulation carried through to the designers and manufacturers. There were no standards of any kind.

Aviation has always been in the public eye, as it still is today. As the number of aircraft increased, so did the number of accidents (Figures 15-1-1), and many pioneer aviators lost their lives during this period. Some of the more spectacular accidents caused serious public outcry. Each new incident or accident added to the call for regulation of aviation.

Learning Objectives

REVIEW

- The process to obtain aviation maintenance technician certification

DESCRIBE

- Operation, guidelines and regulations of the Federal Aviation Administration
- Types of maintenance and inspections

EXPLAIN

- The components of human factors

Left. The privileges and responsibilities of an Aircraft Maintenance Technician are a complex issue. You are not responsible for prior work by someone else. You are responsible for your own work, and must do the return-to-service entry in the log books. You stay responsible for that work until someone else supercedes it at a later date.

Photo courtesy of Duncan Aviation

Figure 15-1-1. Boeing Air Transport pilot Frank Yager walked away from this crash in 1926.

Photo courtesy of Air Mail Pioneers

Figure 15-1-2. The first U.S. pilot's license was issued to the head of the newly formed Aeronautics Branch, William MacCracken, in 1927. The first federal aircraft mechanic's license was issued three months later.

Photo courtesy of the FAA

As a result, plans were made to license pilots (Figure 15-1-2) and mechanics and place them under the supervision of the federal government. At the same time, the government began registering airworthy aircraft (Figure 15-1-3). It was suggested that this could be done by the Bureau of Steamboat Inspection, but Senator Hiram Bingham of Connecticut was successful in pushing through the Air Commerce Act of 1926. This bill gave the government responsibility for fostering air commerce, for establishing airways and aids to air navigation, and for making and enforcing safety rules.

The act allowed the new Aeronautics Branch of the Department of Commerce to supply money for air navigation facilities so that the routes (used largely, at this time, for the transport of mail and airfreight, a new and booming enterprise) were safer.

The transcontinental air route that connected San Francisco, Omaha, Chicago, and New York was divided in two in 1927. While Boeing began contract service on the western route from San Francisco to Chicago, National Air Transport took over the eastern Chicago-to-New York sector.

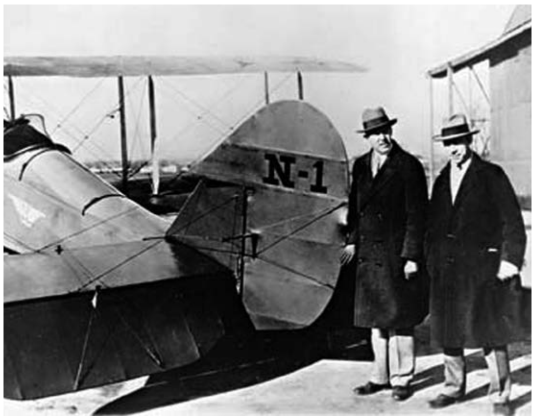


Figure 15-1-3. This former airmail plane was bought by the Aeronautics Branch in 1927 and became the first federally registered aircraft. The letter *N* was assigned to the U.S. by international agreement in 1919.

Photo courtesy of the National Archives

Along with the switch in management of the country's routes, airfields were handed over to local governments to pay for, manage, and maintain. The Dept. of Commerce took over construction of the Transcontinental Air Mail Route, which included 17 radio stations (Figure 15-1-4), hundreds of light beacons (Figure 15-1-5), and 92 emergency landing fields with floodlights to provide pilots with weather information. The facilities were staffed by nearly 50 radio operators, more than a dozen aircraft maintenance mechanics, and 84 caretakers.

The Air Commerce Act of 1926 also established the Bureau of Air Commerce within the Dept. of Commerce, led by William P. MacCracken, Jr. The bureau was the predecessor of the Civil Aeronautics Administration, (CAA) which was established by the Civil Aeronautics Act of 1938.

The founding of pilot organizations closely followed the birth of airline companies and regulatory services. The late 1920s and early 1930s saw the formation of the National Air Pilots Association (NAPA) and the Air Line Pilots Association (ALPA). By the dawn of the '30s, there were 47 airmail and 61 passenger airlines in the United States alone.

In the mid 1930s, airline policy makers, fearing the possibility of mid-air accidents caused by increased traffic, christened the first Airway Traffic Control Station in Cleveland. A year later, sites were added in New Jersey (Figure 15-1-6) and Chicago. En-route controllers, as they were called, tracked planes' positions with chalkboards and maps, using telephones to contact dispatchers, radio operators, and airport traffic controllers with updates and instructions.

Aside from the regulation of civil aviation, the CAA also regulated the business and operation of the growing airline industry. The CAA not only regulated the airlines operationally, it also established a route system that controlled which airline could fly to what cities, as well as what a passenger could be charged for the flight. With that control came a set of subsidies that "leveled the playing field" by establishing an income level for each flight. If not enough seats were sold to reach the level, the CAA made up the difference between actual income and the government established income level. Twenty years later, the CAA was replaced by the Federal Aviation Agency by passage of the Federal Aviation Act of 1958. The CAA was retained and still operated the seat-mile subsidy.

In 1967, the Federal Aviation Agency was placed under the Dept. of Transportation. The name was then changed to Federal Aviation Administration.

In the 1980s, the U.S. went through a process of de-regulating many federally supported institutions. The airline industry was one of them. As the de-regulation process worked itself out, it caused a large number of problems for the airline industry. Individual airlines that relied heavily on the seat-mile subsidy found themselves in serious financial trouble. Indeed, many never recovered.

Operational levels of the FAA. The FAA is involved in every facet of civil aviation. There are regional offices in the continental United States, with additional international regional offices to assist the FAA in promoting air safety standards.

In addition to the regional offices, there are Flight Standards District Offices (FSDOs) located near major aviation centers throughout the country. These offices provide oversight and enforcement of federal regulations throughout the country. In addition, the Manufacturing Inspection District Offices (MIDO) provide oversight of the prime aircraft manufacturers (PAM) and their suppliers.

A major FAA facility located at Will Rogers International Airport, Oklahoma City, is the Mike Monroney Aeronautical Center (MMAC). All airman and aircraft certification records and files are maintained there. Other operations, such as training of air traffic controllers, pilot flight test examiners, and many other functions are conducted at the MMAC.

Guidelines of the FAA. Any organization as large and complex as the FAA must have legal guidelines within which the bureaucracy must operate. Title 14 of the Code of Federal Regulations (14 CFR) gives the FAA the authority to conduct its operations and gives its directives legal status. These directives are published as the Federal Aviation Regulations and are the basis for all enforcement actions taken by the FAA.

Figure 15-1-4. A radio shack in Cheyenne, Wyoming.
Photo courtesy of Air Mail Pioneers

FAA Regulations

Development. During the development phase of a new aircraft, engine, or component design, the designers must work within the constraints of FAR Part 23: Airworthiness Standards; Normal, Utility, Acrobatic, and Commuter Category Airplanes. As a new design proceeds through the development and testing phases of construction, each component and system must meet the standards as prescribed by FAR Part 23.

On completion of development and testing and type acceptance by FAA inspectors, the aircraft is awarded an Airworthiness Certificate under the provisions of FAR Part 21: Certification Procedures for Products and Parts.

Operation. As the aircraft is delivered to the purchaser, it must be flown by a licensed pilot, which is covered under FAR Part 61, Certification: Pilots and Flight Instructors.

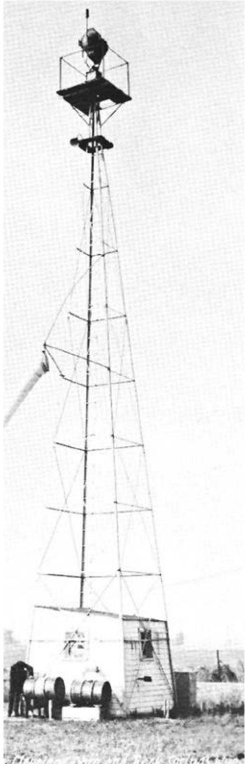


Figure 15-1-5. The Air Commerce Act of 1926 gave the Dept. of Commerce control over the as-yet-unfinished transcontinental lighted airway, which included light beacons and weather radio stations to improve flight safety. *Photo courtesy of Air Mail Pioneers*

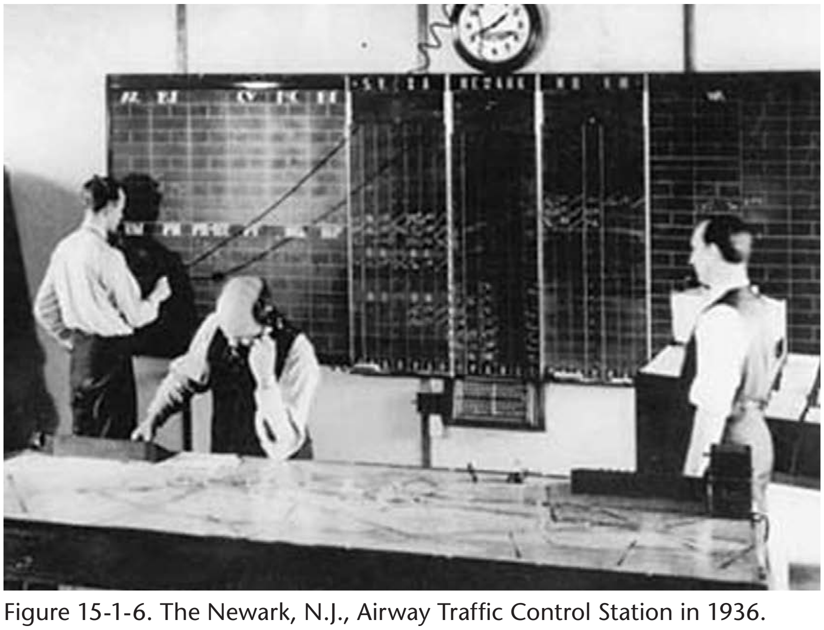


Figure 15-1-6. The Newark, N.J., Airway Traffic Control Station in 1936. Pointed markers known as "shrimp boats" were moved across maps to track an aircraft's flight progress. *Photo courtesy of the FAA*

Figure 15-2-1. All computerized testing is accomplished by outside firms contracted to the FAA. The results of those tests, though, come from the FAA itself. *Photo courtesy of Duncan Aviation*

The owner of the aircraft is required to maintain and operate this aircraft as directed by FAR Part 91: General Operating and Flight Rules.

