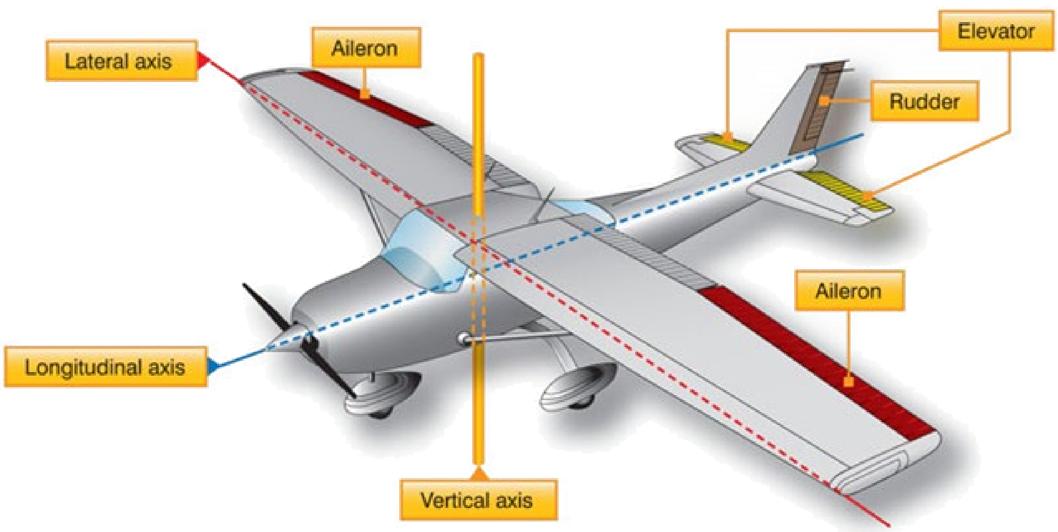
International AeroTech Academy

AMT 204 Flight Controls



AMT 204 Flight Controls

Introduction

Three topics that are directly related to the manufacture, operation, and repair of aircraft are: aerodynamics, aircraft assembly, and rigging. Each of these subject areas, though studied separately, eventually connect to provide a scientific and physical understanding of how an aircraft is prepared for flight. A logical place to start with these three topics is the study of basic aerodynamics. By studying aerodynamics, a person becomes familiar with the fundamentals of aircraft flight.

Basic Aerodynamics

Aerodynamics is the study of the dynamics of gases, the interaction between a moving object and the atmosphere being of primary interest for this handbook. The movement of an object and its reaction to the air flow around it can be seen when watching water passing the bow of a ship. The major difference between water and air is that air is compressible and water is incompressible. The action of the airflow over a body is a large part of the study of aerodynamics. Some common aircraft terms, such as rudder, hull, water line, and keel beam, were borrowed from nautical terms.

Many textbooks have been written about the aerodynamics of aircraft flight. It is not necessary for an airframe and powerplant (A&P) mechanic to be as knowledgeable as an aeronautical engineer about aerodynamics. The mechanic must be able to understand the relationships between how an aircraft performs in flight and its reaction to the forces acting on its structural parts. Understanding why aircraft are designed with particular types of primary and secondary control systems and why the surfaces must be aerodynamically smooth becomes essential when maintaining today's complex aircraft.

The theory of flight should be described in terms of the laws of flight because what happens to an aircraft when it flies is not based upon assumptions, but upon a series of facts. Aerodynamics is a study of laws which have been proven to be the physical reasons why an airplane flies. The term aerodynamics is derived from the combination of two Greek words: "aero," meaning air, and "dyne," meaning force of power. Thus, when "aero" joins "dynamics" the result is "aerodynamics"—the study of objects in motion through the air and the forces that produce or change such motion.

Aerodynamically, an aircraft can be defined as an object traveling through space that is affected by the changes in atmospheric conditions. To state it another way, aerodynamics covers the relationships between the aircraft, relative wind, and atmosphere.

The Atmosphere

Before examining the fundamental laws of flight, several basic facts must be considered, namely that an aircraft operates in the air. Therefore, those properties of air that affect the control and performance of an aircraft must be understood.

The air in the earth's atmosphere is composed mostly of nitrogen and oxygen. Air is considered a fluid because it fits the definition of a substance that has the ability to flow or assume the shape of the container in which it is enclosed. If the container is heated, pressure increases; if cooled, the pressure decreases. The weight of air is heaviest at sea level where it has been compressed by all of the air above. This compression of air is called atmospheric pressure.

Pressure

Atmospheric pressure is usually defined as the force exerted against the earth's surface by the weight of the air above that surface. Weight is force applied to an area that results in pressure. Force (F) equals area (A) times pressure (P), or $F = AP$. Therefore, to find the amount of pressure, divide area into force ($P = F/A$). A column of air (one square inch) extending from sea level to the top of the atmosphere weighs approximately 14.7 pounds; therefore, atmospheric pressure is stated in pounds per square inch (psi). Thus, atmospheric pressure at sea level is 14.7 psi.

Atmospheric pressure is measured with an instrument called a barometer, composed of mercury in a tube that records atmospheric pressure in inches of mercury ("Hg). *[Figure 2-1]* The standard measurement in aviation altimeters

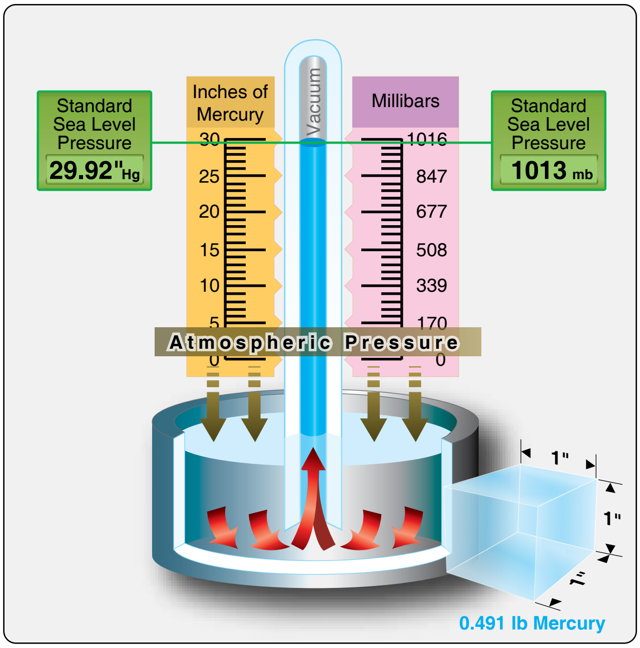


Figure 2-1. *Barometer used to measure atmospheric pressure.*

and U.S. weather reports has been "Hg. However, worldwide weather maps and some non-U.S. manufactured aircraft instruments indicate pressure in millibars (mb), a metric unit. At sea level, when the average atmospheric pressure is 14.7 psi, the barometric pressure is 29.92 "Hg, and the metric measurement is 1013.25 mb.

An important consideration is that atmospheric pressure varies with altitude. As an aircraft ascends, atmospheric pressure drops, oxygen content of the air decreases, and temperature drops. The changes in altitude affect an aircraft's performance in such areas as lift and engine horsepower. The effects of temperature, altitude, and density of air on aircraft performance are covered in the following paragraphs.

Density

Density is weight per unit of volume. Since air is a mixture of gases, it can be compressed. If the air in one container is under half as much pressure as an equal amount of air in an 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. For the equal weight of air, that which is under the greater pressure occupies only half the volume of that under half the pressure.

The density of gases is governed by the following rules:

1. Density varies in direct proportion with the pressure.
2. 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 greater. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit of 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 it can absorb.

1. Absolute humidity is the weight of water vapor in a unit volume of air.
2. Relative humidity is the ratio, in percent, of the moisture actually in the air to the moisture it would hold if it were saturated at the same temperature and pressure.

Assuming that the temperature and pressure remain the same, the density of the air varies inversely with the humidity. On damp days, the air density is less than on dry days. For this reason, an aircraft requires a longer runway for takeoff on damp days than it does on dry days.

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 dry air containing no moisture.

Aerodynamics & the Laws of Physics

The law of conservation of energy states that energy may neither be created nor destroyed.

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 and the aircraft are in motion with respect to the air and to the earth.

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 flow of air around an object caused by the movement of either the air or the object, or both, is called the relative wind.

Velocity & Acceleration

The terms "speed" and "velocity" are often used interchangeably, but they do not have the same meaning. Speed is the rate of motion in relation to time, 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 miles per hour (mph). At the end of this time, the aircraft may be over the Atlantic Ocean, Pacific Ocean, Gulf of Mexico, or, if its flight were in a circular path, it may even be back over New York City. If this same aircraft flew at a velocity of 260 mph 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 and denotes 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 another aircraft reducing its velocity is an example of negative acceleration, or deceleration.

Newton's Laws of Motion

The fundamental laws governing the action of air about a wing are known as Newton's laws of motion.

Newton's first law is normally referred to as the law of inertia. It simply means that a body at rest does not move unless force is applied to it. If a body is moving at uniform speed in a straight line, force must be applied to increase or decrease the speed.

According to Newton's law, since air has mass, it is a body. When an aircraft is on the ground with its engines off, inertia keeps the aircraft at rest. An aircraft is moved from its state of rest by the thrust force created by a propeller, or by the expanding exhaust, or both. When an aircraft 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 states that if a body moving with uniform speed is acted upon by an external force, the change of motion is proportional to the amount of the force, and motion takes place in the direction in which the force acts. This law may be stated mathematically as follows:

$$\text{Force} = \text{mass} \times \text{acceleration } (F = ma)$$

If an aircraft is flying against a headwind, it is slowed down. If the wind is coming from either side of the aircraft's heading, the aircraft is pushed off course unless the pilot takes corrective action against the wind direction.

Newton's third law is the law of action and reaction. This law states that for every action (force) there is an equal and opposite reaction (force). This law can be illustrated by the example of firing a gun. The action is the forward movement of the bullet while the reaction is the backward recoil of the gun.

The three laws of motion that have been discussed 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 & 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. The cambered (curved) surface of an airfoil (wing) affects the airflow exactly as a constriction in a tube affects airflow. *[Figure 2-2]* Diagram A of *Figure 2-2* illustrates the effect of air passing through a constriction in a tube. In Diagram B, 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 velocity increases and its pressure decreases; an area of low pressure is 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. The 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 of an airfoil produces the other one-fourth of the total lift.

Airfoil

An airfoil is a surface designed to obtain lift from the air through which it moves. Thus, it can be stated that any part of the aircraft that converts air resistance into lift is an airfoil. The profile of a conventional wing is an excellent example of an airfoil. *[Figure 2-3]* 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. Air flowing over the top surface of the wing must reach the trailing edge of the wing in the same amount of time as the air flowing under the wing. To do this, the air passing over the top surface moves at a

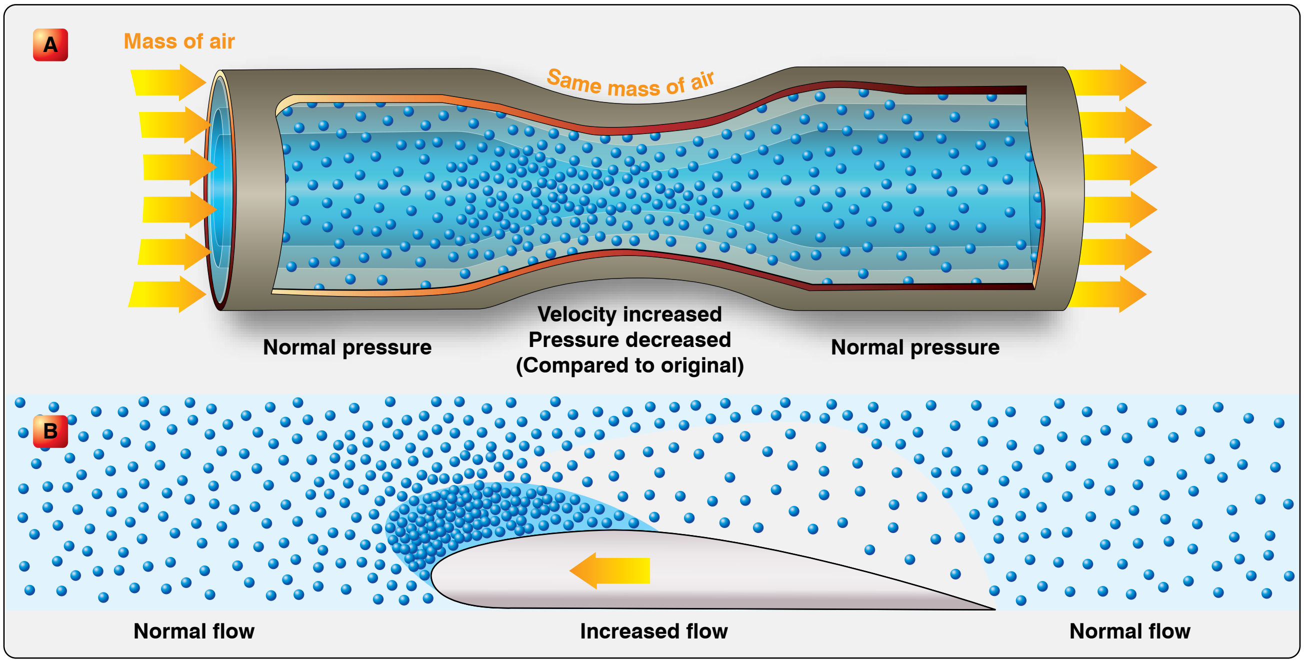


Figure 2-2. *Bernoulli's Principle.*

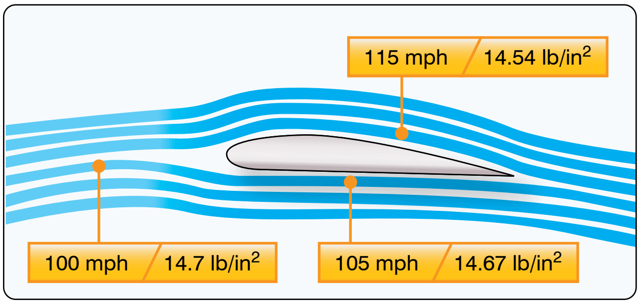


Figure 2-3. *Airflow over a wing section.*

greater velocity than the air passing below the wing because of the greater distance it must travel along the top surface. This increased velocity, according to Bernoulli's Principle, means a corresponding decrease in pressure on the surface. Thus, a pressure differential is created between the upper and lower surfaces of the wing, forcing the wing upward in the direction of the lower pressure.

Within limits, lift can be increased by increasing the angle of attack (AOA), wing area, velocity, density of the air, or by changing the shape of the airfoil. When the force of lift on an aircraft's wing equals the force of gravity, the aircraft maintains level flight.

Shape of the Airfoil

Individual airfoil section properties differ from those properties of the wing or aircraft as a whole 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.

The shape of the airfoil determines the amount of turbulence or skin friction that it produces, consequently affecting the efficiency of the wing. 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. If the wing has a high fineness ratio, it is a very thin wing. A thick wing has a low fineness ratio. A wing with a high fineness ratio produces a large amount of skin friction. A wing with a low fineness ratio produces 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.

The efficiency of a wing is measured in terms of the lift to drag ratio (L/D). This ratio varies with the AOA but reaches a definite maximum value for a particular AOA. At this angle, the wing has reached its maximum efficiency. The shape of the airfoil is the factor that determines the AOA 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.

High-lift wings and 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 increases 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. Thus, high-lift wings have a large positive camber on the upper surface and a slightly 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.

It is also known that the larger the wingspan, as compared to the chord, the greater the lift obtained. This comparison is called aspect ratio. The higher the aspect ratio, the greater the lift. In spite of the benefits from an increase in aspect ratio, it was found that definite limitations were defined by structural and drag considerations.

On the other hand, an airfoil that is perfectly streamlined and offers little wind resistance sometimes does not have enough lifting power to take the aircraft off the ground. Thus, modern aircraft have airfoils which strike a medium between extremes, the shape depending on the purposes of the aircraft for which it is designed.

Angle of Incidence

The acute angle the wing chord makes with the longitudinal axis of the aircraft is called the angle of incidence, or the angle of wing setting. *[Figure 2-4]* 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.

Angle of Attack (AOA)

Before beginning the discussion on AOA and its effect on airfoils, first consider the terms chord and center of pressure (CP) as illustrated in *Figure 2-5*.

The chord of an airfoil or wing section is an imaginary straight line that passes through the section from the leading edge to the trailing edge, as shown in *Figure 2-5*. The chord line provides one side of an angle that ultimately forms the AOA. The other side of the angle is formed by a line indicating the direction of the relative airstream. Thus, AOA is defined as the angle between the chord line of the wing and the direction of the relative wind. This is not to be confused with the angle of incidence, illustrated in *Figure 2-4*, which is the angle between the chord line of the wing and the longitudinal axis of the aircraft.

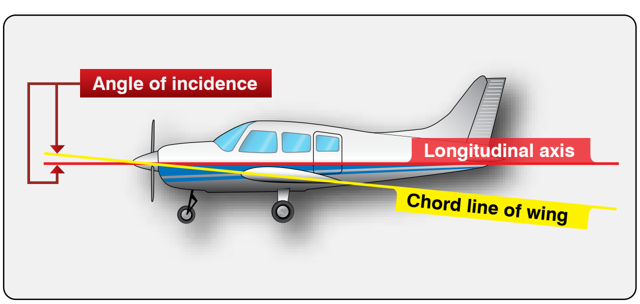


Figure 2-4. *Angle of incidence.*

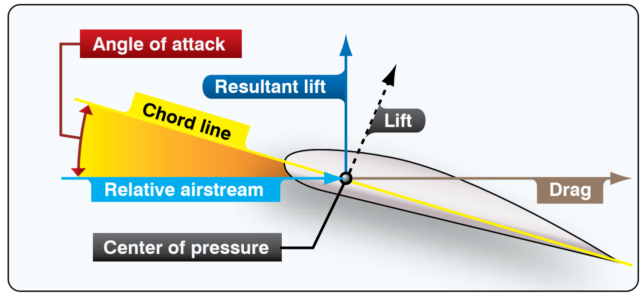


Figure 2-5. *Airflow over a wing section.*

On each part of an airfoil or wing surface, a small force is present. This force is of a different 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. That sum is called the "resultant force" (lift). This resultant force has magnitude, direction, and location, and can be represented as a vector, as shown in *Figure 2-5*. The point of intersection of the resultant force line with the chord line of the airfoil is called the center of pressure (CP). The CP moves along the airfoil chord as the AOA changes. Throughout most of the flight range, the CP moves forward with increasing AOA and rearward as the AOA decreases. The effect of increasing AOA on the CP is shown in *Figure 2-6*.

The AOA changes as the aircraft's attitude changes. Since the AOA has a great deal to do with determining lift, it is given primary consideration when designing airfoils. In a properly designed airfoil, the lift increases as the AOA is increased. When the AOA is increased gradually toward a positive AOA, the lift component increases rapidly up to a certain point and then suddenly begins to drop off. During this action the drag component increases slowly at first, then rapidly as lift begins to drop off.

When the AOA 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 the area of decreased pressure is now filled by this burbling air. When this occurs, the amount of lift drops and drag becomes excessive. The force of gravity exerts itself, and the nose of the aircraft drops. This is a stall. Thus, the burble point is the stalling angle.

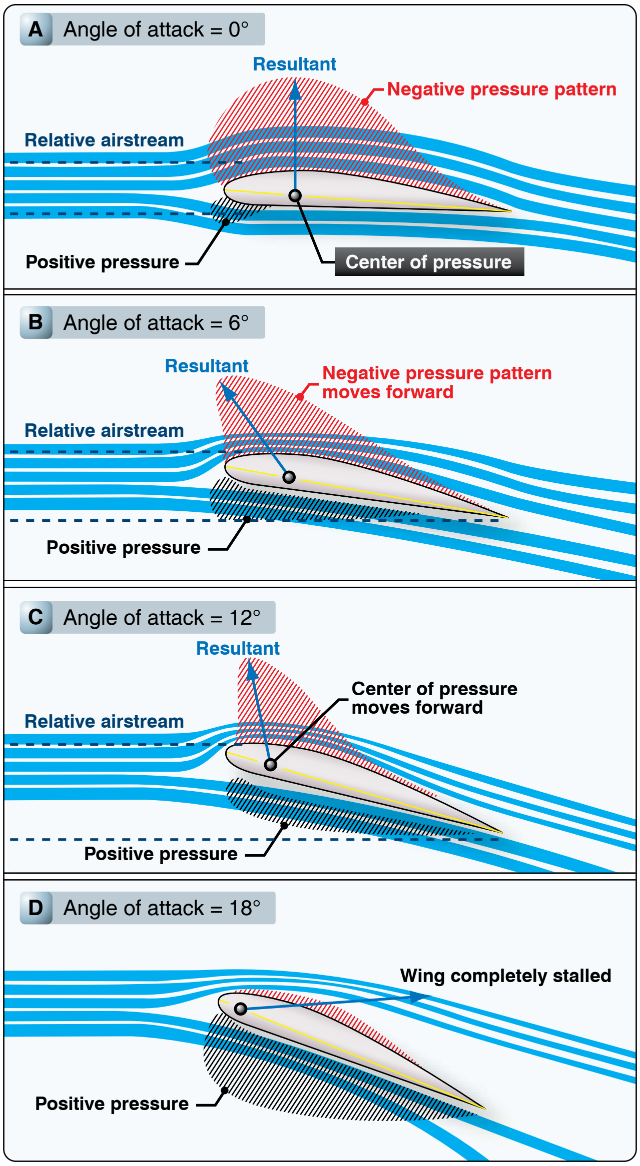


Figure 2-6. *Effect on increasing angle of attack.*

As previously seen, the distribution of the pressure forces over the airfoil varies with the AOA. The application of the resultant force, or CP, varies correspondingly. As this angle increases, the CP moves forward; as the angle decreases, the CP moves back. The unstable travel of the CP is characteristic of almost all airfoils.

