Chapter 2

Aerodynamics, Aircraft Assembly, and Rigging

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 and U.S. weather reports has been "Hg. However, world-wide weather maps and some non-U.S. manufactured aircraft instruments indicate pressure in millibars (mb), a metric unit.

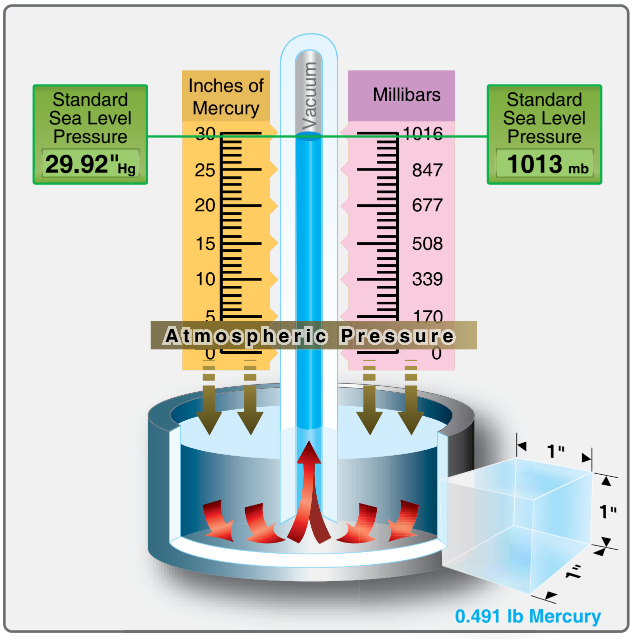


Figure 2-1. *Barometer used to measure atmospheric pressure.*

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 and 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 and 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:

Force = mass × 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 and Subsonic Flow

Bernoulli's principle states that when a fluid (air) flowing through a tube reaches a constriction, or narrowing, of the tube, the speed of the fluid flowing through that constriction is increased and its pressure is decreased. 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 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.

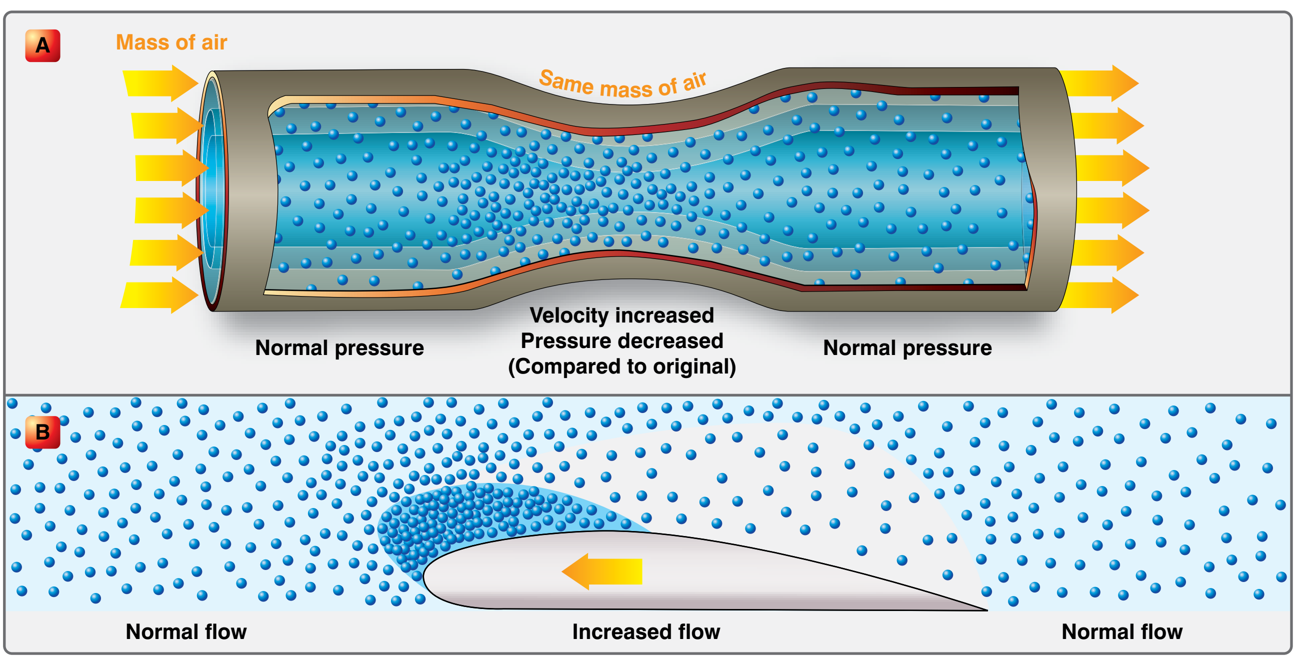


Figure 2-2. *Bernoulli's Principle.*

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.

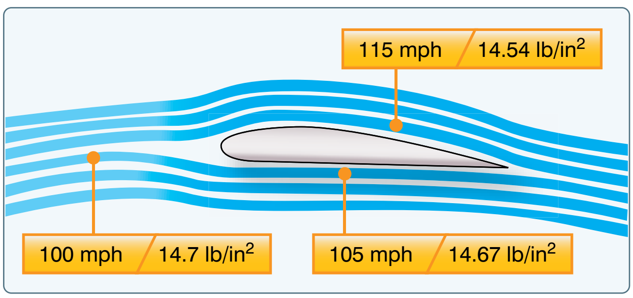


Figure 2-3. *Airflow over a wing section.*

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 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.

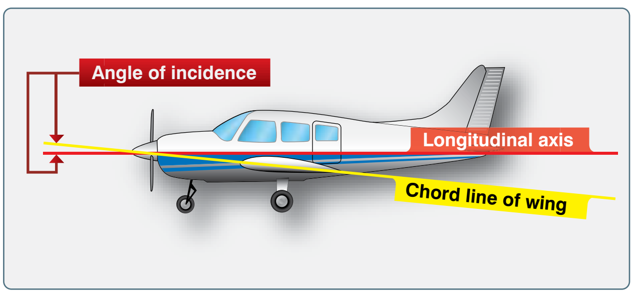


Figure 2-4. *Angle of incidence.*

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.

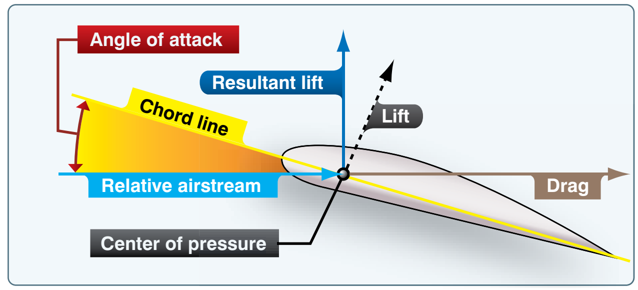


Figure 2-5. *Airflow over a wing section.*

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.

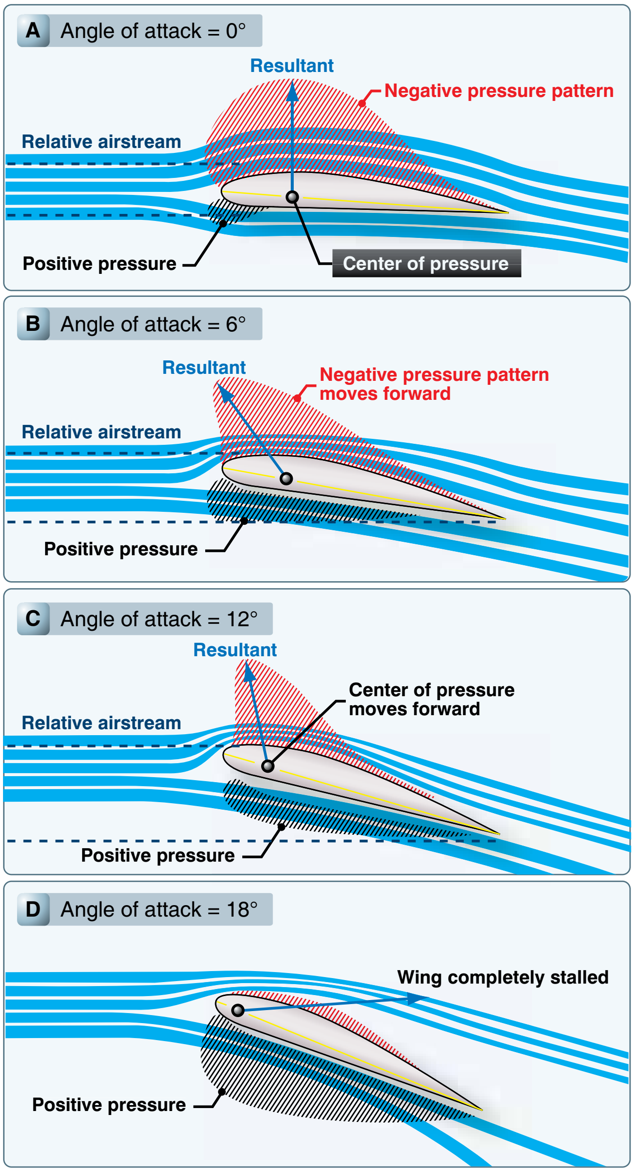


Figure 2-6. *Effect on increasing angle of attack.*

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 and Drag

An aircraft in flight is the center of a continuous battle of forces. Actually, this conflict is not as violent as it sounds, but it is the key to all maneuvers performed in the air. There is nothing mysterious about these forces; they are definite and known. The directions in which they act can be calculated, and the aircraft itself is designed to take advantage of each of them. In all types of flying, flight calculations are based on the magnitude and direction of four forces: weight, lift, drag, and thrust. *[Figure 2-7]*

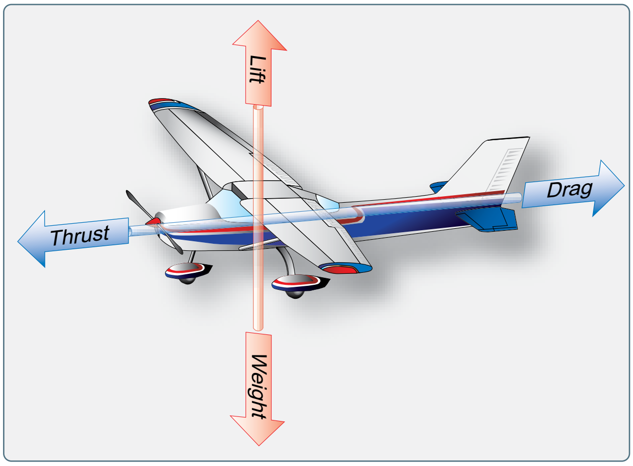


Figure 2-7. *Forces in action during flight.*

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.
3. 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]*

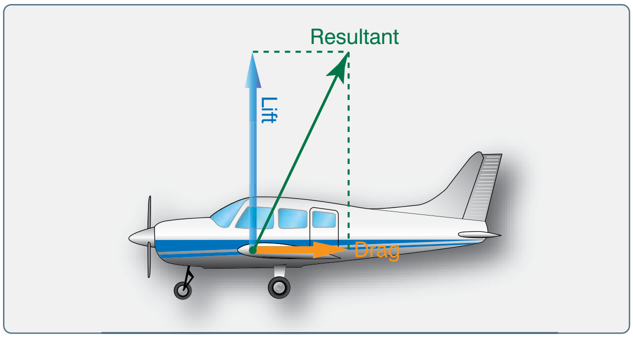


Figure 2-8. *Resultant of lift and drag.*

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 2-4)*. 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]*

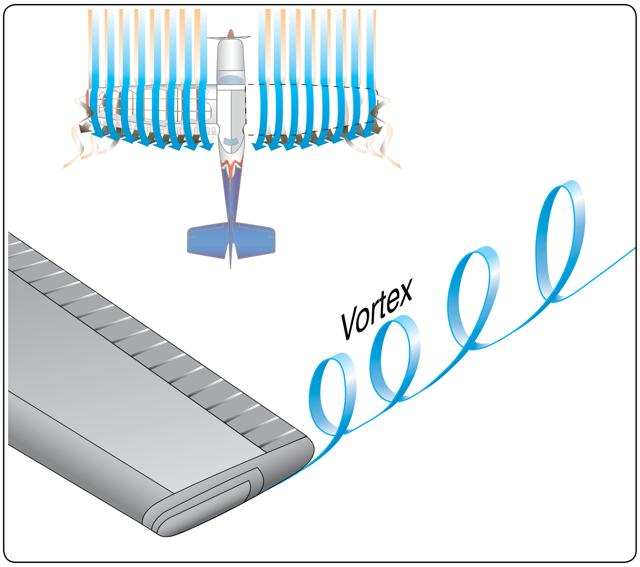


Figure 2-9. *Wingtip vortices.*

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 were 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 axis. *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 and 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.

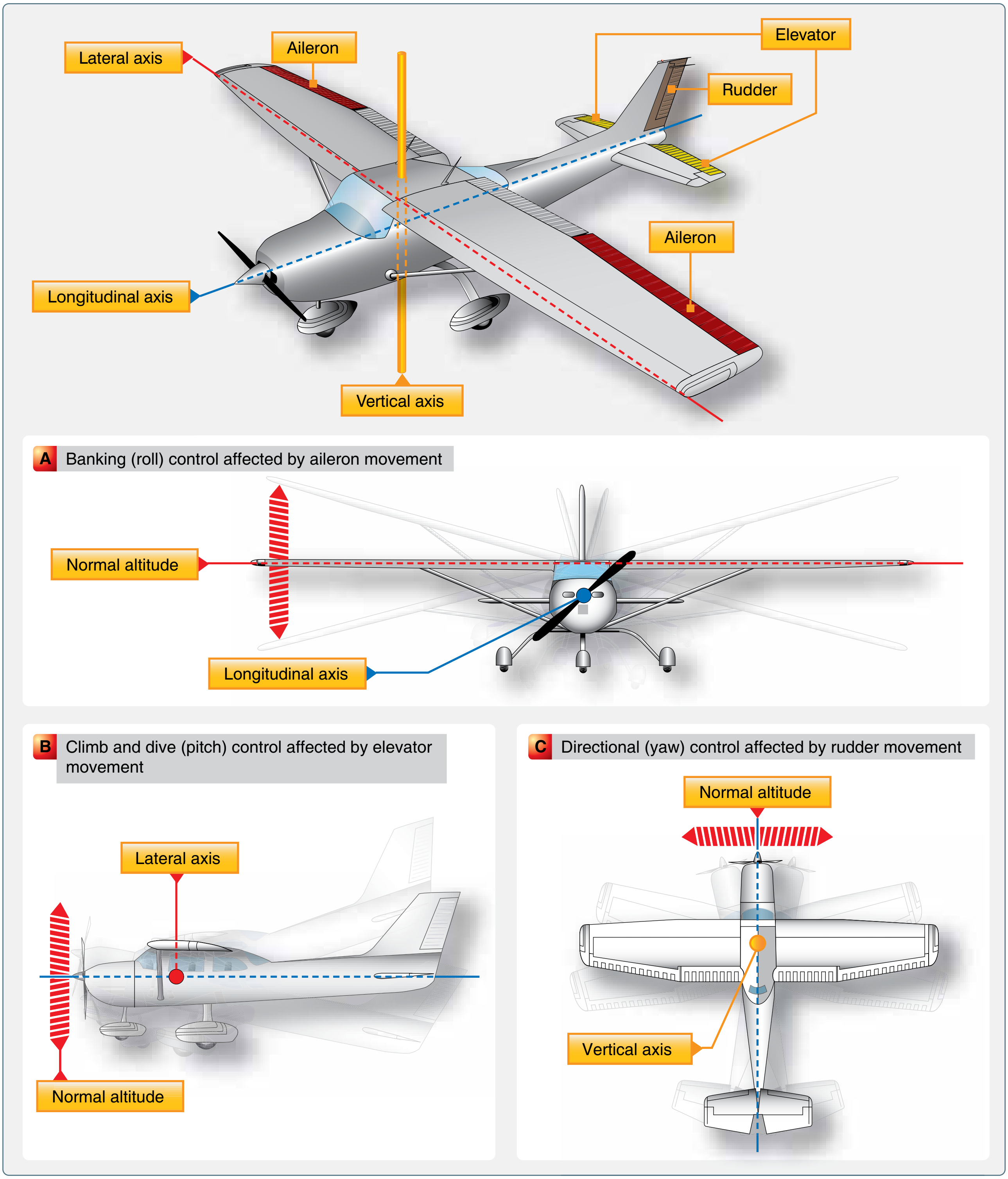


Figure 2-10. *Motion of an aircraft about its axes.*

The three types of static stability are defined by the character 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*.

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 his or her 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.

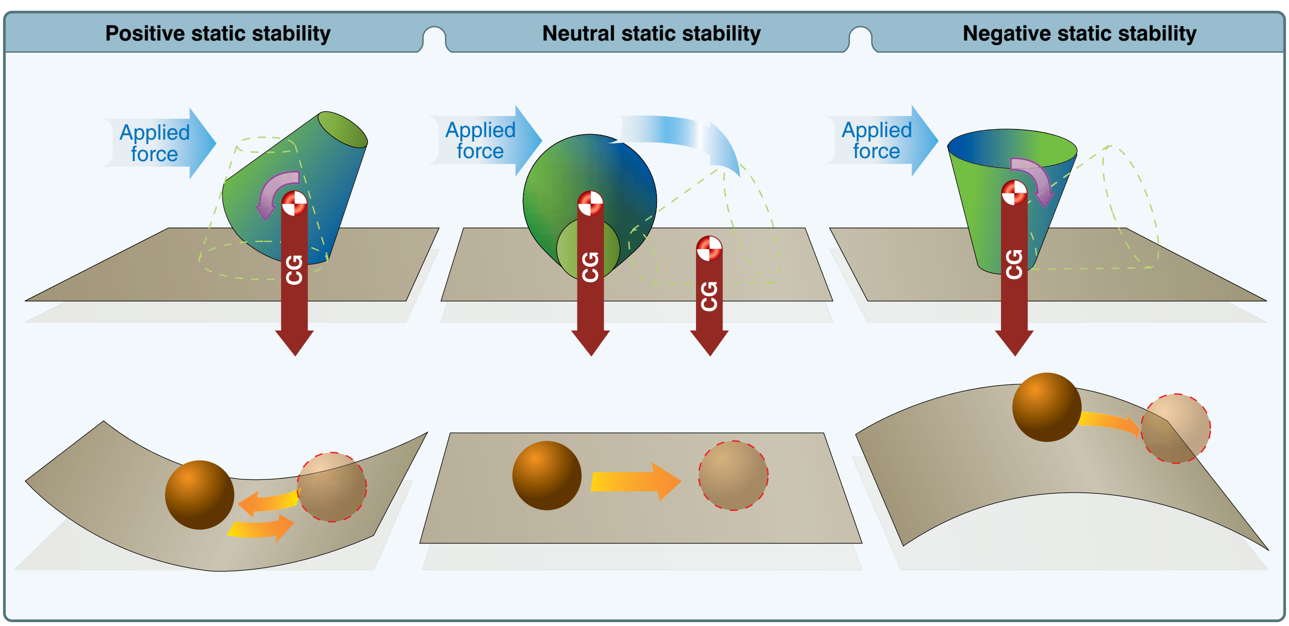


Figure 2-11. *Three types of stability.*

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 joystick. 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.