All maintenance, inspection, and repairs must be performed in accordance with the requirements of FAR Part 43: Maintenance, Preventive Maintenance, Rebuilding, and Alteration, and by personnel certified to perform maintenance in accordance with the requirements of FAR Part 65: Certification: Airmen Other Than Flight Crewmembers.

While it may not be necessary that each person applying for an airman certificate memorize the contents of each and every FAR, all should have a good working knowledge of the various parts. Each of the FARs mentioned so far will have at least one section that will apply to you as you work towards an Aviation Maintenance Technician certificate.

Section 2

Aviation Maintenance Technician Certification

The A&P Certificate

If you have gotten as far as reading this section of the textbook, you more than likely have already been presented with the material covered here. Most of it bears repeating, so we will present it here.

Application. The technician applicant must be at least 18 years of age, and he or she must be able to read, write, speak, and understand the English language. An applicant who is to be employed by a US carrier outside of the United States, however, is not required to speak English. His or her certificate must be endorsed, "Valid only outside of the United States." All of the prescribed tests must be completed within a period of 24 months after graduation or initial approval for testing, and each applicant must comply with the sections of FAR Part 65, Subpart D, applicable to the rating they seek.

The applicant for a technician's license must present an appropriate graduation certificate or certificate of completion from a certified aviation maintenance technical school, or documentary evidence of at least 18 months' experience maintaining or altering airframes, for the airframe rating. For the powerplant rating, documentary evidence must be presented covering at least 18 months' experience maintaining or altering powerplants. For both ratings, a total of 30 months' experience performing the duties appropriate to both ratings must be submitted. Generally, this is in the form of a signed letter or affidavit from your employer.

If you are involved in aircraft maintenance in any branch of the armed forces, you can get credit for most of your experience. You must get an official letter from your military employer outlining your experience and present it to a FSDO. The FSDO has a chart that includes what kind and how much credit you may receive for your military experience. You can only receive the credit for your actual work; special schools do not count. In addition, you must still take the examinations. Normally this will take some study to make the transition from the military to the civilian way of doing things.

Testing. After satisfying the experience requirements, the technician applicant must pass a written test covering the construction and maintenance of airframes, powerplants, or both. The tests are still referred to as the written tests, but are computerized (Figure 15-2-1). A list of testing centers should be available from your school, your local FSDO, or from the Internet.

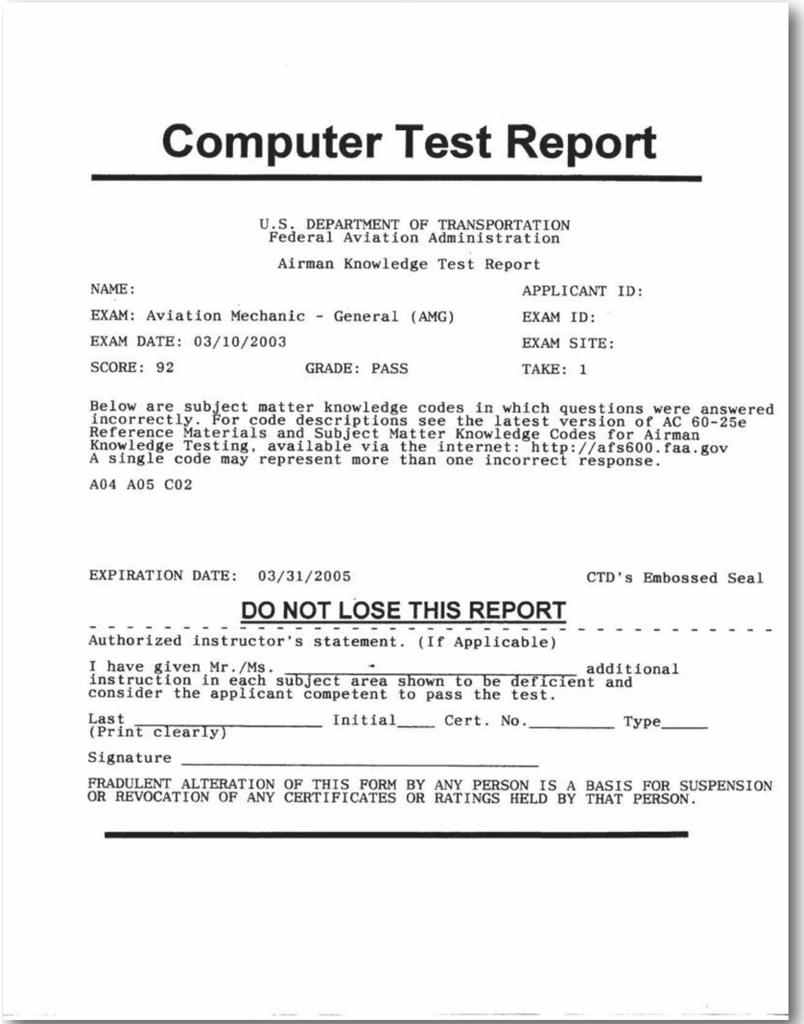
The written tests for the aviation technician's certificate consist of three separate examinations. They are:

- **The general examination**. This examination consists of 50 multiple-choice questions covering aviation mechanic general subjects. Each question on the examination has a value of two points, and a grade of 70 percent is required for a passing score.
- **The airframe examination**. This examination consists of 100 questions and is

divided into two parts. Part I consists of 25 questions covering airframe structures and each question has a value of four points. Part II consists of 75 questions covering airframe systems and components and each question has a value of 1.33 points. The written test record will have both grades recorded for the airframe examination.

- **The powerplant examination**. This examination also consists of 100 questions and is divided into two parts, just as the airframe examination. Part I consists of 25 questions covering powerplant theory and maintenance and each question has a value of four points. Part II consists of 75 questions covering powerplant systems and components and each question has a value of 1.33 points. The powerplant written test record will have both grades recorded for the powerplant examination.

The technician applicant must successfully pass all sections of the A&P technicians exam with a minimum grade of 70 percent. The written test results (Form Advisory Circular 8080-2, (figure 15-2-2) which the applicant will receive from the Airman's Record Center (MMAC), will have five test grades recorded on the three forms. The general examination score will be on a separate test form and is identified by the letters AMG. The Airframe test scores will be identified by the letters AMA and two scores will be recorded on this form. The Powerplant test scores will be identified by the letters AMP and two test scores will be recorded on this form.


Computer Test Report

U.S. DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration

Airman Knowledge Test Report

NAME: APPLICANT ID:
EXAM: Aviation Mechanic - General (AMG) EXAM ID:
EXAM DATE: 03/10/2003 EXAM SITE:
SCORE: 92 GRADE: PASS TAKE: 1

Below are subject matter knowledge codes in which questions were answered incorrectly. For code descriptions see the latest version of AC 60-25e Reference Materials and Subject Matter Knowledge Codes for Airman Knowledge Testing, available via the internet: http://afs600.faa.gov
A single code may represent more than one incorrect response.

A04 A05 C02

EXPIRATION DATE: 03/31/2005 CTD's Embossed Seal

DO NOT LOSE THIS REPORT

Authorized instructor's statement. (If Applicable)

I have given Mr./Ms. ______________ additional instruction in each subject area shown to be deficient and consider the applicant competent to pass the test.

Last ______________ Initial____ Cert. No.________ Type_____
(Print clearly)

Signature ______________________________

FRADULENT ALTERATION OF THIS FORM BY ANY PERSON IS A BASIS FOR SUSPENSION OR REVOCATION OF ANY CERTIFICATES OR RATINGS HELD BY THAT PERSON.

Figure 15-2-2. Form AC 8080-2, the Airman Written Test Report, lists the results of each applicant's test and will indicate all pass/fail grades by subject area.

Figure 15-2-3. The new, permanent A&P cetificate is a credit card-sized plastic document.

After receiving the written test score, the applicant then must pass an oral and practical examination covering the same basic subjects administered by a Designated Mechanic Examiner (DME), who will ask oral questions and assign practical projects of certain maintenance procedures to test knowledge and proficiency in each of the areas of maintenance.

The applicant who successfully passes the oral and practical examinations may be awarded a temporary technician's certificate by the DME. In some FAA jurisdictions, the temporary certificate is awarded by the FAA local office after receiving the test reports from the DME. The temporary certificate is issued to allow time for review of the technician's application and supplementary documents. The temporary certificate is effective for a period of no more than 120 days. With a temporary in hand, the technician is certified to pursue his or her A&P career. A permanent certificate (Figure 15-2-3) will be mailed to him or her.