Boundary Layer

In the study of physics and fluid mechanics, a boundary layer is that layer of fluid in the immediate vicinity of a bounding surface. In relation to an aircraft, the boundary layer is the part of the airflow closest to the surface of the aircraft. In designing high-performance aircraft, considerable attention is paid to controlling the behavior of the boundary layer to minimize pressure drag and skin friction drag.

Thrust & 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 2-7]*

An aircraft in flight is acted upon by four forces:

1. Gravity or weight—the force that pulls the aircraft toward the earth. Weight is the force of gravity acting downward upon everything that goes into the aircraft, such as the aircraft itself, crew, fuel, and cargo.
2. Lift—the force that pushes the aircraft upward. Lift acts vertically and counteracts the effects of weight.
3. Thrust—the force that moves the aircraft forward. Thrust is the forward force produced by the powerplant that overcomes the force of drag.
4. Drag—the force that exerts a braking action to hold the aircraft back. Drag is a backward deterrent force and is caused by the disruption of the airflow by the wings, fuselage, and protruding objects.

These four forces are in perfect balance only when the aircraft is in straight-and-level unaccelerated flight.

The forces 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 and in the same direction as the relative wind. These forces are actually the components that produce a resultant lift force on the wing. *[Figure 2-8]*

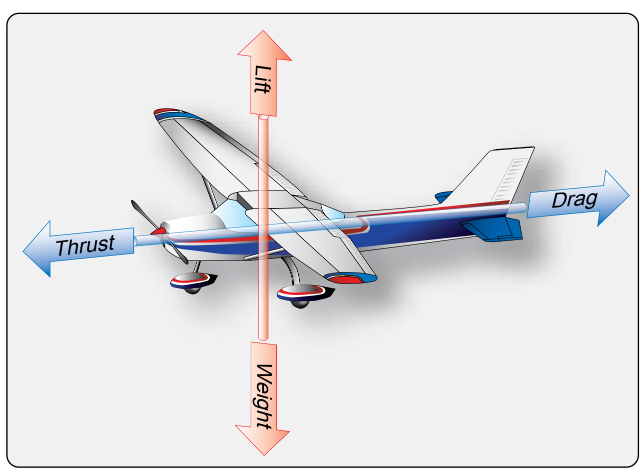


Figure 2-7. *Forces in action during flight.*

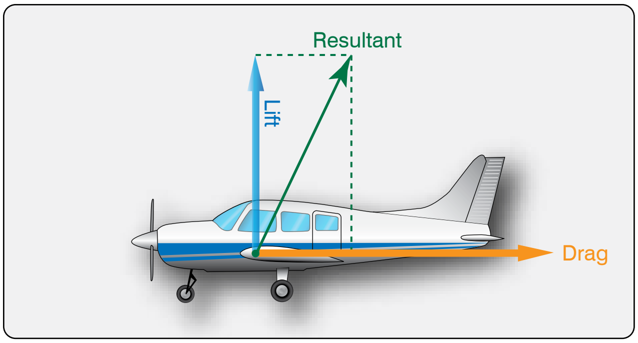


Figure 2-8. *Resultant of lift and drag.*

Weight has a definite relationship with lift, and thrust with drag. These relationships are quite simple, but very important in understanding the aerodynamics of flying. As stated previously, lift is the upward force on the wing 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 (CG). The CG is 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 the weight, the aircraft gains altitude.

Wing area is measured in square feet and includes the part blanked out by the fuselage. Wing area is adequately described as the area of the shadow cast by the wing at high noon. Tests show that lift and drag forces acting on a wing are roughly proportional to the wing area. This means that if the wing area is doubled, all other variables remaining the same, the lift and drag created by the wing is doubled. If the area is tripled, lift and drag are tripled.

Drag must be overcome for the aircraft to move, and movement is essential to obtain lift. To overcome 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 *(page 2-3)*. The turbine engine causes a mass of air to be moved backward at high velocity causing a reaction that moves the aircraft forward.

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 similar to the lift on the wing, but acts in a horizontal direction, pulling the aircraft forward.

Before the aircraft begins to move, thrust must be exerted. The aircraft continues to move and gain speed until thrust and drag are equal. In order to maintain a steady speed, thrust and drag must remain equal, just as lift and weight must be equal for steady, horizontal flight. Increasing the lift means that the aircraft moves upward, whereas decreasing the lift so that 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 revolutions per minute (rpm) 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 rpm 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.

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 on a level course, 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 this handbook considers three: parasite drag, profile drag, and 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 reduced by reducing the number of exposed parts to as few as practical and streamlining their shape, skin friction is the type of parasite drag most difficult to reduce. No surface is perfectly smooth. Even machined surfaces have a ragged uneven appearance when inspected under magnification. 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. The various components of parasite drag are all of the same nature as profile drag.

The action of the airfoil that creates lift also causes induced drag. Remember, the pressure above the wing is less than atmospheric pressure, 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 over the wing tip, thereby setting up a whirlpool of air called a "vortex." *[Figure 2-9]*

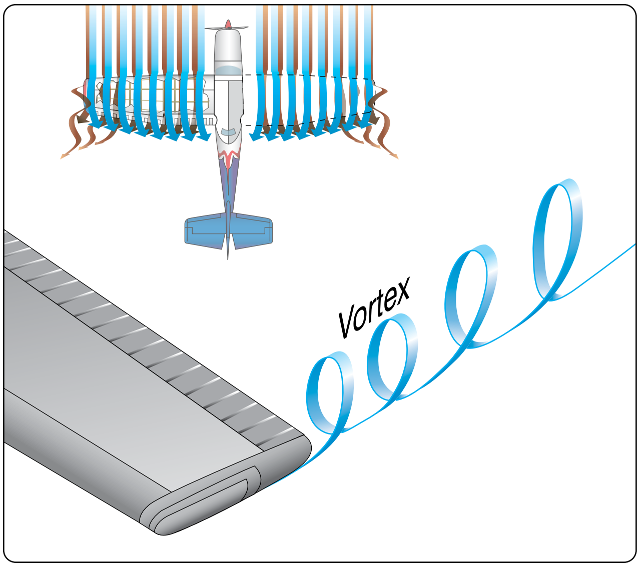


Figure 2-9. *Wingtip vortices.*

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. These vortices increase drag because of the turbulence produced, and constitute induced drag.

Just as lift increases with an increase in AOA, induced drag also increases as the AOA becomes greater. This occurs because, as the AOA is increased, the pressure difference between the top and bottom of the wing becomes greater. This causes more violent vortices to be set up, resulting in more turbulence and more induced drag.

Center of Gravity (CG)

Gravity is the pulling force that tends to draw all bodies within the earth's gravitational field to the center of the earth. The CG may be considered the point at which all the weight of the aircraft is concentrated. If the aircraft was supported at its exact CG, it would balance in any position. CG is of major importance in an aircraft, for its position has a great bearing upon stability.

The CG is determined by the general design of the aircraft. The designers estimate how far the CP travels. They then fix the CG in front of the CP for the corresponding flight speed in order to provide an adequate restoring moment for flight equilibrium.

The Axes of an Aircraft

Whenever an aircraft changes its attitude in flight, it must turn about one or more of three axes. *Figure 2-10* 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, or pitch, axis. The axis that passes through the center, from top to bottom, is called the vertical, or yaw, axis. Roll, pitch, and yaw 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 & Control

An aircraft must have sufficient stability to maintain a uniform flightpath 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. Control is the pilot action of moving the flight controls, providing the aerodynamic force that induces the aircraft to follow a desired flightpath. When an aircraft is said to be controllable, it means that the aircraft 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.

Three terms that appear in any discussion of stability and control are: stability, maneuverability, and controllability. Stability is the characteristic of an aircraft that tends to cause it to fly (hands off) in a straight-and-level flightpath. Maneuverability is the characteristic of an aircraft to be directed along a desired flightpath 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.

Static Stability

An aircraft is in a state of equilibrium when the sum of all the forces acting on the aircraft and all the moments is equal to zero. An aircraft in equilibrium experiences no accelerations, and the aircraft continues in a steady condition of 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

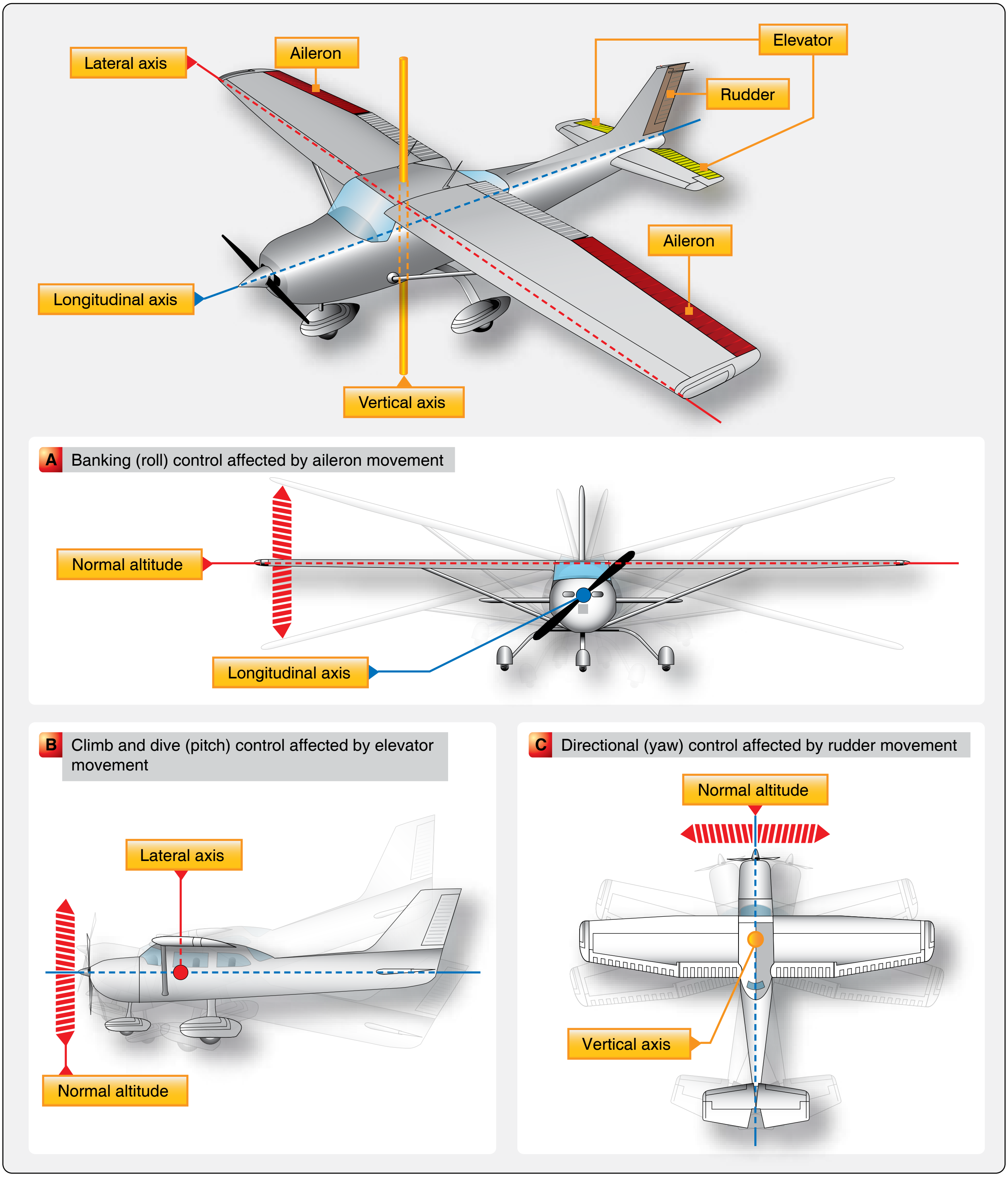


Figure 2-10. *Motion of an aircraft about its axes.*

of movement 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 tendency, but remains in equilibrium in the direction of disturbance. These three types of stability are illustrated in *Figure 2-11*.

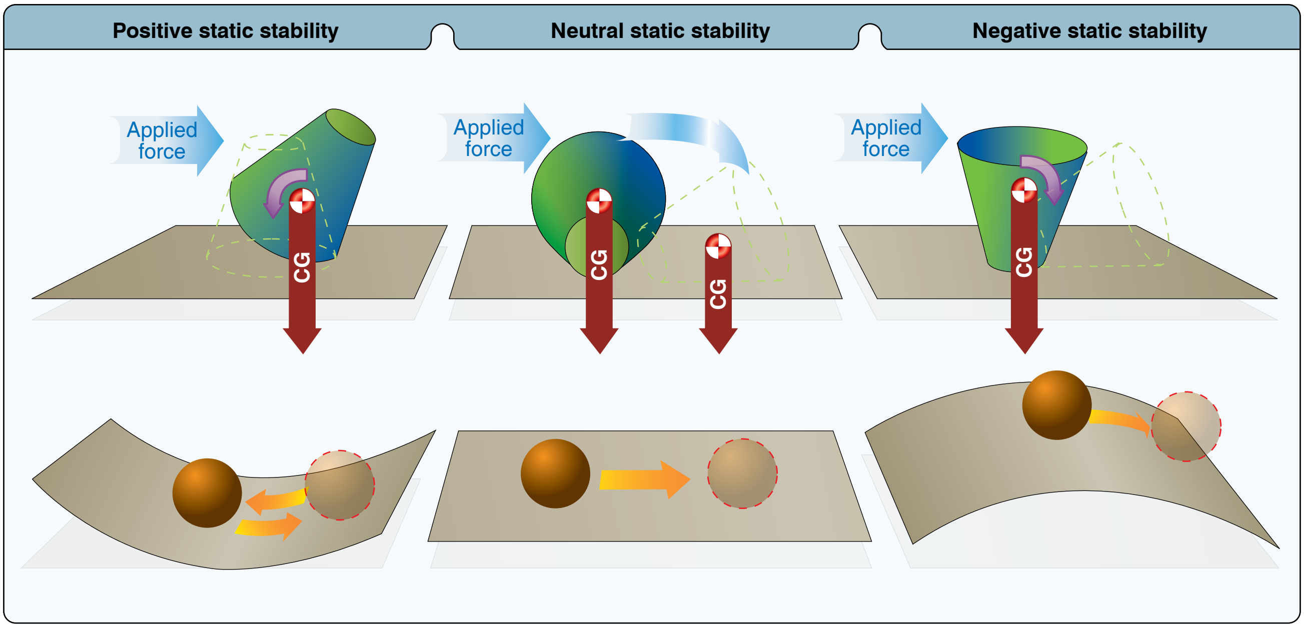


Figure 2-11. *Three types of stability.*

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 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 of the aircraft.

Longitudinal Stability

When an aircraft has a tendency to keep a constant AOA with reference to the relative wind (i.e., it does not tend to 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 which controls longitudinal stability. The action of the stabilizer depends upon the speed and AOA of the aircraft.

Directional Stability

Stability about 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 their hands and feet off the controls. If an aircraft recovers automatically from a skid, it has been well designed for directional balance. The vertical stabilizer is the primary surface that controls directional stability. Directional stability can be designed into an aircraft, where appropriate, by using a large dorsal fin, a long fuselage, and sweptback wings.

Lateral Stability

Motion about the aircraft's 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.

Dutch Roll

A Dutch Roll is an aircraft motion consisting of an out-of-phase combination of yaw and roll. Dutch roll stability can be artificially increased by the installation of a yaw damper.

Primary Flight Controls

The primary controls are the ailerons, elevator, and the rudder, which provide the aerodynamic force to make the aircraft follow a desired flightpath. *[Figure 2-10]* The flight control surfaces are hinged or movable airfoils designed to change the attitude of the aircraft by changing the airflow over the aircraft's surface during flight. These surfaces are used for moving the aircraft about its three axes.

Typically, the ailerons and elevators are operated from the flight deck by means of a control stick, a wheel, and yoke assembly and on some of the newer design aircraft, a joy-stick. The rudder is normally operated by foot pedals on most aircraft. Lateral control is the banking movement or roll of an aircraft that is controlled by the ailerons. Longitudinal control is the climb and dive movement or pitch of an aircraft that is controlled by the elevator. Directional control is the left and right movement or yaw of an aircraft that is controlled by the rudder.

Trim Controls

Included in the trim controls are the trim tabs, servo tabs, balance tabs, and spring tabs. Trim tabs are small airfoils recessed into the trailing edges of the primary control surfaces. *[Figure 2-12]* Trim tabs can be used to correct any tendency of the aircraft to move toward an undesirable flight attitude. Their purpose is to enable the pilot to trim out any unbalanced condition which may exist during flight, without exerting any pressure on the primary controls.

Servo tabs, sometimes referred to as flight tabs, are used primarily on the large main control surfaces. They aid in moving the main control surface and holding it in the desired position. Only the servo tab moves in response to movement by the pilot of the primary flight controls.

Balance tabs are designed to move in the opposite direction of the primary flight control. Thus, aerodynamic forces acting on the tab assist in moving the primary control surface.

Spring tabs are similar in appearance to trim tabs, but serve an entirely different purpose. Spring tabs are used for the same purpose as hydraulic actuators—to aid the pilot in moving the primary control surface.

Figure 2-13 indicates how each trim tab is hinged to its parent primary control surface, but is operated by an independent control.

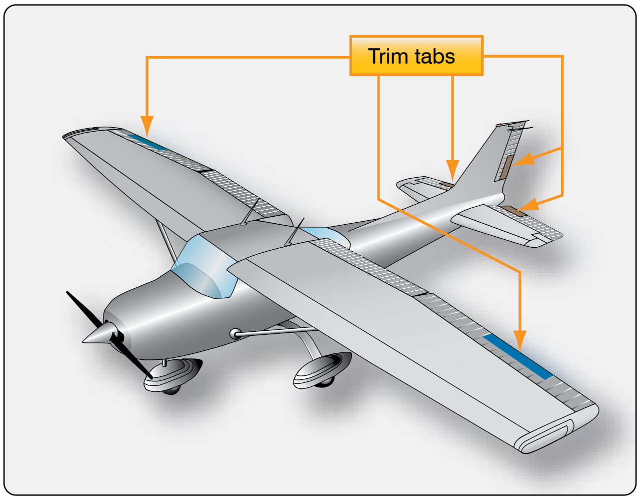


Figure 2-12. *Trim tabs.*

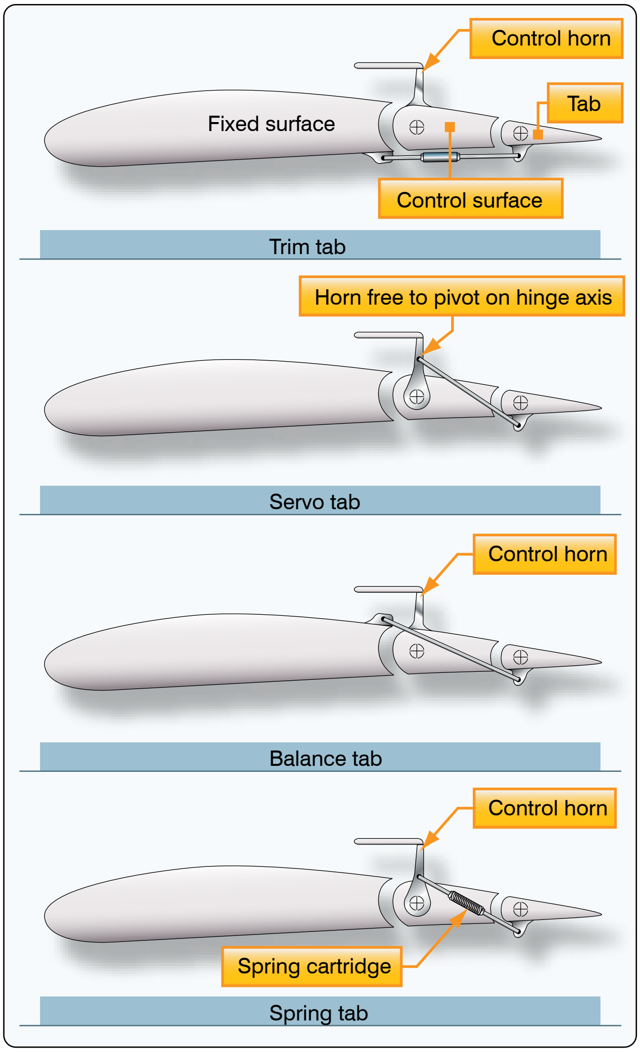


Figure 2-13. *Types of trim tabs.*

Auxiliary Lift Devices

Included in the auxiliary lift devices group of flight control surfaces are the wing flaps, spoilers, speed brakes, slats, leading edge flaps, and slots.