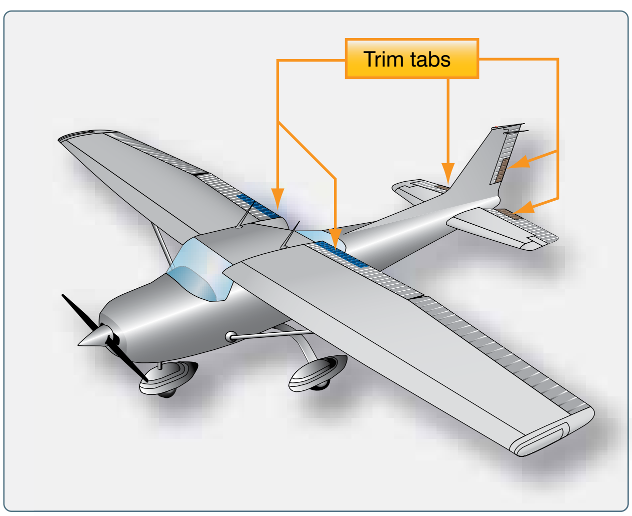


Figure 2-12. *Trim tabs.*

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.

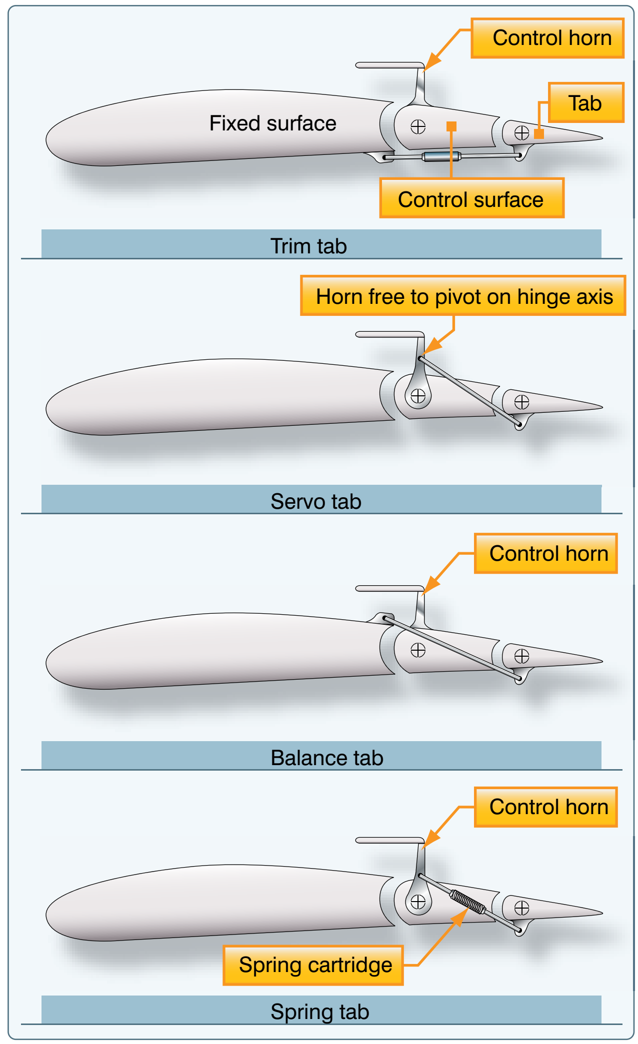


Figure 2-13. *Types of trim tabs.*

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.

The trailing edge airfoils (flaps) increase the wing area, thereby increasing lift on takeoff, and decrease 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 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). The flap (termed slat by some manufacturers) and slot create additional lift at the lower speeds of takeoff and landing. *[Figure 2-14]*

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]*

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.

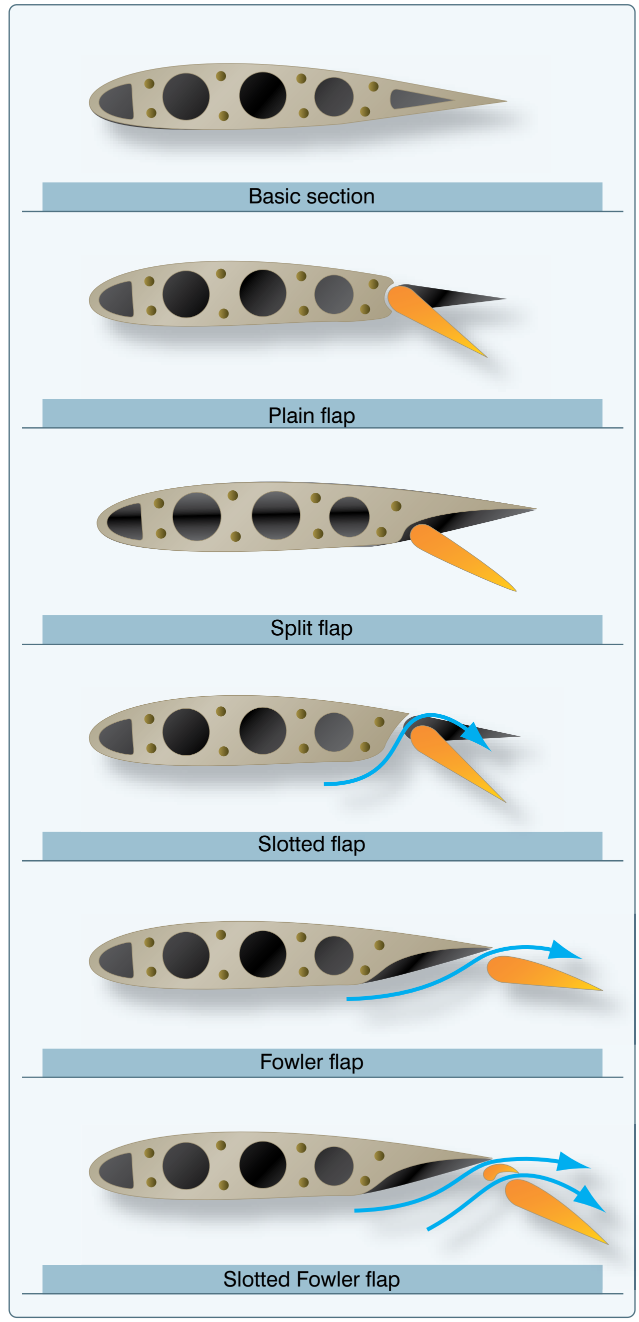


Figure 2-14. *Types of wing flaps.*

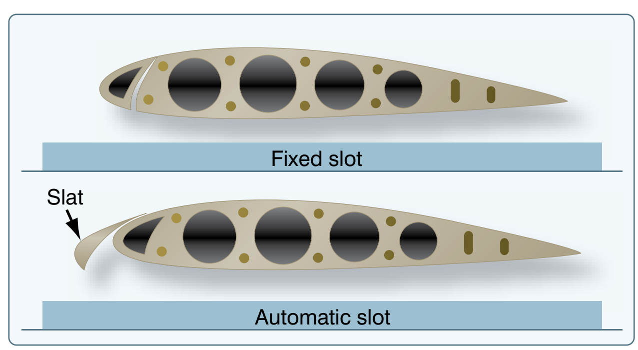


Figure 2-15. *Wing slots.*

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 Boeing 737 with winglets.

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

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]*

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

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

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 angles of attack. Their purpose is to provide better slow speed handling and stall characteristics. *[Figure 2-20]*

Figure 2-20. *Aircraft stall fence.*

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 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]*

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

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.
- 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.

Rotary-Wing Aircraft Assembly and Rigging

The flight control units located in the flight deck of all helicopters are very nearly the same. All helicopters have either one or two of each of the following: collective pitch control, throttle grip, cyclic pitch control, and directional control pedals. *[Figure 2-22]* Basically, these units do the same things, regardless of the type of helicopter on which they are installed; however, the operation of the control system varies greatly by helicopter model.

Rigging the helicopter coordinates the movements of the flight controls and establishes the relationship between the main rotor and its controls, and between the tail rotor and its controls. Rigging is not a difficult job, but it requires great precision and attention to detail. Strict adherence to rigging procedures described in the manufacturer's maintenance manuals and service instructions is a must. Adjustments, clearances, and tolerances must be exact.

Rigging of the various flight control systems can be broken down into the following three major steps:

1. Placing the control system in a specific position—holding it in position with pins, clamps, or jigs, then adjusting the various linkages to fit the immobilized control component.
2. Placing the control surfaces in a specific reference position—using a rigging jig, a precision bubble protractor, or a spirit level to check the angular difference between the control surface and some fixed surface on the aircraft. *[Figure 2-23]*
3. Setting the maximum range of travel of the various components—this adjustment limits the physical movement of the control system.

After completion of the static rigging, a functional check of the flight control system must be accomplished. The nature of the functional check varies with the type of helicopter and system concerned, but usually includes determining that:

1. The direction of movement of the main and tail rotor blades is correct in relation to movement of the pilot's controls.

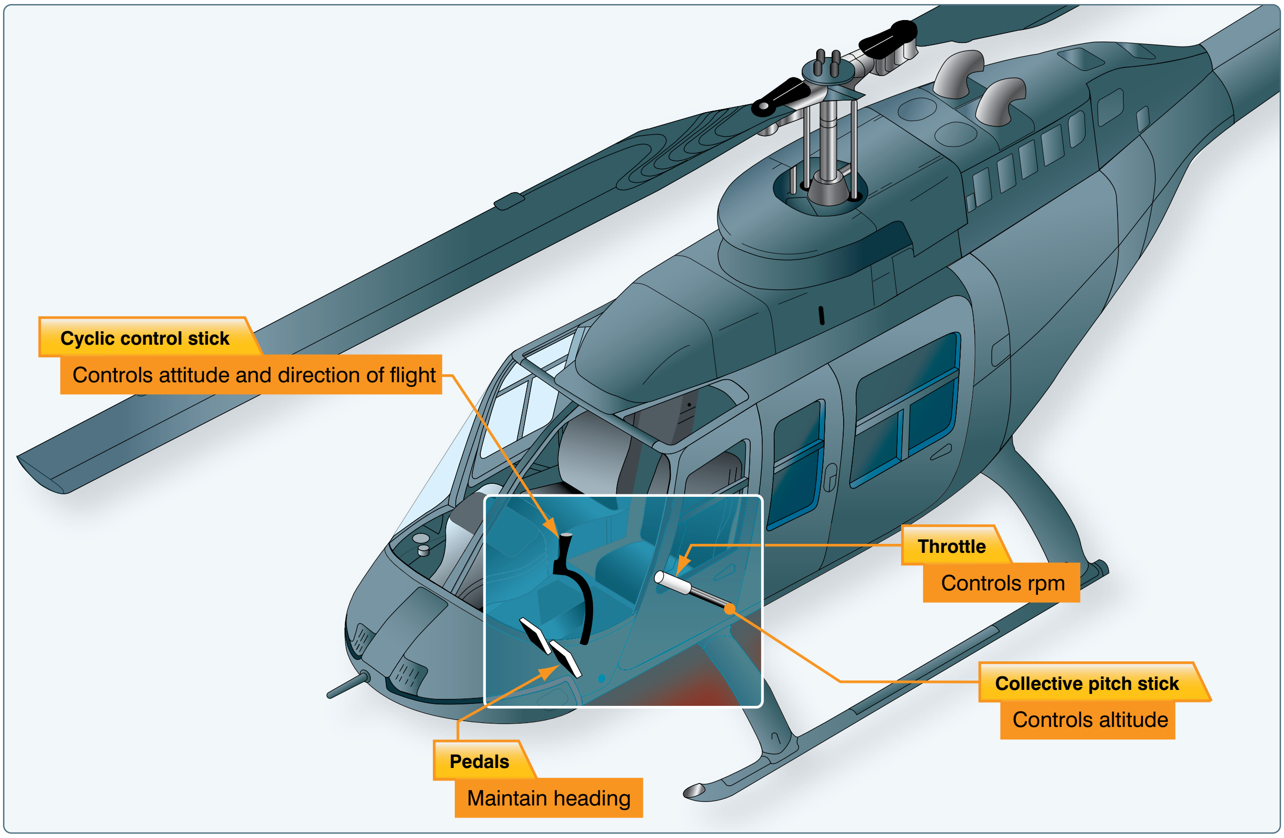


Figure 2-22. *Controls of a helicopter and the principal function of each.*

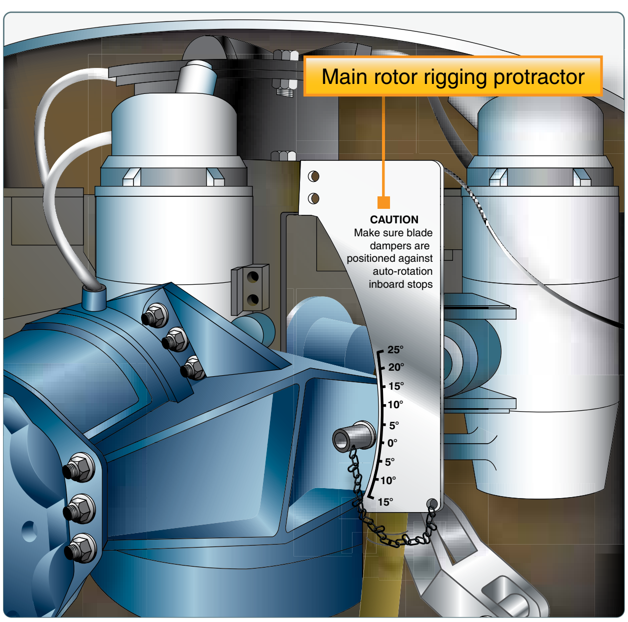


Figure 2-23. *A typical rigging protractor.*

2. The operation of interconnected control systems (engine throttle and collective pitch) is properly coordinated.
3. The range of movement and neutral position of the pilot's controls are correct.
4. The maximum and minimum pitch angles of the main rotor blades are within specified limits. This includes checking the fore-and-aft and lateral cyclic pitch and collective pitch blade angles.
5. The tracking of the main rotor blades is correct.
6. In the case of multirotor aircraft, the rigging and movement of the rotor blades are synchronized.
7. When tabs are provided on main rotor blades, they are correctly set.
8. The neutral, maximum, and minimum pitch angles and coning angles of the tail rotor blades are correct.
9. When dual controls are provided, they function correctly and in synchronization.

Upon completion of rigging, a thorough check should be made of all attaching, securing, and pivot points. All bolts, nuts, and rod ends should be properly secured and safetied as specified in the manufacturers' maintenance and service instructions.

Configurations of Rotary-Wing Aircraft

Autogyro

An autogyro is an aircraft with a free-spinning horizontal rotor that turns due to passage of air upward through the rotor. This air motion is created from forward motion of the aircraft resulting from either a tractor or pusher configured engine/propeller design. *[Figure 2-24]*

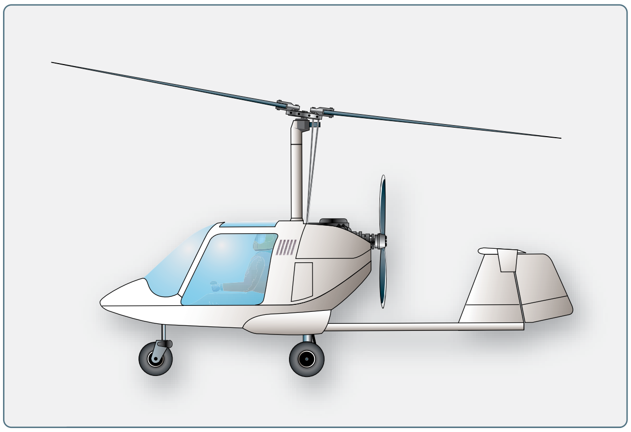


Figure 2-24. *An autogyro.*

Single Rotor Helicopter

An aircraft with a single horizontal main rotor that provides both lift and direction of travel is a single rotor helicopter. A secondary rotor mounted vertically on the tail counteracts the rotational force (torque) of the main rotor to correct yaw of the fuselage. *[Figure 2-25]*

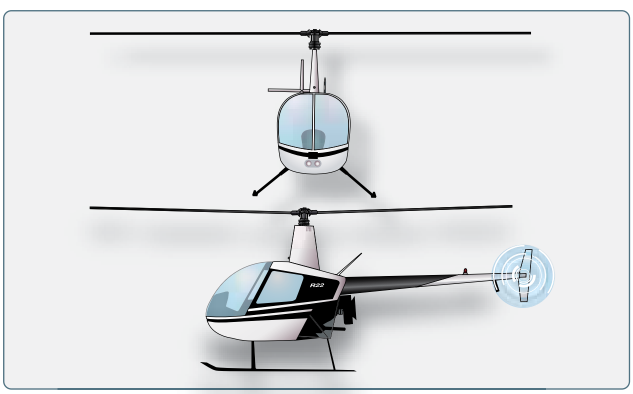


Figure 2-25. *Single rotor helicopter.*

Dual Rotor Helicopter

An aircraft with two horizontal rotors that provide both the lift and directional control is a dual rotor helicopter. The rotors are counterrotating to balance the aerodynamic torque and eliminate the need for a separate antitorque system. *[Figure 2-26]*

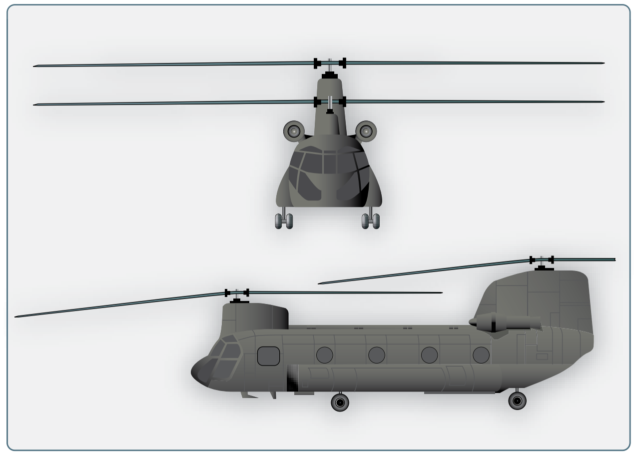


Figure 2-26. *Dual rotor helicopter.*

Types of Rotor Systems

Fully Articulated Rotor

A fully articulated rotor is found on aircraft with more than two blades and allows movement of each individual blade in three directions. In this design, each blade can rotate about the pitch axis to change lift; each blade can move back and forth in plane, lead and lag; and flap up and down through a hinge independent of the other blades. *[Figure 2-27]*

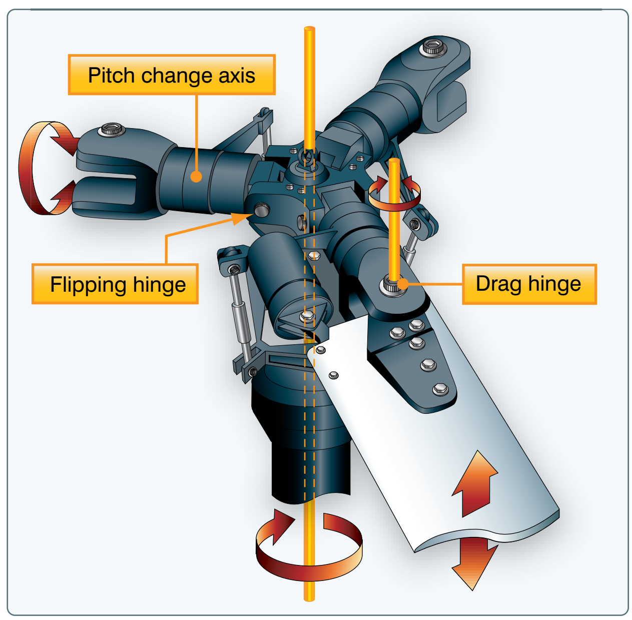


Figure 2-27. *Articulated rotor head.*

Semirigid Rotor

The semirigid rotor design is found on aircraft with two rotor blades. The blades are connected in a manner such that as one blade flaps up, the opposite blade flaps down.