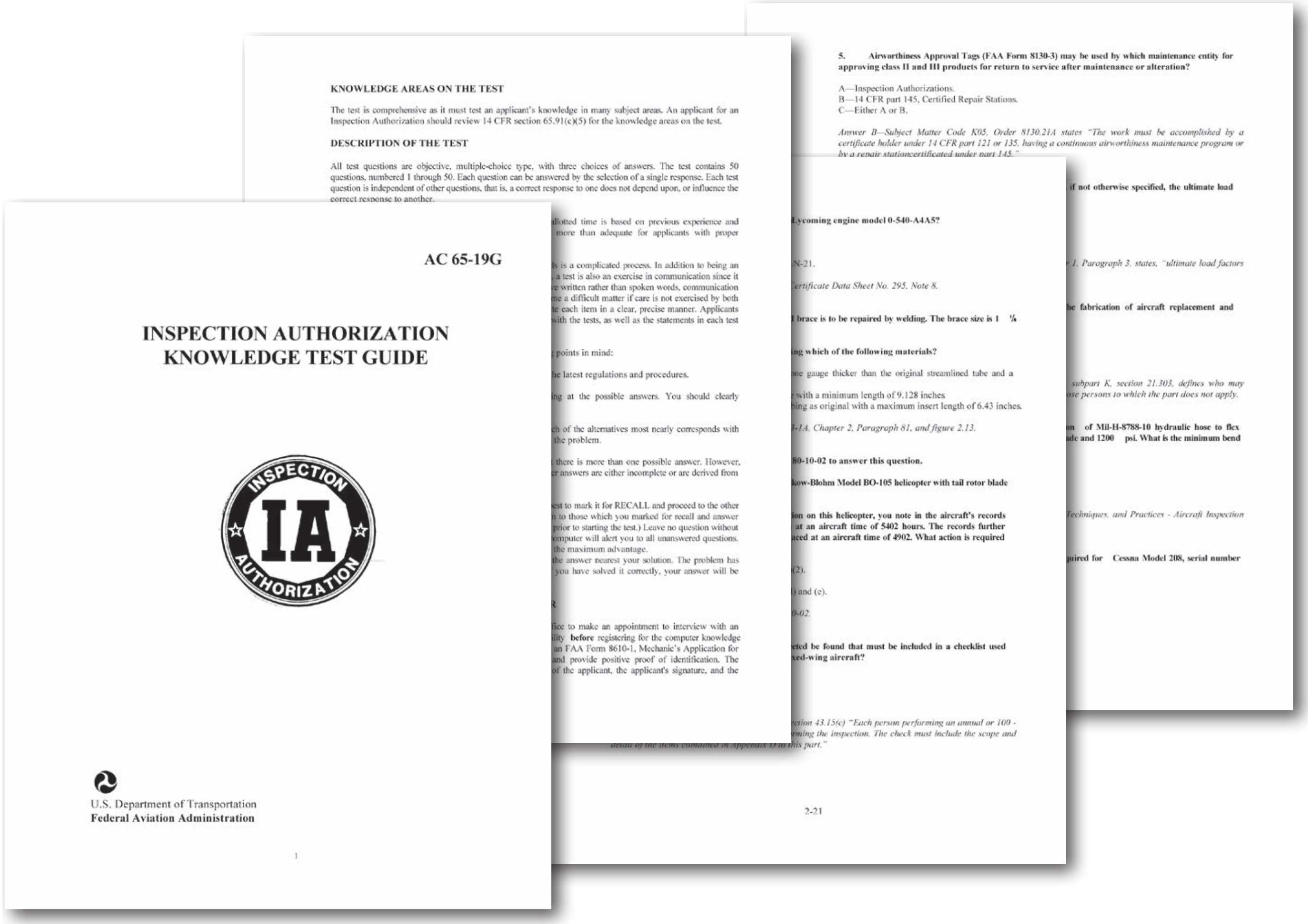


Figure 15-2-4. AC 65-19 is the official IA study guide. Aftermarket study guides are also available.

Privileges and limitations. Newly licensed A&P technicians may perform maintenance, preventive maintenance, or alterations on aircraft, engines, appliances, and parts for which they are rated. They may not perform major repair or major alterations to propellers, nor may they perform any repair or alteration to instruments.

A&P technicians may also perform the 100-hour inspection of aircraft and powerplants for which they are rated if they have performed the work before and understand the current instructions of the manufacturer and the maintenance manuals (MM) for the specific operations they are performing. Note that it is almost impossible to comply with this part of the regulations unless you are working under the supervision of a certified technician that has the requisite experience.

A&P technicians must not exercise the privileges of their rating unless they have performed the duties of a technician for at least six months within the preceding 24 months.

The holder of a certificate shall notify the FAA within 30 days after any change in his or her permanent mailing address, as per 14 CFR Part 65.21.

Except for repairman certificates, a certificate or rating issued is effective until it is surrendered, suspended, or revoked, according to 14 CFR Part 66.15.

The Inspection Authorization (IA) rating. The A&P technician who has held both the airframe and powerplant ratings for a period of three years and has been actively engaged in maintaining civil aircraft for two years prior to applying for the IA examinations, who has the equipment, tools, facilities, and inspection data available, and has a fixed base of operations where the applicant may be reached during a normal work week, is entitled to an inspection authorization rating. The applicant must also pass a written examination on the ability to inspect according to safety standards for returning aircraft to service after major repairs and major alterations, and after annual and progressive inspections performed under FAR Part 43.

The IA examination is a comprehensive test covering many diverse and complicated situations which the inspector may encounter while exercising the privileges of the rating.

The FAA tests are designed to test the applicant's knowledge of many areas of maintenance covered by the FARs and other technical data (Figure 15-2-4).

Eligibility is established at the local FAA Flight Standards District Office (FSDO) prior to taking the Inspection Authorization Knowledge Test. You are eligible for the IA Knowledge Test if you meet the requirements of Title 14 of the Code of Federal Regulations (14CFR) part 65, section 65.91(c).

The IA Knowledge Test is comprehensive as it must test knowledge in many subject areas. When applying for an IA you should review 14 CFR 65.91 (c)(5) for the knowledge areas on the test.

All test questions are multiple-choice. The test contains 50 questions. Each question can be answered by the selection of a single response. Each question is independent of other questions; therefore, a correct response to one does not depend upon, or influence the correct response to another.

The maximum time allowed for the test is 3 hours. The allotted time is based on previous experience and educational statistics. This amount of time is considered more than adequate if you have prepared properly.

The IA test has been considered by some as an open book test because of the use of reference material during the test. To view the test in this manner is a misconception. It should be noted that during the test, there are subject areas for which reference material is not included in the test supplement. These areas will draw on skills acquired as an airframe and powerplant mechanic and which are necessary to properly inspect work performed by others.

Once an applicant has met the qualifications for the IA and has received authorization to take the test from the FAA, a computer testing site must be found. This may be done by contacting the computer testing designees (CTDs) on their 1-800 number. LaserGrade's phone number is 1-800-211-2753. CATS phone number is 1-800-947-4228. A complete listing of test centers may be found on the internet at www.afs600.faa.gov under the heading "Airman Testing Standards (AFS630)".

Upon completion of the test, you will receive your Airman Test Report, with the centers embossed seal, which reflects your score. The minimum passing score is 70. If the test is failed, there will be a 90-day waiting period before retesting is allowed.

Cheating or other unauthorized conduct. As stated in 14 CFR Part 65.20, falsification, alteration, or fraudulent reproduction of certificates, logbooks, reports, and records is a basis for suspension or revocation of any airman or ground instructor certificate or rating held by that individual.

Computer testing centers follow strict security procedures to avoid test compromise. These procedures are established by the FAA and are covered in FAA Order 8080.6, Conduct of Airman Knowledge Tests. The FAA has directed all testing centers to terminate a test at any time a test proctor suspects a cheating incident has occurred. An FAA investigation will then follow. If the investigation determines that cheating or other unauthorized conduct has occurred, any airman certificate that you hold may be revoked, and you may not be allowed to take a test for 1 year.

If you have the required experience level and knowledge, skill, and aptitude to obtain an IA rating, talk to your employer about your desires. Also note that the IA rating is indeed a rating, not another license.

The Repairman's Certificate

The repairman's certificate is for personnel who do not hold the technicians certificate, but are otherwise competent in one or more specialty areas (FAR Part 145: Repair Stations). The repairman certificate is issued to personnel performing maintenance, inspection, manufacturing, or alterations in FAA-approved repair stations. These repair stations may be approved by the FAA for one or more specific functions; for instance, maintenance and overhaul of aircraft instruments, powerplants, accessories such as starters, generators, fuel cells, tires, exhaust systems, and many other specialized maintenance areas.

The repairman's certificate is available to specially qualified personnel who have at least 18 months' practical experience in the procedures, practices, inspection methods, etc., of the specific area for which the person is to be employed.

The repairman may gain this experience by attending a formal training course that is acceptable to the Administrator and is specifically designed to qualify the applicant for the job the applicant is seeking.

The repairman applicant must be 18 years of age, and be able to read, speak, and understand the English language. The repairman certificate is valid only as long as the repairman is employed in the repair station for which the certificate is held.

To be eligible for	You must
A repairman certificate (light-sport aircraft)	(i) Be at least 18 years old. (ii) Be able to read, speak, write, and understand English. If for medical reasons you cannot meet one of these requirements, the FAA may place limits on your repairman certificate necessary to safely perform the actions authorized by the certificate and rating. (iii) Demonstrate the requisite skill to determine whether a light-sport aircraft is in a condition for safe operation, and (iv) Be a citizen of the United States, or a citizen of a foreign country who has been lawfully admitted for permanent residence in the United States.
A repairman certificate (light-sport aircraft) with an inspection rating	(i) Be at least 18 years old. (ii) Be able to read, speak, write, and understand English. If for medical reasons you cannot meet one of these requirements, the FAA may place limits on your repairman certificate necessary to safely perform the actions authorized by the certificate and rating.
A repairman certificate (light-sport aircraft) with a maintenance rating	(i) Meet the requirements of paragraph (1) of this section, and (ii) Complete a training course acceptable to the FAA on maintain the particular class of light-sport aircraft for which you intend to exercise the privileges of this rating. The training course must, at a minimum, provide the following number of hours of instruction: (A) For airplane class privileges—120 hours. (B) For weight-shift control aircraft class privileges—104 hours. (C) For powered parachute class privileges—104 hours. (D) For lighter than air class privileges—80 hours. (E) For glider class privileges—80 hours.