The auxiliary groups may be divided into two subgroups: those whose primary purpose is lift augmenting and those whose primary purpose is lift decreasing. In the first group are the flaps, both trailing edge and leading edge (slats), and slots. The lift decreasing devices are speed brakes and spoilers.

Lift Augmenting

Flaps are located on the trailing edge of the wing and are moveable to increase the wing area, thereby increasing lift on takeoff, and decreasing the speed during landing. These airfoils are retractable and fair into the wing contour. Others are simply a portion of the lower skin which extends into the airstream, thereby slowing the aircraft. Leading edge flaps, also referred to as slats, are airfoils extended from and retracted into the leading edge of the wing. Some installations create a slot (an opening between the extended airfoil and the leading edge). *[Figure 2-14]* At low airspeeds, this slot increases lift and improves handling characteristics, allowing the aircraft to be controlled at airspeeds below the normal landing speed.

Other installations have permanent slots built in the leading edge of the wing. At cruising speeds, the trailing edge and leading edge flaps (slats) are retracted into the wing proper. Slats are movable control surfaces attached to the leading edges of the wings. 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. At low airspeeds, this increases lift and improves handling characteristics, allowing the aircraft to be controlled at airspeeds below the normal landing speed. *[Figure 2-15]*

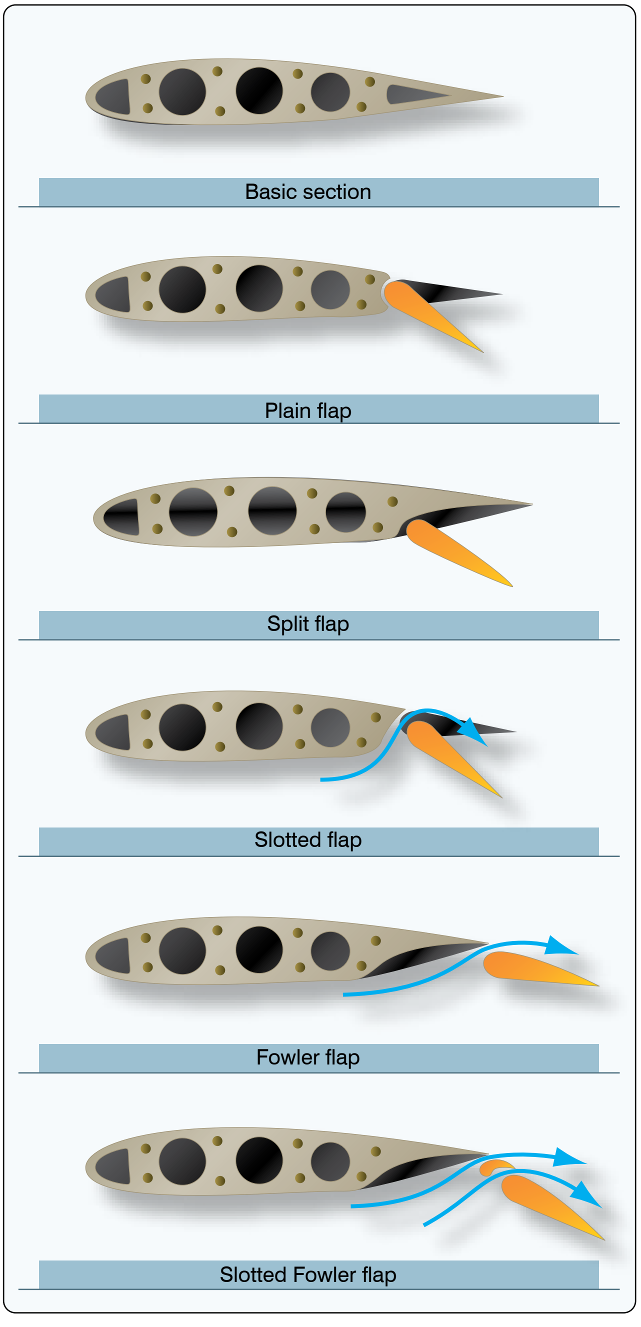


Figure 2-14. *Types of wing flaps.*

Lift Decreasing

Lift decreasing devices are the speed brakes (spoilers). In some installations, there are two types of spoilers. The ground spoiler is extended only after the aircraft is on the ground, thereby assisting in the braking action. The flight spoiler assists in lateral control by being extended whenever the aileron on that wing is rotated up. When actuated as speed brakes, the spoiler panels on both wings raise up. In-flight spoilers may also be located along the sides, underneath the fuselage, or back at the tail. *[Figure 2-16]* In some aircraft designs, the wing panel on the up aileron side rises more than the wing panel on the down aileron side. This provides speed brake operation and lateral control simultaneously.

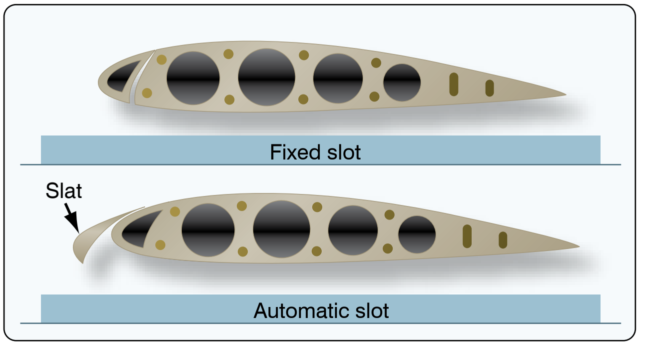


Figure 2-15. *Wing slots.*

Figure 2-16. *Speed brake.*

Winglets

Winglets are the near-vertical extension of the wingtip that reduces the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. By reducing the induced drag at the tips of the wings, fuel consumption goes down and range is extended. *Figure 2-17* shows an example of a Learjet 60 with winglets.

Canard Wings

A canard wing aircraft is an airframe configuration of a fixed-wing aircraft in which a small wing or horizontal airfoil is ahead of the main lifting surfaces, rather than behind them as in a conventional aircraft. The canard may be fixed, movable, or designed with elevators. Good examples of aircraft with canard wings are the Rutan VariEze and Beechcraft 2000 Starship. *[Figures 2-18* and *2-19]*

Wing Fences

Wing fences are flat metal vertical plates fixed to the upper surface of the wing. They obstruct spanwise airflow along the wing, and prevent the entire wing from stalling at once. They are often attached on swept-wing aircraft to prevent the spanwise movement of air at high AOA. Their purpose is to provide better slow speed handling and stall characteristics. *[Figure 2-20]*

Control Systems for Large Aircraft

Mechanical Control

This is the basic type of system that was used to control early aircraft and is currently used in smaller aircraft where aerodynamic forces are not excessive. The controls are mechanical and manually operated.

The mechanical system of controlling an aircraft can include cables, push-pull tubes, and torque tubes. The cable system is the most widely used because deflections of the structure to which it is attached do not affect its operation. Some aircraft incorporate control systems that are a combination of all three. These systems incorporate cable assemblies, cable guides, linkage, adjustable stops, and control surface snubber or mechanical locking devices. These surface locking devices, usually referred to as a gust lock, limits the external wind forces from damaging the aircraft while it is parked or tied down.

Hydromechanical Control

As the size, complexity, and speed of aircraft increased, actuation of controls in flight became more difficult. It soon became apparent that the pilot needed assistance to overcome

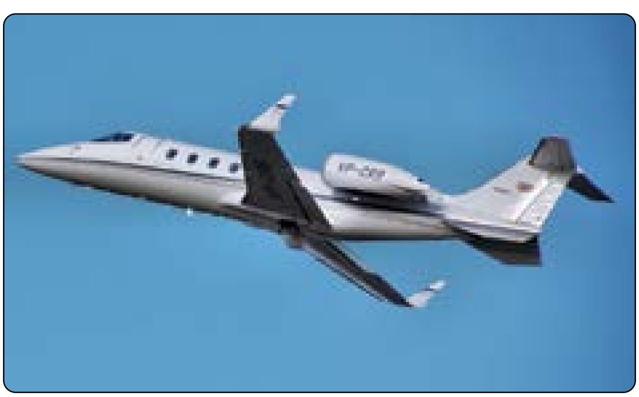


Figure 2-17. *Winglets on a Bombardier Learjet 60.*

Figure 2-18. *Canard wings on a Rutan VariEze.*

Figure 2-19. *The Beechcraft 2000 Starship has canard wings.*

Figure 2-20. *Aircraft stall fence.*

the aerodynamic forces to control aircraft movement. Spring tabs, which were operated by the conventional control system, were moved so that the airflow over them actually moved the primary control surface. This was sufficient for the aircraft operating in the lowest of the high speed ranges (250–300 mph). For higher speeds, a power-assisted (hydraulic) control system was designed.

Conventional cable or push-pull tube systems link the flight deck controls with the hydraulic system. With the system activated, the pilot's movement of a control causes the mechanical link to open servo valves, thereby directing hydraulic fluid to actuators, which convert hydraulic pressure into control surface movements.

Because of the efficiency of the hydromechanical flight control system, the aerodynamic forces on the control surfaces cannot be felt by the pilot, and there is a risk of overstressing the structure of the aircraft. To overcome this problem, aircraft designers incorporated artificial feel systems into the design that provided increased resistance to the controls at higher speeds. Additionally, some aircraft with hydraulically powered control systems are fitted with a device called a stick shaker, which provides an artificial stall warning to the pilot.

Fly-By-Wire Control

The fly-by-wire (FBW) control system employs electrical signals that transmit the pilot's actions from the flight deck through a computer to the various flight control actuators. The FBW system evolved as a way to reduce the system weight of the hydromechanical system, reduce maintenance costs, and improve reliability. Electronic FBW control systems can respond to changing aerodynamic conditions by adjusting flight control movements so that the aircraft response is consistent for all flight conditions. Additionally, the computers can be programmed to prevent undesirable and dangerous characteristics, such as stalling and spinning.

Many of the new military high-performance aircraft are not aerodynamically stable. This characteristic is designed into the aircraft for increased maneuverability and responsive performance. Without the computers reacting to the instability, the pilot would lose control of the aircraft.

The Airbus A-320 was the first commercial airliner to use FBW controls. Boeing used them in their 777 and newer design commercial aircraft. The Dassault Falcon 7X was the first business jet to use a FBW control system.

High-Speed Aerodynamics

High-speed aerodynamics, often called compressible aerodynamics, is a special branch of study of aeronautics. It is utilized by aircraft designers when designing aircraft capable of speeds approaching Mach 1 and above. Because it is beyond the scope and intent of this handbook, only a brief overview of the subject is provided.

In the study of high-speed aeronautics, the compressibility effects on air must be addressed. This flight regime is characterized by the Mach number, a special parameter named in honor of Ernst Mach, the late 19th century physicist who studied gas dynamics. Mach number is the ratio of the speed of the aircraft to the local speed of sound and determines the magnitude of many of the compressibility effects.

As an aircraft moves through the air, the air molecules near the aircraft are disturbed and move around the aircraft. The air molecules are pushed aside much like a boat creates a bow wave as it moves through the water. If the aircraft passes at a low speed, typically less than 250 mph, the density of the air remains constant. But at higher speeds, some of the energy of the aircraft goes into compressing the air and locally changing the density of the air. The bigger and heavier the aircraft, the more air it displaces and the greater effect compression has on the aircraft.

This effect becomes more important as speed increases. Near and beyond the speed of sound, about 760 mph (at sea level), sharp disturbances generate a shockwave that affects both the lift and drag of an aircraft and flow conditions downstream of the shockwave. The shockwave forms a cone of pressurized air molecules which move outward and rearward in all directions and extend to the ground. The sharp release of the pressure, after the buildup by the shockwave, is heard as the sonic boom. *[Figure 2-21]*

Listed below are a range of conditions that are encountered by aircraft as their designed speed increases.

- Subsonic conditions occur for Mach numbers less than one (100–350 mph). For the lowest subsonic conditions, compressibility can be ignored.

Figure 2-21. *Breaking the sound barrier.*

- As the speed of the object approaches the speed of sound, the flight Mach number is nearly equal to one, M = 1 (350–760 mph), and the flow is said to be transonic. At some locations on the object, the local speed of air exceeds the speed of sound. Compressibility effects are most important in transonic flows and lead to the early belief in a sound barrier. Flight faster than sound was thought to be impossible. In fact, the sound barrier was only an increase in the drag near sonic conditions because of compressibility effects. Because of the high drag associated with compressibility effects, aircraft are not operated in cruise conditions near Mach 1.
- Supersonic conditions occur for numbers greater than Mach 1, but less then Mach 3 (760–2,280 mph). Compressibility effects of gas are important in the design of supersonic aircraft because of the shockwaves that are generated by the surface of the object. For high supersonic speeds, between Mach 3 and Mach 5 (2,280–3,600 mph), aerodynamic heating becomes a very important factor in aircraft design.
- For speeds greater than Mach 5, the flow is said to be hypersonic. At these speeds, some of the energy of the object now goes into exciting the chemical bonds which hold together the nitrogen and oxygen molecules of the air. At hypersonic speeds, the chemistry of the air must be considered when determining forces on the object. When the space shuttle re-enters the atmosphere at high hypersonic speeds, close to Mach 25, the heated air becomes an ionized plasma of gas, and the spacecraft must be insulated from the extremely high temperatures.

Additional technical information pertaining to high-speed aerodynamics can be found at bookstores, libraries, and numerous sources on the Internet. As the design of aircraft evolves and the speeds of aircraft continue to increase into the hypersonic range, new materials and propulsion systems will need to be developed. This is the challenge for engineers, physicists, and designers of aircraft in the future.

Airplane Assembly & Rigging

The primary assembly of a type certificated aircraft is normally performed by the manufacturer at the factory. The assembly includes putting together the major components, such as the fuselage, empennage, wing sections, nacelles, landing gear, and installing the powerplant. Attached to the wing and empennage are primary flight control surfaces including ailerons, elevators, and rudder. Additionally, installation of auxiliary flight control surfaces may include wing flaps, spoilers, speed brakes, slats, and leading edge flaps.

The assembly of other aircraft outside of a manufacturer's facility is usually limited to smaller size and experimental amateur-built aircraft. Typically, after a major overhaul, repair, or alteration, the reassembly of an aircraft may include reattaching wings to the fuselage, balancing of and installation of flight control surfaces, installation of the landing gear, and installation of the powerplant(s).

Rebalancing of Control Surfaces

This section is presented for familiarization purposes only. Explicit instructions for the balancing of control surfaces are given in the manufacturer's service and overhaul manuals for the specific aircraft and must be followed closely.

Any time repairs on a control surface add weight fore or aft of the hinge center line, the control surface must be rebalanced. When an aircraft is repainted, the balance of the control surfaces must be checked. Any control surface that is out of balance is unstable and does not remain in a streamlined position during normal flight. For example, an aileron that is trailing edge heavy moves down when the wing deflects upward, and up when the wing deflects downward. Such a condition can cause unexpected and violent maneuvers of the aircraft. In extreme cases, fluttering and buffeting may develop to a degree that could cause the complete loss of the aircraft.

Rebalancing a control surface concerns both static and dynamic balance. A control surface that is statically balanced is also dynamically balanced.

Static Balance

Static balance is the tendency of an object to remain stationary when supported from its own CG. There are two ways in which a control surface may be out of static balance. They are called underbalance and overbalance.

When a control surface is mounted on a balance stand, a downward travel of the trailing edge below the horizontal position indicates underbalance. Some manufacturers indicate this condition with a plus (+) sign. An upward movement of the trailing edge, above the horizontal position indicates overbalance. This is designated by a minus (–) sign. These signs show the need for more or less weight in the correct area to achieve a balanced control surface, as shown in *Figure 2-60*.

A tail-heavy condition (static underbalance) causes undesirable flight performance and is not usually allowed. Better flight operations are gained by nose-heavy static overbalance. Most manufacturers advocate the existence of nose-heavy control surfaces.

Dynamic Balance

Dynamic balance is that condition in a rotating body wherein all rotating forces are balanced within themselves so that no vibration is produced while the body is in motion. Dynamic balance as related to control surfaces is an effort to maintain balance when the control surface is submitted to movement on the aircraft in flight. It involves the placing of weights in the correct location along the span of the surfaces. The

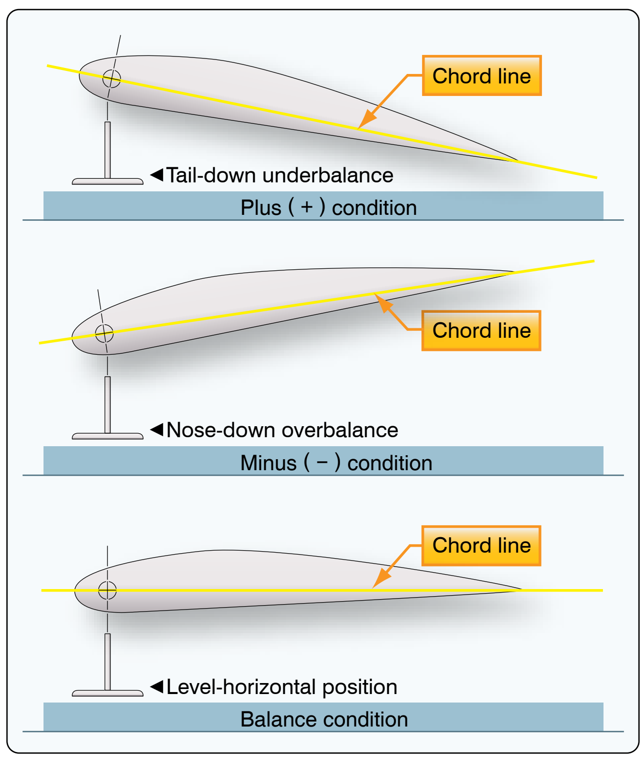


Figure 2-60. *Control surface static balance.*

location of the weights are, in most cases, forward of the hinge center line.

Rebalancing Procedures

Repairs to a control surface or its tabs generally increase the weight aft of the hinge center line, requiring static rebalancing of the control surface system, as well as the tabs. Control surfaces to be rebalanced should be removed from the aircraft and supported, from their own points, on a suitable stand, jig, or fixture. *[Figure 2-61]*

Trim tabs on the surface should be secured in the neutral position when the control surface is mounted on the stand. The stand must be level and be located in an area free of air currents. The control surface must be permitted to rotate freely about the hinge points without binding. Balance condition is determined by the behavior of the trailing edge when the surface is suspended from its hinge points. Any excessive friction would result in a false reaction as to the overbalance or underbalance of the surface.

When installing the control surface in the stand or jig, a neutral position should be established with the chord line of the surface in a horizontal position. Use a bubble protractor to determine the neutral position before continuing balancing procedures. *[Figure 2-62]*

Sometimes a visual check is all that is needed to determine whether the surface is balanced or unbalanced. Any trim tabs or other assemblies that are to remain on the surface during balancing procedures should be in place. If any assemblies or parts must be removed before balancing, they should be removed.

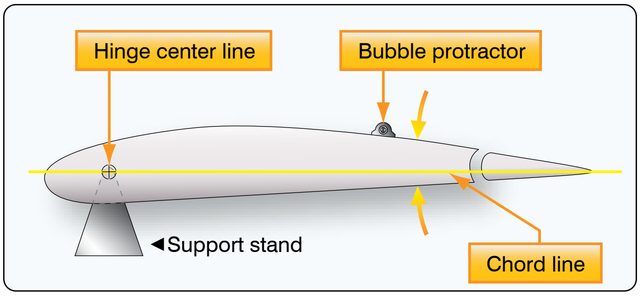


Figure 2-62. *Establishing a neutral position of the control surface.*

Rebalancing Methods

Several methods of balancing (rebalancing) control surfaces are in use by the various manufacturers of aircraft. The most common are the calculation method, scale method, and the balance beam method.