Rigid Rotor

The rigid rotor system is a rare design but potentially offers the best properties of both the fully articulated and semirigid rotors. In this design, the blade roots are rigidly attached to the rotor hub. The blades do not have hinges to allow lead-lag or flapping. Instead, the blades accommodate these motions by using elastomeric bearings. Elastomeric bearings are molded, rubber-like materials that are bonded to the appropriate parts. Instead of rotating like conventional bearings, they twist and flex to allow proper movement of the blades.

Forces Acting on the Helicopter

One of the differences between a helicopter and a fixed-wing aircraft is the main source of lift. The fixed-wing aircraft derives its lift from a fixed airfoil surface while the helicopter derives lift from a rotating airfoil called the rotor.

During hovering flight in a no-wind condition, the tip-path plane is horizontal, that is, parallel to the ground. Lift and thrust act straight up; weight and drag act straight down. The sum of the lift and thrust forces must equal the sum of the weight and drag forces in order for the helicopter to hover.

During vertical flight in a no-wind condition, the lift and thrust forces both act vertically upward. Weight and drag both act vertically downward. When lift and thrust equal weight and drag, the helicopter hovers; if lift and thrust are less than weight and drag, the helicopter descends vertically; if lift and thrust are greater than weight and drag, the helicopter rises vertically.

For forward flight, the tip-path plane is tilted forward, thus tilting the total lift-thrust force forward from the vertical. This resultant lift-thrust force can be resolved into two components: lift acting vertically upward and thrust acting horizontally in the direction of flight. In addition to lift and thrust, there is weight, the downward acting force, and drag, the rearward acting or retarding force of inertia and wind resistance.

In straight-and-level, unaccelerated forward flight, lift equals weight and thrust equals drag. (Straight-and-level flight is flight with a constant heading and at a constant altitude.) If lift exceeds weight, the helicopter climbs; if lift is less than weight, the helicopter descends. If thrust exceeds drag, the helicopter increases speed; if thrust is less than drag, it decreases speed.

In sideward flight, the tip-path plane is tilted sideward in the direction that flight is desired, thus tilting the total lift-thrust vector sideward. In this case, the vertical or lift component is still straight up, weight straight down, but the horizontal or thrust component now acts sideward with drag acting to the opposite side.

For rearward flight, the tip-path plane is tilted rearward and tilts the lift-thrust vector rearward. The thrust is then rearward and the drag component is forward, opposite that for forward flight. The lift component in rearward flight is straight up; weight, straight down.

Torque Compensation

Newton's third law of motion states "To every action there is an equal and opposite reaction." As the main rotor of a helicopter turns in one direction, the fuselage tends to rotate in the opposite direction. This tendency for the fuselage to rotate is called torque. Since torque effect on the fuselage is a direct result of engine power supplied to the main rotor, any change in engine power brings about a corresponding change in torque effect. The greater the engine power, the greater the torque effect. Since there is no engine power being supplied to the main rotor during autorotation, there is no torque reaction during autorotation.

The force that compensates for torque and provides for directional control can be produced by various means. The defining factor is dictated by the design of the helicopter, some of which do not have a torque issue. Single main rotor designs typically have an auxiliary rotor located on the end of the tail boom. This auxiliary rotor, generally referred to as a tail rotor, produces thrust in the direction opposite the torque reaction developed by the main rotor. *[Figure 2-25]* Foot pedals in the flight deck permit the pilot to increase or decrease tail rotor thrust, as needed, to neutralize torque effect.

Other methods of compensating for torque and providing directional control include the Fenestron® tail rotor system, an SUD Aviation design that employs a ducted fan enclosed by a shroud. Another design, called NOTAR®, a McDonald Douglas design with no tail rotor, employs air directed through a series of slots in the tail boom, with the balance exiting through a 90° duct located at the rear of the tail boom. *[Figure 2-28]*

Figure 2-28. *Aerospatiale Fenestron tail rotor system (left) and the McDonnell Douglas NOTAR® System (right).*

Gyroscopic Forces

The spinning main rotor of a helicopter acts like a gyroscope. As such, it has the properties of gyroscopic action, one of which is precession. Gyroscopic precession is the resultant action or deflection of a spinning object when a force is applied to this object. This action occurs approximately 90° in the direction of rotation from the point where the force is applied. *[Figure 2-29]* Through the use of this principle, the tip-path plane of the main rotor may be tilted from the horizontal.

Examine a two-bladed rotor system to see how gyroscopic precession affects the movement of the tip-path plane. Moving the cyclic pitch control increases the angle of attack (AOA) of one rotor blade with the result that a greater lifting force is applied at that point in the plane of rotation. This same control movement simultaneously decreases the AOA of the other blade the same amount, thus decreasing the lifting force applied at that point in the plane of rotation. The blade with the increased AOA tends to flap up; the blade with the

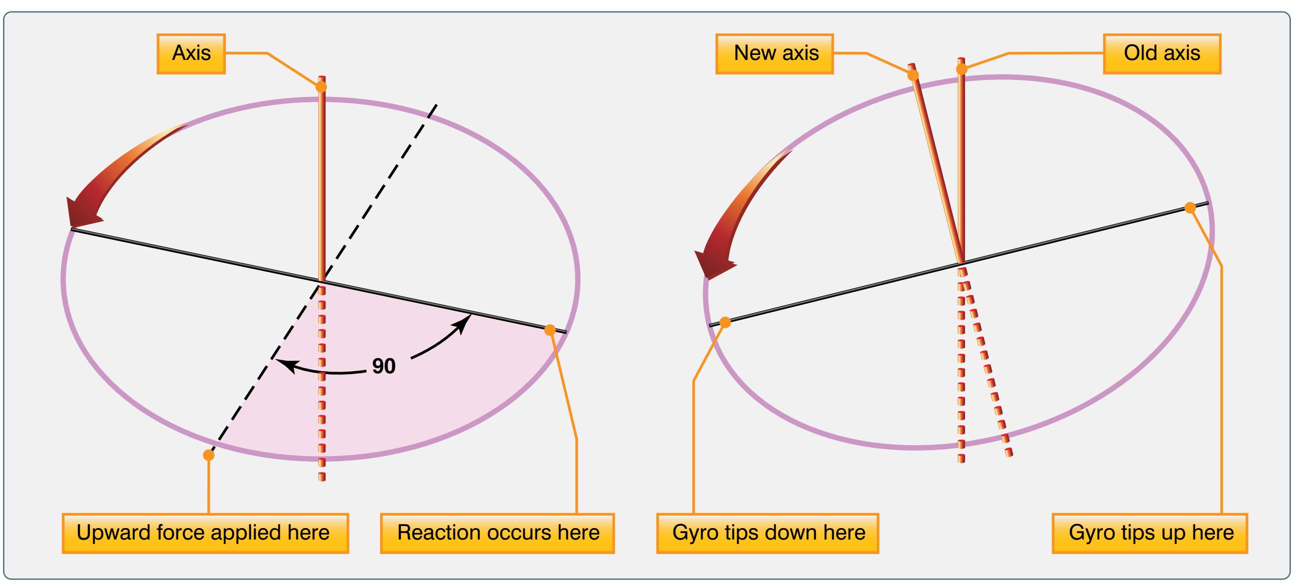


Figure 2-29. *Gyroscopic precession principle.*

decreased AOA tends to flap down. Because the rotor disk acts like a gyro, the blades reach maximum deflection at a point approximately 90° later in the plane of rotation. As shown in *Figure 2-30*, the retreating blade AOA is increased and the advancing blade AOA is decreased resulting in a tipping forward of the tip-path plane, since maximum deflection takes place 90° later when the blades are at the rear and front, respectively. In a rotor system using three or more blades, the movement of the cyclic pitch control changes the AOA of each blade an appropriate amount so that the end result is the same.

The movement of the cyclic pitch control in a two-bladed rotor system increases the AOA of one rotor blade with the result that a greater lifting force is applied at this point in the plane of rotation. This same control movement simultaneously decreases the AOA of the other blade a like amount, thus decreasing the lifting force applied at this point in the plane of rotation. The blade with the increased AOA tends to rise; the blade with the decreased AOA tends to lower. However, gyroscopic precession prevents the blades from rising or lowering to maximum deflection until a point approximately 90° later in the plane of rotation.

In a three-bladed rotor, the movement of the cyclic pitch control changes the AOA of each blade an appropriate amount so that the end result is the same, a tipping forward of the tip-path plane when the maximum change in AOA is made as each blade passes the same points at which the maximum increase and decrease are made for the two-bladed rotor as shown in *Figure 2-30*. As each blade passes the 90° position on the left, the maximum increase in AOA occurs. As each blade passes the 90° position to the right, the maximum decrease in AOA occurs. Maximum deflection takes place 90° later, maximum upward deflection at the rear and maximum downward deflection at the front; the tip-path plane tips forward.

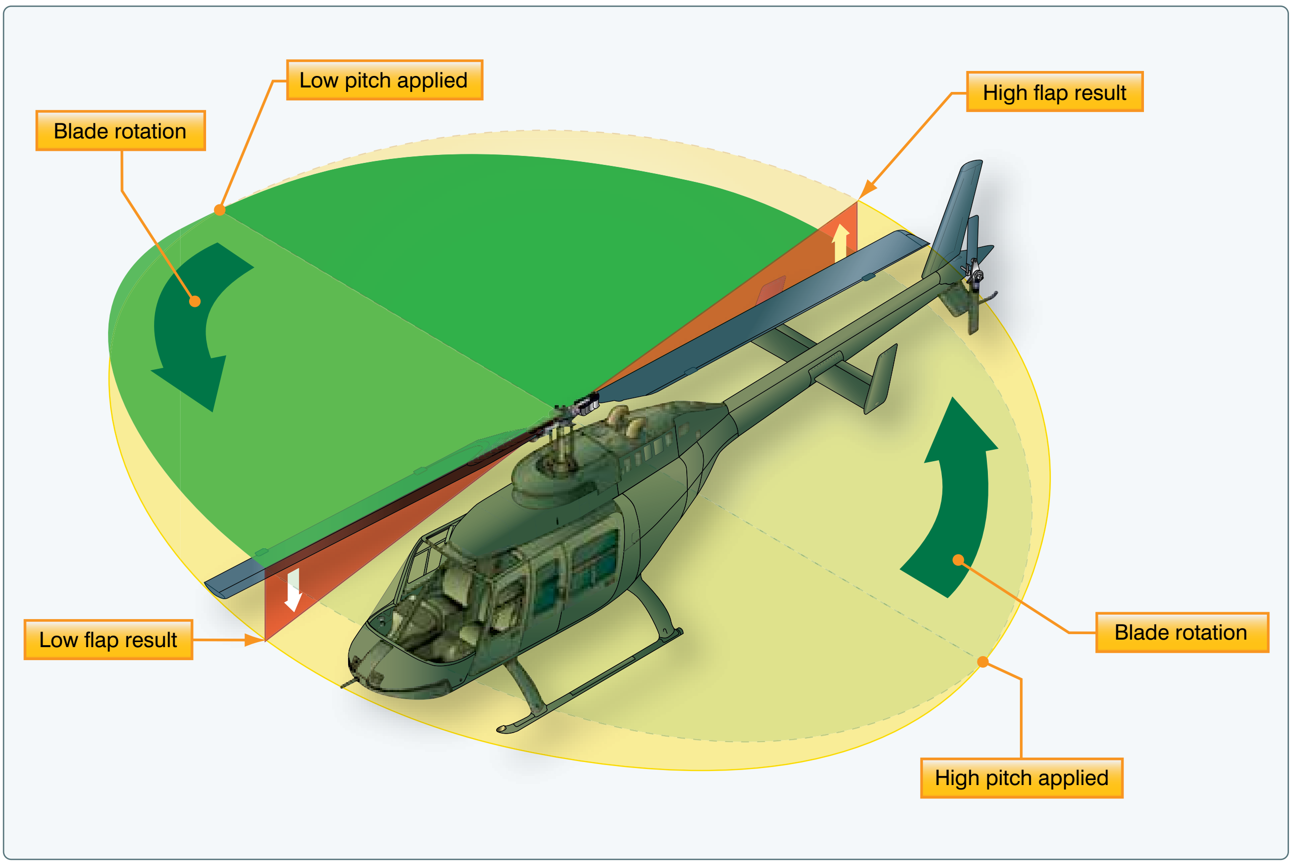


Figure 2-30. *Gyroscopic precession.*

Helicopter Flight Conditions

Hovering Flight

During hovering flight, a helicopter maintains a constant position over a selected point, usually a few feet above the ground. For a helicopter to hover, the lift and thrust produced by the rotor system act straight up and must equal the weight and drag, which act straight down. *[Figure 2-31]* While hovering, the amount of main rotor thrust can be changed to maintain the desired hovering altitude. This is done by changing the angle of incidence (by moving the collective) of the rotor blades and hence the AOA of the main rotor blades. Changing the AOA changes the drag on the rotor blades, and the power delivered by the engine must change as well to keep the rotor speed constant.

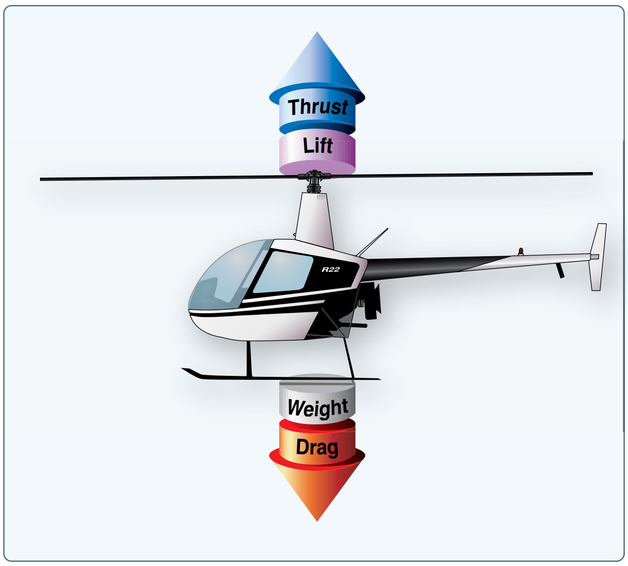


Figure 2-31. *To maintain a hover at a constant altitude, enough lift and thrust must be generated to equal the weight of the helicopter and the drag produced by the rotor blades.*

The weight that must be supported is the total weight of the helicopter and its occupants. If the amount of lift is greater than the actual weight, the helicopter accelerates upwards until the lift force equals the weight gain altitude; if thrust is less than weight, the helicopter accelerates downward. When operating near the ground, the effect of the closeness to the ground changes this response.

The drag of a hovering helicopter is mainly induced drag incurred while the blades are producing lift. There is, however, some profile drag on the blades as they rotate through the air. Throughout the rest of this discussion, the term drag includes both induced and profile drag.

An important consequence of producing thrust is torque. As discussed earlier, Newton's Third Law states that for every action there is an equal and opposite reaction. Therefore, as the engine turns the main rotor system in a counterclockwise direction, the helicopter fuselage tends to turn clockwise. The amount of torque is directly related to the amount of engine power being used to turn the main rotor system. Remember, as power changes, torque changes.

To counteract this torque-induced turning tendency, an antitorque rotor or tail rotor is incorporated into most helicopter designs. A pilot can vary the amount of thrust produced by the tail rotor in relation to the amount of torque produced by the engine. As the engine supplies more power to the main rotor, the tail rotor must produce more thrust to overcome the increased torque effect. This is done through the use of antitorque pedals.

Translating Tendency or Drift

During hovering flight, a single main rotor helicopter tends to drift or move in the direction of tail rotor thrust. This drifting tendency is called translating tendency. *[Figure 2-32]*

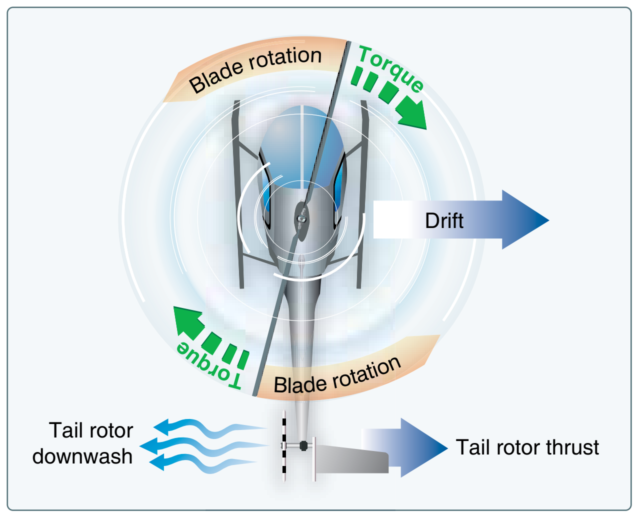


Figure 2-32. *A tail rotor is designed to produce thrust in a direction opposite torque. The thrust produced by the tail rotor is sufficient to move the helicopter laterally.*

To counteract this drift, one or more of the following features may be used. All examples are for a counterclockwise rotating main rotor system.

- The main transmission is mounted at a slight angle to the left (when viewed from behind) so that the rotor mast has a built-in tilt to oppose the tail rotor thrust.
- Flight controls can be rigged so that the rotor disk is tilted to the right slightly when the cyclic is centered. Whichever method is used, the tip-path plane is tilted slightly to the left in the hover.
- If the transmission is mounted so the rotor shaft is vertical with respect to the fuselage, the helicopter

"hangs" left skid low in the hover. The opposite is true for rotor systems turning clockwise when viewed from above.

- In forward flight, the tail rotor continues to push to the right, and the helicopter makes a small angle with the wind when the rotors are level and the slip ball is in the middle. This is called inherent sideslip.

Ground Effect

When hovering near the ground, a phenomenon known as ground effect takes place. This effect usually occurs at heights between the surface and approximately one rotor diameter above the surface. The friction of the ground causes the downwash from the rotor to move outwards from the helicopter. This changes the relative direction of the downwash from a purely vertical motion to a combination of vertical and horizontal motion. As the induced airflow through the rotor disk is reduced by the surface friction, the lift vector increases. This allows a lower rotor blade angle for the same amount of lift, which reduces induced drag. Ground effect also restricts the generation of blade tip vortices due to the downward and outward airflow making a larger portion of the blade produce lift. When the helicopter gains altitude vertically, with no forward airspeed, induced airflow is no longer restricted, and the blade tip vortices increase with the decrease in outward airflow. As a result, drag increases which means a higher pitch angle, and more power is needed to move the air down through the rotor.