Table 15-2-1. Basic requirements for an LSA repairman certificate.

A repairman may not perform any maintenance or repairs on any item that they are not certificated. They also may not perform the duties for which they are certificated outside their place of employment.

The Light Sport Aircraft (LSA) Repairman

The FAA has certificated a new class of aircraft, the Light Sport Aircraft, or LSA. The construction, maintenance, and inspections requirements are defined by the aviation industry in documents known as consensus standards. The FAA has accepted this concept of industry-generated standards. The manufacturer and the owner/operator now have a much greater role in the documentation and safety reporting process.

These aircraft can be maintained by an A&P or by the owner/operator if they hold a Repairman Certificate with the Maintenance rating as defined in FAR part 65. These requirements are in Table 15-2-1.

Those who perform maintenance on an LSA must posses at least a Repairman Certificate with the Maintenance Rating, as defined in FAR part 65. This is after a course that specializes in a particular type of LSA, such as:

- Airplane
- Powered parachute
- Weight shift control
- Gyroplane
- Lighter than air
- Glider

Unlike the A&P certificate which can be obtained by experience (18 months airframes, 18 months powerplants or 30 months combined) or by completing an AMT school (minimum 1900 hrs. of instruction) the repairman with a maintenance rating must have specific instruction on that class of aircraft. The consensus standards may also require schooling from the specific aircraft manufacture before any maintenance or inspections can be performed.

Generally, an A&P can perform maintenance or a condition inspection when they can show that they either:

- Worked on an LSA before
- Were trained to work on an LSA or
- Were supervised by a technician or repairman with experience on LSAs

The consensus standards may detail specific privileges and limitations for the technician. An extensive examination of the standards and the manufacturer's requirements should be done before starting any work, failure to do so may result in certificate action by the FAA. One example is the Rotax engine. Rotax does not allow a major overhaul of its engines in the field. The engine must be returned to Rotax or an authorized repair station for overhaul.

The maintenance record entry for a condition inspection must include the aircraft total time in-service, the name, signature, certificate number, and type of certificate held by the person performing the inspection.

The Light Sport Aircraft (LSA) is an aircraft that meets the requirements of the Title 14 of the Code of Federal Regulations. Some of these requirements are:

- Maximum takeoff weight of 1,230 lbs
- Maximum airspeed of 120 kts
- Maximum stall speed of not more than 45 kts
- Operated in day VFR conditions only

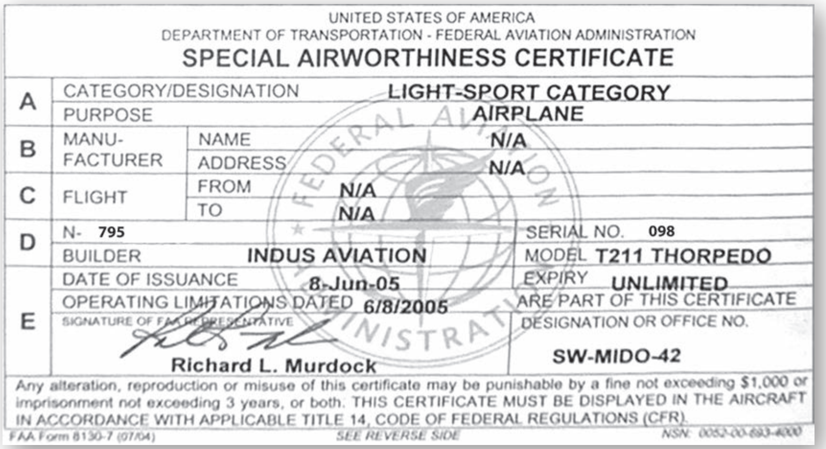
Some aircraft may meet these requirements but not be LSA aircraft. The aircraft may have a Standard Airworthiness Certificate issued at the time of manufacture. The only way to make sure that the aircraft is an LSA is to verify the Airworthiness Certificate in the aircraft (Figure 15-2-5). If the certificate is for Standard Airworthiness then the aircraft must be maintained to those standards and not the LSA standards.

All the standards regarding the design, operation, and maintenance of LSA come from industry-based consensus standards, which the FAA has accepted. Since the FAA did not develop the standards, they have allowed the industry to take the lead on administering and regulating those standards.

The consensus standards may be found at the American Society for Testing Materials (ASTM) website, www.astm.org for a fee.

The consensus standards define a new term in the maintenance and inspection vocabulary: Safety Directive or SD. This is the equivalent of an Airworthiness Directive (AD) and carries the same regulatory requirements. The aircraft manufacturer, not the FAA ,issue the SD. The manufacturer is responsible for tracking, evaluating, and issuing the SD based on data it collects from the owner/operators. They are required to notify the manufacturers of any discrepancies that could result in an unsafe condition. The FAA is only involved from an enforcement standpoint, since the FAR's prohibit the operation of an aircraft that has a known safety problem.

The FAA has made maintenance on an LSA easier by reducing the paperwork and oversight of the technician. The trade off is that the owner must assume added responsibilities as defined by the consensus standards. Standard F2295-03 lists several owner/operator responsibilities:


UNITED STATES OF AMERICA
DEPARTMENT OF TRANSPORTATION - FEDERAL AVIATION ADMINISTRATION
SPECIAL AIRWORTHINESS CERTIFICATE

A	CATEGORY/DESIGNATION		LIGHT-SPORT CATEGORY
	PURPOSE		AIRPLANE
B	MANU-FACTURER	NAME	N/A
		ADDRESS	N/A
C	FLIGHT	FROM	N/A
		TO	N/A
D	N- 795		SERIAL NO. 098
	BUILDER	INDUS AVIATION	MODEL T211 THORPEDO
E	DATE OF ISSUANCE	8-Jun-05	EXPIRY UNLIMITED
	OPERATING LIMITATIONS DATED	6/8/2005	ARE PART OF THIS CERTIFICATE
	SIGNATURE OF FAA REPRESENTATIVE	Richard L. Murdock	DESIGNATION OR OFFICE NO. SW-MIDO-42

Any alteration, reproduction or misuse of this certificate may be punishable by a fine not exceeding $1,000 or imprisonment not exceeding 3 years, or both. THIS CERTIFICATE MUST BE DISPLAYED IN THE AIRCRAFT IN ACCORDANCE WITH APPLICABLE TITLE 14, CODE OF FEDERAL REGULATIONS (CFR).

FAA Form 8130-7 (07/04) SEE REVERSE SIDE NSN: 0052-00-693-4000

Figure 15-2-5. LSA Airworthiness Certificate.

- Comply with maintenance and continued airworthiness information provided by the manufacturer
- Provide the manufacturer with current contact information
- Notify the manufacturer of any safety of flight issue
- Comply with all manufacturer-issued notices of corrective action
- Comply with all applicable aviation authority regulations in regard to maintaining the airworthiness of the LSA
- Ensure that any needed corrective action be completed as specified in a notice, or by the next scheduled annual inspection.

The applicable provisions of part 43 state that the entire part 43 applies to LSA except for those portions that pertain to major repairs and major alterations. Since all maintenance will be regulated by consensus standards through the manufacturer, there is no need for a paper trail to be left with the FAA; the manufacturers assume that responsibility.

The LSA represents a new class of aircraft that will impact maintenance shops around the country. Before any work is performed, the regulatory and maintenance requirements must be carefully considered.

Duties and Responsibilities

The choice of your life's work can be influenced by many things; desire for a steady job, better salaries, upward mobility, family history, or personal desires. When you chose to enter a mechanical field, the choice of Aircraft Maintenance Technician is frequently based on a love of machinery that really does something—it flies.

When you chose aircraft maintenance as a career, you entered a unique field. You not only will learn the "nuts and bolts" of the subject, you also will learn the "how and why." You will learn how to look at something and see the complete process. Just knowing that something is bent or broken and fixing it is not enough because not much can happen by itself. Frequently the damage you are looking at had its beginning somewhere upstream of the actual item. By replacing the item only, you are working at the bottom of the chain of events that caused it to become damaged or to fail. That means it will fail again, and the second failure may cause even more damage.

Section 3

Maintenance and Inspection Requirements

Types of Maintenance

Major alterations. Any change in the aircraft structure which causes it to deviate from its original type certificate or specification, or which may result in changes to the weight and balance or maximum gross weight of the aircraft, may be a major alteration. A list of major alterations covering the airframe, powerplant, propeller, and appliances is contained in FAR Part 43, appendix A, and should be referenced when any alteration is made on an aircraft or its parts. If an item can't be properly classified from this list, you may have to contact your FSDO for a determination.

Major alterations must be recorded and approved by submitting FAA Form 337, Major Repair or Alteration.

Minor alterations. The official definition of a minor alteration is any alteration that is not a major alteration. The decision to be made may not be agreeable to all parties, and the final decision will be made by the FAA. When in doubt, a safe course to follow may be to treat all alterations as major, and let the FAA decide which are minor and which are major. Figure 15-3-1 is an example of a major airframe alteration.

Major repairs. Repairs involving the strengthening, reinforcing, splicing, etc., of primary structural members or their replacement by riveting or welding, are classified as major repairs. FAR Part 43, appendix A, lists 28 specific items for the airframe — and more for the powerplant, propellers, and appliances — as a guide for maintenance technicians.

Minor repairs. The definition of minor repair in FAR Part 1, is much the same as the minor alteration, and the same guidelines may apply for the determination of a repair category. If the repair follows normal procedures, is covered in the MM, and does not require extensive disassembly or complex maintenance operations, then it may be a minor repair. Changing a runout engine with a new or overhauled engine of the same type and model would not require approval by the holder of an IA and is a minor repair, even though it is not a simple operation.