The calculation method of balancing a control surface has one advantage over the other methods in that it can be performed without removing the surface from the aircraft. In using the calculation method, the weight of the material from the repair area and the weight of the materials used to accomplish the repair must be known. Subtract the weight removed from the weight added to get the resulting net gain in the amount added to the surface. The distance from the hinge center line to the center of the repair area is then measured in inches. This distance must be determined to the nearest one-hundredth of an inch. *[Figure 2-63]*

The next step is to multiply the distance times the net weight of the repair. This results in an inch-pounds (in-lb) answer. If the in-lb result of the calculations is within specified tolerances, the control surface is considered balanced. If

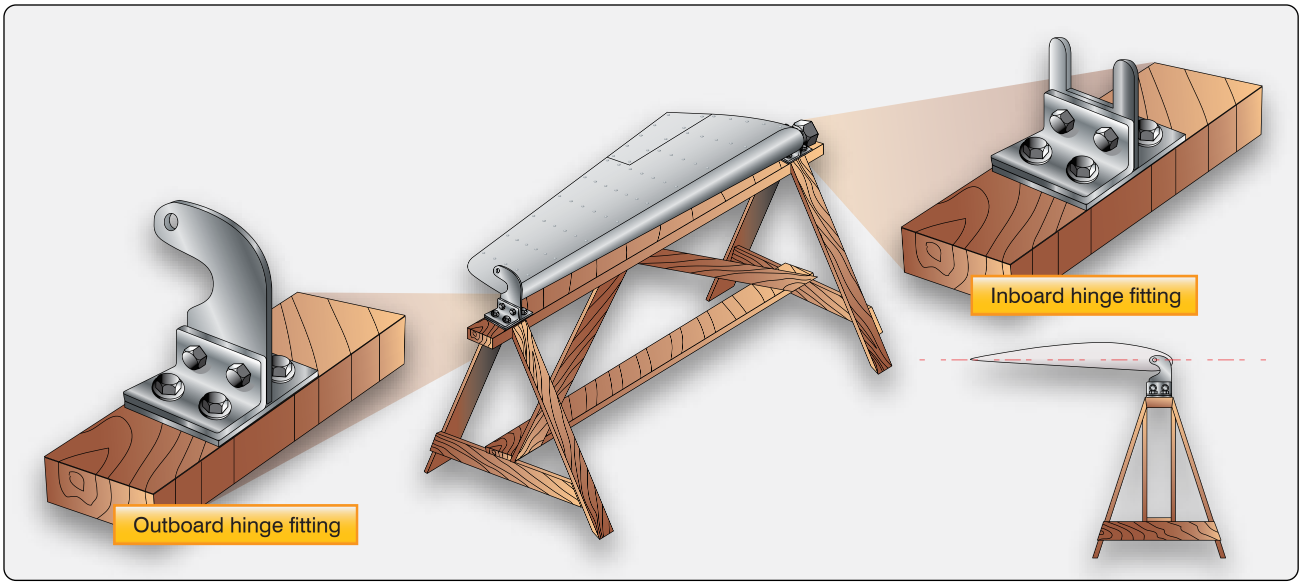


Figure 2-61. *Locally fabricated balancing fixture.*

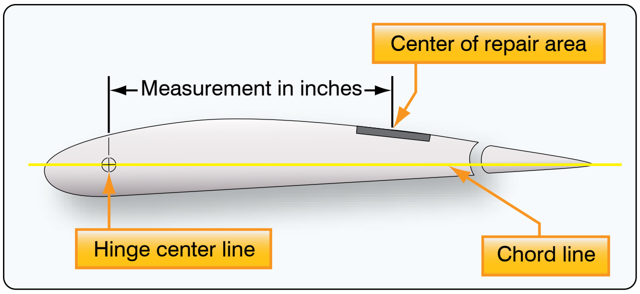


Figure 2-63. *Calculation method measurement.*

it is not within specified limits, consult the manufacturer's service manuals for the needed weights, material to use for weights, design for manufacture, and installation locations for addition of the weights.

The scale method of balancing a control surface requires the use of a scale that is graduated in hundredths of a pound. A support stand and balancing jigs for the surface are also required. *Figure 2-64* illustrates a control surface mounted for rebalancing purposes. Use of the scale method requires the removal of the control surface from the aircraft.

The balance beam method is used by the Cessna and Piper Aircraft companies. This method requires that a specialized tool be locally fabricated. The manufacturer's maintenance manual provides specific instructions and dimensions to fabricate the tool.

Once the control surface is placed on level supports, the weight required to balance the surface is established by moving the sliding weight on the beam. The maintenance manual indicates where the balance point should be. If the surface is found to be out of tolerance, the manual explains where to place weight to bring it into tolerance.

Aircraft manufacturers use different materials to balance control surfaces, the most common being lead or steel. Larger aircraft manufacturers may use depleted uranium because it has a heavier mass than lead. This allows the counterweights to be made smaller and still retain the same weight. Specific safety precautions must be observed when handling counterweights of depleted uranium because it is radioactive. The manufacturer's maintenance manual and service instructions must be followed and all precautions observed when handling the weights.

Aircraft Rigging

Aircraft rigging involves the adjustment and travel of movable flight controls which are attached to aircraft major surfaces, such as wings and vertical and horizontal stabilizers. Ailerons are attached to the wings, elevators are attached to the horizontal stabilizer, and the rudder is attached to the vertical

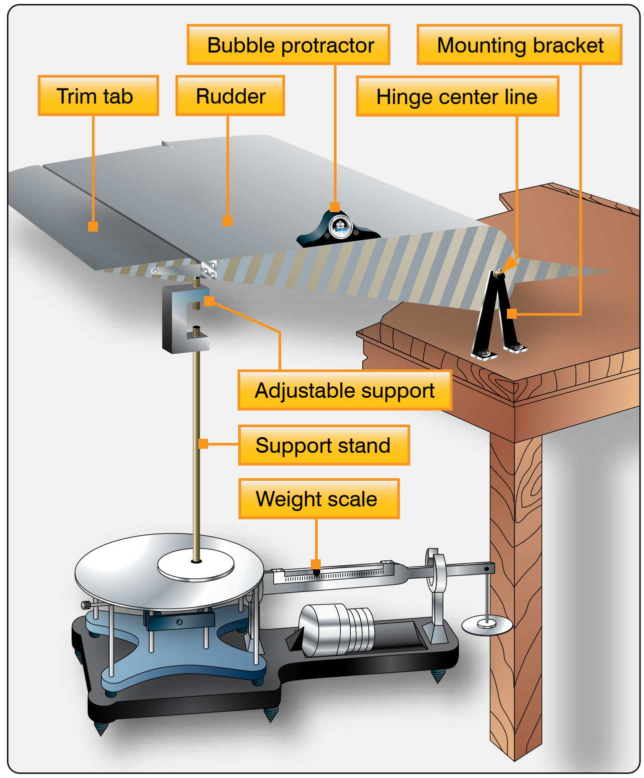


Figure 2-64. *Balancing setup.*

stabilizer. Rigging involves setting cable tension, adjusting travel limits of flight controls, and setting travel stops.

In addition to the flight controls, rigging is also performed on various components to include engine controls, flight deck controls, and retractable landing gear component parts. Rigging also includes the safetying of the attaching hardware using various types of cotter pins, locknuts, or safety wire.

Rigging Specifications

Type Certificate Data Sheet

The Type Certificate Data Sheet (TCDS) is a formal description of an aircraft, engine, or propeller. It is issued by the Federal Aviation Administration (FAA) when the FAA determines that the product meets the applicable requirements for certification under 14 CFR. It lists the limitations and information required for type certification, including airspeed limits, weight limits, control surface movements, engine make and model, minimum crew, fuel type, thrust limits, rpm limits, etc., and the various components eligible for installation on the product.

Maintenance Manual

A maintenance manual is developed by the manufacturer of the applicable product and provides the recommended and acceptable procedures to be followed when maintaining or repairing that product. Maintenance personnel are required by regulation to follow the applicable instructions set forth by the manufacturer. The Limitations section of the manual lists "life limits" of the product or its components that must be complied with during inspections and maintenance.

Structural Repair Manual (SRM)

The structural repair manual is developed by the manufacturer's engineering department to be used as a guideline to assist in the repair of common damage to a specific aircraft structure. It provides information for acceptable repairs of specific sections of the aircraft.

Manufacturer's Service Information

Information from the manufacturer may be in the form of information bulletins, service instructions, service bulletins, service letters, etc., that the manufacturer publishes to provide instructions for product improvement. Service instructions may include a recommended modification or repair that precedes the issuance of an Airworthiness Directive (AD). Service letters may provide more descriptive procedures or revise sections of the maintenance manuals. They may also include instructions for the installation and repair of optional equipment, not listed in the Type Certificate Data Sheet (TCDS).

Airplane Assembly

Aileron Installation

The manufacturer's maintenance and illustrated parts book must be followed to ensure the correct procedures and hardware are being used for installation of the control surfaces. All of the control surfaces require specific hardware, spacers, and bearings be installed to ensure the surface does not jam or become damaged during movement. After the aileron is connected to the flight deck controls, the control system must be inspected to ensure the cables/push-pull rods are routed properly. When a balance cable is installed, check for correct attachment and operation to determine the ailerons are moving in the proper direction and opposite each other.

Flap Installation

The design, installation, and systems that operate flaps are as varied as the models of airplanes on which they are installed. As with any system on a specific aircraft, the manufacturer's maintenance manual and the illustrated parts book must be followed to ensure the correct procedures and parts are used. Simple flap systems are usually operated manually by cables and/or torque tubes. Typically, many of the smaller manufactured airplane designs have flaps that are actuated by torque tubes and chains through a gear box driven by an electric motor.

Empennage Installation

The empennage, consisting of the horizontal and vertical stabilizer, is not normally removed and installed, unless the aircraft was damaged. Elevators, rudders, and stabilators are rigged the same as any other control surface, using the instructions provided in the manufacturer's maintenance manuals.

Control Operating Systems

Cable Systems

There are various types of cable:

- Material—aircraft control cables are fabricated from carbon steel or stainless (corrosion resistant) steel. Additionally, some manufacturers use a nylon coated cable that is produced by extruding a flexible nylon coating over corrosion-resistant steel (CRES) cable. By adding the nylon coating to the corrosion resistant steel cable, it increases the service life by protecting the cable strands from friction wear, keeping dirt and grit out, and dampening vibration which can work-harden the wires in long runs of cable.
- Cable construction—the basic component of a cable is a wire. The diameter of the wire determines the total diameter of the cable. A number of wires are preformed into a helical or spiral shape and then formed into a strand. These preformed strands are laid around a straight center strand to form a cable.
- Cable designations—based on the number of strands and wires in each strand. The 7 × 19 cable is made up of seven strands of 19 wires each. Six of these strands are laid around the center strand. This cable is very flexible and is used in primary control systems and in other locations where operation over pulleys is frequent. The 7 × 7 cable consists of seven strands of seven wires each. Six of these strands are laid around the center strand. This cable is of medium flexibility and is used for trim tab controls, engine controls, and indicator controls. *[Figure 2-65]*

Types of control cable termination include:

- Woven splice—a hand-woven 5-tuck splice used on aircraft cable. The process is very time consuming and produces only about 75 percent of the original cable

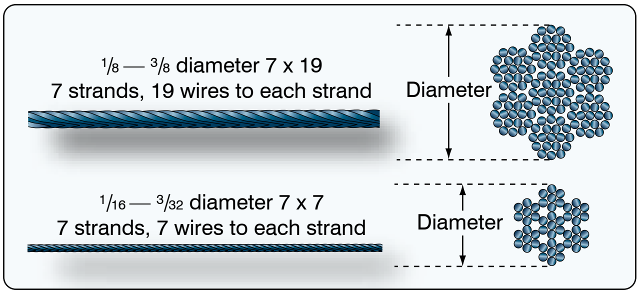


Figure 2-65. *Cable construction and cross-section.*

strength. The splice is rarely used except on some antique aircraft where the effort is made to keep all parts in their original configuration.

- Nicopress® process—a patented process using copper sleeves and may be used up to the full rated strength of the cable when the cable is looped around a thimble. *[Figure 2-66]* This process may also be used in place of the 5-tuck splice on cables up to and including $^3/_8$-inch diameter. Whenever this process is used for cable splicing, it is imperative that the tools, instructions, and data supplied by Nicopress® be followed exactly to ensure the desired cable function and strength is attained. The use of sleeves that are fabricated of material other than copper requires engineering approval for the specific application by the FAA.
- Swage-type terminals—manufactured in accordance with Army-Navy (AN) and Military Standards (MS), are suitable for use in civil aircraft up to, and including, maximum cable loads. *[Figure 2-67]*

When swaging tools are used, it is imperative that all the manufacturer's instructions, including 'go' and 'no-go' dimensions, be followed exactly to avoid defective and inferior swaging. Compliance with all of the instructions should result in the terminal developing the full-rated strength of the cable. The following basic procedures are used when swaging terminals onto cable ends:

- Cut the cable to length, allowing for growth during swaging. Apply a preservative compound to the cable end before insertion into the terminal barrel. Measure the internal length of the terminal end/barrel of the fitting to determine the proper length of the cable to be inserted. Transfer that measurement to the end of the cable and mark it with a piece of masking tape wrapped around the cable. This provides a positive mark to ensure the cable did not slip during the swaging process.

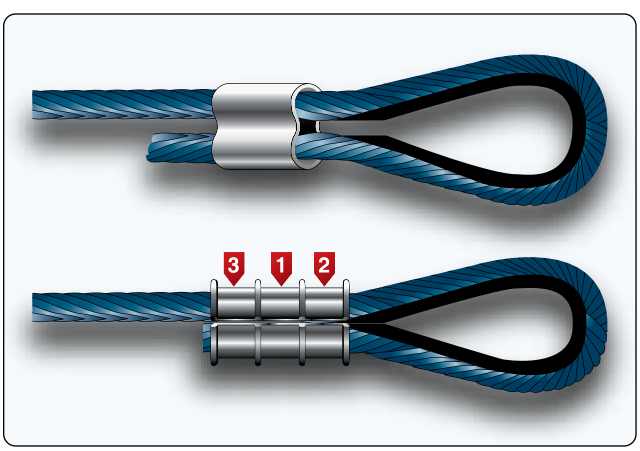


Figure 2-66. *Typical Nicopress® thimble-eye splice.*

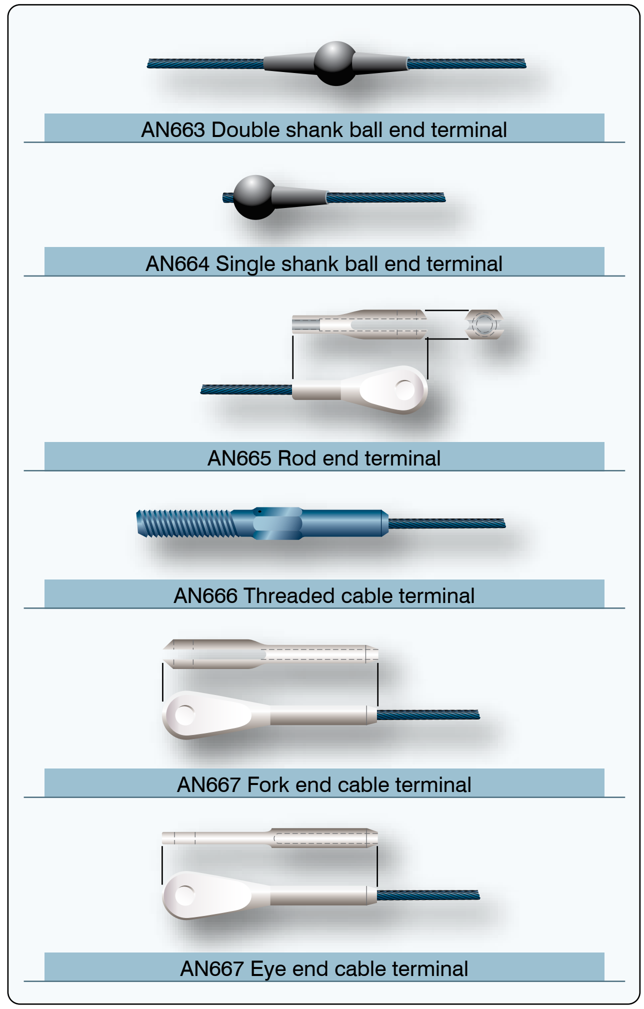


Figure 2-67. *Swage-type terminal fittings.*

Note: Never solder the cable ends to prevent fraying since the solder greatly increases the tendency of the cable to pull out of the terminal.

- Insert the cable into the terminal approximately one inch and bend it toward the terminal. Then, push the cable end all the way into the terminal. The bending action puts a slight kink in the cable end and provides enough friction to hold the terminal in place until the swaging operation is performed. *[Figure 2-68]*
- Accomplish the swaging operation in accordance with the instructions furnished by the manufacturer of the swaging equipment.
- Inspect the terminal after swaging to determine that it is free of die marks and splits and is not out of round. Check the cable for slippage at the masking tape and for cut and broken wire strands.
- Using a go/no-go gauge supplied by the swaging tool manufacturer or a micrometer and swaging chart, check the terminal shank diameter for proper dimension. *[Figures 2-69* and *2-70]*

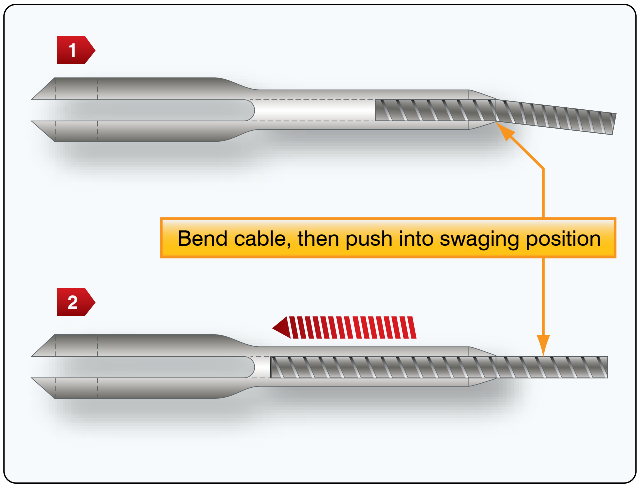


Figure 2-68. *Insertion of cable into terminal.*

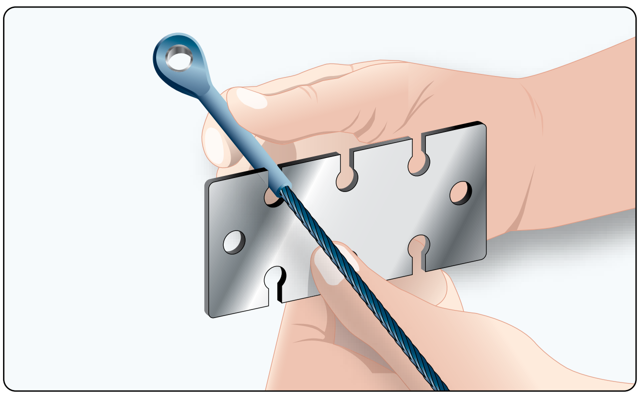


Figure 2-69. *Gauging terminal shank dimension after swaging.*

- Test the cable by proof-loading locally fabricated splices and newly installed swage terminal cable fittings for proper strength before installation. This is conducted by slowly applying a test load equal to 60 percent of the rated breaking strength of the cable listed in *Figure 2-71*.

This load should be held for at least 3 minutes. Any testing of this type can be dangerous. Suitable guards should be placed over the cable during the test to prevent injury to personnel in the event of cable failure. If a proper test fixture is not available, the load test should be contracted out and performed by a properly equipped facility.

Cable Inspection

Aircraft cable systems are subject to a variety of environmental conditions and deterioration. Wire or strand breakage is easy to recognize visually. Other kinds of deterioration, such as wear, corrosion, and distortion, are not easily seen. Special attention should be given to areas where cables pass through battery compartments, lavatories, and wheel wells. These are prime areas for corrosion. Special attention should be given to critical fatigue areas. Those areas are defined as anywhere the cable runs over, under, or around a pulley, sleeve, or through a fairlead; or any section where the cable is flexed, rubbed, or within 1 foot of a swaged-on fitting. Close inspection in these critical fatigue areas can be performed by rubbing a rag along the cable. If there are any broken strands, the rag snags on the cable. A more detailed inspection can be performed in areas that may be corroded or indicate a fatigue failure by loosing or removing the cable and bending it. This technique reveals internal broken strands not readily apparent from the outside. *[Figure 2-72]*

Cable System Installation

Cable Guides

Pulleys are used to guide cables and also to change the direction of cable movement. Pulley bearings are sealed and need no lubrication other than the lubrication done at the factory. Brackets fastened to the structure of the aircraft support the pulleys. Cables passing over pulleys are kept in place by guards. The guards are close fitting to prevent jamming or

		Before Swaging				After Swaging	
Cable size (inches)	Wire strands	Outside diameter	Bore diameter	Bore length	Swaging length	Minimum breaking strength (pounds)	Shank diameter *
1/16	7 x 7	0.160	0.078	1.042	0.969	480	0.138
3/32	7 x 7	0.218	0.109	1.261	1.188	920	0.190
1/8	7 x 19	0.250	0.141	1.511	1.438	2,000	0.219
5/32	7 x 19	0.297	0.172	1.761	1.688	2,800	0.250
3/16	7 x 19	0.359	0.203	2.011	1.938	4,200	0.313
7/32	7 x 19	0.427	0.234	2.261	2.188	5,600	0.375
1/4	7 x 19	0.494	0.265	2.511	2.438	7,000	0.438
9/32	7 x 19	0.563	0.297	2.761	2.688	8,000	0.500
5/16	7 x 19	0.635	0.328	3.011	2.938	9,800	0.563
3/8	7 x 19	0.703	0.390	3.510	3.438	14,400	0.625

*Use gauges in kit for checking diameters.