Ground effect is at its maximum in a no-wind condition over a firm, smooth surface. Tall grass, rough terrain, and water surfaces alter the airflow pattern, causing an increase in rotor tip vortices. *[Figure 2-33]*

Coriolis Effect (Law of Conservation of Angular Momentum)

The Coriolis effect is also referred to as the law of conservation of angular momentum. It states that the value of angular momentum of a rotating body does not change unless an external force is applied. In other words, a rotating body continues to rotate with the same rotational velocity until some external force is applied to change the speed of rotation. Angular momentum is moment of inertia (mass times distance from the center of rotation squared) multiplied by speed of rotation. Changes in angular velocity, known as angular acceleration and deceleration, take place as the mass of a rotating body is moved closer to or further away from the axis of rotation. The speed of the rotating mass increases or decreases in proportion to the square of the radius. An excellent example of this principle is a spinning ice skater. The skater begins rotation on one foot, with the other leg and both arms extended. The rotation of the skater's body is relatively slow. When a skater draws both arms and one leg inward, the moment of inertia (mass times radius squared) becomes much smaller and the body is rotating almost faster than the eye can follow. Because the angular momentum must remain constant (no external force applied), the angular velocity must increase. The rotor blade rotating about the rotor hub possesses angular momentum. As the rotor begins to cone due to G-loading maneuvers, the diameter or the disk shrinks. Due to conservation of angular momentum, the blades continue to travel the same speed even though the blade tips have a shorter distance to travel due to reduced disk diameter. The action results in an increase in rotor rpm. Most pilots arrest this increase with an increase in collective pitch. Conversely, as G-loading subsides and the rotor disk flattens out from the loss of G-load induced coning, the blade tips

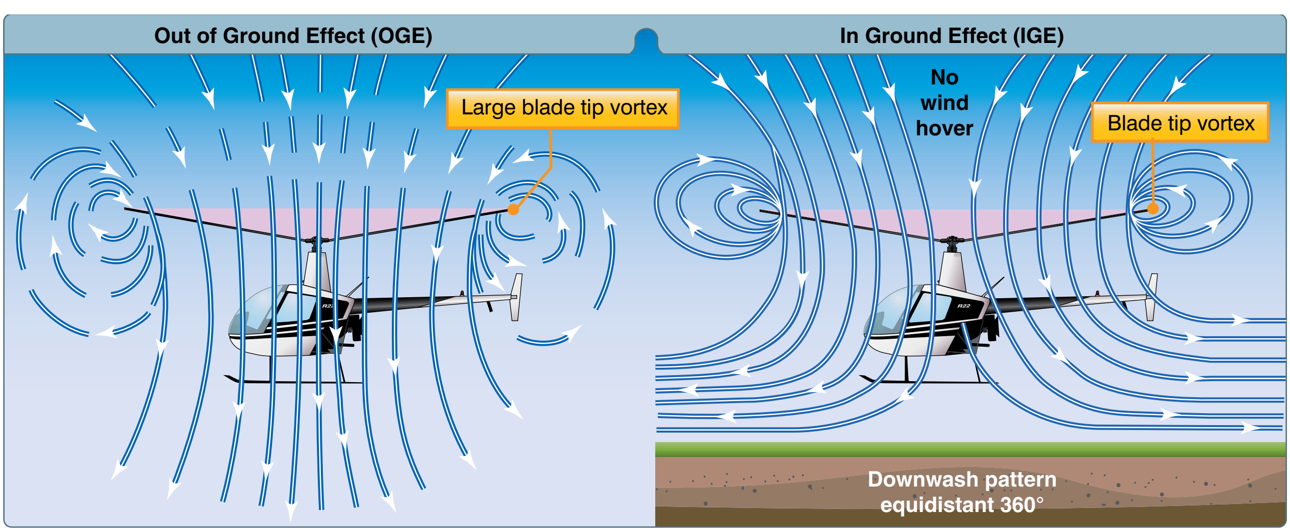


Figure 2-33. *Air circulation patterns change when hovering out of ground effect (OGE) and when hovering in ground effect (IGE).*

now have a longer distance to travel at the same tip speed. This action results in a reduction of rotor rpm. However, if this drop in the rotor rpm continues to the point at which it attempts to decrease below normal operating rpm, the engine control system adds more fuel/power to maintain the specified engine rpm. If the pilot does not reduce collective pitch as the disk unloads, the combination of engine compensation for the rpm slow down and the additional pitch as G-loading increases may result in exceeding the torque limitations or power the engines can produce.

Vertical Flight

Hovering is actually an element of vertical flight. Increasing the AOA of the rotor blades (pitch) while keeping their rotation speed constant generates additional lift and the helicopter ascends. Decreasing the pitch causes the helicopter to descend. In a no wind condition, when lift and thrust are less than weight and drag, the helicopter descends vertically. If lift and thrust are greater than weight and drag, the helicopter ascends vertically. *[Figure 2-34]*

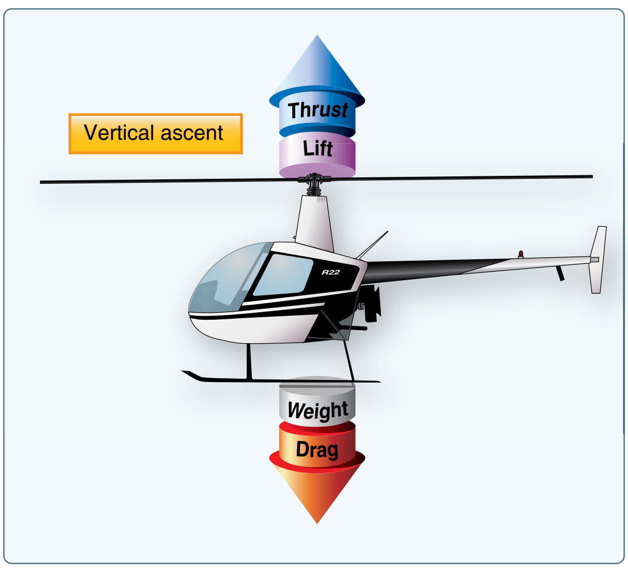


Figure 2-34. *To ascend vertically, more lift and thrust must be generated to overcome the forces of weight and drag.*

Forward Flight

In steady forward flight with no change in airspeed or vertical speed, the four forces of lift, thrust, drag, and weight must be in balance. Once the tip-path plane is tilted forward, the total lift-thrust force is also tilted forward. This resultant lift-thrust force can be resolved into two components—lift acting vertically upward and thrust acting horizontally in the direction of flight. In addition to lift and thrust, there is weight (the downward acting force) and drag (the force opposing the motion of an airfoil through the air). *[Figure 2-35]*

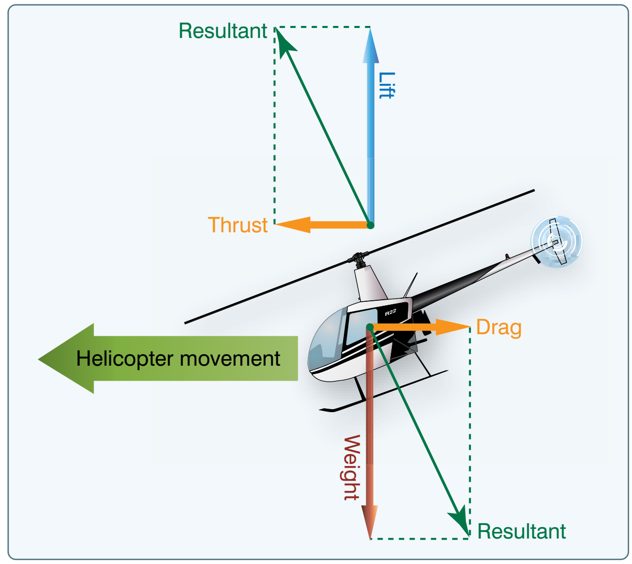


Figure 2-35. *The power required to maintain a straight-and-level flight and a stabilized airspeed.*

In straight-and-level (constant heading and at a constant altitude), unaccelerated forward flight, lift equals weight and thrust equals drag. If lift exceeds weight, the helicopter accelerates vertically until the forces are in balance; if thrust is less than drag, the helicopter slows until the forces are in balance. As the helicopter moves forward, it begins to lose altitude because lift is lost as thrust is diverted forward. However, as the helicopter begins to accelerate, the rotor system becomes more efficient due to the increased airflow. The result is excess power over that which is required to hover. Continued acceleration causes an even larger increase in airflow through the rotor disk and more excess power. In order to maintain unaccelerated flight, the pilot must not make any changes in power or in cyclic movement. Any such changes would cause the helicopter to climb or descend. Once straight-and-level flight is obtained, the pilot should make note of the power (torque setting) required and not make major adjustments to the flight controls. *[Figure 2-36]*

Translational Lift

Improved rotor efficiency resulting from directional flight is called translational lift. The efficiency of the hovering rotor system is greatly improved with each knot of incoming wind gained by horizontal movement of the aircraft or surface wind. As incoming wind produced by aircraft movement or surface wind enters the rotor system, turbulence and vortices are left behind and the flow of air becomes more horizontal. In addition, the tail rotor becomes more aerodynamically efficient during the transition from hover to forward flight. Translational thrust occurs when the tail rotor becomes more aerodynamically efficient during the transition from hover

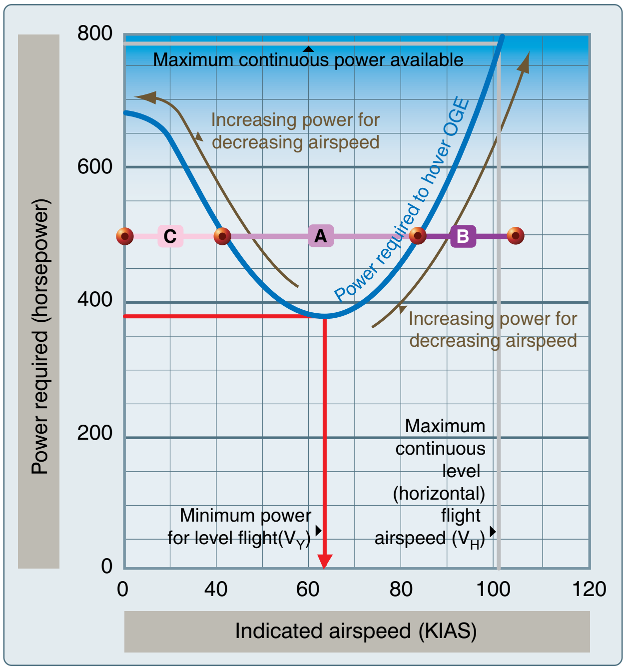


Figure 2-36. *Changing force vectors results in aircraft movement.*

to forward flight. As the tail rotor works in progressively less turbulent air, this improved efficiency produces more antitorque thrust, causing the nose of the aircraft to yaw left (with a main rotor turning counterclockwise) and forces the pilot to apply right pedal (decreasing the AOA in the tail rotor blades) in response. In addition, during this period, the airflow affects the horizontal components of the stabilizer found on most helicopters which tends to bring the nose of the helicopter to a more level attitude. *Figure 2-37* and *Figure 2-38* show airflow patterns at different speeds and how airflow affects the efficiency of the tail rotor.

Effective Translational Lift (ETL)

While transitioning to forward flight at about 16–24 knots, the helicopter experiences effective translational lift (ETL). As mentioned earlier in the discussion on translational lift, the rotor blades become more efficient as forward airspeed increases. Between 16–24 knots, the rotor system completely outruns the recirculation of old vortices and begins to work in relatively undisturbed air. The flow of air through the rotor system is more horizontal, therefore induced flow and induced drag are reduced. The AOA is subsequently increased, which makes the rotor system operate more efficiently. This increased efficiency continues with increased airspeed until the best climb airspeed is reached, and total drag is at its lowest point.

As speed increases, translational lift becomes more effective, the nose rises or pitches up, and the aircraft rolls to the right. The combined effects of dissymmetry of lift, gyroscopic precession, and transverse flow effect cause this tendency. It is important to understand these effects and anticipate correcting for them. Once the helicopter is transitioning through ETL, the pilot needs to apply forward and left lateral cyclic input to maintain a constant rotor-disk attitude. *[Figure 2-39]*

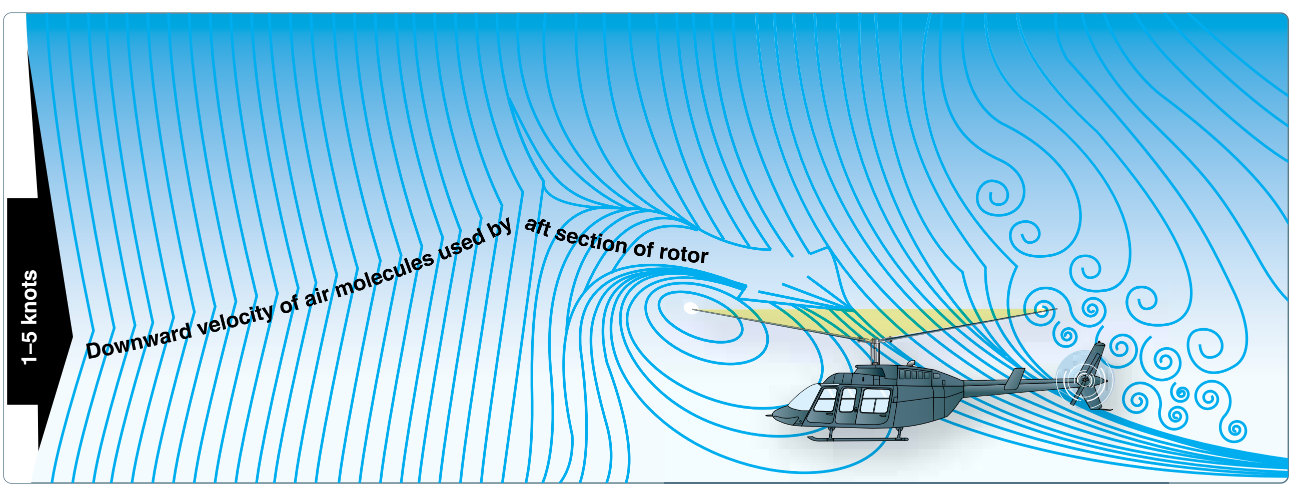


Figure 2-37. *The airflow pattern for 1–5 knots of forward airspeed. Note how the downwind vortex is beginning to dissipate and induced flow down through the rear of the rotor system is more horizontal.*

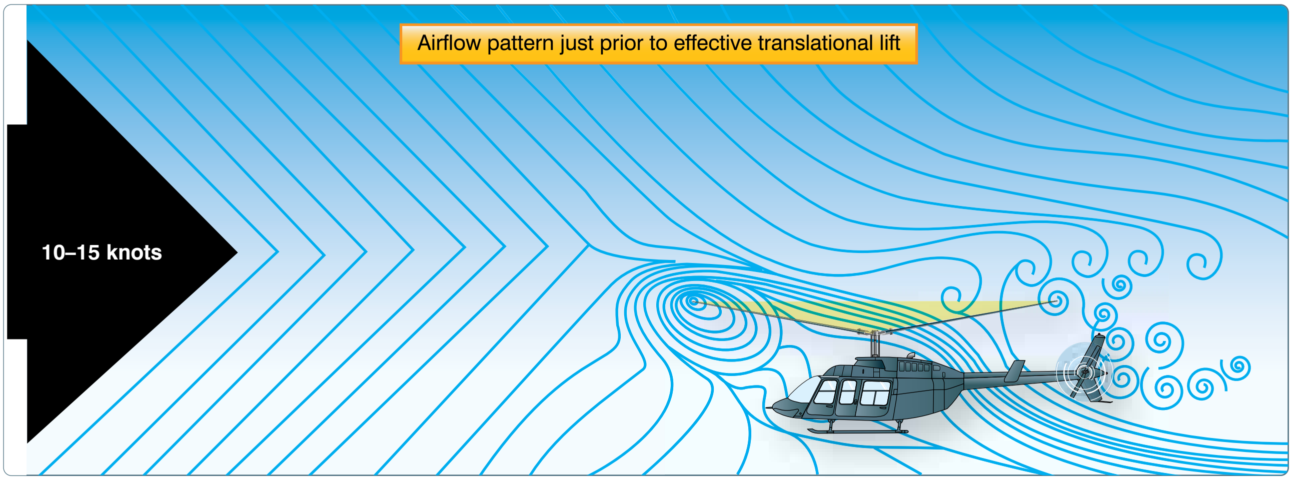


Figure 2-38. *An airflow pattern at a speed of 10–15 knots. At this increased airspeed, the airflow continues to become more horizontal. The leading edge of the downwash pattern is being overrun and is well back under the nose of the helicopter.*

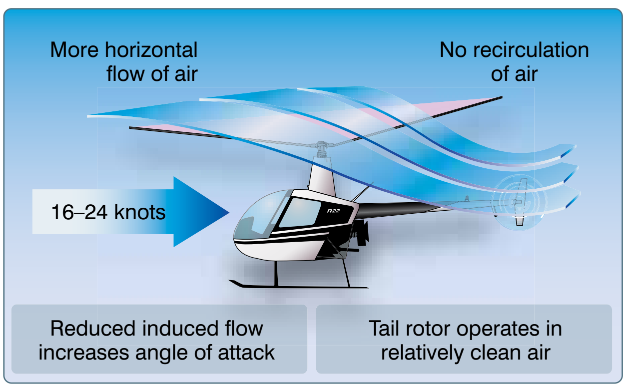


Figure 2-39. *Effective translational lift is easily recognized in actual flight by a transient induced aerodynamic vibration and increased performance of the helicopter.*

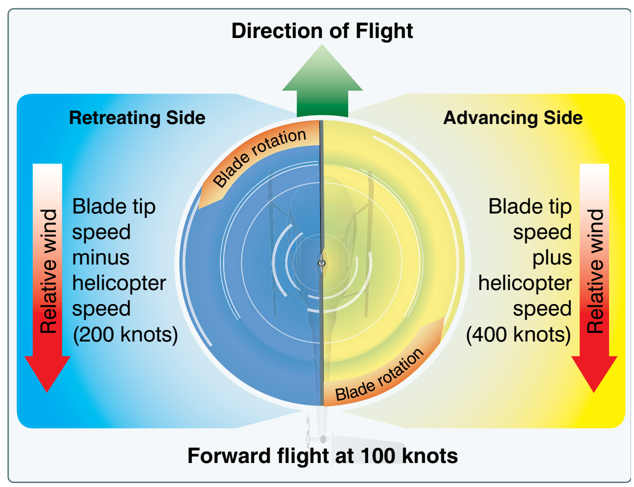


Figure 2-40. *The blade tip speed of this helicopter is approximately 300 knots. If the helicopter is moving forward at 100 knots, the relative windspeed on the advancing side is 400 knots. On the retreating side, it is only 200 knots. This difference in speed causes a dissymmetry of lift.*

Dissymmetry of Lift

Dissymmetry of lift is the differential (unequal) lift between advancing and retreating halves of the rotor disk caused by the different wind flow velocity across each half. This difference in lift would cause the helicopter to be uncontrollable in any situation other than hovering in a calm wind. There must be a means of compensating, correcting, or eliminating this unequal lift to attain symmetry of lift.