Preventive maintenance. Preventive maintenance consists of routine aircraft service items such as oil and fuel service, and putting air in the tires. Routine preventive maintenance tasks can be performed by the pilot/owner on his or her own aircraft.

FAR Part 43, appendix A. This appendix lists 29 specific items which require simple operations and involves no complex assembly operations.

FAR Section 43.3. This authorizes the holder of a pilot's certificate issued under **FAR Part 61** to perform preventive maintenance on any aircraft owned or operated by that pilot, unless it is being operated under FAR Parts 121, 127, 129 or 135 which are commercial air-carrier-type operations.

FAR Section 43.9. This section directs that each person who maintains, performs preventive maintenance, rebuilds, or alters an aircraft, airframe, aircraft engine, propeller, appliance, or component part shall make a maintenance entry in the maintenance record of that equipment. This requirement is equally binding on the owner/pilot when performing the preventive maintenance functions, as it is on the A&P technician performing maintenance and repairs to aircraft and powerplants.

Types Of Inspections

Preflight inspections. This inspection is normally performed by the pilot prior to flying the aircraft and consists mostly of an operational check of flight surfaces, inspection of fuselage, engine servicing, and general condition of the aircraft.

Annual inspection. **FAR Part 91, General Operating Rules**, states that no one may operate an aircraft unless, within the preceding 12 months, it has had an annual inspection.

The annual inspection must be performed by the manufacturer, an approved repair station, or an A&P technician who holds the IA rating. The aircraft is inspected in accordance with FAR Part 43, appendix D, using a checklist designed to cover those areas listed in appendix D. Most manufacturers publish a recommended checklist which includes those items listed in appendix D. The IA performing the inspection may also provide a checklist of his own choosing, but in any case, appendix D specifies the minimum items which must be covered during the annual inspection.

If the aircraft is determined to be in an airworthy condition, conforms to its Type Certificate, and has no outstanding ADs applied to the aircraft or its appliances, the IA will approve the aircraft for return to service.

In the event the aircraft is determined to be in an un-airworthy condition, the inspection may be signed off in the aircraft logbooks as being completed, but a list of the un-airworthy items must be provided for the owner. These items must be corrected and the aircraft approved for return to service by a person authorized under FAR Part 65 before it is released for flight.

The un-airworthy items may be corrected by the pilot/owner if they are preventive maintenance items, or by an A&P technician if they are minor repairs and maintenance operations not requiring an IA or repair station certification. Each un-airworthy item should be entered in the logbooks and approved for return to service by the person approving the work before the aircraft is released for flight.

100-hour inspection. All general aviation aircraft operated for hire, flight instruction, charter, banner towing, sightseeing, aerial photography, etc., must have the aircraft inspected every 100 hours of operation. This 100-hour inspection is in addition to the annual inspection described in FAR Part 91.409(a)(1), annual inspection.

The scope and detail of the two inspections are identical, but an A&P technician may perform the 100-hour inspection and approve the aircraft for return to service. The A&P technician may disapprove the aircraft for return to service if it is discovered that it is not in an airworthy condition. The technician must give the owner a list of the discrepancies and un-airworthy items just as the holder of the IA must for an annual inspection.

Progresive inspections. The progressive inspection program is explained in detail in FAR Part 91.409(d), and the procedures for setting up the program are beyond the scope of this publication. The program is designed for operators who cannot afford to have their aircraft grounded for the annual and 100-hour inspections for long periods of time.

Figure 15-3-1. This camera hatch is certainly a major alteration. A modification of this type would likely require the services of a DER (Designated Engineering Representative).

The annual inspection items are divided into four sections and each segment is performed every three months, or at other time intervals if approved by the local FAA office. The aircraft will have a detailed inspection performed on one segment, i.e., wings, and center section, and a routine inspection of the remainder of the aircraft. The aircraft is returned to service, and 90 days later, a detailed inspection of another segment of the aircraft, i.e., powerplant, is given a detailed inspection, followed by a routine inspection of the remaining sections of the airframe. Figure 15-3-2 shows an airplane undergoing a progresive inspection.

A complete detailed inspection of the aircraft must be performed over the 12-month period beginning when the aircraft is approved for the progressive inspection program.

Continuous inspections. FAR Section 91.409 directs that the owners of large aircraft with a gross takeoff weight of 12,500 pounds or more, multi-engine turbo jet, or turbo propeller-equipped airplanes must select, identify (in the maintenance records), and use one of the following inspection programs for that airplane:

- A continuous airworthiness inspection program that is part of a continuous airworthiness program currently in use by a person holding an air carrier operating certificate or an operating certificate issued under the provisions of FAR Part 121, Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of

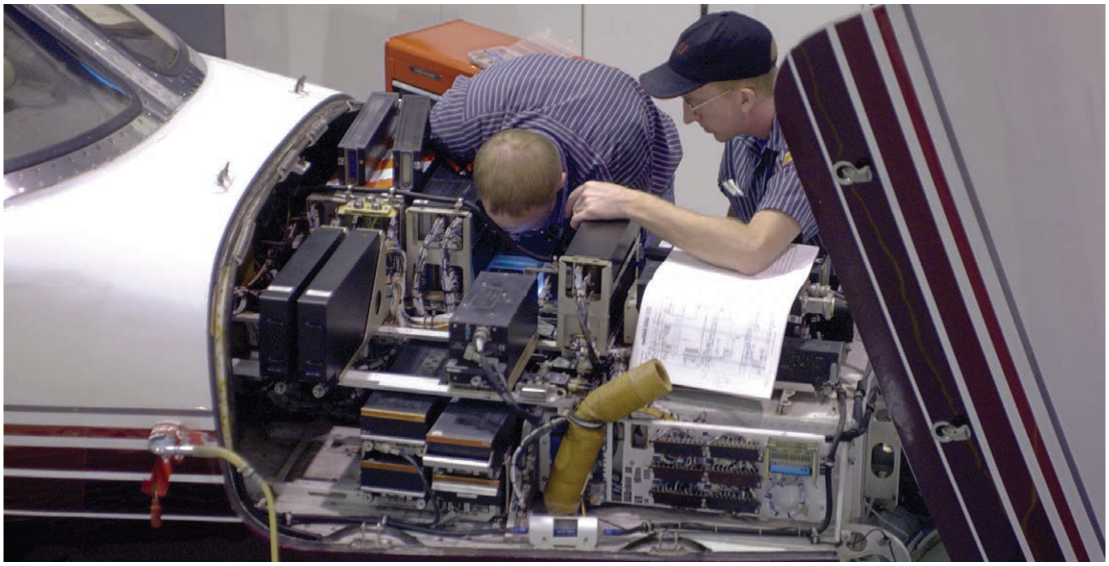


Figure 15-3-2. In a progressive inspection system, the complete inspection is broken down into sections. Each section comprises an inspection period. *Photo courtesy of Duncan Aviation*

Large Aircraft; FAR Part 127, Certification and Operations of Scheduled Air Carriers with Helicopters; or FAR Part 135, Air Taxi Operators and Commercial Operators

- An approved aircraft inspection program approved under FAR Section 135.419, and currently in use by a person holding an operating certificate issued under FAR Part 135

- A current inspection program recommended by the manufacturer

- Any other inspection program established by the registered owner or operator and approved by the FAA

These inspection programs are comprehensive and require large maintenance organizations with extensive personnel requirements and complex maintenance and inspection facilities and equipment.

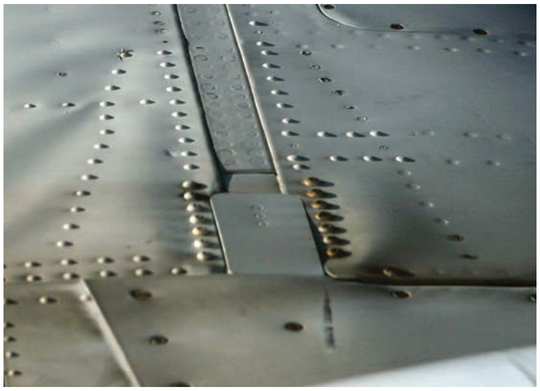


Figure 15-3-3. Severe turbulence can leave permanent wrinkles in wing skins.

Special Inspections

Altimeter and static system checks. All aircraft operating under Instrument Flight Rules (IFR) in controlled airspace must have the altimeter and static system checked within the preceding 24 calendar months as specified in FAR Section 91.411 or FAR Part 43, appendix E.

Transponder checks. No person may operate an air traffic control transponder unless that transponder has been checked within the preceding 24 calendar months and found to comply with appendix F of FAR Part 43.

Emergency locator transmitter (ELT) check. The ELT is normally checked by the pilot. The maintenance technician will only be concerned with the battery replacement date. See FAR Part 91.207.

Overweight or hard landing. An overweight or exceptionally hard landing may overload the landing gear, inflict structural damage to the aircraft structure, pull rivets, wrinkle the aircraft skin, and crack or break attachment fittings and castings.

When making an inspection for this type of damage, remember that a shock at one end of a structural member may be transmitted throughout its length. A close inspection of all rivets, bolts, and attaching hardware along the entire length of the member is necessary.

An accurate inspection for cracks or the full extent of visible cracks cannot be made by a simple visual inspection. It is important in overweight or severe turbulence inspection that possible cracks be found. Due to the vital importance of major structural members in the structural integrity of the aircraft, the use of dye-penetrant inspection procedures or other nondestructive testing methods is recommended by many aircraft manufacturers.

In some types of bonded, composite type of structures, the manufacturers suggest using a coin, such as a quarter, and bouncing it lightly on the suspected surface while holding it between the thumb and forefinger. A delaminated or un-bonded spot will have a dull low pitch sound, while a good bonded structure will have a higher pitch, sharp ringing sound.

An extensive examination should be made after a hard landing for cracks, pulled rivets, broken attachment fittings, and wrinkled skin before further flight of the aircraft. The manufacturer's instructions regarding overweight landings should be followed.