Figure 2-70. *Straight shank terminal dimensions.*

				Minimum Breaking Strength (Pounds)		
Nominal diameter of wire rope cable	Construction	Tolerance on diameter (plus only)	Allowable increase of diameter at cut end	MIL-W-83420 COMP A	MIL-W-83420 COMP B (CRES)	MIL-C-18375 (CRES)
INCHES		INCHES	INCHES	POUNDS	POUNDS	POUNDS
1/32	3 x 7	0.006	0.006	110	110	
3/64	7 x 7	0.008	0.008	270	270	
1/16	7 x 7	0.010	0.009	480	480	360
1/16	7 x 19	0.010	0.009	480	480	
3/32	7 x 7	0.012	0.010	920	920	700
3/32	7 x 19	0.012	0.010	1,000	920	
1/8	7 x 19	0.014	0.011	2,000	1,760	1,300
5/32	7 x 19	0.016	0.017	2,800	2,400	2,000
3/16	7 x 19	0.018	0.019	4,200	3,700	2,900
7/32	7 x 19	0.018	0.020	5,000	5,000	3,800
1/4	7 x 19	0.018	0.021	6,400	6,400	4,900
9/32	7 x 19	0.020	0.023	7,800	7,800	6,100
5/16	7 x 19	0.022	0.024	9,800	9,000	7,600
11/32	7 x 19	0.024	0.025	12,500		
3/8	7 x 19	0.026	0.027	14,400	12,000	11,000
7/16	6 x 19 IWRC	0.030	0.030	17,600	16,300	14,900
1/2	6 x 19 IWRC	0.033	0.033	22,800	22,800	19,300
9/16	6 x 19 IWRC	0.036	0.036	28,500	28,500	24,300
5/8	6 x 19 IWRC	0.039	0.039	35,000	35,000	30,100
3/4	6 x 19 IWRC	0.045	0.045	49,600	49,600	42,900
7/8	6 x 19 IWRC	0.048	0.048	66,500	66,500	58,000
1	6 x 19 IWRC	0.050	0.050	85,400	85,400	75,200
1 - 1/8	6 x 19 IWRC	0.054	0.054	106,400	106,400	
1 - 1/4	6 x 19 IWRC	0.057	0.057	129,400	129,400	
1 - 3/8	6 x 19 IWRC	0.060	0.060	153,600	153,600	
1 - 1/2	6 x 19 IWRC	0.062	0.062	180,500	180,500	

Figure 2-71. *Flexible cable construction.*

to prevent the cables from slipping off when they slacken due to temperature variations. Pulleys should be examined to ensure proper lubrication; smooth rotation and freedom from abnormal cable wear patterns which can provide an indication of other problems in the cable system. *[Figure 2-73]*

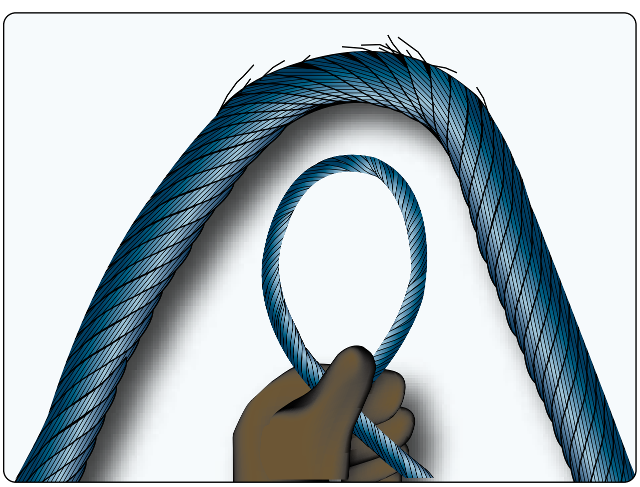


Figure 2-72. *Cable inspection technique.*

Fairleads may be made from a nonmetallic material, such as phenolic, or a metallic material, such as soft aluminum. The fairlead completely encircles the cable where it passes through holes in bulkheads or other metal parts. Fairleads are used to guide cables in a straight line through or between structural members of the aircraft. Fairleads should never deflect the alignment of a cable more than 3° from a straight line.

Pressure seals are installed where cables (or rods) move through pressure bulkheads. The seal grips tightly enough to prevent excess air pressure loss but not enough to hinder movement of the cable. Pressure seals should be inspected at regular intervals to determine that the retaining rings are in place. If a retaining ring comes off, it may slide along the cable and cause jamming of a pulley. *[Figure 2-74]*

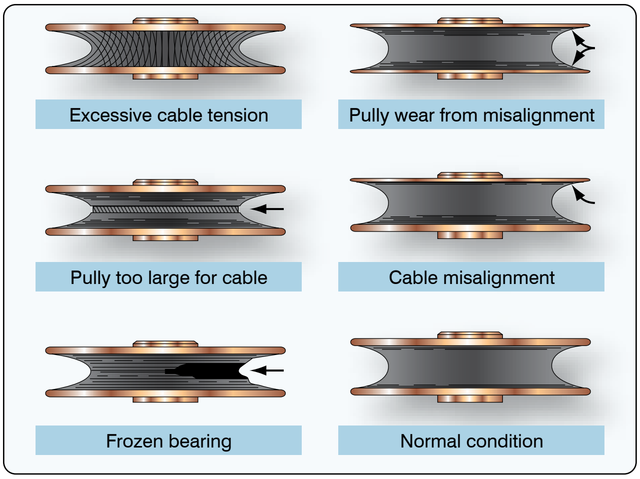


Figure 2-73. *Pulley wear patterns.*

Travel Adjustment

Control surfaces should move a certain distance in either direction from the neutral position. These movements must be synchronized with the movement of the flight deck controls. The flight control system must be adjusted (rigged) to obtain these requirements. The tools for measuring surface travel primarily include protractors, rigging fixtures, contour templates, and rulers. These tools are used when rigging flight control systems to assure that the desired travel has been obtained. Generally speaking, the rigging consists of the following:

1. Positioning the flight control system in neutral and temporarily locking it there with rig pins or blocks;
2. Adjusting system cable tension and maintaining rudder, elevator, and ailerons in the neutral position; and
3. Adjusting the control stops to the aircraft manufacturer's specifications.

Cable Tension

For the aircraft to operate as it was designed, the cable tension for the flight controls must be correct. To determine the amount of tension on a cable, a tensiometer is used. When properly maintained, a tensiometer is 98 percent accurate. 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. Several manufacturers make a variety of tensiometers, each type designed for different kinds of cable, cable sizes, and cable tensions. *[Figure 2-75]*

Rigging Fixtures

Rigging fixtures and templates are special tools (gauges) designed by the manufacturer to measure control surface travel. Markings on the fixture or template indicate desired control surface travel.

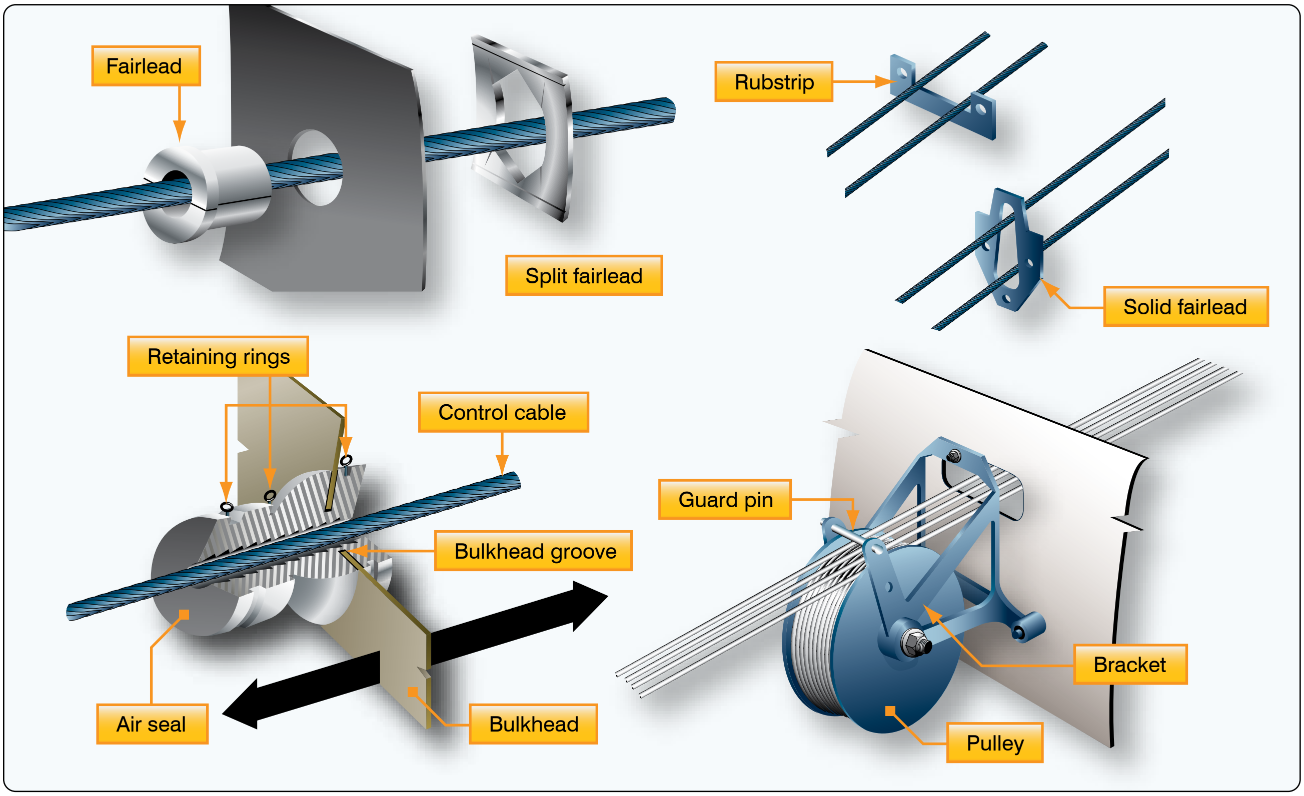


Figure 2-74. *Cable guides.*

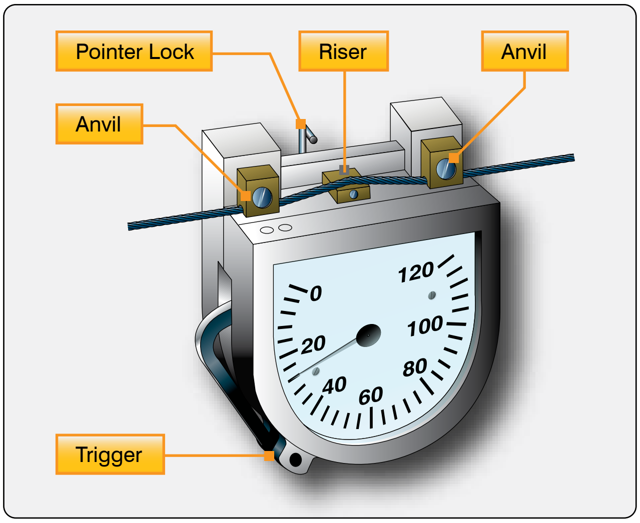


Figure 2-75. *Tensiometer.*

Tension Regulators

Cable tension regulators are used in some flight control systems because there is considerable difference in temperature expansion of the aluminum aircraft structure and the steel control cables. Some large aircraft incorporate tension regulators in the control cable systems to maintain a given cable tension automatically. The unit consists of a compression spring and a locking mechanism that allows the spring to make correction in the system only when the cable system is in neutral.

Turnbuckles

A turnbuckle assembly is a mechanical screw device consisting of two threaded terminals and a threaded barrel. *[Figure 2-76]* 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 internal threads. The end of the barrel with the left-hand threads can usually be identified by a groove or knurl around that end of the barrel.

When installing a turnbuckle in a control system, it is necessary to screw both of the terminals an equal number of turns into the barrel. It is also essential that all turnbuckle terminals be screwed into the barrel until not more than three threads are exposed on either side of the turnbuckle barrel. After a turnbuckle is properly adjusted, it must be safetied. There are a number of methods to safety a turnbuckle and/or other types of swaged cable ends that are satisfactory. A double-wrap safety wire method is preferred.

Some turnbuckles are manufactured and designed to accommodate special locking devices. A typical unit is shown in *Figure 2-77*.

Cable Connectors

In addition to turnbuckles, cable connectors are used in some systems. These connectors enable a cable length to be quickly connected or disconnected from a system. *Figure 2-78* illustrates one type of cable connector in use.

Spring-Back

With a control cable properly rigged, the flight control should hit its stops at both extremes prior to the flight deck control. The spring-back is the small extra push that is needed for the flight deck control to hit its mechanical stop.

Push Rods (Control Rods)

Push rods are used as links in the flight control system to give push-pull motion. They may be adjusted at one or both ends. *Figure 2-79* shows the parts of a push rod. Notice that it consists of a tube with threaded rod ends. An adjustable antifriction rod end, or rod end clevis, attaches at each end of the tube. The rod end, or clevis, permits attachment of the tube to flight control system parts. The checknut, when tightened, prevents the rod end or clevis from loosening. They may have adjustments at one or both ends.

The rods should be perfectly straight, unless designed to be otherwise. When installed as part of a control system, the assembly should be checked for correct alignment and free movement.

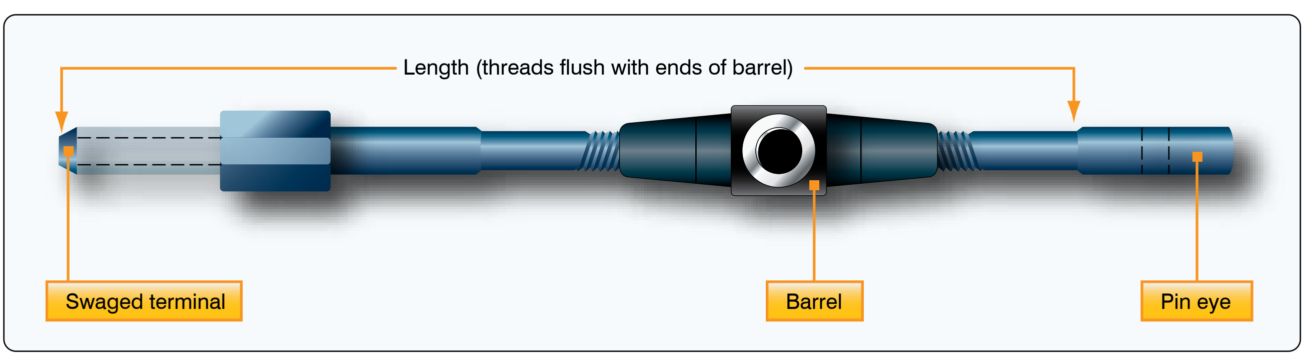


Figure 2-76. *Typical turnbuckle assembly.*

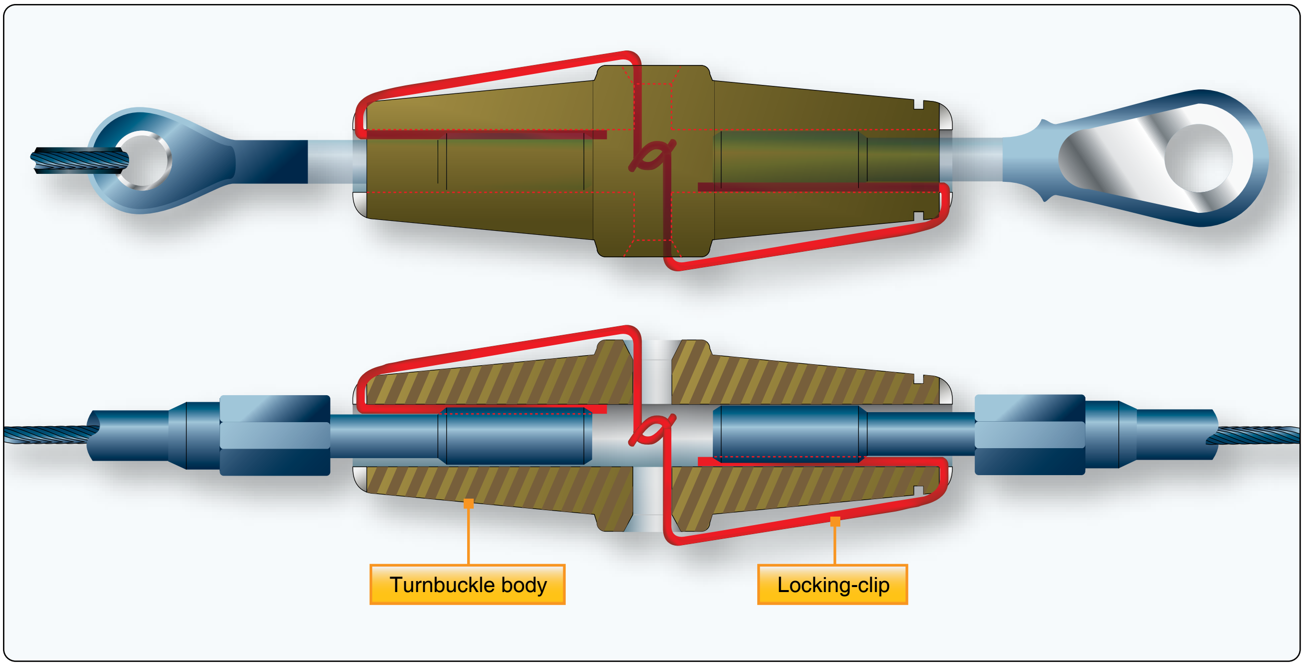


Figure 2-77. *Clip-type locking device and assembling in turnbuckle.*

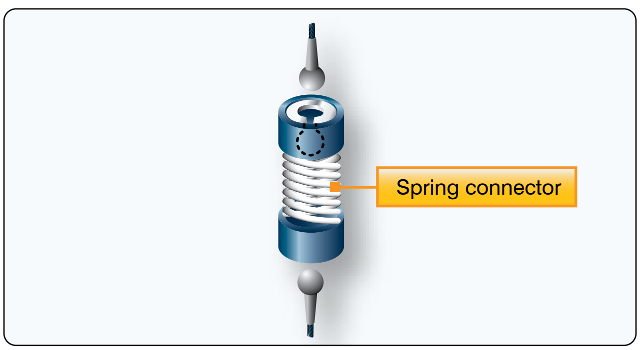


Figure 2-78. *Spring-type connector.*

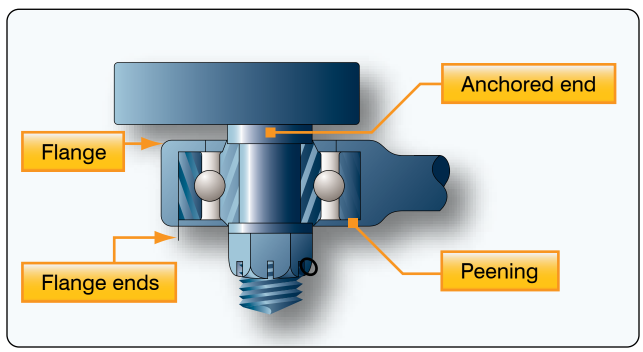


Figure 2-80. *Attached rod end.*

It is possible for control rods fitted with bearings to become disconnected because of failure of the peening that retains the ball races in the rod end. This can be avoided by installing the control rods so that the flange of the rod end is interposed between the ball race and the anchored end of the attaching pin or bolt as shown in *Figure 2-80*.

Another alternative is to place a washer, having a larger diameter than the hole in the flange, under the retaining nut on the end of the attaching pin or bolt. This retains the rod on the bolt in the event of a bearing failure.