When the helicopter moves through the air, the relative airflow through the main rotor disk is different on the advancing side than on the retreating side. The relative wind encountered by the advancing blade is increased by the forward speed of the helicopter; while the relative windspeed acting on the retreating blade is reduced by the helicopter's forward airspeed. Therefore, as a result of the relative windspeed, the advancing blade side of the rotor disk produces more lift than the retreating blade side. *[Figure 2-40]*

If this condition was allowed to exist, a helicopter with a counterclockwise main rotor blade rotation would roll to the left because of the difference in lift. In reality, the main rotor blades flap and feather automatically to equalize lift across the rotor disk. Articulated rotor systems, usually with three or more blades, incorporate a horizontal hinge (flapping hinge) to allow the individual rotor blades to move, or flap up and down as they rotate. A semirigid rotor system (two blades) utilizes a teetering hinge, which allows the blades to flap as a unit. When one blade flaps up, the other blade flaps down.

As the rotor blade reaches the advancing side of the rotor disk, it reaches its maximum upward flapping velocity. *[Figure 2-41A]* When the blade flaps upward, the angle between the chord line and the resultant relative wind decreases. This decreases the AOA, which reduces the amount of lift produced by the blade. At position C, the rotor blade is at its maximum downward flapping velocity. Due to downward flapping, the angle between the chord line and the resultant relative wind increases. This increases the AOA and thus the amount of lift produced by the blade.

The combination of blade flapping and slow relative wind acting on the retreating blade normally limits the maximum forward speed of a helicopter. At a high forward speed, the retreating blade stalls due to high AOA and slow relative wind speed. This situation is called "retreating blade stall" and is evidenced by a nose-up pitch, vibration, and a rolling tendency—usually to the left in helicopters with counterclockwise blade rotation.

Pilots can avoid retreating blade stall by not exceeding the never-exceed speed. This speed is designated V_{NE} and is indicated on a placard and marked on the airspeed indicator by a red line.

During aerodynamic flapping of the rotor blades as they compensate for dissymmetry of lift, the advancing blade achieves maximum upward flapping displacement over the nose and maximum downward flapping displacement over the tail. This causes the tip-path plane to tilt to the rear and is referred to as blowback. *Figure 2-42* shows how the rotor disk is originally oriented with the front down following the initial cyclic input. As airspeed is gained and flapping eliminates dissymmetry of lift, the front of the disk comes

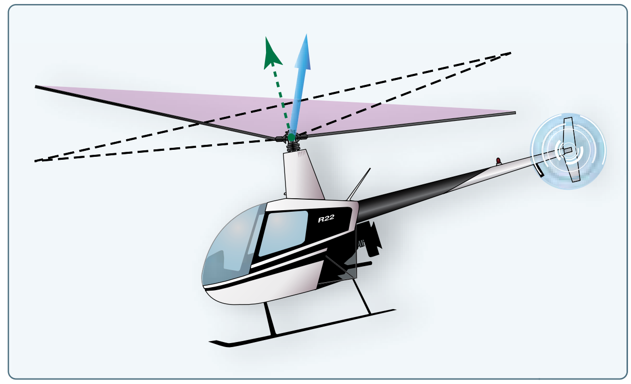


Figure 2-42. *To compensate for blowback, move the cyclic forward. Blowback is more pronounced with higher airspeeds.*

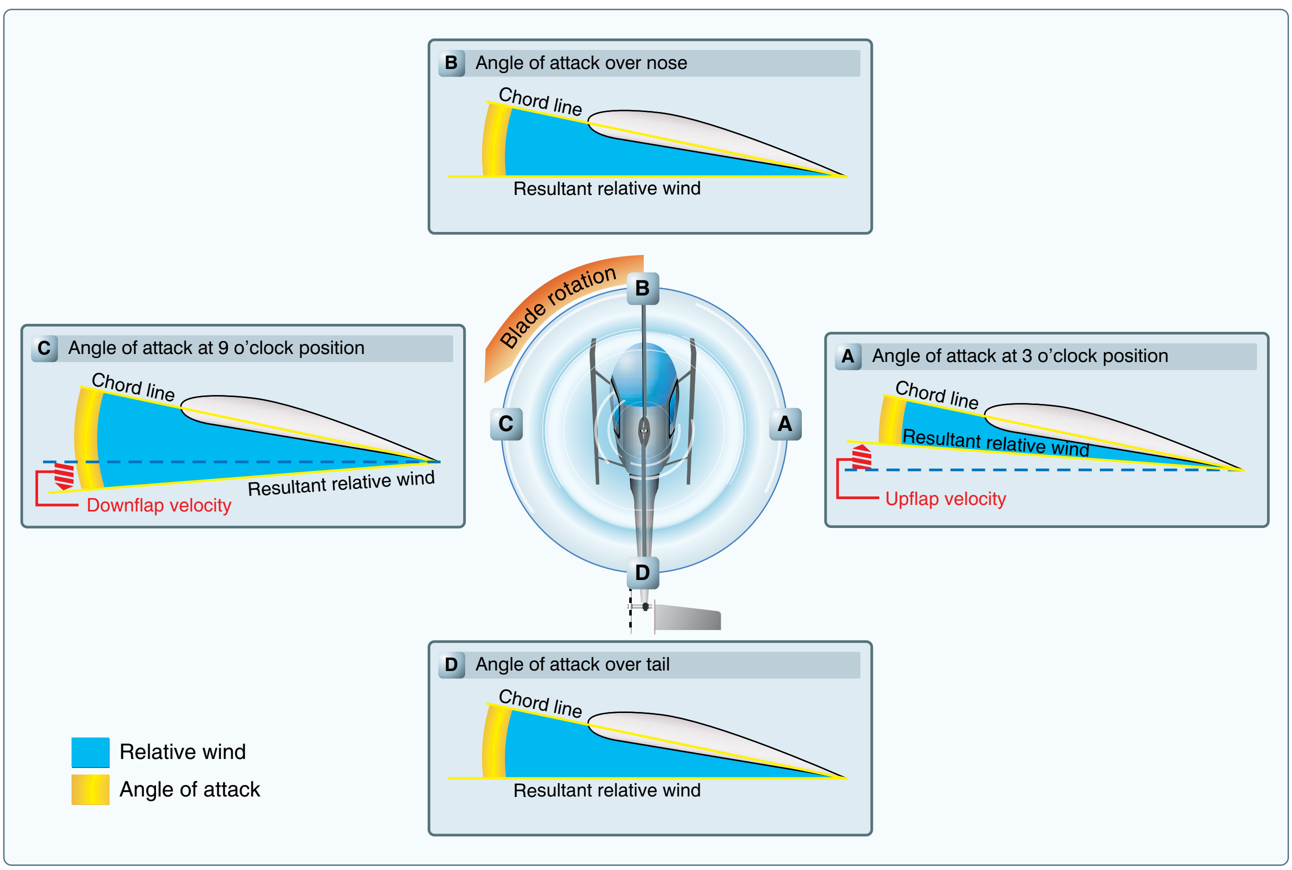


Figure 2-41. *The combined upward flapping (reduced lift) of the advancing blade and downward flapping (increased lift) of the retreating blade equalizes lift across the main rotor disk counteracting dissymmetry of lift.*

up, and the back of the disk goes down. This reorientation of the rotor disk changes the direction in which total rotor thrust acts; the helicopter's forward speed slows, but can be corrected with cyclic input. The pilot uses cyclic feathering to compensate for dissymmetry of lift allowing him or her to control the attitude of the rotor disk.

Cyclic feathering compensates for dissymmetry of lift (changes the AOA) in the following way. At a hover, equal lift is produced around the rotor system with equal pitch and AOA on all the blades and at all points in the rotor system (disregarding compensation for translating tendency). The rotor disk is parallel to the horizon. To develop a thrust force, the rotor system must be tilted in the desired direction of movement. Cyclic feathering changes the angle of incidence differentially around the rotor system. Forward cyclic movements decrease the angle of incidence at one part on the rotor system while increasing the angle at another part. Maximum downward flapping of the blade over the nose and maximum upward flapping over the tail tilt both rotor disk and thrust vector forward. To prevent blowback from occurring, the pilot must continually move the cyclic forward as the velocity of the helicopter increases. *Figure 2-42* illustrates the changes in pitch angle as the cyclic is moved forward at increased airspeeds. At a hover, the cyclic is centered and the pitch angle on the advancing and retreating blades is the same. At low forward speeds, moving the cyclic forward reduces pitch angle on the advancing blade and increases pitch angle on the retreating blade. This causes a slight rotor tilt. At higher forward speeds, the pilot must continue to move the cyclic forward. This further reduces pitch angle on the advancing blade and further increases pitch angle on the retreating blade. As a result, there is even more tilt to the rotor than at lower speeds.

This horizontal lift component (thrust) generates higher helicopter airspeed. The higher airspeed induces blade flapping to maintain symmetry of lift. The combination of flapping and cyclic feathering maintains symmetry of lift and desired attitude on the rotor system and helicopter.

Autorotation

Autorotation is the state of flight in which the main rotor system of a helicopter is being turned by the action of air moving up through the rotor rather than engine power driving the rotor. In normal, powered flight, air is drawn into the main rotor system from above and exhausted downward, but during autorotation, air moves up into the rotor system from below as the helicopter descends. Autorotation is permitted mechanically by a freewheeling unit, which is a special clutch mechanism that allows the main rotor to continue turning even if the engine is not running. If the engine fails, the freewheeling unit automatically disengages the engine from the main rotor allowing the main rotor to rotate freely. It is the means by which a helicopter can be landed safely in the event of an engine failure; consequently, all helicopters must demonstrate this capability in order to be certificated. *[Figure 2-43]*

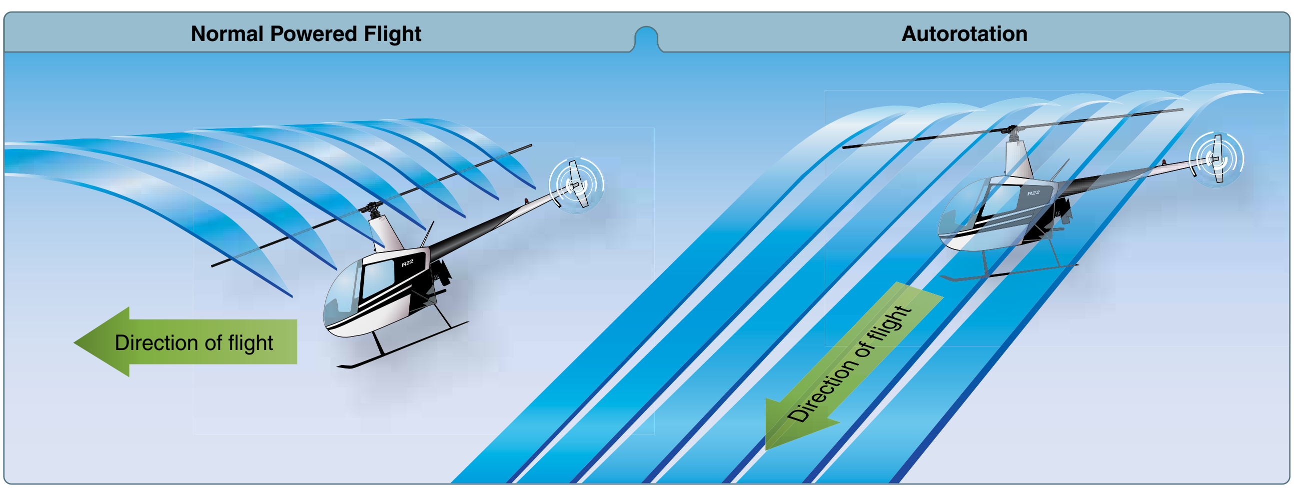


Figure 2-43. *During an autorotation, the upward flow of relative wind permits the main rotor blades to rotate at their normal speed. In effect, the blades are "gliding" in their rotational plane.*

Rotorcraft Controls

Swash Plate Assembly

The purpose of the swash plate is to transmit control inputs from the collective and cyclic controls to the main rotor blades. It consists of two main parts: the stationary swash plate and the rotating swash plate. *[Figure 2-44]*

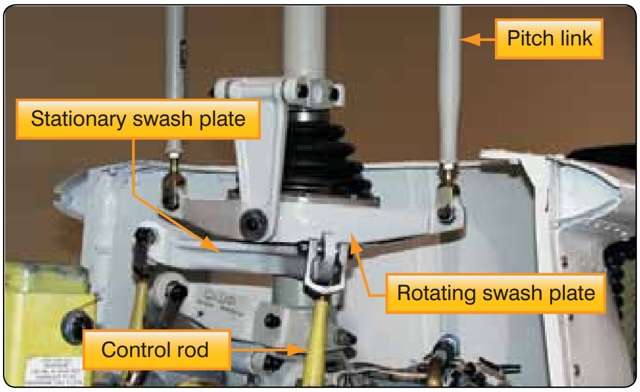


Figure 2-44. *Stationary and rotating swash plate.*

The stationary swash plate is mounted around the main rotor mast and connected to the cyclic and collective controls by a series of pushrods. It is restrained from rotating by an antidrive link but is able to tilt in all directions and move vertically. The rotating swash plate is mounted to the stationary swash plate by a uniball sleeve. It is connected to the mast by drive links and is allowed to rotate with the main rotor mast. Both swash plates tilt and slide up and down as one unit. The rotating swash plate is connected to the pitch horns by the pitch links.

There are three major controls in a helicopter that the pilot must use during flight. They are the collective pitch control, cyclic pitch control, and antitorque pedals or tail rotor control. In addition to these major controls, the pilot must also use the throttle control, which is mounted directly to the collective pitch control in order to fly the helicopter.

Collective Pitch Control

The collective pitch control is located on the left side of the pilot's seat and is operated with the left hand. The collective is used to make changes to the pitch angle of all the main rotor blades simultaneously, or collectively, as the name implies. As the collective pitch control is raised, there is a simultaneous and equal increase in pitch angle of all main rotor blades; as it is lowered, there is a simultaneous and equal decrease in pitch angle. This is done through a series of mechanical linkages, and the amount of movement in the collective lever determines the amount of blade pitch change. *[Figure 2-45]* An adjustable friction control helps prevent inadvertent collective pitch movement.

Figure 2-45. *Raising the collective pitch control increases the pitch angle by the same amount on all blades.*

Throttle Control

The function of the throttle is to regulate engine rpm. If the correlator or governor system does not maintain the desired rpm when the collective is raised or lowered, or if those systems are not installed, the throttle must be moved manually with the twist grip to maintain rpm. The throttle control is much like a motorcycle throttle, and works almost the same way; twisting the throttle to the left increases rpm, twisting the throttle to the right decreases rpm. *[Figure 2-46]*

Figure 2-46. *A twist grip throttle is usually mounted on the end of the collective lever. The throttles on some turbine helicopters are mounted on the overhead panel or on the floor in the cockpit.*

Governor/Correlator

A governor is a sensing device that senses rotor and engine rpm and makes the necessary adjustments in order to keep rotor rpm constant. Once the rotor rpm is set in normal operations, the governor keeps the rpm constant, and there is no need to make any throttle adjustments. Governors are common on all turbine helicopters (as it is a function of the fuel control system of the turbine engine), and used on some piston-powered helicopters.

A correlator is a mechanical connection between the collective lever and the engine throttle. When the collective lever is raised, power is automatically increased and when lowered, power is decreased. This system maintains rpm close to the desired value, but still requires adjustment of the throttle for fine tuning.

Some helicopters do not have correlators or governors and require coordination of all collective and throttle movements. When the collective is raised, the throttle must be increased; when the collective is lowered, the throttle must be decreased. As with any aircraft control, large adjustments of either collective pitch or throttle should be avoided. All corrections should be made with smooth pressure.

In piston helicopters, the collective pitch is the primary control for manifold pressure, and the throttle is the primary control for rpm. However, the collective pitch control also influences rpm, and the throttle also influences manifold pressure; therefore, each is considered to be a secondary control of the other's function. Both the tachometer (rpm indicator) and the manifold pressure gauge must be analyzed to determine which control to use. *Figure 2-47* illustrates this relationship.

If manifold pressure is	and rpm is	Solution
LOW	LOW	Increasing the throttle increases manifold pressure and rpm
HIGH	LOW	Lowering the collective pitch decreases manifold pressure and increases rpm
LOW	HIGH	Raising the collective pitch increases manifold pressure and decreases rpm
HIGH	HIGH	Reducing the throttle decreases manifold pressure and rpm

Figure 2-47. *Relationship between manifold pressure, rpm, collective, and throttle.*

Cyclic Pitch Control

The cyclic pitch control is mounted vertically from the cockpit floor, between the pilot's legs or, in some models, between the two pilot seats. *[Figure 2-48]* This primary flight control allows the pilot to fly the helicopter in any horizontal direction; fore, aft, and sideways. The total lift force is always perpendicular to the tip-path place of the main rotor. The purpose of the cyclic pitch control is to tilt the tip-path plane in the direction of the desired horizontal direction. The cyclic control changes the direction of this force and controls the attitude and airspeed of the helicopter.

The rotor disk tilts in the same direction the cyclic pitch control is moved. If the cyclic is moved forward, the rotor disk tilts forward; if the cyclic is moved aft, the disk tilts aft, and so on. Because the rotor disk acts like a gyro, the mechanical linkages for the cyclic control rods are rigged in such a way that they decrease the pitch angle of the rotor blade approximately 90° before it reaches the direction of cyclic displacement, and increase the pitch angle of the rotor blade approximately 90° after it passes the direction of displacement. An increase in pitch angle increases AOA; a decrease in pitch angle decreases AOA. For example, if the cyclic is moved forward, the AOA decreases as the rotor blade passes the right side of the helicopter and increases on the left side. This results in maximum downward deflection

Figure 2-48. *The cyclic pitch control may be mounted vertically between the pilot's knees or on a teetering bar from a single cyclic located in the center of the helicopter. The cyclic can pivot in all directions.*

of the rotor blade in front of the helicopter and maximum upward deflection behind it, causing the rotor disk to tilt forward.

Antitorque Pedals

The antitorque pedals are located on the cabin floor by the pilot's feet. They control the pitch and, therefore, the thrust of the tail rotor blades. *[Figure 2-49]* Newton's Third Law applies to the helicopter fuselage and how it rotates in the opposite direction of the main rotor blades unless counteracted and controlled. To make flight possible and to compensate for this torque, most helicopter designs incorporate an antitorque rotor or tail rotor. The antitorque pedals allow the pilot to control the pitch angle of the tail rotor blades which in forward flight puts the helicopter in longitudinal trim and while at a hover, enables the pilot to turn the helicopter 360°. The antitorque pedals are connected to the pitch change mechanism on the tail rotor gearbox and allow the pitch angle on the tail rotor blades to be increased or decreased.

Figure 2-49. *Antitorque pedals compensate for changes in torque and control heading in a hover.*

Helicopters that are designed with tandem rotors do not have an antitorque rotor. These helicopters are designed with both rotor systems rotating in opposite directions to counteract the torque, rather than using a tail rotor. Directional antitorque pedals are used for directional control of the aircraft while in flight, as well as while taxiing with the forward gear off the ground. With the right pedal displaced forward, the forward rotor disk tilts to the right, while the aft rotor disk tilts to the left. The opposite occurs when the left pedal is pushed forward; the forward rotor disk inclines to the left, and the aft rotor disk tilts to the right. Differing combinations of pedal and cyclic application can allow the tandem rotor helicopter to pivot about the aft or forward vertical axis, as well as pivoting about the center of mass.