Severe turbulence inspections. Inspections following flight into severe turbulence may cause many of the same problems associated with hard landings. In addition to the twisting and bending stresses, severe flexing of the wings and control surfaces may occur. Fuel cell leaks are a common occurrence in this type of flexing in heavy turbulence (Figure 15-3-3).

The integral fuel tank, commonly referred to as a wet wing, is a network of interlocking seams. Leaking fuel can travel along a seam or from one seam to another, and may not be apparent on the external surface in the same vicinity of the leak. Applying the sealant to a general area where a leak is evident may not always correct the leak, but may direct the leaking fuel in another direction causing the leak to reappear later at another point.

Inspections of engines after hot starts and stackfires or sudden stoppage should be performed in accordance with the engine manufacturer's recommendations. AC 43.13-1B contains inspection procedures for engine sudden stoppage which may be followed if there are no specific recommendations made by the engine manufacturer.

Section 4

Human Factors

Human Factors is a difficult thing to describe, but is extremely important in the performance of an AMT's job. Partly, it is being aware of the way AMT's and their co-workers approach the job, the things that cause mistakes to be made and trying to apply some logic to the process. Another part of the process is determining what causes people to make mistakes. Once the cause has been determined, processes can be modified or devised to reduce the error rate. The goal of Human Factors is to reduce the maintenance error rate to the lowest level possible. A reduced error rate saves lives.

Many employers have a formal human factors training program and use a study of human factors in developing their inspection and verification processes. When you learn why something happens, you can then develop processes to make sure the outcome is desirable. Checks and balances to make sure everything is accomplished correctly and can be developed that the outcome will be desirable and predictable.

While it is difficult for a single person to perform in a human factors environment if no formal program exists, it is possible to apply the principles to your own work. Helping AMT's recognize some of the things that cause errors is the purpose of this chapter.

Maintenance evolution. Newer aircraft contain materials, powerplants, and electronic subsystems that did not exist in earlier models, and the number of older aircraft has increased. Technicians use more and more sophisticated equipment and procedures. One aspect of aviation maintenance that has not changed, however, is that most maintenance tasks are still accomplished by human technicians and inspectors.

While the aircraft on which they work have evolved dramatically over the last 50 years, maintenance workers still exhibit all of the capabilities, limitations, and idiosyncrasies that are part of being human. The addition of new materials and electronic systems has not meant a reduction in the workload or required skill set for maintenance supervisors and technicians. Because of the blend of aircraft in commercial fleets, aviation maintenance workers must maintain the skills and knowledge required to keep a wide variety of both new and old aircraft flying.

The field of human factors has its roots firmly planted in aviation. The first identifiable work in the area of equipment design and human performance was done during World War II. This work was concerned primarily with eliminating certain accidents related to cockpit design and aircrew performance. In fact, much of the pioneering work related to equipment design, training, human performance under stress, vigilance, and other topics was conducted and published in the period following the war.

Prior to the war-related research, most people held a fairly simplistic view of how people interacted with their environment. The idea of humans as infinitely flexible seemed to guide most design. It soon became apparent, however, that human users' interaction with their

Figure 15-4-1. The Aloha Airlines mishap focused the need for improved corrosion inspections and an aging fleet inspection process.

Photo courtesy of NTSB

jobs and equipment is much more complex than we thought. In addition to the size, shape, and placement of controls and displays, other, mostly psychological, elements were found to affect human performance.

Most of the human factors research directed toward the aviation industry, until recently, has been aimed primarily at cockpit and flight crew issues. Cockpit Resource Management (CRM) has been a huge success. However, it is now apparent that the public's safety rests on the proper conduct of three sets of activities: design, operation, and maintenance.

Aging aircraft. Because of a series of in-flight mishaps, Congress and the Federal Aviation Administration (FAA) have focused on the design of maintenance tasks, equipment, and training. Perhaps the most famous mishap occurred in 1988, when an Aloha Airlines B737-200 suffered structural fuselage failure and subsequent decompression (Figure 15-4-1). The National Transportation Safety Board (NTSB) conducted an investigation of this accident and cited several human factors issues associated with older aircraft.

As a direct result of the Aloha Airlines accident, the FAA convened an International Conference on Aging Aircraft in June, 1988. After the second such conference, a leading FAA researcher noted that "the more we looked at problems in maintenance operations, and particularly those of aging aircraft, the more we saw human factors as some part of the problem."

Certain aging aircraft mishaps have provided the impetus to examine human factors issues, but these issues relate to all types of aviation maintenance, not just to the older part of the fleet. In fact, many human factors guidelines that apply to other types of industries—in workplace design, job safety, and facility design —also apply to aviation maintenance.

These issues can usually be placed into one of more the following broadly-drawn categories:

- Effective and efficient training for technicians and inspectors
- On-the-job safety of maintenance workers
- Reducing human errors that compromise public safety
- Reducing the overall cost of maintenance

Training. Many human factors issues directly affect how easy or how difficult it is to learn certain maintenance-related skills. The FAA sets minimum curriculum for Part 147 schools and performance requirements for aviation maintenance technicians and inspectors. Certain aspects of the systems to be maintained, the technicians' job and workplace, and the tools they use to do their job affect how long it takes them to become proficient at their tasks and how likely it is that they will commit errors.

Worker safety. Numerous studies and statistical reports show that the workplace can be dangerous. This is especially true for work environments with heavy parts being moved about, with rotating machinery, with toxic or hazardous materials, and with work locations that are above the ground (Figure 15-4-2). All those factors are present in aviation maintenance shops. The study of human factors has made significant general contributions to workplace safety. Much of this work is directly applicable to the aviation maintenance workplace.

Public safety. The ultimate fear of any maintenance supervisor, technician, or inspector is that an error, once committed, will remain undiscovered and ultimately lead to an accident. The vast body of human factors research shows the certainty that human beings will commit errors. The saying that "to err is human" has a sound scientific basis. Studies have shown that the proportion of all accidents caused by human error is in the 60 to 80 percent range, not including design errors.

Cost. There is a tendency on the part of management to see any type of analysis or evaluation as an extra-cost program. Human factors programs require a small amount of time and money that is recouped in added productivity and safety. The general goal of all human factors programs is to provide a safe and efficient working environment.

Figure 15-4-2. The use of platforms and lifts is necessary to access specific areas of some aircraft for inspection and repair. *Photo courtesy of Duncan Aviation*

The Federal Aviation Regulations do not presently contain explicit human factors requirements. Regulations related to maintenance performance, such as Parts 43.13 and 43.15, Part 121-Subpart L, and Part 135-Subpart J, are obviously based on human factors types of considerations, however, they do not invoke specific human factors guidelines or standards.

Basic human factors concepts apply to the aviation maintenance domain. In fact, human factors practitioners would argue that such concepts are so fundamental that they apply to all situations in which humans interact with other system components.

Detection and perception. As a result of a vast amount of sensory research, we know several facts regarding perception. We know the minimum levels of stimuli needed for detection by each of our senses. These are called threshold values for detection. We also know generally how many different, distinct levels of a particular stimulus humans can distinguish.

We know that there is a difference between detection and perception. Detection refers to the physical response of our senses, or detectors, in the presence of some event or stimulus. Perception refers to the combination of psychological and physical (called psychophysical) processes that allow us to know that we've detected something.

We know that certain environmental characteristics affect our ability to perceive events. Physical and psychological stress, attention demands, workload, and other conditions common in the aviation maintenance environment can cause a loss of perceptual capabilities.

Errors. One essential fact of human nature is that people make errors. This tendency to make errors is so pronounced and widespread that we simply assume that errors will occur. There is no such thing as error-free operation by humans. Researchers have been fascinated by the nature of human errors. Names have been given to different types of errors; e.g., a slip is different from a mistake.

Certain types of errors are caused by simple physical incompatibilities. For example, printed characters can be confused when they are too small. Other types of errors are caused by complex psychological factors. Still other errors are caused by certain types of stress such as fatigue or severe time limits.

Fortunately, we know a lot about what causes errors and how to design systems that minimize the likelihood of certain types of errors. The important point is that regardless of the precautions we take, errors will occur. If we depend on error-free human performance, our system eventually will fail. For errors we cannot avoid, we must design system elements so as to minimize their effects.

Habituation. We often hear that people are extremely adaptable. That is, we can get used to pretty much anything, given enough time. If we see, hear, feel, smell, or taste the same stimulus frequently or continuously, our response to it gradually decreases. Eventually, the stimulus arouses no perceptible response. When this happens, we have habituated to the stimulus—we got used to it.

Habituation occurs both physically and psychologically. Physically, a constant stimulus becomes imperceptible. If a job task is particularly hazardous, we're likely to be very careful the first few (or few hundred) times we perform it. Eventually, however, we will habituate to the danger and then must constantly remind ourselves to be careful.

Habituation is a useful coping mechanism for living in the real world. It serves to filter the stimuli that are constantly bombarding us. In the aviation maintenance environment, though, habituation allows us to adapt to dangerous or noxious environments and to ignore potentially dangerous indicators.

Human Capabilities and Limitations

Perhaps the most fundamental human factors concept is that people have certain capabilities and limitations that must be considered. In other engineering disciplines, it is commonly understood that system components have a range of performance capability. For example, the rivets used to attach aluminum skin to a fuselage can withstand forces that act to pull them apart. Everyone agrees that these rivets will eventually fail if enough force is applied to them. While the precise range of human capabilities and limitations might not be as well-known as the performance range of mechanical or electrical components, the same principles apply.

Unlike mechanical components, humans rarely suffer catastrophic failures. More frequently, however, exceeding human capabilities results in subtle consequences, such as increased errors, inability to attend to all of the tasks at hand, poor judgment, etc. Also unlike inanimate components, human performance is affected by social, emotional, cognitive, and psychological elements. Since human performance tends to be more variable than that of non-human system components, engineers try to provide adequate design margins for human operators.