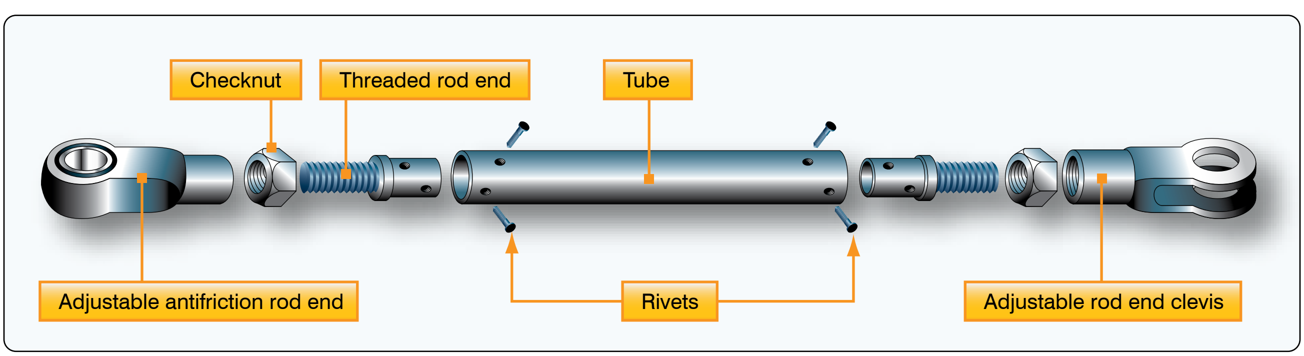


Figure 2-79. *Push rod.*

Torque Tubes

Where an angular or twisting motion is needed in a control system, a torque tube is installed. *Figure 2-81* shows how a torque tube is used to transmit motion in opposite directions.

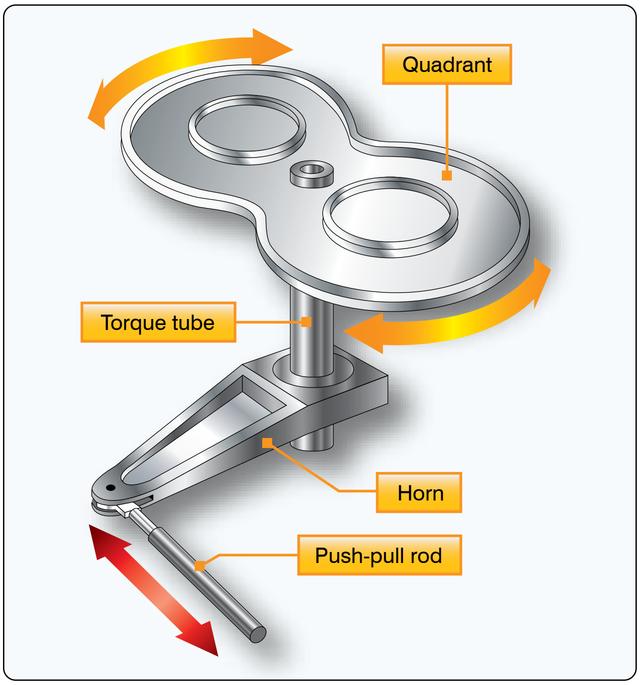


Figure 2-81. *Torque tube.*

Cable Drums

Cable drums are used primarily in trim tab systems. As the trim tab control wheel is moved clockwise or counterclockwise, the cable drum winds or unwinds to actuate the trim tab cables. *[Figure 2-82]*

Rigging Checks

All aircraft assembly and rigging must be performed in accordance with the requirements prescribed by the specific aircraft and/or aircraft component manufacturer. Correctly following the procedures provides for proper operation of the components in regard to their mechanical and aerodynamic function and ensures the structural integrity of the aircraft. Rigging procedures are detailed in the applicable manufacturer's maintenance or service manuals and applicable structural repair manuals. Additionally, aircraft specification or TCDS also provide information regarding control surface movement and weight and balance limits.

The purpose of this section is to explain the methods of checking the relative alignment and adjustment of an aircraft's main structural components. It is not intended to imply that the procedures are exactly as they may be in a particular aircraft. When rigging an aircraft, always follow the procedures and methods specified by the aircraft manufacturer.

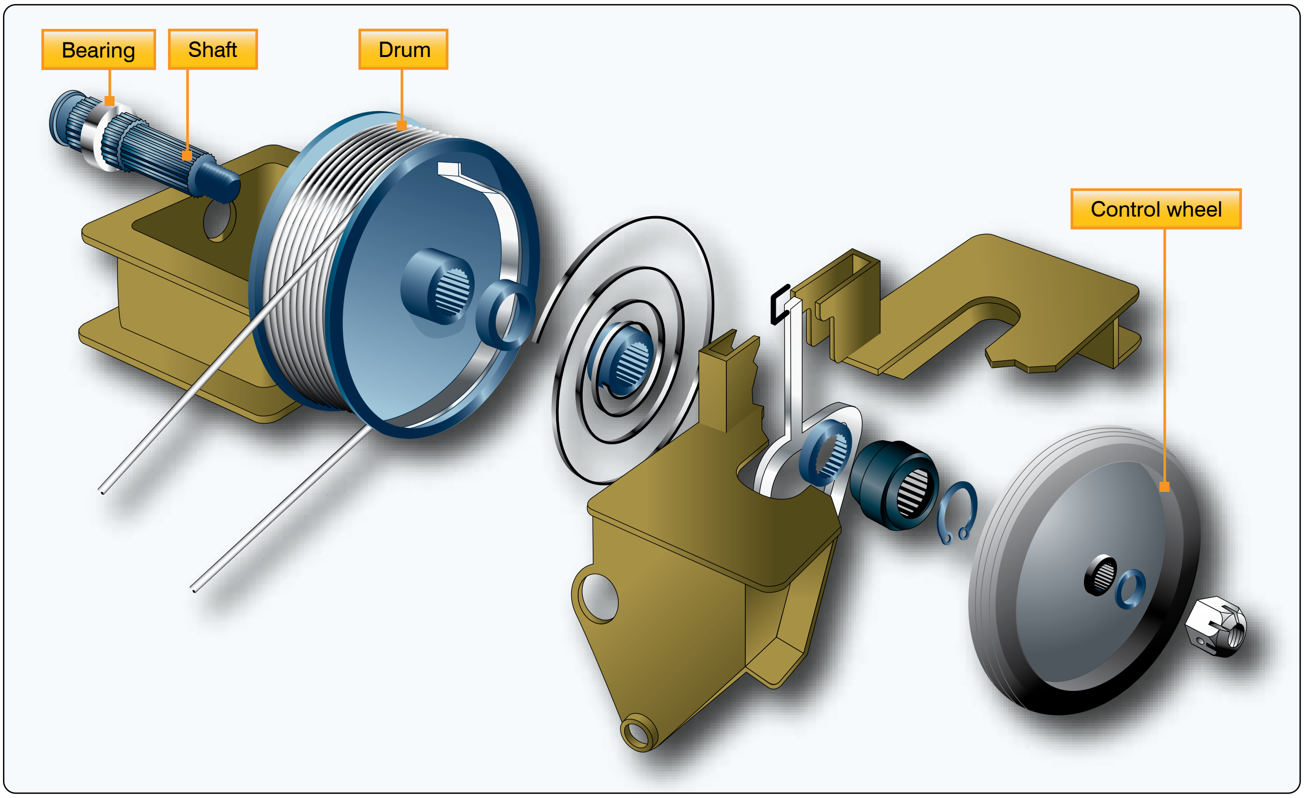


Figure 2-82. *Trim tab cable drum.*

Structural Alignment

The position or angle of the main structural components is related to a longitudinal datum line parallel to the aircraft center line and a lateral datum line parallel to a line joining the wing tips. Before checking the position or angle of the main components, the aircraft must be jacked and leveled.

Small aircraft usually have fixed pegs or blocks attached to the fuselage parallel to or coincident with the datum lines. A spirit level and a straight edge are rested across the pegs or blocks to check the level of the aircraft. This method of checking aircraft level also applies to many of the larger types of aircraft. However, the grid method is sometimes used on large aircraft. The grid plate is a permanent fixture installed on the aircraft floor or supporting structure. *[Figure 2-83]*

When the aircraft is to be leveled, a plumb bob is suspended from a predetermined position in the ceiling of the aircraft over the grid plate. The adjustments to the jacks necessary to level the aircraft are indicated on the grid scale. The aircraft is level when the plumb bob is suspended over the center point of the grid.

Certain precautions must be observed in all instances when jacking an aircraft. Normally, rigging and alignment checks should be performed in an enclosed hangar. If this cannot be accomplished, the aircraft should be positioned with the nose into the wind.

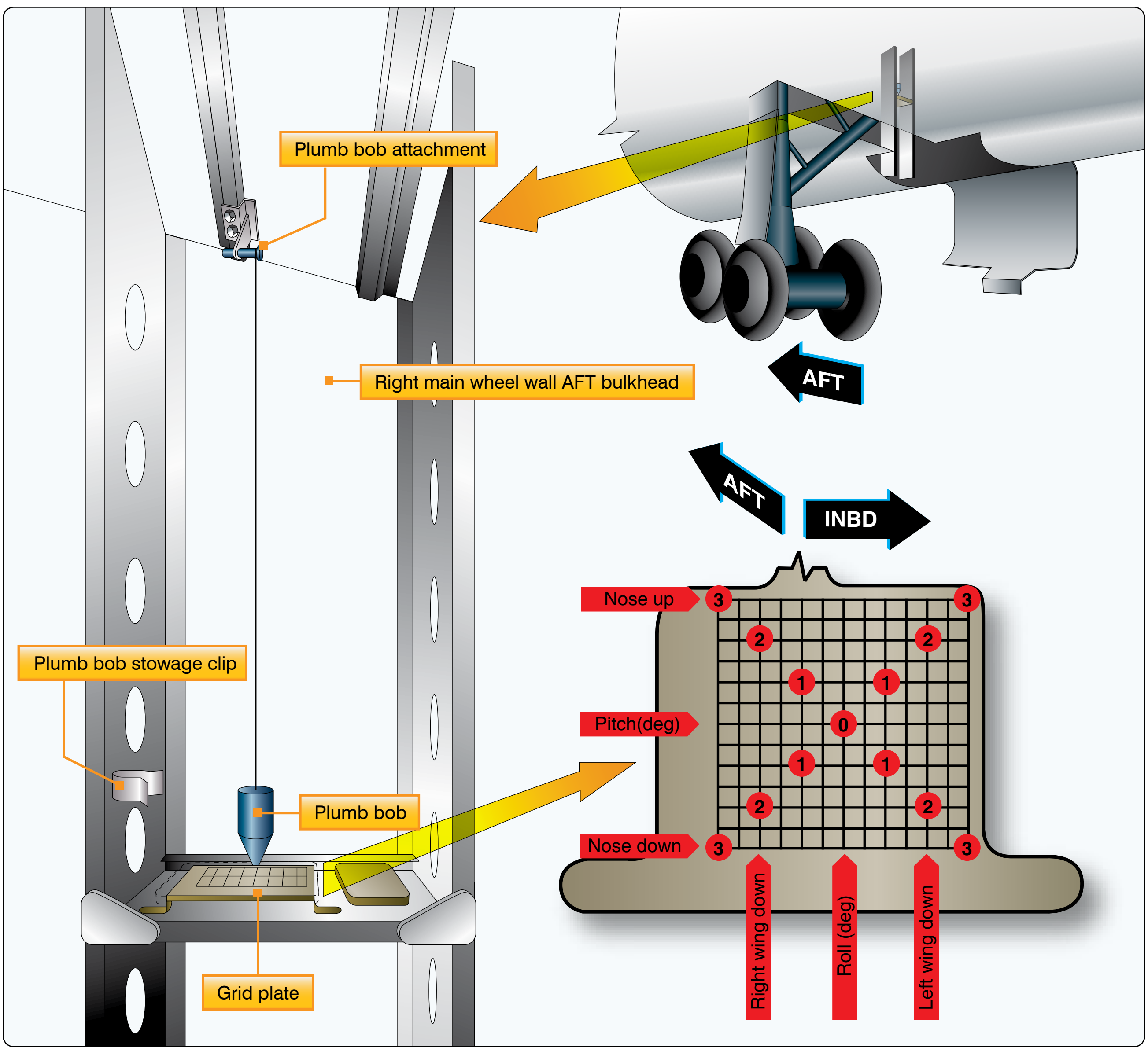


Figure 2-83. *Grid plate installed.*

The weight and loading of the aircraft should be exactly as described in the manufacturer's manual. In all cases, the aircraft should not be jacked until it is determined that the maximum jacking weight (if applicable) specified by the manufacturer is not exceeded.

With a few exceptions, the dihedral and incidence angles of conventional modern aircraft cannot be adjusted. Some manufacturers permit adjusting the wing angle of incidence to correct for a wing-heavy condition. The dihedral and incidence angles should be checked after hard landings or after experiencing abnormal flight loads to ensure that the components are not distorted and that the angles are within the specified limits.

There are several methods for checking structural alignment and rigging angles. Special rigging boards that incorporate, or on which can be placed, a special instrument (spirit level or inclinometer) for determining the angle are used on some aircraft. On a number of aircraft, the alignment is checked using a transit and plumb bobs or a theodolite and sighting rods. The particular equipment to use is usually specified in the manufacturer's maintenance manual.

When checking alignment, a suitable sequence should be developed and followed to be certain that the checks are made at all the positions specified. The alignment checks specified usually include:

- Wing dihedral angle
- Wing incidence angle
- Verticality of the fin
- Engine alignment
- A symmetry check
- Horizontal stabilizer incidence
- Horizontal stabilizer dihedral

Checking Dihedral

The dihedral angle should be checked in the specified positions using the special boards provided by the aircraft manufacturer. If no such boards are available, a straight edge and a inclinometer can be used. Dihedral is normally checked using the front spar. The methods for checking dihedral are shown in *Figure 2-84*.

It is important that the dihedral be checked at the positions specified by the manufacturer. Certain portions of the wings or horizontal stabilizer may sometimes be horizontal or, on rare occasions, anhedral angles may be present.

Checking Incidence

Incidence is usually checked in at least two specified positions on the surface of the wing to ensure that the wing is free from twist. A variety of incidence boards are used to check the incidence angle. Some have stops at the forward edge, which must be placed in contact with the leading edge of the wing. Others are equipped with location pegs which fit into some specified part of the structure. The purpose in either case is to ensure that the board is fitted in exactly the position intended. In most instances, the boards are kept clear of the wing contour by short extensions attached to the board. A typical incidence board is shown in *Figure 2-85*.

When used, the board is placed at the specified locations on the surface being checked. If the incidence angle is correct, a inclinometer on top of the board reads zero, or within a specified tolerance of zero. Modifications to the areas where incidence boards are located can affect the reading. For example, if leading edge deicer boots have been installed, the position of a board having a leading edge stop is affected.

Checking Fin Verticality

After the rigging of the horizontal stabilizer has been checked, the verticality of the vertical stabilizer relative to the lateral datum can be checked. The measurements are taken from a given point on either side of the top of the fin to a given point on the left and right horizontal stabilizers. *[Figure 2-86]* The measurements should be similar within prescribed limits. When it is necessary to check the alignment of the rudder

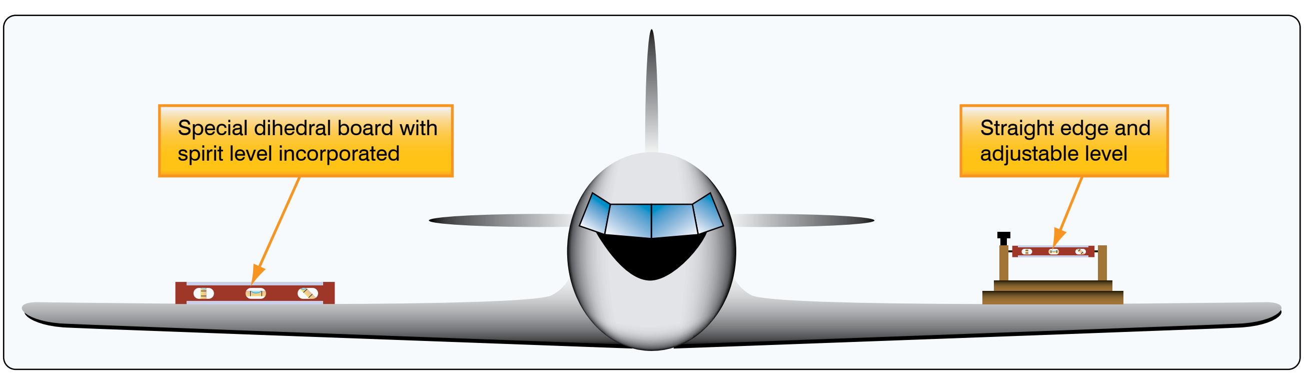


Figure 2-84. *Checking dihedral.*

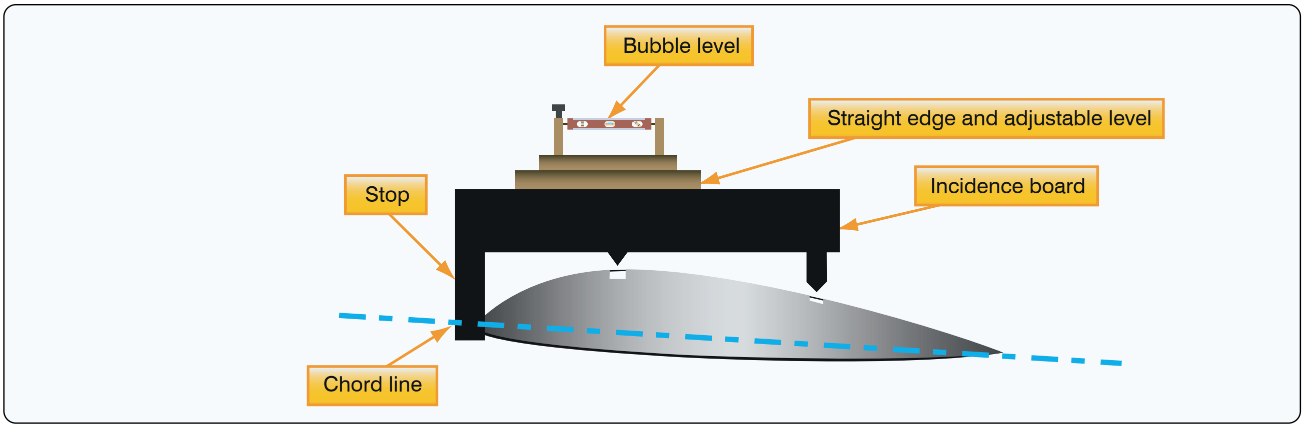


Figure 2-85. *A typical incidence board.*

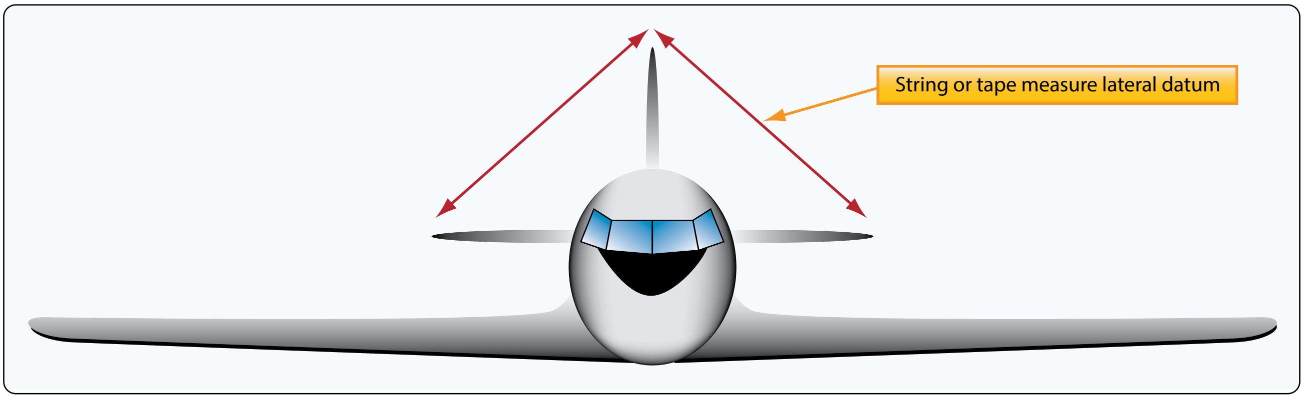


Figure 2-86. *Checking fin verticality.*

hinges, remove the rudder and pass a plumb bob line through the rudder hinge attachment holes. The line should pass centrally through all the holes. It should be noted that some aircraft have the leading edge of the vertical fin offset to the longitudinal center line to counteract engine torque.

Checking Engine Alignment

Engines are usually mounted with the thrust line parallel to the horizontal longitudinal plane of symmetry. However, this is not always true when the engines are mounted on the wings. Checking to ensure that the position of the engines, including any degree of offset is correct, depends largely on the type of mounting. Generally, the check entails a measurement from the center line of the mounting to the longitudinal center line of the fuselage at the point specified in the applicable manual. *[Figure 2-87]*

Symmetry Check

The principle of a typical symmetry check is illustrated in *Figure 2-87*. The precise figures, tolerances, and checkpoints for a particular aircraft are found in the applicable service or maintenance manual.