Stabilizer Systems

Bell Stabilizer Bar System

Arthur M. Young discovered that stability could be increased significantly with the addition of a stabilizer bar perpendicular to the two blades. The stabilizer bar has weighted ends, which cause it to stay relatively stable in the plane of rotation. The stabilizer bar is linked with the swash plate in a manner that reduces the pitch rate. The two blades can flap as a unit and, therefore, do not require lag-lead hinges (the whole rotor slows down and accelerates per turn). Two-bladed systems require a single teetering hinge and two coning hinges to permit modest coning of the rotor disk as thrust is increased. The configuration is known under multiple names, including Hiller panels, Hiller system, Bell-Hiller system, and flybar system.

Offset Flapping Hinge

The offset flapping hinge is offset from the center of the rotor hub and can produce powerful moments useful for controlling the helicopter. The distance of the hinge from the hub (the offset) multiplied by the force produced at the hinge produces a moment at the hub. Obviously, the larger the offset, the greater the moment for the same force produced by the blade.

The flapping motion is the result of the constantly changing balance between lift, centrifugal, and inertial forces. This rising and falling of the blades is characteristic of most helicopters and has often been compared to the beating of a bird's wing. The flapping hinge, together with the natural flexibility found in most blades, permits the blade to droop considerably when the helicopter is at rest and the rotor is not turning over. During flight, the necessary rigidity is provided by the powerful centrifugal force that results from the rotation of the blades. This force pulls outward from the tip, stiffening the blade, and is the only factor that keeps it from folding up.

Stability Augmentation Systems (SAS)

Some helicopters incorporate stability augmentation systems (SAS) to help stabilize the helicopter in flight and in a hover. The simplest of these systems is a force trim system, which uses a magnetic clutch and springs to hold the cyclic control in the position at which it was released. More advanced systems use electric actuators that make inputs to the hydraulic servos. These servos receive control commands from a computer that senses helicopter attitude. Other inputs, such as heading, speed, altitude, and navigation information may be supplied to the computer to form a complete autopilot system. The SAS may be overridden or disconnected by the pilot at any time.

SAS reduces pilot workload by improving basic aircraft control harmony and decreasing disturbances. These systems are very useful when the pilot is required to perform other duties, such as sling loading and search and rescue operations.

Helicopter Vibration

The following paragraphs describe the various types of vibrations. *Figure 2-50* shows the general levels into which frequencies are divided.

Extreme Low Frequency Vibration

Extreme low frequency vibration is pretty well limited to pylon rock. Pylon rocking (two to three cycles per second) is inherent with the rotor, mast, and transmission system. To keep the vibration from reaching noticeable levels, transmission mount dampening is incorporated to absorb the rocking.

Helicopter Vibration Types	
Frequency Level	Vibration
Extreme low frequency	Less than 1/rev PYLON ROCK
Low frequency	1/rev or 2/rev type vibration
Medium frequency	Generally 4, 5, or 6/rev
High frequency	Tail rotor speed or faster

Figure 2-50. *Various helicopter vibration types.*

Low Frequency Vibration

Low frequency vibrations (1/rev and 2/rev) are caused by the rotor itself. 1/rev vibrations are of two basic types: vertical or lateral. A 1/rev is caused simply by one blade developing more lift at a given point than the other blade develops at the same point.

Medium Frequency Vibration

Medium frequency vibration (4/rev and 6/rev) is another vibration inherent in most rotors. An increase in the level of these vibrations is caused by a change in the capability of the fuselage to absorb vibration, or a loose airframe component, such as the skids, vibrating at that frequency.

High Frequency Vibration

High frequency vibrations can be caused by anything in the helicopter that rotates or vibrates at extremely high speeds. The most common and obvious causes: loose elevator linkage at swashplate horn, loose elevator, or tail rotor balance and track.

Rotor Blade Tracking

Blade tracking is the process of determining the positions of the tips of the rotor blade relative to each other while the rotor head is turning, and of determining the corrections necessary to hold these positions within certain tolerances. The blades should all track one another as closely as possible. The purpose of blade tracking is to bring the tips of all blades into the same tip path throughout their entire cycle of rotation. Various methods of blade tracking are explained in the following paragraphs.

Flag and Pole

The flag and pole method, as shown in *Figure 2-51,* shows the relative positions of the rotor blades. The blade tips are marked with chalk or a grease pencil. Each blade tip should be marked with a different color so that it is easy to determine the relationship of the other tips of the rotor blades to each other. This method can be used on all types of helicopters that do not have jet propulsion at the blade tips. Refer to the applicable maintenance manual for specific procedures.

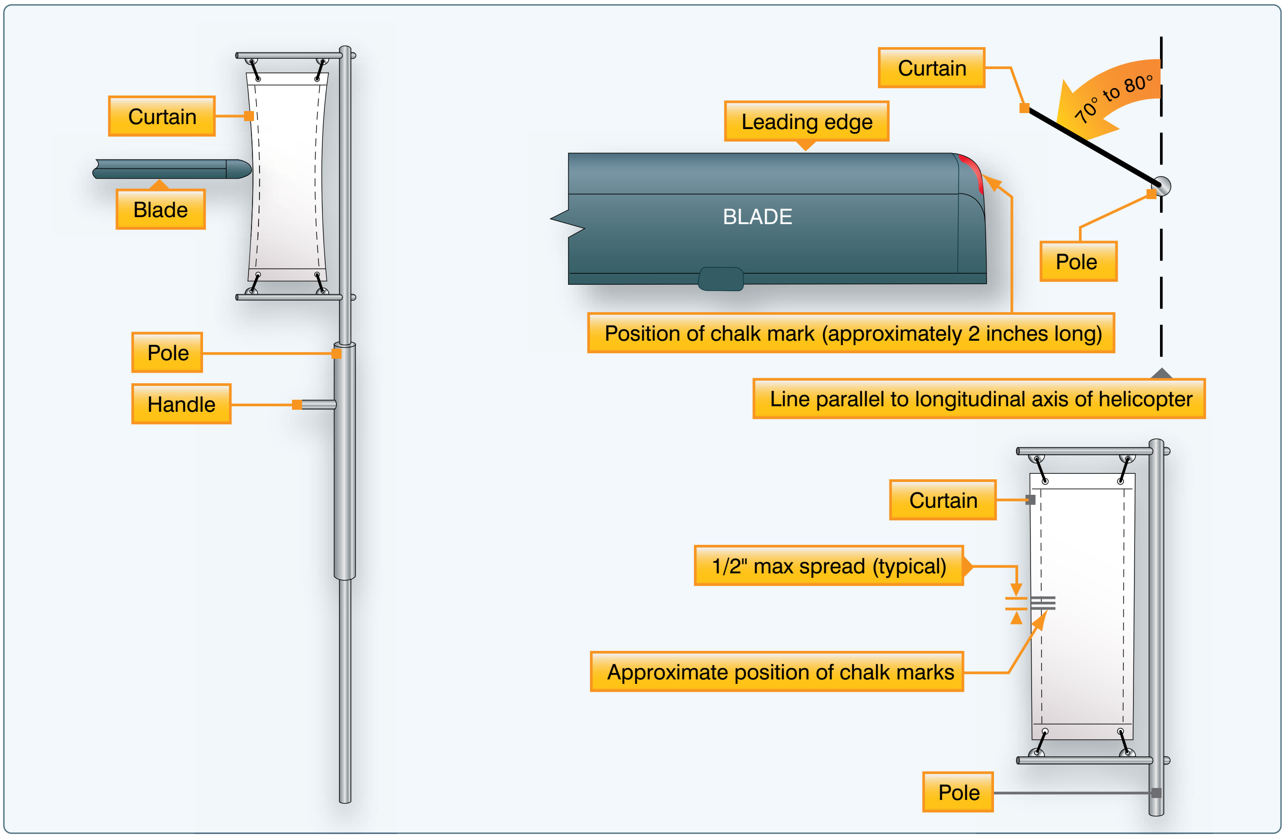


Figure 2-51. *Flag and pole blade tracking.*

Electronic Blade Tracker

The most common electronic blade tracker consists of a Balancer/Phazor, Strobex Tracker, and Vibrex Tester. *[Figures 2-52* through *2-54]* The Strobex blade tracker permits blade tracking from inside or outside the helicopter while on the ground or inside the helicopter in flight. The system uses a highly concentrated light beam flashing in sequence with the rotation of the main rotor blades so that a fixed target at the blade tips appears to be stopped. Each blade is identified by an elongated retroreflective number taped or attached to the underside of the blade in a uniform location. When viewed at an angle from inside the helicopter, the taped numbers will appear normal. Tracking can be accomplished with tracking tip cap reflectors and a strobe light. The tip caps are temporarily attached to the tip of each blade. The high-intensity strobe light flashes in time with the rotating blades. The strobe light operates from the aircraft electrical power supply. By observing the reflected tip cap image, it is possible to view the track of the rotating blades. Tracking is accomplished in a sequence of four separate steps: ground tracking, hover verification, forward flight tracking, and auto rotation rpm adjustment.

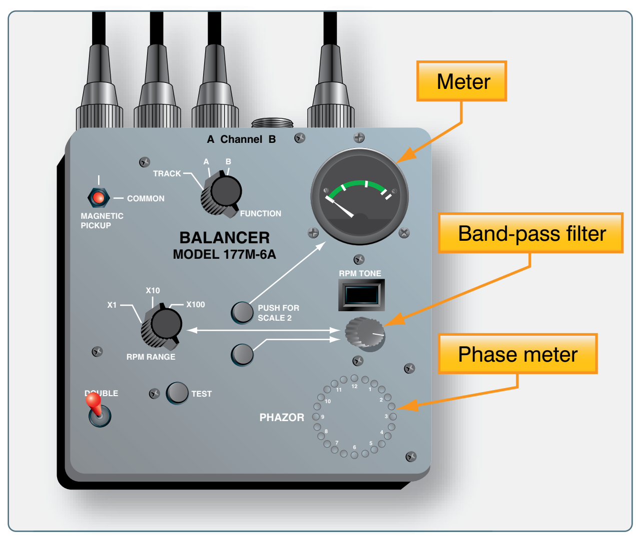


Figure 2-52. *Balancer/Phazor.*

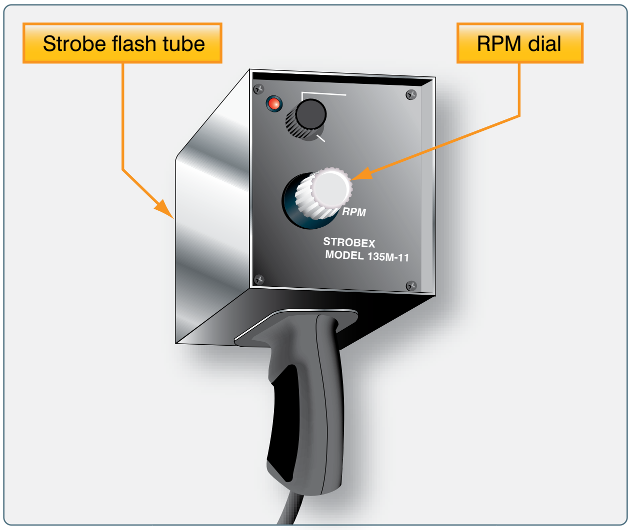


Figure 2-53. *Strobex tracker.*

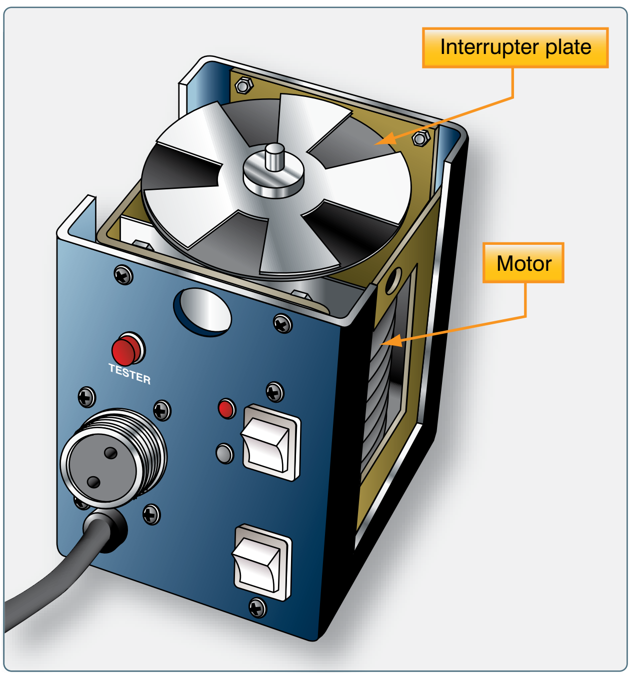


Figure 2-54. *Vibrex tracker.*

Tail Rotor Tracking

The marking and electronic methods of tail rotor tracking are explained in the following paragraphs.

Marking Method

Procedures for tail rotor tracking using the marking method, as shown in *Figure 2-55*, are as follows:

- After replacement or installation of tail rotor hub, blades, or pitch change system, check tail rotor rigging and track tail rotor blades. Tail rotor tip clearance shall be set before tracking and checked again after tracking.

Figure 2-55. *Tail rotor tracking.*

- The strobe-type tracking device may be used if available. Instructions for use are provided with the device. Attach a piece of soft rubber hose six inches long on the end of a ½ × ½ inch pine stick or other flexible device. Cover the rubber hose with Prussian blue or similar type of coloring thinned with oil.

NOTE: Ground run-up shall be performed by authorized personnel only. Start engine in accordance with applicable maintenance manual. Run engine with pedals in neutral position. Reset marking device on underside of tail boom assembly. Slowly move marking device into disk of tail rotor approximately one inch from tip. When near blade is marked, stop engine and allow rotor to stop. Repeat this procedure until tracking mark crosses over to the other blade, then extend pitch control link of unmarked blade one half turn.

Electronic Method

The electronic Vibrex balancing and tracking kit is housed in a carrying case and consists of a Model 177M-6A Balancer, a Model 135M-11 Strobex, track and balance charts, an accelerometer, cables, and attaching brackets.

The Vibrex balancing kit is used to measure and indicate the level of vibration induced by the main rotor and tail rotor of a helicopter. The Vibrex analyzes the vibration induced by out-of-track or out-of-balance rotors, and then by plotting vibration amplitude and clock angle on a chart the amount and location of rotor track or weight change is determined. In addition, the Vibrex is used in troubleshooting by measuring the vibration levels and frequencies or rpm of unknown disturbances.

Rotor Blade Preservation and Storage

Accomplish the following requirements for rotor blade preservation and storage:

- Condemn, demilitarize, and dispose of locally any blade which has incurred nonrepairable damage.
- Tape all holes in the blade, such as tree damage, or foreign object damage (FOD) to protect the interior of the blade from moisture and corrosion.
- Thoroughly remove foreign matter from the entire exterior surface of blade with mild soap and water.
- Protect blade outboard eroded surfaces with a light coating of corrosion preventive or primer coating.
- Protect blade main bolt hole bushing, drag brace retention bolt hole bushing, and any exposed bare metal (i.e., grip and drag pads) with a light coating of corrosion preventive.
- Secure blade to shock-mounted support and secure container lid.
- Place copy of manufacturer's blade records, containing information required by Title 14 of the Code of Federal Regulations (14 CFR) section 91.417(a)(2)(ii), and any other blade records in a waterproof bag and insert into container record tube.
- Obliterate old markings from the container that pertained to the original shipment or to the original item it contained. Stencil the blade National Stock Number (NSN), model, and serial number, as applicable, on the outside of the container.

Helicopter Power Systems

Powerplant

The two most common types of engines used in helicopters are the reciprocating engine and the turbine engine. Reciprocating engines, also called piston engines, are generally used in smaller helicopters. Most training helicopters use reciprocating engines because they are relatively simple and inexpensive to operate. Turbine engines are more powerful and are used in a wide variety of helicopters. They produce a tremendous amount of power for their size but are generally more expensive to operate.

Reciprocating Engine

The reciprocating engine consists of a series of pistons connected to a rotating crankshaft. As the pistons move up and down, the crankshaft rotates. The reciprocating engine gets its name from the back-and-forth movement of its internal parts. The four-stroke engine is the most common type, and refers to the four different cycles the engine undergoes to produce power. *[Figure 2-56]*

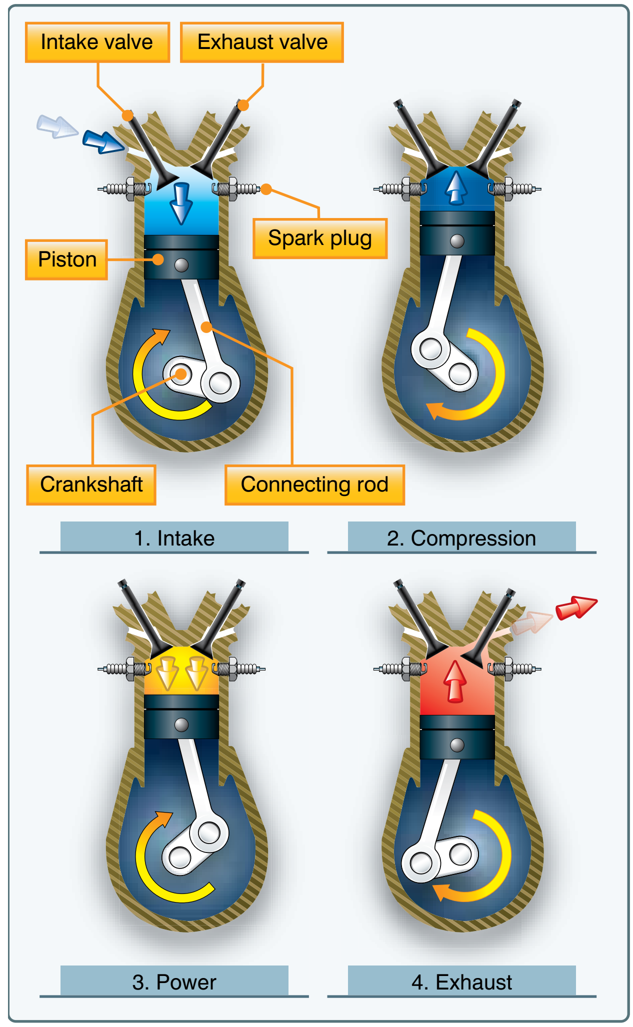


Figure 2-56. *The arrows indicate the direction of motion of the crankshaft and piston during the four-stroke cycle.*

When the piston moves away from the cylinder head on the intake stroke, the intake valve opens and a mixture of fuel and air is drawn into the combustion chamber. As the cylinder moves back toward the cylinder head, the intake valve closes, and the fuel/air mixture is compressed. When compression is nearly complete, the spark plugs fire and the compressed mixture is ignited to begin the power stroke. The rapidly expanding gases from the controlled burning of the fuel/air mixture drive the piston away from the cylinder head, thus providing power to rotate the crankshaft. The piston then moves back toward the cylinder head on the exhaust stroke where the burned gases are expelled through the opened exhaust valve. Even when the engine is operated at a fairly low speed, the four-stroke cycle takes place several hundred times each minute. In a four-cylinder engine, each cylinder operates on a different stroke. Continuous rotation of a crankshaft is maintained by the precise timing of the power strokes in each cylinder.