Performance Shaping Factor. This term, usually called by its acronym PSF, was introduced in the late 1960s to help conceptually frame the idea of human reliability. In its most general meaning, a PSF is anything that can affect human performance. Theoretically, PSFs can have either a positive or negative effect on human performance. However, discussion of PSFs is often limited to those elements that adversely affect performance. For example, poor training is a PSF that is known to increase errors.

PSFs are usually categorized as either internal or external. External PSFs are outside the individual worker or user, usually some characteristic of the workplace, the task, or the organization. Internal PSFs come from within the person and are typically related to skills, stress, or other physiological, psychological, or social element. Typical examples of external PSFs are poor workspace layout, adverse environmental conditions, inadequate training, poorly designed tools, etc. Common internal PSFs are high stress, a disruptive social environment, and low skill levels.

Anything that causes human performance levels to increase or decrease can be considered a PSF and thus subject to analysis and mitigation using human factors techniques. This is true even for topics not traditionally considered within the scope of human factors, such as sexual harassment, substance abuse, etc. At least one study has shown that stress like that caused by such emotional factors can increase the probability of human error by a factor of two to five.

Physical Compatibility

People come in myriad shapes, sizes and physical conditions. Human factors professionals

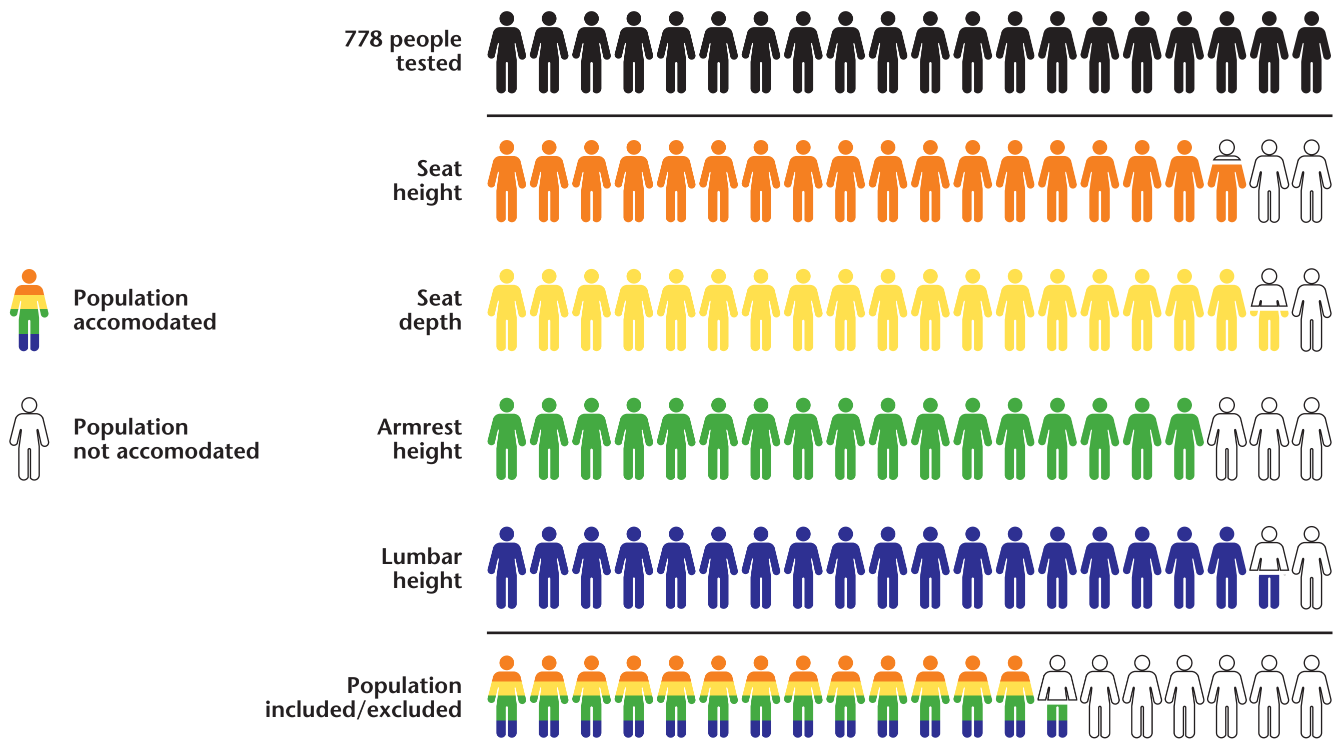


Figure 15-4-3. Anthropometrics, by its application, will mean that a certain portion of the population will be outside the design parameters.

have recognized and studied this. It turns out that a seemingly simple idea isn't simple at all when we have to consider this range of human variation in the design of hardware and workplaces. The three elements most closely related to the concept of physical compatibility are anthropometrics, biomechanics, and work physiology.

Anthropometrics. The study of human body dimensions is known as anthropometrics. Many anthropometrical studies, generally conducted by the military, have produced tabled values of various body dimensions (Figure 15-4-3). These studies typically have measured certain physical characteristics of many individuals and then reported results in terms of gender and percentiles within each gender. For example, a value for the dimension seated eye height for a 75th percentile male is interpreted to mean that 75% of all males in the population have a seated eye height lower than this value.

Several aspects of anthropometrics are worth noting. First, women tend to be smaller than men. This probably isn't a big surprise, but it has profound implications for design. In general, we try to design to accommodate the 5th through the 95th percentiles for human workers. For example, if we're interested in standing height, we have to design to accommodate a range from the 5th percentile female to the 95th percentile male.

Second, there is a common, incorrect tendency to interpret percentiles in terms of averages. If one were to design a product for the 50th percentile of a particular dimension, half the potential user population would probably have difficulty using it.

Third, people tend not to fall into the same percentile for multiple body dimensions. People with small hands don't necessarily also have short legs. If we designed for the 5th through 95th percentiles, we would expect to exclude only 10 percent of the population. However, one study found that by imposing such limits on 13 body dimensions, 52 percent of the population was excluded. The idea that any particular individual will fall into the same percentile for all body dimensions is often called the myth of the average person.

Biomechanics. Maintenance tasks typically involve doing, as well as thinking about, something. The science of biomechanics addresses issues of movement, leverage, and strength. From a biomechanical perspective, the human body is a series of physical links (bones) connected at certain points (joints) that allow various movements.

While biomechanics is an independent field of study, human factors practitioners often use its principles to analyze work tasks. There is a large body of information related to strength available in various postures, to the range of motion for each major joint in the body and to strength and motion differences between males and females. Biomechanical limitations largely determine our ability to perform certain tasks and our risk of specific types of injuries. Figure 15-4-4, shows a technician performing a component replacement in an awkward biomechanical position.

Work physiology. Most human work tends to be distributed over time rather than lumped into discrete actions. The physical sciences define work as the application of force over some distance. The science of work physiology studies the type, amount, rate, and duration of human workers' energy expenditure. People vary in the strength they can bring to bear on a task; they also differ in their capacities to perform different types of work over time.

Stereotypical Behavior

As we grow up in a particular culture, we learn to do things in a certain way. Since we see that things work in a particular way over a long period, we develop expectations that they will always work that way. When we want to turn on a light from a wall switch, we flip the switch up. When we see a red light or sign on the highway, we interpret that as a requirement to stop or as a sign of danger. This type of behavior is learned and is called stereotypical behavior.

Stereotypical behavior is important in human factors. When a task or control works as one expects, it conforms to stereotype. When it doesn't, it violates stereotype. The more a task or tool incorporates stereotypes, the easier it is to learn. Since we've already learned stereotypical behavior, we don't have to learn it again.

There are two important aspects of stereotypical behavior. First, such behavior is culture-specific. In most of Europe, light switches have to be moved down to turn a light on. In China, the color red is associated with happiness, not danger. Also, we don't think about our stereotypical behaviors. They are so ingrained that we just do them when the proper stimulus occurs.

This is worth noting, since we tend to revert to stereotypical behavior in the presence of stress or lack of attention. A good example of such reversion is that for one used to driving on the right side of road it is quite easy to make a transition to right-hand drive automobiles and to driving in the left lane. In a high-stress situation, such as making an avoidance maneuver, the same person will inevitably take actions appropriate for a left-hand drive car.

Figure 15-4-4. Some maintenance tasks are difficult to perform because of biomechanics. It is sometimes difficult to conform to the job at hand.

Photo courtesy of Duncan Aviation

Stress

Another seemingly simple concept is that of stress. Through experience, we've learned that certain events or conditions cause us to feel stress. Like workload, though, stress is a difficult concept to quantify. Also like workload, stress is usually defined in terms of its effects on performance. In the human factors world, stress is a very general idea. Many events or conditions produce measurable decreases in performance. Events and conditions that cause stress are called stressors.

Two aspects of stressors are important to understand both for their broad range and for their effects on individuals. Stressors can be physical, environmental, task-related, organizational, or psychological. Examples of stressors include injury, fatigue, heat, cold, time pressure, workload, personality conflicts, family problems, and substance abuse. Just about anything that affects the way we live and work can act as a stressor.

The effects of stressors vary greatly from person to person. A condition that causes great stress in one person might cause none in another.

As with workload, stress is measured by its effects. There are some objectively measurable physical effects of stress, such as elevated blood pressure, increased perspiration, etc. However, these effects don't always accompany stress. Stress is usually inferred by a decrease in task performance.

In the aviation maintenance environment, there are many identifiable stressors. Fatigue caused by working at night and time pressure to get aircraft back into revenue service are two obvious conditions almost certain to cause stress. In stressful circumstances, it is very important that jobs, workplaces, work schedules, tools, facilities, and procedures incorporate human factors principles.