On small aircraft, the measurements between points are usually taken using a steel tape. When measuring long distances, it is suggested that a spring scale be used with the tape to obtain equal tension. A five-pound pull is usually sufficient.

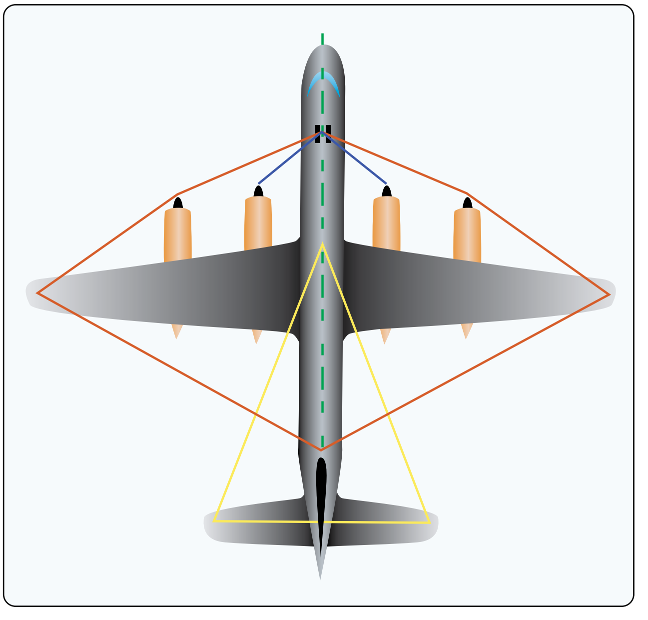
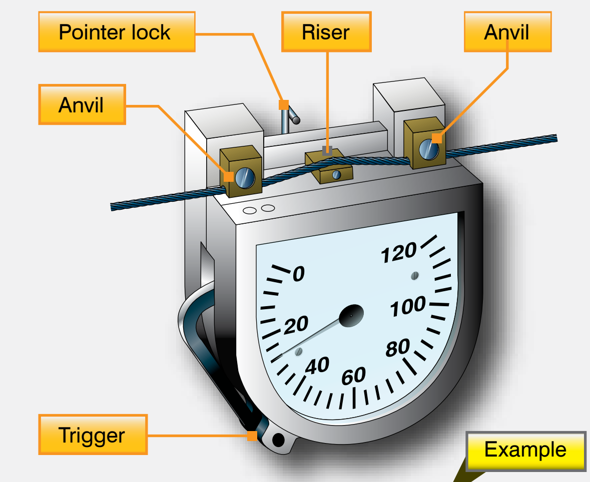


Figure 2-87. *Typical measurements used to check aircraft symmetry.*

On large aircraft, the positions at which the dimensions are to be taken are usually chalked on the floor. This is done by suspending a plumb bob from the checkpoints and marking the floor immediately under the point of each plumb bob. The measurements are then taken between the centers of each marking.

Cable Tension

When it has been determined that the aircraft is symmetrical and structural alignment is within specifications, the cable tension and control surface travel can be checked. To determine the amount of tension on a cable, a tensiometer is used. When properly maintained, a tensiometer is 98 percent accurate. Tensiometers are calibrated to maintain accuracy. 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. Several manufacturers make a variety of tensiometers, each type designed for different kinds of cable, cable sizes, and cable tensions. One type of tensiometer is illustrated in *Figure 2-88*.



No. 1			Riser	No. 2		No. 3	
Diameter			Tension (lb)	5/32	3/16	7/32	1/4
1/16	3/32	1/8					
12	16	21	30	12	20		
19	23	29	40	17	26		
25	30	36	50	22	32		
31	36	43	60	26	37		
36	42	50	70	30	42		
41	48	57	80	34	47		
46	54	63	90	38	52		
51	60	69	100	42	56		
			110	46	60		
			120	50	64		

Figure 2-88. *Cable tensiometer and sample conversion chart.*

Following the manufacturer's instructions, lower the trigger. Then, place the cable to be tested under the two anvils and close the trigger (move it up). Movement of the trigger pushes up the riser, which pushes the cable at right angles to the two clamping points under the anvils. The force that is required to do this is indicated by the dial pointer. As the sample chart beneath the illustration shows, different numbered risers are used with different size cables. Each riser has an identifying number and is easily inserted into the tensiometer.

Included with each tensiometer is a conversion chart, which is used to convert the dial reading to pounds. The dial reading is converted to pounds of tension as follows. Using a No. 2 riser to measure the tension of a 5/32" diameter cable, a reading of 30 is obtained. The actual tension (see chart) of the cable is 70 lbs. Referring to the chart, also notice that a No. 1 riser is used with 1/16", 3/32", and 1/8" cable. Since the tensiometer is not designed for use in measuring 7/32" or 1/4" cable, no values are shown in the No. 3 riser column of the chart.

When actually taking a reading of cable tension in an aircraft, it may be difficult to see the dial. Therefore, a pointer lock is built in on the tensiometer. 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 returns to zero.

Another variable that must be taken into account when adjusting cable tension is the ambient temperature of cable and the aircraft. To compensate for temperature variations, cable rigging charts are used when establishing cable tensions in flight control, landing gear, and other cable-operated systems. *[Figure 2-89]*

To use the chart, determine the size of the cable that is to be adjusted and the ambient air temperature. For example, assume that the cable size is 1/8" diameter, which is a 7-19 cable and the ambient air temperature is 85 °F. Follow the 85 °F line upward to where it intersects the curve for 1/8" cable. Extend a horizontal line from the point of intersection to the right edge of the chart. The value at this point indicates the tension (rigging load in pounds) to establish on the cable. The tension for this example is 70 pounds.

Control Surface Travel

In order for a control system to function properly, it must be correctly adjusted. Correctly rigged control surfaces move through a prescribed arc (surface-throw) and are synchronized with the movement of the flight deck controls. Rigging any control system requires that the aircraft manufacturer's instructions be followed as outlined in their maintenance manual.

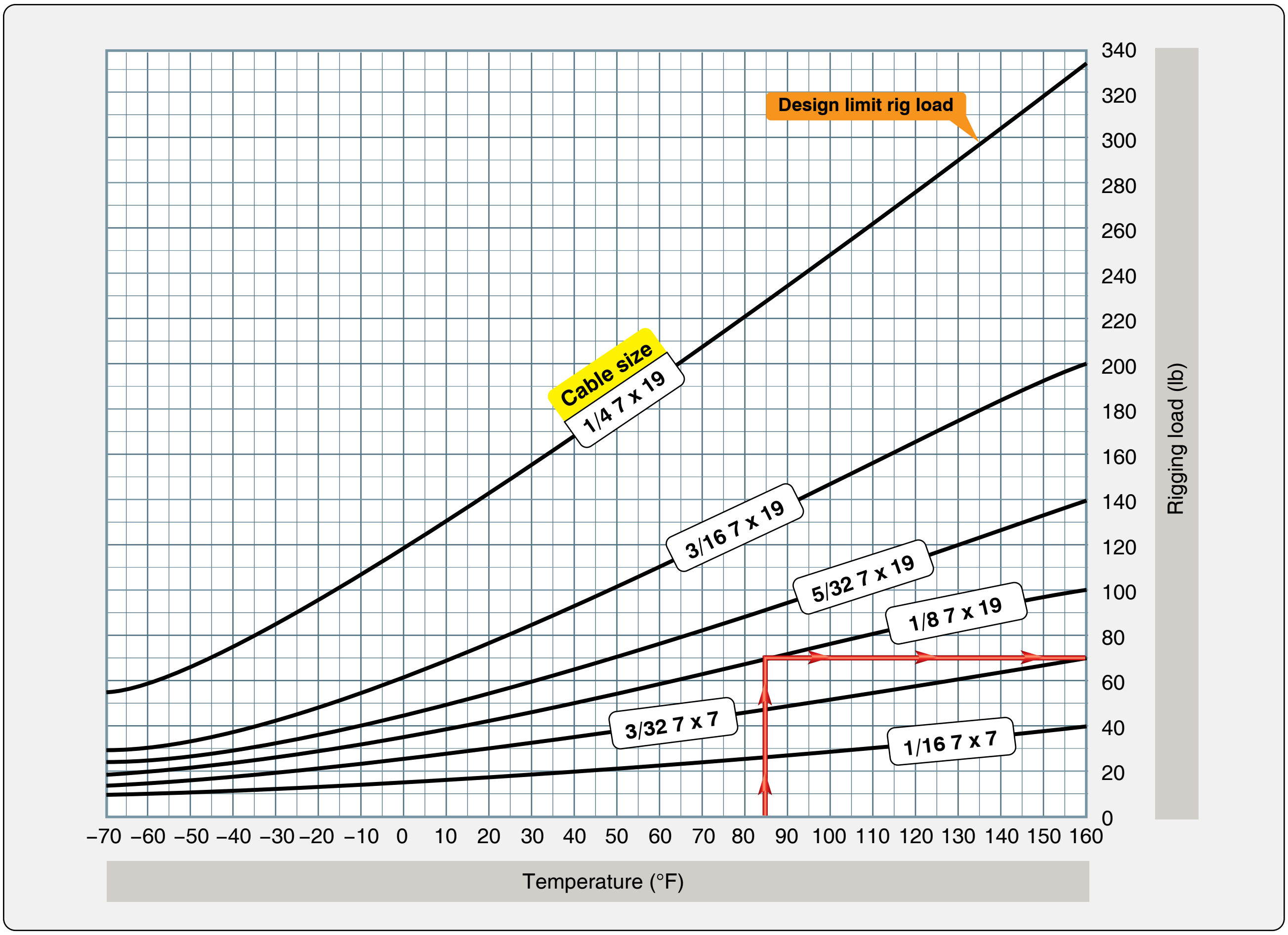


Figure 2-89. *Typical cable rigging chart.*

Therefore, the explanations in this chapter are limited to the three general steps listed below:

1. Lock the flight deck control, bellcranks, and the control surfaces in the neutral position.
2. Adjust the cable tension, maintaining the rudder, elevators, or ailerons in the neutral position.
3. Adjust the control stops to limit the control surface travel to the dimensions given for the aircraft being rigged.

The range of movement of the controls and control surfaces should be checked in both directions from neutral. There are various tools used for measuring surface travel, including protractors, rigging fixtures, contour templates, and rulers. These tools are used when rigging flight control systems to ensure that the aircraft is properly rigged and the manufacturer's specifications have been complied with.

Rigging fixtures and contour templates are special tools (gauges) designed by the manufacturer to measure control surface travel. Markings on the fixture or template indicate desired control surface travel. In many instances, the aircraft manufacturer gives the travel of a particular control surface in degrees and inches. If the travel in inches is provided, a ruler can be used to measure surface travel in inches.

Protractors are tools for measuring angles in degrees. Various types of protractors are used to determine the travel of flight control surfaces. One protractor that can be used to measure aileron, elevator, or wing flap travel is the universal propeller protractor shown in *Figure 2-90*.

This protractor is made up of a frame, disc, ring, and two spirit levels. The disc and ring turn independently of each other and of the frame. (The center spirit level is used to position the frame vertically when measuring propeller blade angle.) The center spirit level is used to position the disc when measuring control surface travel. A disc-to-ring lock is provided to secure the disc and ring together when the zero on the ring vernier scale and the zero on the disc degree scale align. The ring-to-frame lock prevents the ring from moving when the disc is moved. Note that they start at

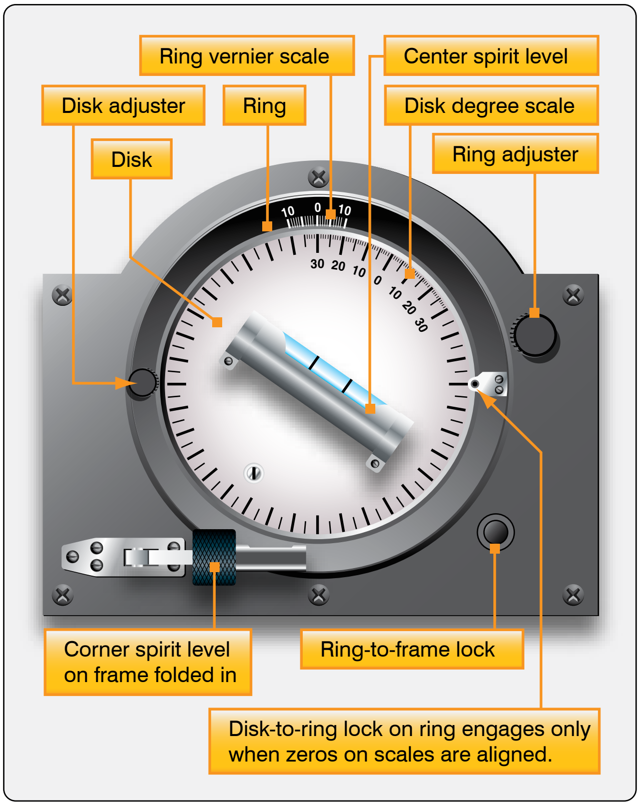


Figure 2-90. *Universal propeller protractor.*

the same point and advance in opposite directions. A double 10-part vernier is marked on the ring.

The rigging of the trim tab systems is performed in a similar manner. The trim tab control is set to the neutral (no trim) position, and the surface tab is usually adjusted to streamline with the control surface. However, on some aircraft, the specifications may require that the trim tabs be offset a degree or two from streamline when in the neutral position. After the tab and tab control are in the neutral position, adjust the control cable tension.

Pins, usually called rig pins, are sometimes used to simplify the setting of pulleys, levers, bellcranks, etc., in their neutral positions. A rig pin is a small metallic pin or clip. When rig pins are not provided, the neutral positions can be established by means of alignment marks, by special templates, or by taking linear measurements.

If the final alignment and adjustment of a system are correct, it should be possible to withdraw the rigging pins easily. Any undue tightness of the pins in the rigging holes indicates incorrect tensioning or misalignment of the system.

After a system has been adjusted, the full and synchronized movement of the controls should be checked. When checking the range of movement of the control surface, the controls must be operated from the flight deck and not by moving the control surfaces. During the checking of control surface travel, ensure that chains, cables, etc., have not reached the limit of their travel when the controls are against their respective stops.

Adjustable and nonadjustable stops (whichever the case requires) are used to limit the throw-range or travel movement of the ailerons, elevator, and rudder. Usually there are two sets of stops for each of the three main control surfaces. One set is located at the control surface, either in the snubber cylinders or as structural stops; the other, at the flight deck control. Either of these may serve as the actual limit stop. However, those situated at the control surface usually perform this function. The other stops do not normally contact each other, but are adjusted to a definite clearance when the control surface is at the full extent of its travel. These work as override stops to prevent stretching of cables and damage to the control system during violent maneuvers. When rigging control systems, refer to the applicable maintenance manual for the sequence of steps for adjusting these stops to limit the control surface travel.

Where dual controls are installed, they must be synchronized and function satisfactorily when operated from both positions.

Trim tabs and other tabs should be checked in a manner similar to the main control surfaces. The tab position indicator must be checked to see that it functions correctly. If jackscrews are used to actuate the trim tab, check to see that they are not extended beyond the specified limits when the tab is in its extreme positions.

After determining that the control system functions properly and is correctly rigged, it should be thoroughly inspected to determine that the system is correctly assembled and operates freely over the specified range of movement.

Checking & Safetying the System

Whenever rigging is performed on any aircraft, it is good practice to have a second set of eyes inspect the control system to make certain that all turnbuckles, rod ends, and attaching nuts and bolts are correctly safetied.

As a general rule, all fasteners on an aircraft are safetied in some manner. Safetying is defined as securing by various means any nut, bolt, turnbuckle, etc., on the aircraft so that vibration does not cause it to loosen during operation.

Most aircraft manufacturers have a Standard Practices section in their maintenance manuals. These are the methods that should be used when working on a particular system of a

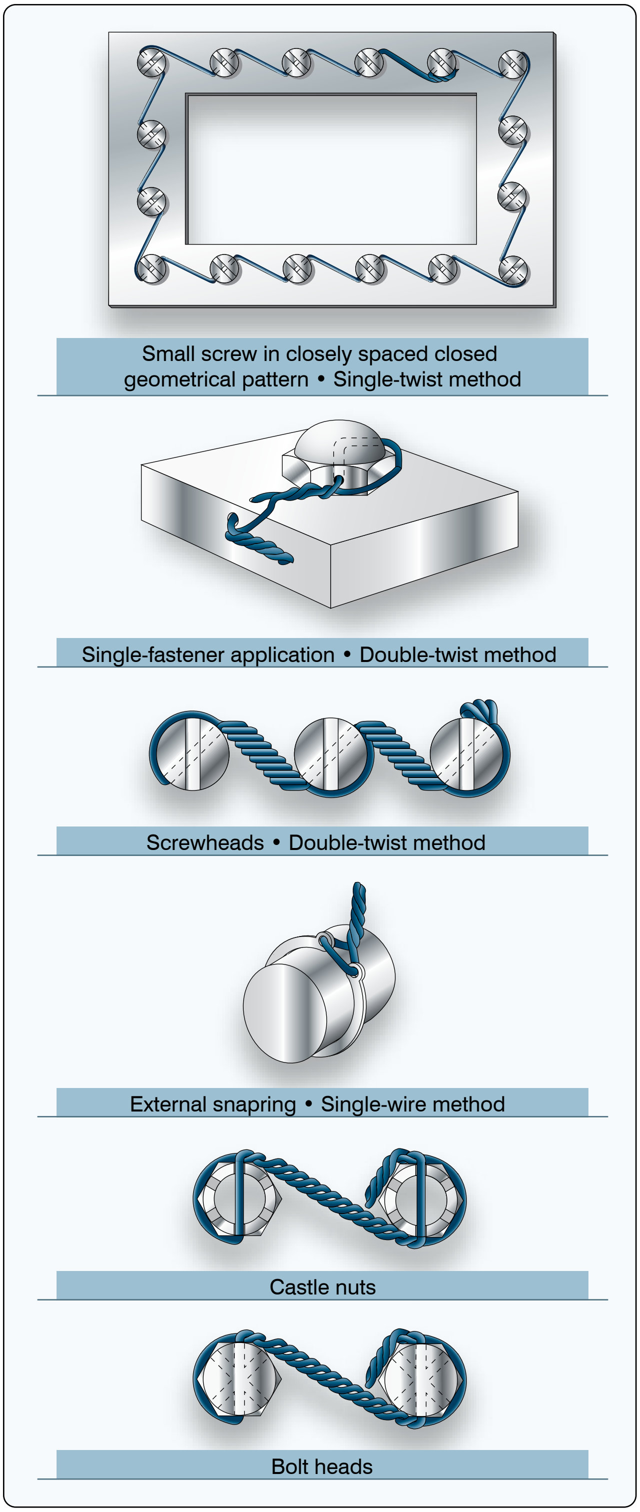


Figure 2-91. *Double-wrap and single safety wire methods for nuts, bolts, and snap rings.*

specific aircraft. However, most standard aircraft hardware has a standard method of being safetied. The following information provides some of the most common methods used in aircraft safetying.

The most commonly used safety wire method is the double-twist, utilizing stainless steel or Monel wire in the .032 to .040-inch diameter range. This method is used on studs, cable turnbuckles, flight controls, and engine accessory attaching bolts. A single-wire method is used on smaller screws, bolts, and/or nuts when they are located in a closely spaced or closed geometrical pattern. The single-wire method is also used on electrical components and in places that are difficult to reach. *[Figure 2-91]*

Safety-of-flight emergency equipment, such as portable fire extinguishers, oxygen regulators, emergency valves, firewall shut-offs, and seals on first-aid kits, are safetied using a single copper wire (.020-inch diameter) or aluminum wire (.031-inch diameter). The wire on this emergency equipment is installed only to indicate the component is sealed or has not been actuated. It must be possible to break the wire seal by hand, without the use of any tools.