Turbine Engine

The gas turbine engine mounted on most helicopters is made up of a compressor, combustion chamber, turbine, and accessory gearbox assembly. The compressor draws filtered air into the plenum chamber and compresses it. The compressed air is directed to the combustion section through discharge tubes where atomized fuel is injected into it. The fuel/air mixture is ignited and allowed to expand. This combustion gas is then forced through a series of turbine wheels causing them to turn. These turbine wheels provide power to both the engine compressor and the accessory gearbox. Power is provided to the main rotor and tail rotor systems through the freewheeling unit which is attached to the accessory gearbox power output gear shaft. The combustion gas is finally expelled through an exhaust outlet. *[Figure 2-57]*

Transmission System

The transmission system transfers power from the engine to the main rotor, tail rotor, and other accessories during normal flight conditions. The main components of the transmission system are the main rotor transmission, tail rotor drive system, clutch, and freewheeling unit. The freewheeling unit, or autorotative clutch, allows the main rotor transmission to drive the tail rotor drive shaft during autorotation. Helicopter transmissions are normally lubricated and cooled with their own oil supply. A sight gauge is provided to check the oil level. Some transmissions have chip detectors located in the sump. These detectors are wired to warning lights located on the pilot's instrument panel that illuminate in the event of an internal problem. The chip detectors on modern helicopters have a "burn off" capability and attempt to correct the situation without pilot action. If the problem cannot be corrected on its own, the pilot must refer to the emergency procedures for that particular helicopter.

Main Rotor Transmission

The primary purpose of the main rotor transmission is to reduce engine output rpm to optimum rotor rpm. This reduction is different for the various helicopters. As an example, suppose the engine rpm of a specific helicopter is 2,700. A rotor speed of 450 rpm would require a 6:1 reduction. A 9:1 reduction would mean the rotor would turn at 300 rpm. Most helicopters use a dual-needle tachometer or a vertical scale instrument to show both engine and rotor rpm or a percentage of engine and rotor rpm. The rotor rpm indicator normally is used only during clutch engagement to monitor rotor acceleration, and in autorotation to maintain rpm within prescribed limits. *[Figure 2-58]*

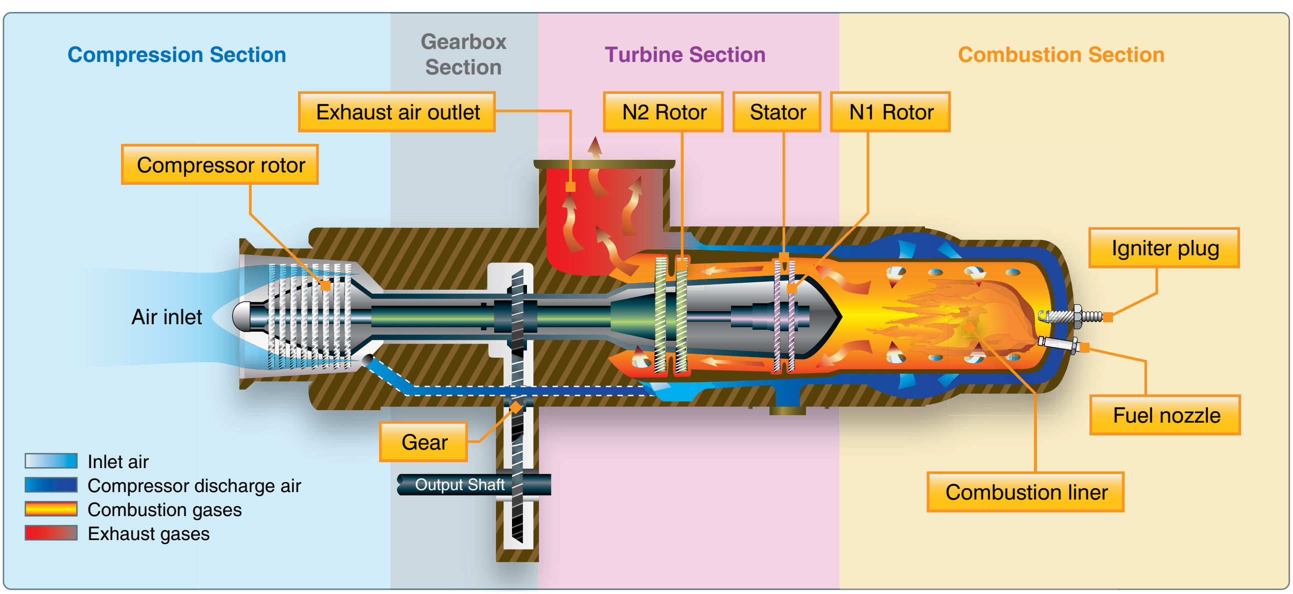


Figure 2-57. *Many helicopters use a turboshaft engine to drive the main transmission and rotor systems. The main difference between a turboshaft and a turbojet engine is that most of the energy produced by the expanding gases is used to drive a turbine rather than producing thrust through the expulsion of exhaust gases.*

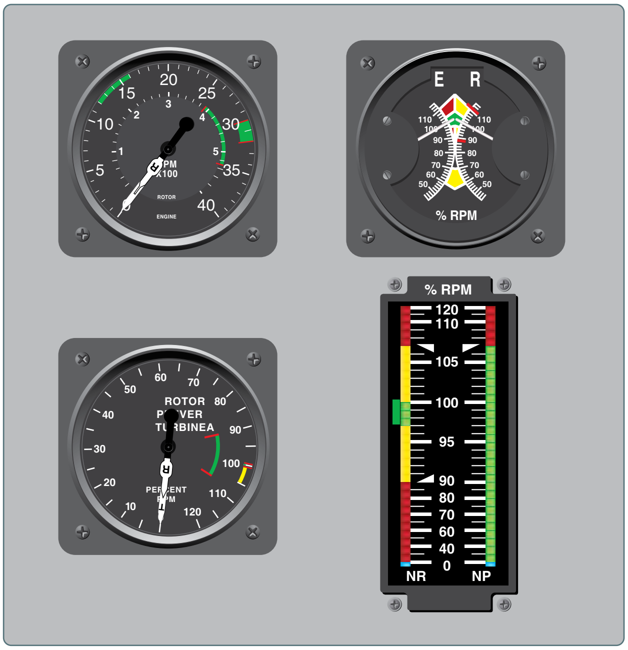


Figure 2-58. *There are various types of dual-needle tachometers; however, when the needles are superimposed, or married, the ratio of the engine rpm is the same as the gear reduction ratio.*

In helicopters with horizontally mounted engines, another purpose of the main rotor transmission is to change the axis of rotation from the horizontal axis of the engine to the vertical axis of the rotor shaft. *[Figure 2-59]*

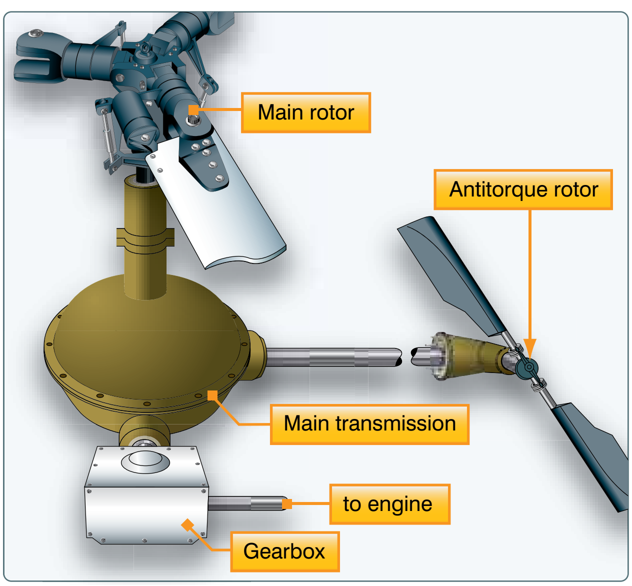


Figure 2-59. *The main rotor transmission and gearbox reduce engine output rpm to optimum rotor rpm and change the axis of rotation of the engine output shaft to the vertical axis for the rotor shaft.*

Clutch

In a conventional airplane, the engine and propeller are permanently connected. However, in a helicopter there is a different relationship between the engine and the rotor. Because of the greater weight of a rotor in relation to the power of the engine, as compared to the weight of a propeller and the power in an airplane, the rotor must be disconnected from the engine when the starter is engaged. A clutch allows the engine to be started and then gradually pick up the load of the rotor.

On free turbine engines, no clutch is required, as the gas producer turbine is essentially disconnected from the power turbine. When the engine is started, there is little resistance from the power turbine. This enables the gas producer turbine to accelerate to normal idle speed without the load of the transmission and rotor system dragging it down. As the gas pressure increases through the power turbine, the rotor blades begin to turn, slowly at first and then gradually accelerate to normal operating rpm.

On reciprocating helicopters, the two main types of clutches are the centrifugal clutch and the belt drive clutch.

Centrifugal Clutch

The centrifugal clutch is made up of an inner assembly and an outer drum. The inner assembly, which is connected to the engine driveshaft, consists of shoes lined with material similar to automotive brake linings. At low engine speeds, springs hold the shoes in, so there is no contact with the outer drum, which is attached to the transmission input shaft. As engine speed increases, centrifugal force causes the clutch shoes to move outward and begin sliding against the outer drum. The transmission input shaft begins to rotate, causing the rotor to turn, slowly at first, but increasing as the friction increases between the clutch shoes and transmission drum. As rotor speed increases, the rotor tachometer needle shows an increase by moving toward the engine tachometer needle. When the two needles are superimposed, the engine and the rotor are synchronized, indicating the clutch is fully engaged and there is no further slippage of the clutch shoes.

Belt Drive Clutch

Some helicopters utilize a belt drive to transmit power from the engine to the transmission. A belt drive consists of a lower pulley attached to the engine, an upper pulley attached to the transmission input shaft, a belt or a series of V-belts, and some means of applying tension to the belts. The belts fit loosely over the upper and lower pulley when there is no tension on the belts. This allows the engine to be started without any load from the transmission. Once the engine is running, tension on the belts is gradually increased. When the rotor and engine tachometer needles are superimposed, the rotor and the engine are synchronized, and the clutch is then fully engaged. Advantages of this system include vibration isolation, simple maintenance, and the ability to start and warm up the engine without engaging the rotor.

Freewheeling Unit

Since lift in a helicopter is provided by rotating airfoils, these airfoils must be free to rotate if the engine fails. The freewheeling unit automatically disengages the engine from the main rotor when engine rpm is less than main rotor rpm. This allows the main rotor and tail rotor to continue turning at normal in-flight speeds. The most common freewheeling unit assembly consists of a one-way sprag clutch located between the engine and main rotor transmission. This is usually in the upper pulley in a piston helicopter or mounted on the accessory gearbox in a turbine helicopter. When the engine is driving the rotor, inclined surfaces in the sprag clutch force rollers against an outer drum. This prevents the engine from exceeding transmission rpm. If the engine fails, the rollers move inward, allowing the outer drum to exceed the speed of the inner portion. The transmission can then exceed the speed of the engine. In this condition, engine speed is less than that of the drive system, and the helicopter is in an autorotative state.

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

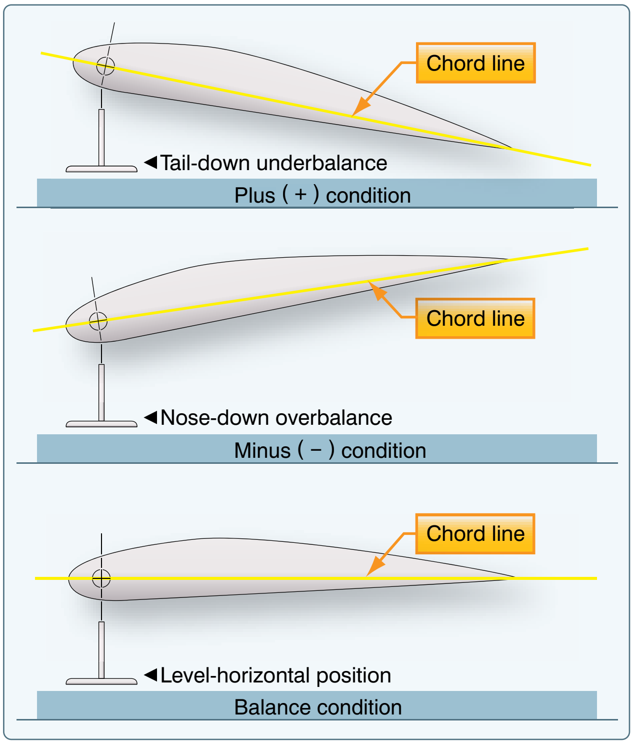


Figure 2-60. *Control surface static balance.*

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]*

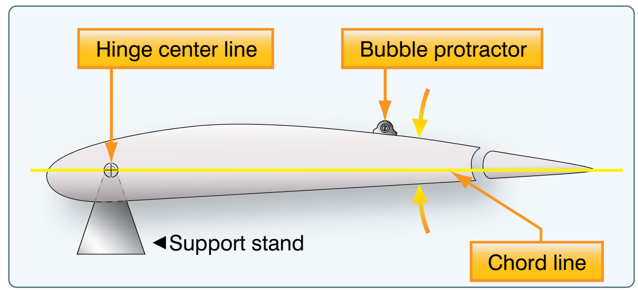


Figure 2-62. *Establishing a neutral position of the control surface.*

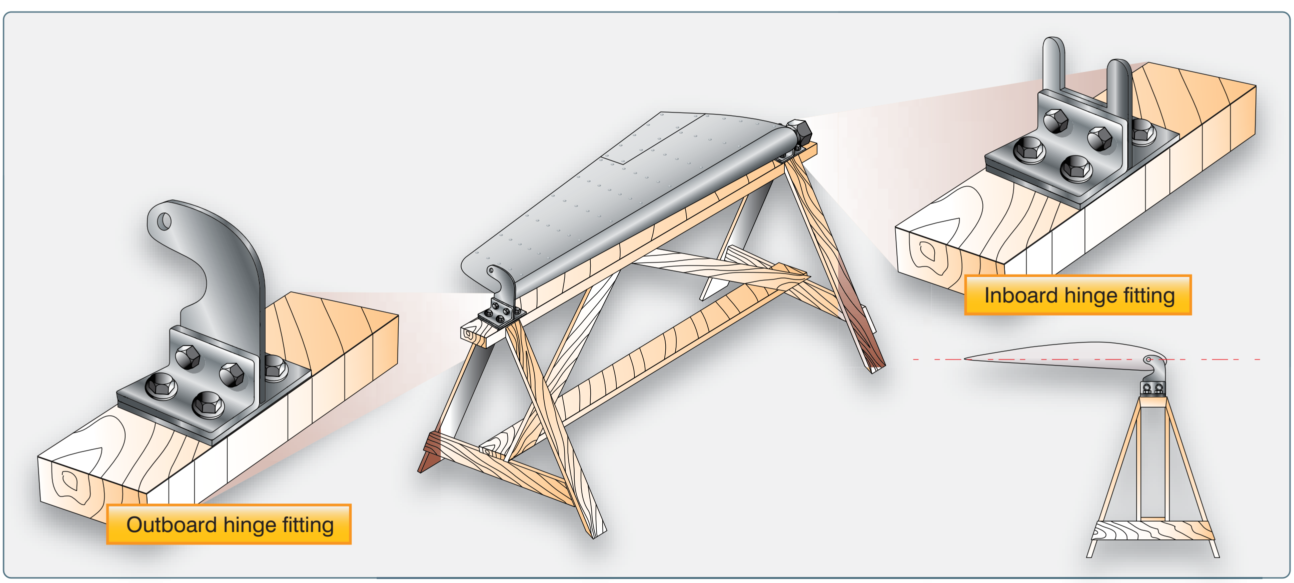


Figure 2-61. *Locally fabricated balancing fixture.*

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.

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]*

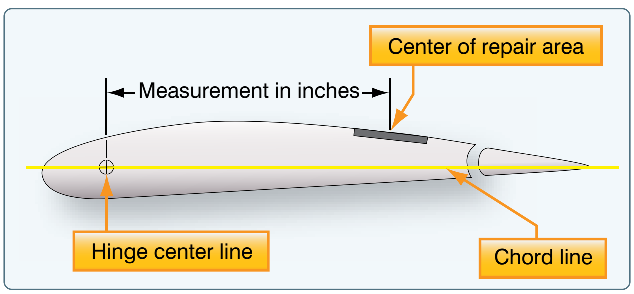


Figure 2-63. *Calculation method measurement.*

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 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.