Systems Approach

Human factors practitioners typically concentrate on the interfaces among people and the other system elements. The important point concerning the systems approach is that humans cannot be considered to be isolated from other system components. This view is similar to that of ecologists: that all elements in nature interact. We can't change one aspect of a system without being concerned about its effects on other system elements.

Usability. The terms usable and intuitive describe a desirable characteristic for a system, product, or procedure. The concept of usability has many facets, some of which are not fully understood or appreciated. There are multiple definitions of usability. Consider the following three most important parts of usability: compatibility, understandability, and effectiveness.

For example, imagine that we must assess the usability of a work card designed to guide a nose gear inspection on an aircraft (Figure 15-4-5). Let's also assume that the card will have to be read from a distance of one yard.

Compatibility. Compatibility refers to the match between a product and the users' physical and perceptual abilities. Users have to be able to see material that must be read, to be able to touch surfaces that must be manipulated, to be able to lift items that have to be physically carried, etc. In the case of our work card example, all graphics and text must be large enough to be recognized and read from a distance of three feet. Also, any colors must provide enough contrast for legibility under the task's lighting conditions.

Understandability. Once we've assured ourselves that a product is compatible with the capabilities of its user, the next step is to evaluate its understandability. A work card could be perfectly compatible, but not understandable. Abbreviations, wording, grammar, and other aspects of the work card might not correspond with the user population's training and experience. Imagine a work card containing technical medical jargon instead of aviation terms. Even if this card were perfectly legible, aviation maintenance technicians would not likely understand it.

Effectiveness. The final component of usability is effectiveness, i.e., the ability of a product or system to support users in their job tasks. This is normally the only facet of usability that interests supervisors and managers. Many factors can cause a compatible and understandable product to be ineffective. For example, the work card in question could be missing a step. As an extreme example of lack of effectiveness, the work card might contain no instructions for nose gear inspection or originally have been designed for a different type of aircraft.

Vigilance

One category of tasks is so prevalent that it has been given a name: vigilance. Vigilance tasks have been studied by human factors researchers since the second world war. Vigilance tasks involve a human monitoring a visual or auditory display for a particular event. Usually, the event that must be detected is relatively rare, i.e., the human monitor doesn't expect it to happen very often.

Early research into vigilance tasks found that the detection performance of military radar operators decreased very rapidly during their watch. Subsequent research in a number of different settings has found much the same phenomenon. Within about a half hour of beginning a vigilance task, detection performance drops dramatically and never recovers during the watch. Many other factors such as fatigue cause vigilance performance to decrease more rapidly and to a lower level.

Vigilance tasks are common in the maintenance domain. Any type of repetitive inspection work in which the probability of finding a problem is low qualifies as a vigilance task. It is quite difficult to mitigate the effects of the loss of sensitivity during a vigilance task.

Workload

While the general idea of workload can apply to both physical and mental aspects of job tasks, mental workload usually gets most of the attention. The basic concept is that people have only so much capacity to perform mental work. If a job task, or set of tasks, exceeds a person's mental capacity, then the workload is excessive and performance drops.

These limits apply to all work domains, including aviation maintenance. It is also clear that people use certain coping mechanisms to deal with high workload: we cope by eliminating all but what we think are the most urgent or important information and tasks. The obvious problem with this coping strategy is that an overloaded technician or inspector might eliminate an important step or fail to identify a problem.

Figure 15-4-5. Maintenance cards that are readable at a distance by a maintenance technician were brought about by research into human factors.
Photo courtesy of Duncan Aviation

Incident Investigation

Errors in aviation maintenance settings are typically identified when they are linked with property damage, injuries, or both, resulting from some type of incident. Such incidents are formally examined with an incident investigation technique. These techniques are collectively known as root cause methods because they attempt to identify and classify all of the proximate causes for a maintenance incident.

A number of formal root cause incident investigation techniques have been developed within the aviation community. All of the existing aviation maintenance error investigation techniques are a combination of checklists and questionnaires, usually combined with interviews and some type of evaluation process. All of these techniques include an embedded database where incident classification information is retained for analysis.

Maintenance Resource Management (MRM)

Team skills. Team skills and coordination are a vital part of the MRM concept.

Competence in team skills tends to be independent of competence in technical skills, yet both skills are equally important in accomplishing the final goal. Unfortunately, organizations rarely devote time and resources to teach these team skills formally. MRM training provides maintenance organizations the vehicle

Figure 15-4-6. Teamwork is essential in today's shop environment. While most job cards cover a small segment of a given maintenance process, jobs must be accomplished in order, checked, and inspected. *Photo courtesy of Duncan Aviation*

to accomplish this. In this way, concepts like inter- and intra-team behavior can be better understood.

Certain qualities differentiate a team of people from a group of people. Among these are size, a common goal, and interdependence. First, team size is an important issue in what constitutes a team. Obviously, teams consist of more than one person.

The addition of more people does not necessarily mean an increase in team performance. Additional team members increase the need for all team members to expend time and resources in order to coordinate the team's activities toward accomplishing its goals. A team with many members may fracture and create sub-groups or cliques that possess goals different from, or even in opposition to, the team's primary goal. In this sense, the return on performance decreases dramatically as more people are added.

For any one particular task, there are an optimum number of people who can do the job — any more or any less will result in a performance loss. Though the optimum number depends on the team task, process loss becomes significant with more than 10 members.

Secondly, a team works together to accomplish a unified goal or goals. That goal could be an engine change or performing a heavy maintenance check. It must be understood that, just as repairing an airplane consists of numerous steps, a team's ultimate goal is also composed of sub-goals. Each sub-goal must be accomplished in order to reach the team's ultimate goal (Figure 15-4-6).

A final quality that is needed to define a team is interdependence. Interdependence is defined as a team situation in which members depend on one another to finish the final job. An activity that can be completed by a single person without having to rely on others is not highly interdependent. For example, even though a group of maintenance personnel can fuel a plane more quickly than one individual alone, if each individual should drop out over time, the person left could still finish the task. Taken together, a team is defined as a group of interdependent individuals working together to complete a specific task.

The amount of interdependence demonstrated by team members may vary when completing their own individual tasks. For example, a maintenance team washing a plane depends only on each team member to contribute to his or her individual task. However, each member relies on one another to achieve his or her final goal (finishing the wash). This is known as additive labor, i.e., each team member adds his or her work to the task at hand. A maintenance team changing out a main gear, on the other hand, has a greater amount of interdependence among the team members to finish the task.

The essential characteristics of a team are:

- A group of interdependent individuals working together to complete a specific task
- All members dependent on one another's knowledge, skills, and abilities to finish the final job
- The amount of interdependence among members may vary from one team to another

Though teams are usually composed of members in the same location at the same time, this may not always be the case. For example, consider a team that performs a heavy maintenance check in a hanger. Because each team member is working on separate parts of the aircraft, they are separated both by location and sometimes by time. However, when analyzed in terms of the ultimate goal (finishing the check) and being interdependent (each member may have unique maintenance skills, such as airframe, powerplant, or avionics skills, etc., that are necessary to perform the heavy check), the definition of a team applies.

Effective Teamwork

There are 10 widely accepted characteristics of an effective team:

- A clear purpose. The team has a clear purpose or mission that is accepted by all members.
- Relaxed interaction. The team is relaxed and informal, with no obvious tensions among members.
- Participation. There is a lot of discussion between members and everyone participates in decisions and/or activities.
- Listening. Each team member actively listens to one another.
- Disagreement. Team members are comfortable expressing disagreement with one another if the situation calls for it.
- Openness. There is full and open communication with no hidden agendas.
- Clear expectations. There are clear expectations about the role of each of the team, and work assignments are fairly distributed among team members.
- Shared leadership. Although there may be a formal team leader, each team member may share leadership responsibilities from time to time as the situation arises.
- Relations with others. The team maintains credibility and good relations with others who may be outside the formal team but who can still affect its functioning.
- Team maintenance. Team members not only focus on their primary goal but spend time recognizing and maintaining the functions of the team itself.

The Dirty Dozen

The Dirty Dozen is a listing of the 12 most common causes of human error in maintenance. Many trainers use the Dirty Dozen as the basis for Human Factors Awareness Training. The FAA, Transport Canada, the European Aviation Safety Agency, and many national aviation authorities recommend the Dirty Dozen as an important component of human interaction. Each of the items of the Dirty Dozen is followed by a strategy for working with the relevant issue. This list is by no means complete.

They are as follows:

1. Complacency – overconfidence from repeated experience on a specific activity
    - Expect to find errors
2. Lack of knowledge – failure to have training, information and/or ability to conduct a task
    - Ask when you don't know
3. Lack of teamwork – failure to work together to complete a shared goal
    - Discuss how a job should be done
4. Distraction – an unlimited number of possible events/conditions that interrupt one's ability to focus on a specific task
    - Go back three steps when you return to a job
5. Fatigue – physical or mental exhaustion threatening work performance
    - Have others check your work
    - Watch for symptoms of fatigue in yourself and others
6. Lack of resources – lack of people, equipment, documentation, time, parts, etc. to complete a task
    - Order parts before they are required
7. Pressure – external or internal forces demanding high-level job performance. Can be real or perceived
    - Ask for extra help
8. Lack of assertiveness – failure to speak up or otherwise document concerns about instructions/orders or an action of others
    - Just say no
9. Lack of communication – failure to transmit, receive, or provide sufficient feedback in order to complete a task
    - Never assume anything
10. Norms – standard practices, usually undocumented, adopted by an organization or group
    - Existing norms don't make it right
11. Stress – physical or mental condition resulting from external forces. It may affect health and quality of work
    - Take a short break when needed
12. Lack of awareness – failure to see a condition, understand what it is, and predict the possible results
    - See the big safety picture

By following steps for effective teamwork and paying diligent attention to the details of the task at hand, each one of the Dirty Dozen is preventable.

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