The use of safety wire pliers, or wire twisters, makes the job of safetying much easier on the mechanic's hands and produces a better finished product. *[Figure 2-92]*

The wire should have six to eight twists per inch of wire and be pulled taut while being installed. Where practicable, install the safety wire around the head of the fastener and twist it in such a manner that the loop of the wire is pulled close to the contour of the unit being safety wired, and in the direction that would have the tendency to tighten the fastener. *[Figure 2-93]*

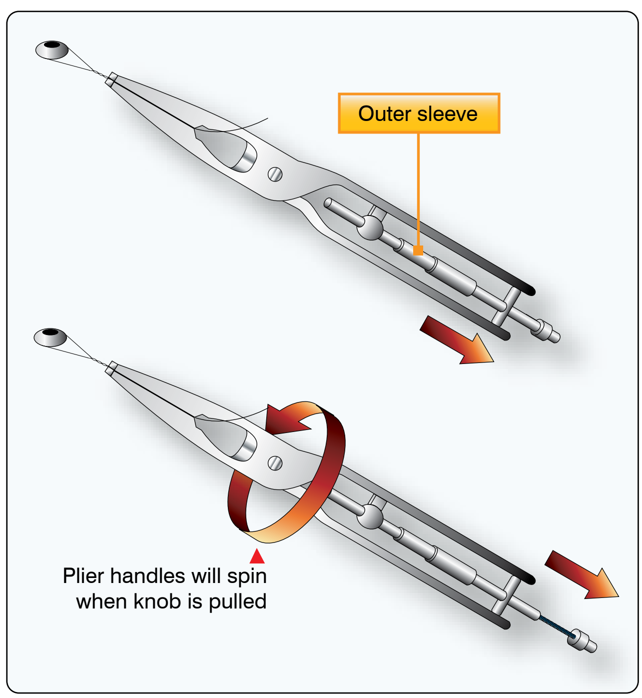


Figure 2-92. *Use of safety-wire pliers or wire twisters.*

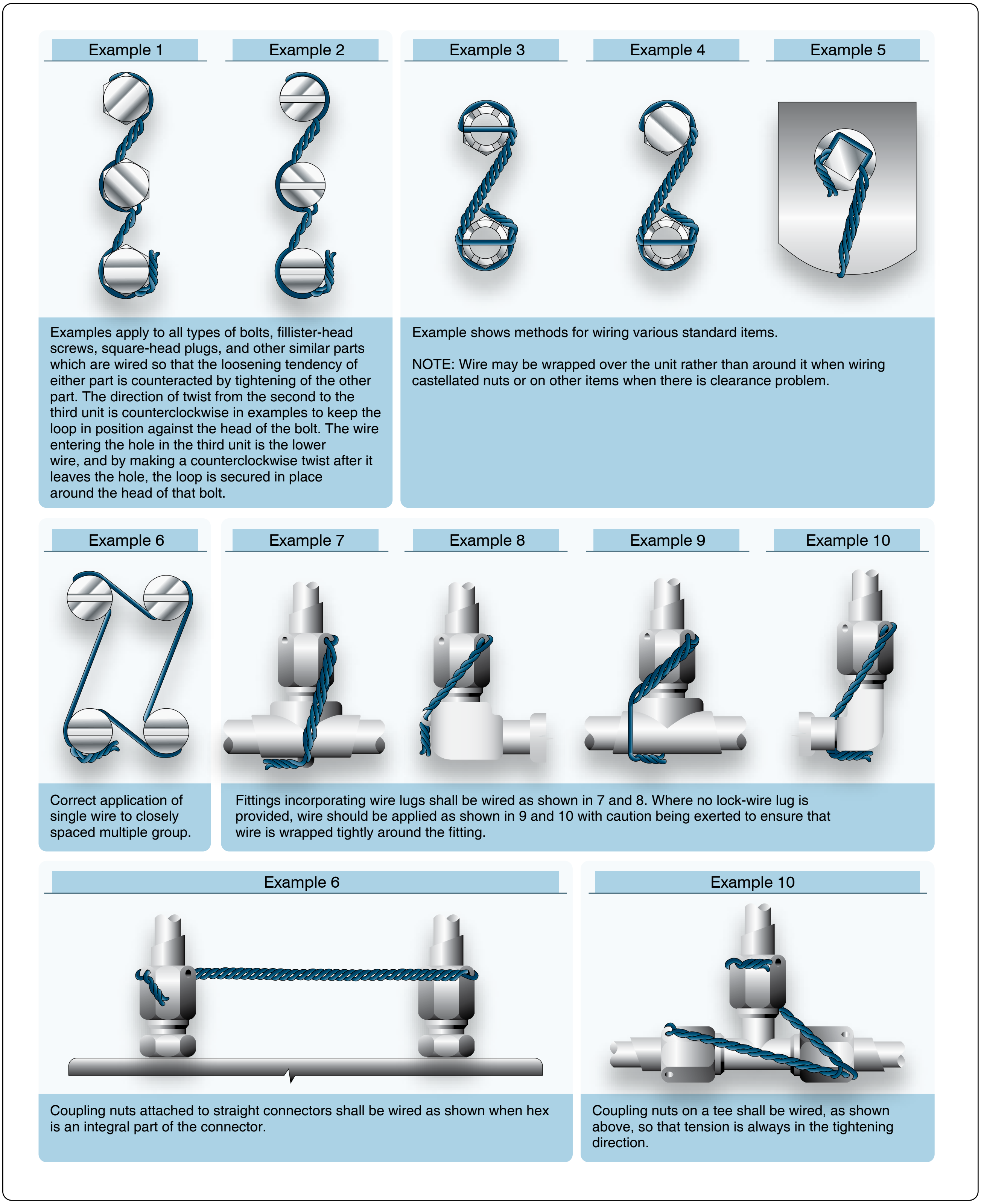


Figure 2-93. *Examples of various fasteners and methods of safetying.*

Cotter pins are used to secure such items as bolts, screws, pins, and shafts. They are used at any location where a turning or actuating movement takes place. The diameter of the cotter pin selected for any application should be the largest size that will fit consistent with the diameter of the cotter pin hole and/or the slots in the castellated nut. Cotter pins, like safety wire, should never be re-used on aircraft. *[Figure 2-94]*

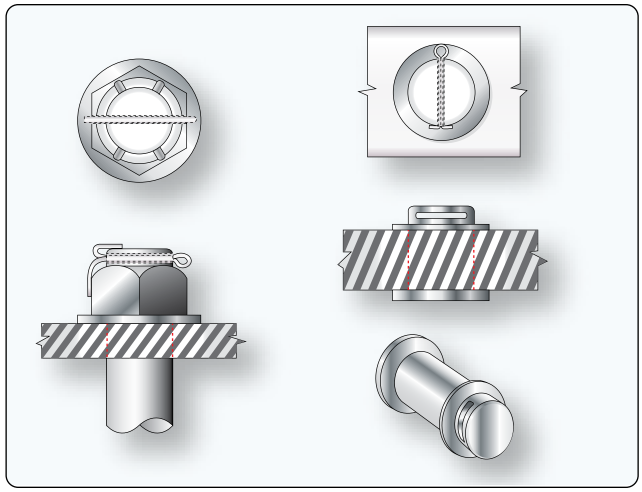


Figure 2-94. *Securing hardware with cotter pins.*

Self-locking nuts are used in applications where they are not removed often. There are two types of self-locking nuts currently in use. One is all metal and the other has an insert, usually of fiber or nylon.

It is extremely important that the manufacturer's Illustrated Parts Book (IPB) be consulted for the correct type and grade of lock nut for various locations on the aircraft. The finish or plating color of the nut identifies the type of application and environment in which it can be used. For example, a cadmium-plated nut is gold in color and provides exceptionally good protection against corrosion, but should not be used in applications where the temperature may exceed 450 °F.

Repeated removal and installation causes the self-locking nut to lose its locking feature. They should be replaced when they are no longer capable of maintaining the minimum prevailing torque. *[Figure 2-95]*

Fine Thread Series	
Thread Size	Minimum Prevailing Torque
7/16 - 20	8 inch-pounds
1/2 - 20	10 inch-pounds
9/16 - 18	13 inch-pounds
5/8 - 18	18 inch-pounds
3/4 - 16	27 inch-pounds
7/8 - 14	40 inch-pounds
1 - 14	55 inch-pounds
1-1/8 - 12	73 inch-pounds
1-1/4 - 12	94 inch-pounds

Coarse Thread Series	
Thread Size	Minimum Prevailing Torque
7/16 - 14	8 inch-pounds
1/2 - 13	10 inch-pounds
9/16 - 12	14 inch-pounds
5/8 - 11	20 inch-pounds
3/4 - 10	27 inch-pounds
7/8 - 9	40 inch-pounds
1 - 8	51 inch-pounds
1-1/8 - 8	68 inch-pounds
1-1/4 - 8	68 inch-pounds

Figure 2-95. *Minimum prevailing torque values for reused self-locking nuts.*

Lock washers may be used with bolts and machine screws whenever a self-locking nut or castellated nut is not applicable. They may be of the split washer spring type, or a multi-serrated internal or external star washer.

Pal nuts may be a second nut tightened against the first and used to force the primary nut thread against the bolt or screw thread. They may also be of the type that are made of stamped spring steel and are to be used only once and replaced with new ones when removed.

Biplane Assembly & Rigging

Biplanes were some of the very first aircraft designs. The first powered heavier-than-air aircraft, the Wright Brothers' Wright Flyer, successfully flown on December 17, 1903, was a biplane.

The first biplanes were designed with very thin wing sections and, consequently, the wing structure needed to be strengthened by external bracing wires. The biplane configuration allowed the two wings to be braced against one another, increasing the structural strength. When the assembly and rigging of a biplane is accomplished in accordance with the approved instructions, a stable airworthy aircraft is the result.

Whether assembling an early model vintage aircraft that may have been disassembled for repair and restoration, or constructing and assembling a new aircraft, the following are some basic alignment procedures to follow.

To start, the fuselage must be level, fore and aft and laterally. The aircraft usually has specific leveling points designated

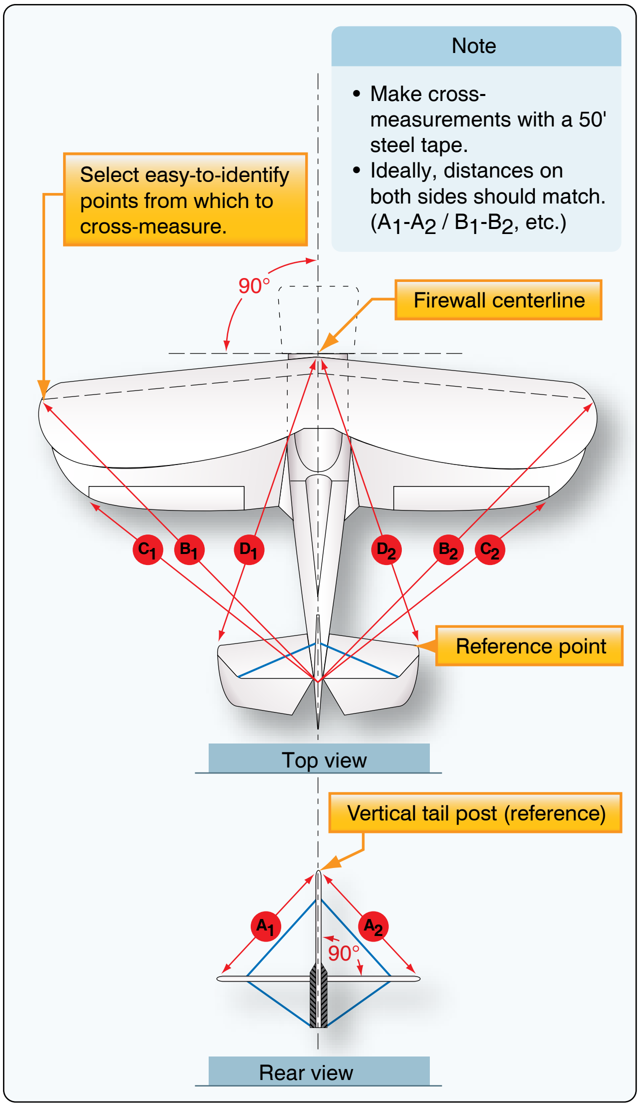


Figure 2-96. *Checking aircraft symmetry.*

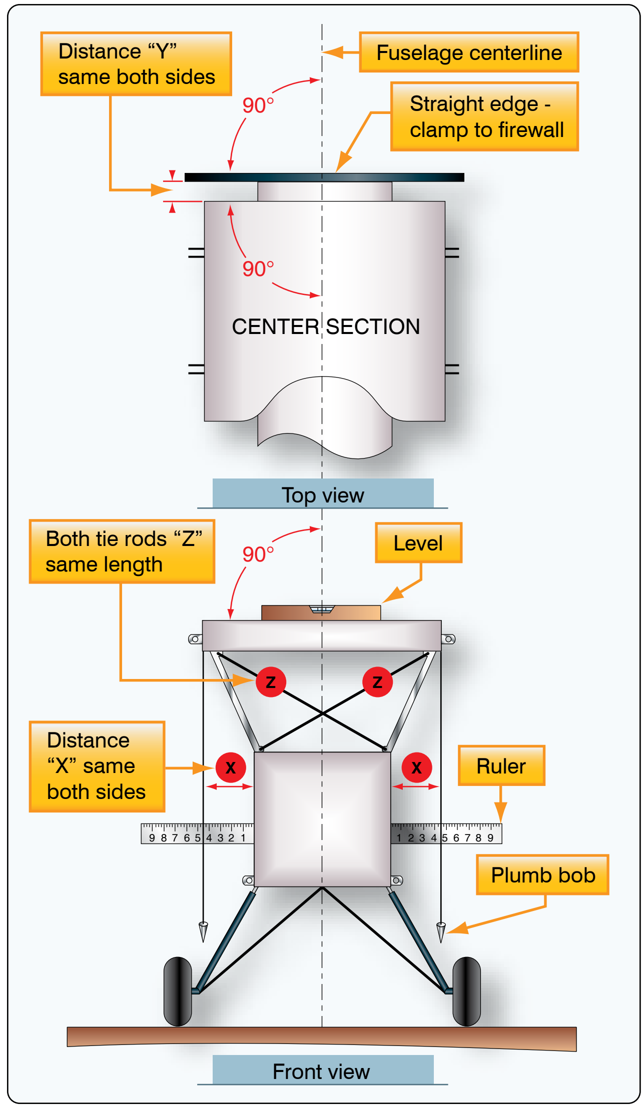


Figure 2-97. *Center section alignment.*

by the manufacturer or indicated on the plans. The fuselage should be blocked up off the landing gear so it is stable. A center line should be drawn on the floor the length of the fuselage and another line perpendicular to it at the firewall, for use as an additional alignment reference.

With the horizontal and vertical tail surfaces installed, the incident angle for the horizontal stabilizer should be set. The tail brace wires should be connected and tightened until the slack is removed. Alignment measurements should be checked as shown in *Figure 2-96*.

Install the elevator and rudder and clamp them in a neutral position. Verify the neutral position of the control stick and rudder pedals in the flight deck and secure them in order to simplify the connecting and final tensioning of the control cables.

If the biplane has a center section for the upper wing, it must be aligned as accurately as possible, because even the smallest error is compounded at the wing tip. Applicable cables and turnbuckles should be connected and the tension set as specified. *[Figure 2-97]* The stagger measurement can be checked as shown in *Figure 2-98*.

The lower wing sections should be individually attached to the fuselage and blocked up for support while the landing wires are connected and adjusted to obtain the dihedral called for in the specifications or plans. *[Figure 2-99]*

Next, connect the outer "N" struts to the left and right sections of the lower wing. Now, the upper wing can be attached and the flying wires installed. The slave struts can be installed and the ailerons connected using the same alignment and adjustment procedures used for the elevator and rudder. The incidence angle can be checked, as shown in *Figure 2-100*.

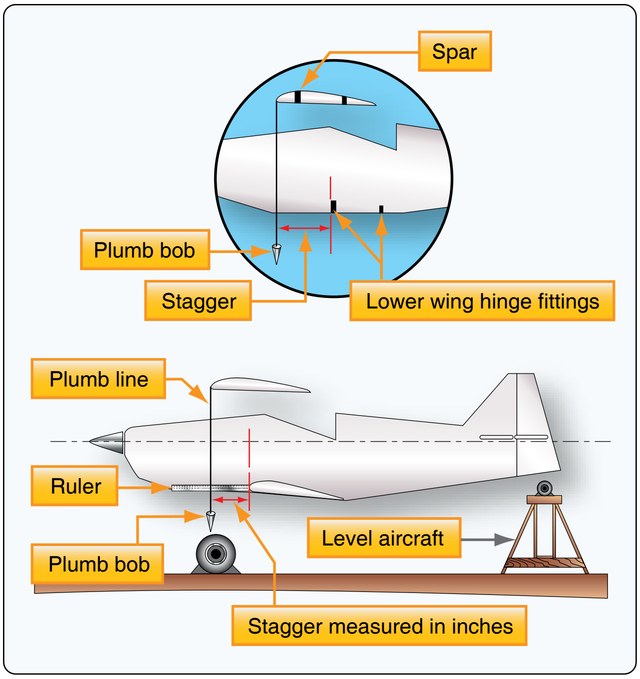


Figure 2-98. *Measuring stagger.*

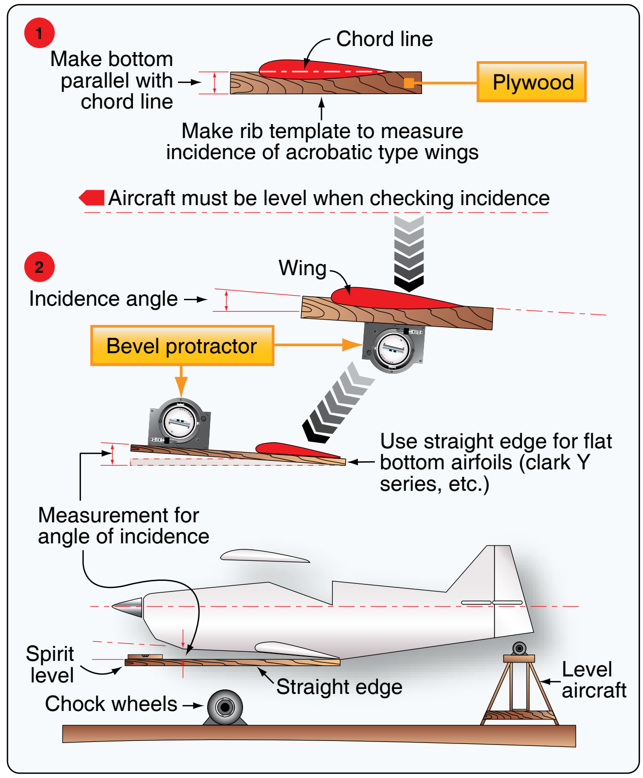


Figure 2-100. *Checking incidence.*

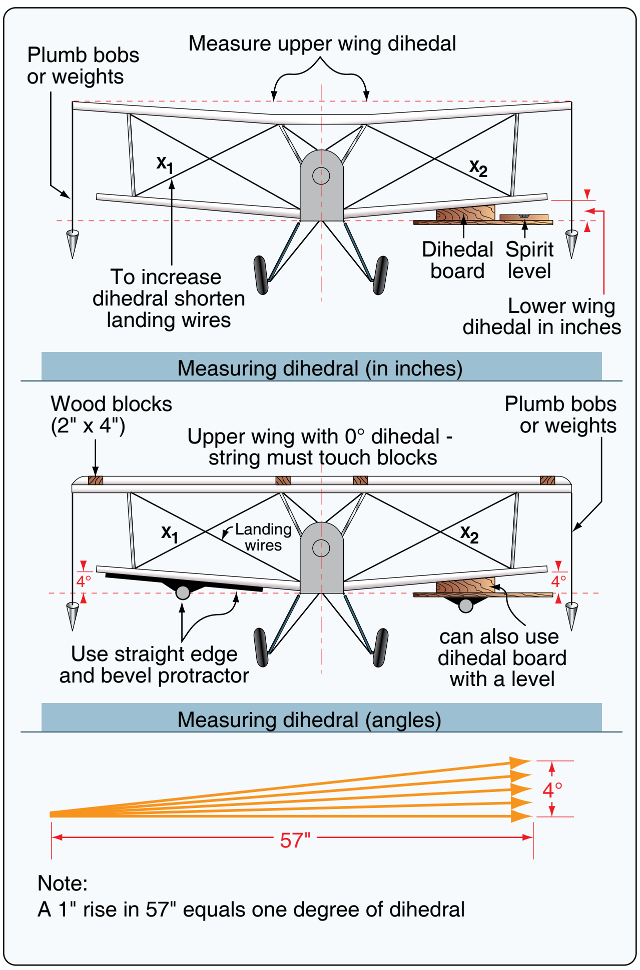


Figure 2-99. *Measuring dihedral.*

Once this point is reached, it is a matter of measuring, checking angles, and adjusting the various components to obtain the overall aircraft symmetry and desired alignment, as shown in *Figure 2-96*.

Also, remember that care should be used when tightening the wing wires because extra stress can be inadvertently induced into the wings. Always loosen one wire before tightening the opposite wire. Flying and landing wires are typically set at about 600 pounds and tail brace wires at about 300 pounds of tension.

When convinced the aircraft is properly rigged, move away from it and take a good look at the finished product. Are the wings symmetrical? Does the dihedral look even? Is the tail section square with the fuselage? Are the wing attaching hardware, flying wires, and control cables safetied? And the final task, before the first flight, is to complete the maintenance record entries.

As with any aircraft maintenance or repair, the instructions and specifications from the manufacturer, or the procedures and recommendations found in the construction plans, should be the primary method to perform the assembly and rigging of the aircraft.