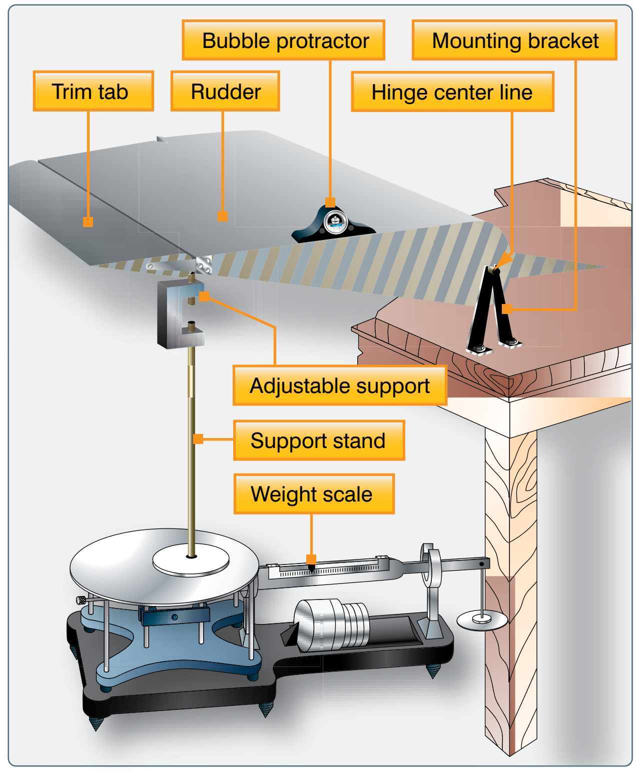


Figure 2-64. *Balancing setup.*

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 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 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]*

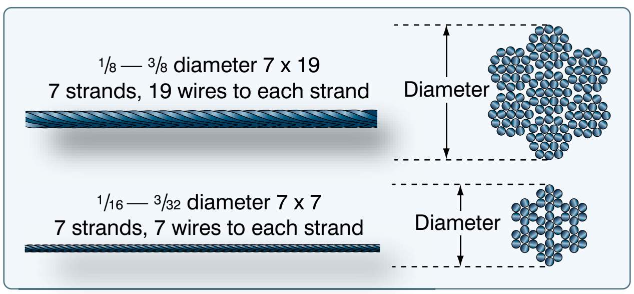


Figure 2-65. *Cable construction and cross-section.*

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 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 ⅜-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]*

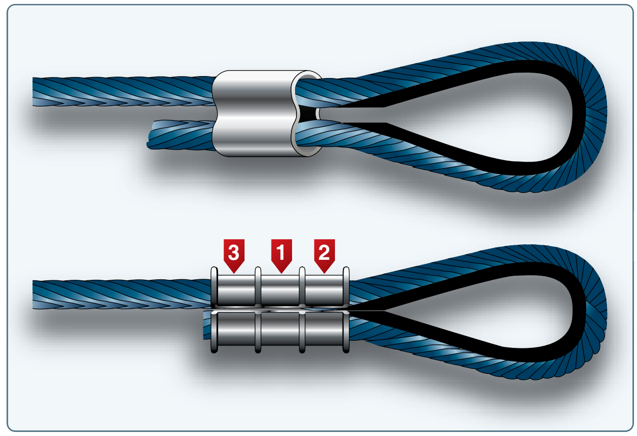


Figure 2-66. *Typical Nicopress® thimble-eye splice.*

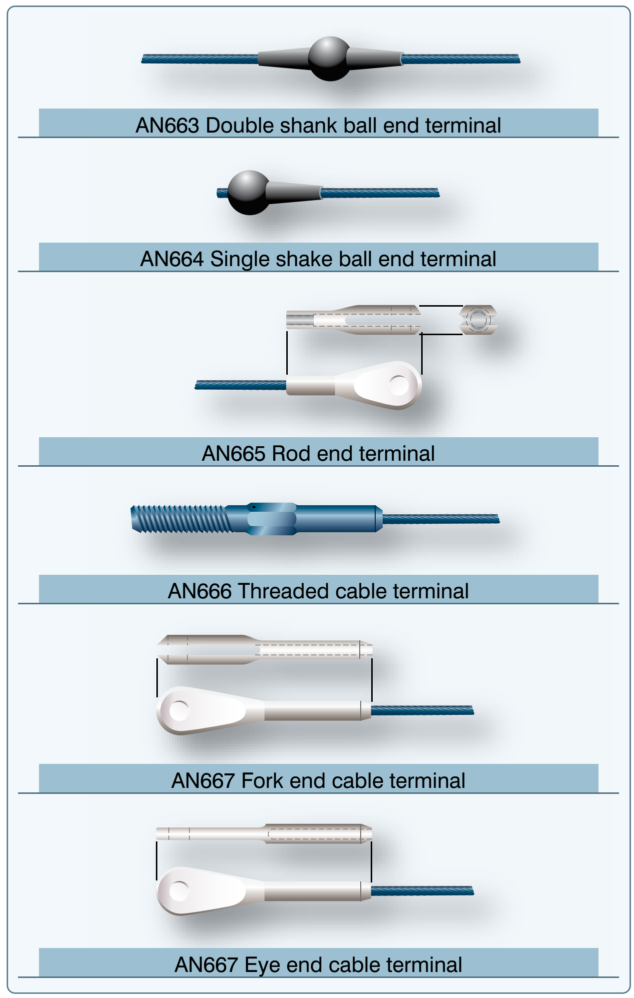


Figure 2-67. *Swage-type terminal fittings.*

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.

  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]*
- 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*.

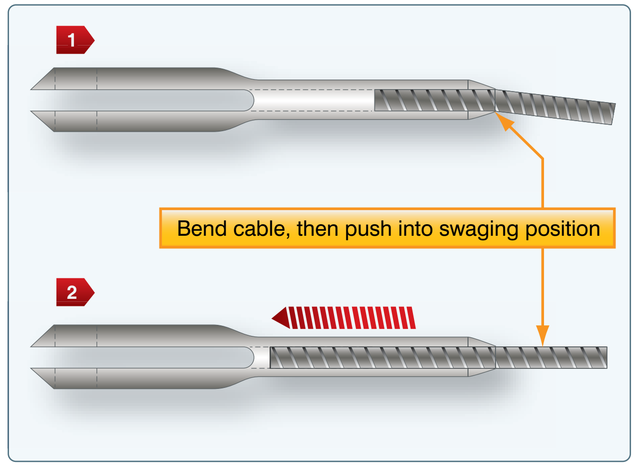


Figure 2-68. *Insertion of cable into terminal.*

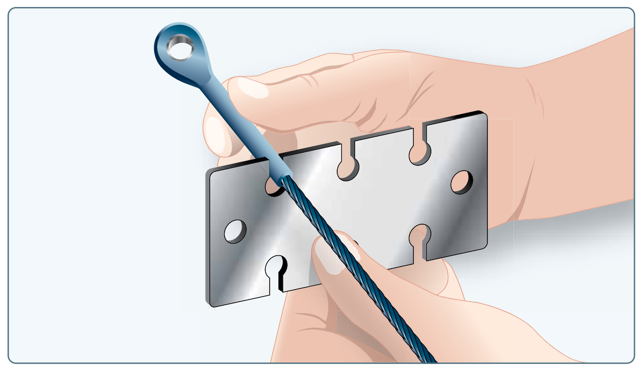


Figure 2-69. *Gauging terminal shank dimension after swaging.*

		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.*

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

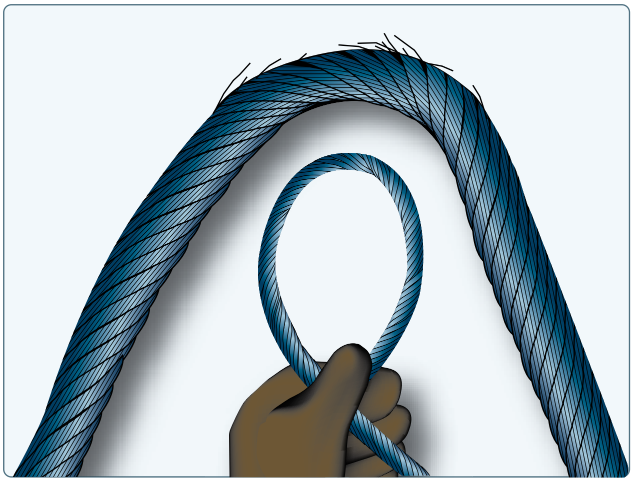


Figure 2-72. *Cable inspection technique.*

jamming or 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]*

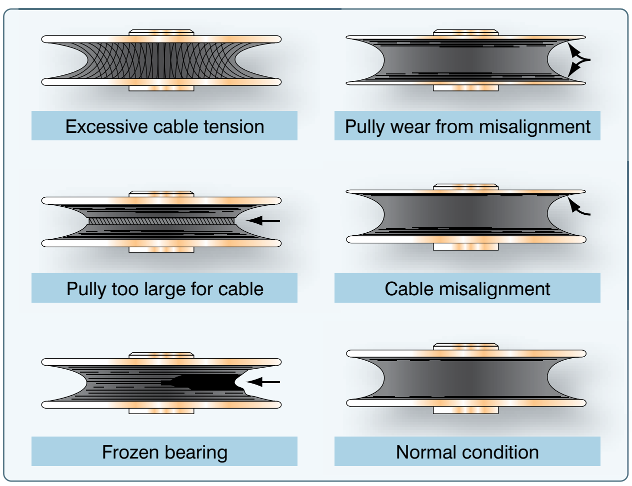


Figure 2-73. *Pulley wear patterns.*

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]*

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.

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.

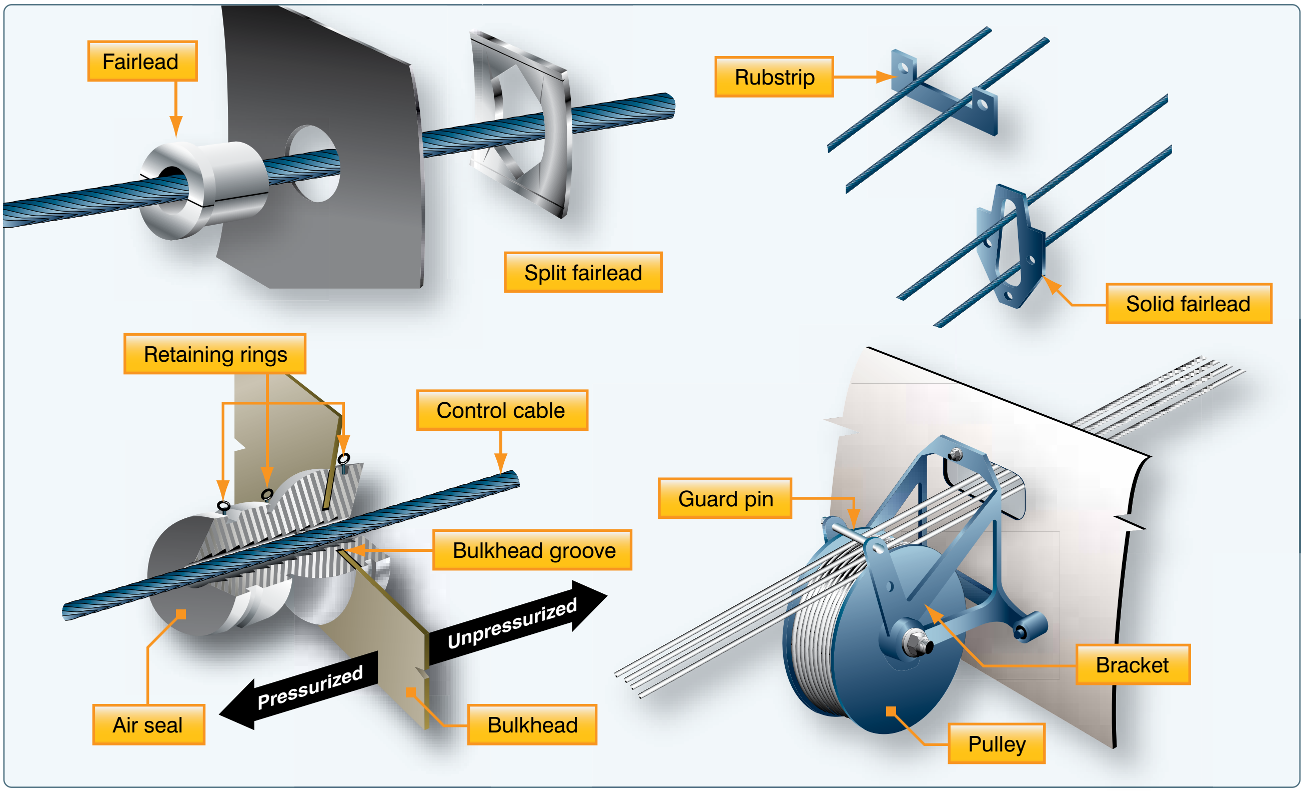


Figure 2-74. *Cable guides.*

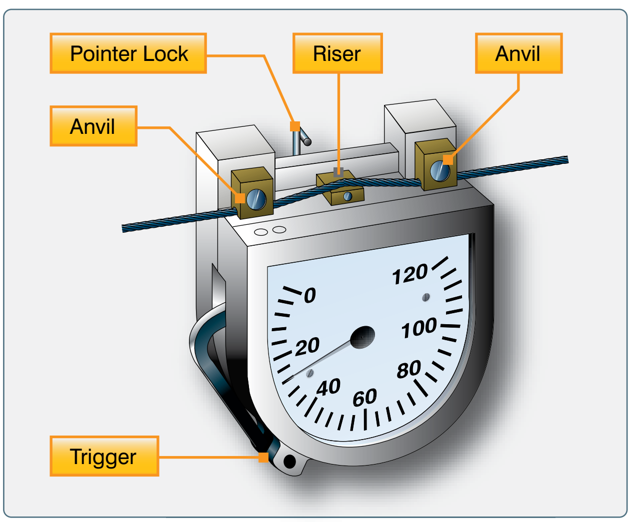


Figure 2-75. *Tensiometer.*

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.

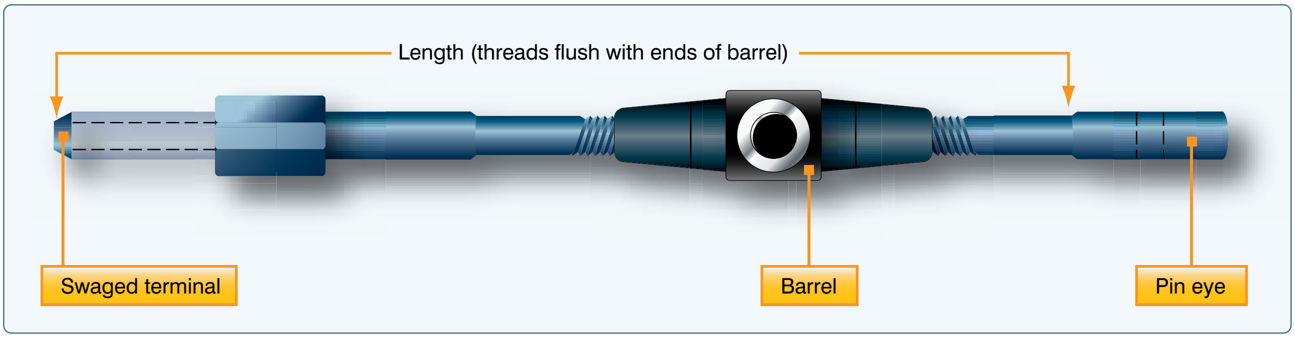


Figure 2-76. *Typical turnbuckle assembly.*

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.

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*.

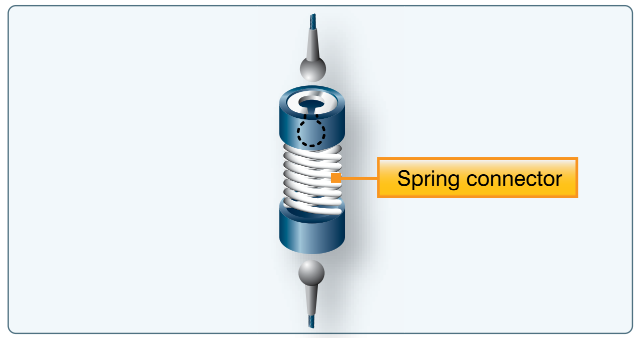


Figure 2-78. *Spring-type connector.*

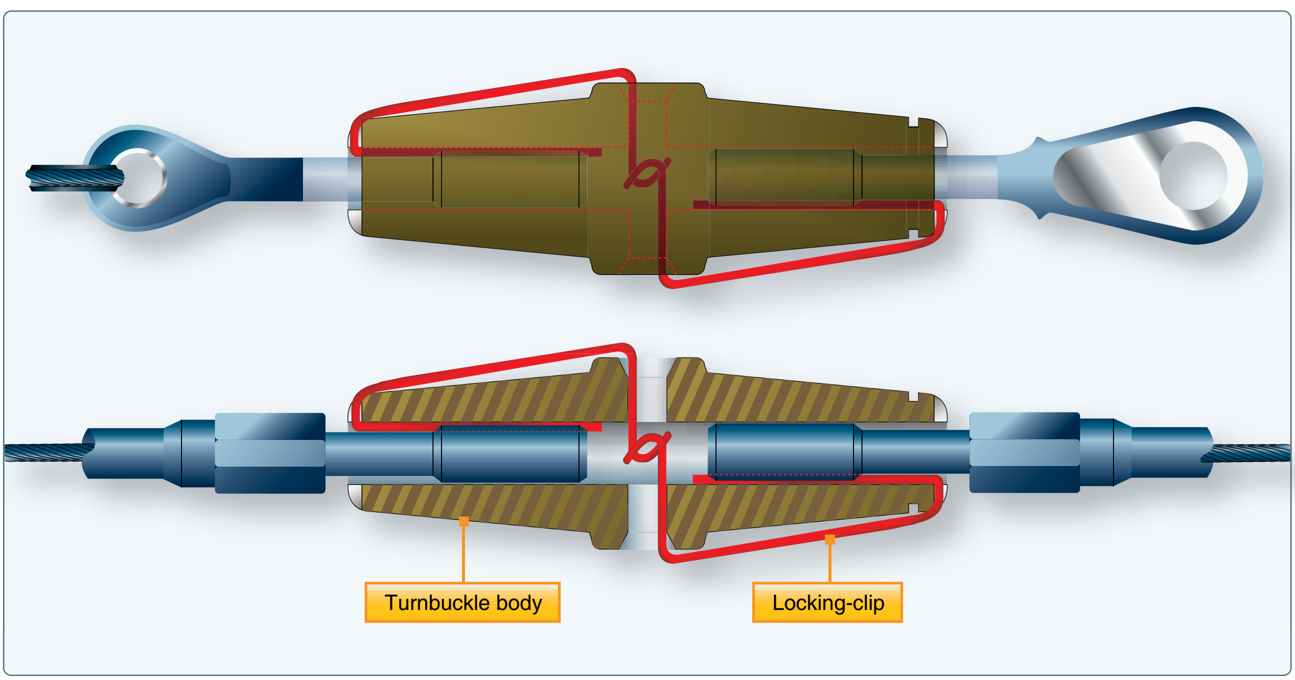


Figure 2-77. *Clip-type locking device and assembling in turnbuckle.*

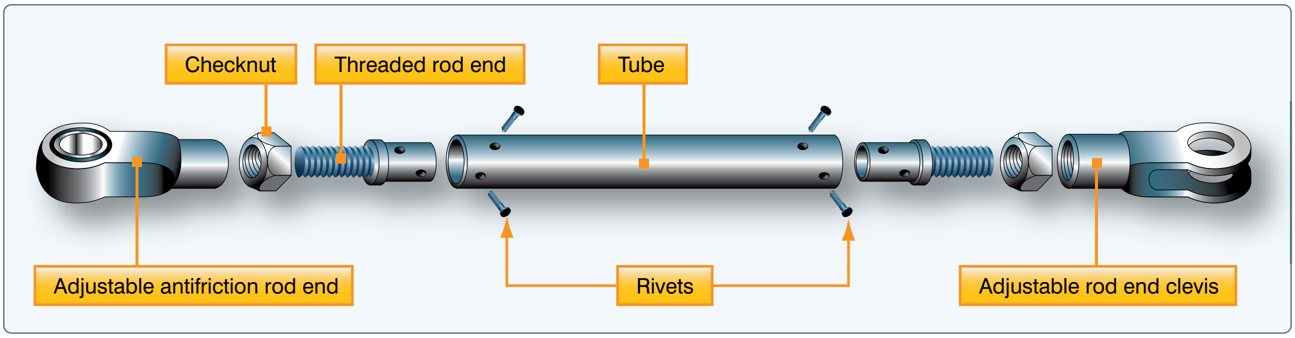


Figure 2-79. *Push rod.*

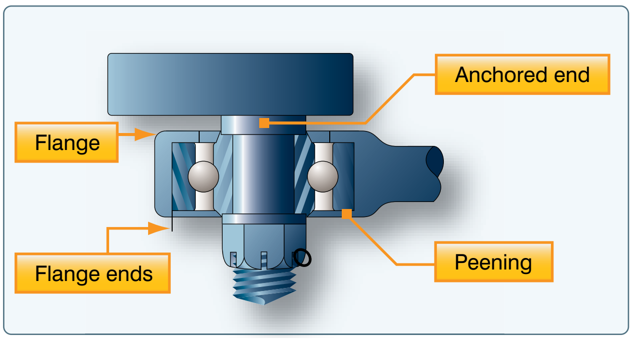


Figure 2-80. *Attached rod end.*

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.

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]*

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 type certificate data sheets (TCDS) also provide information regarding control surface movement and weight and balance limits.

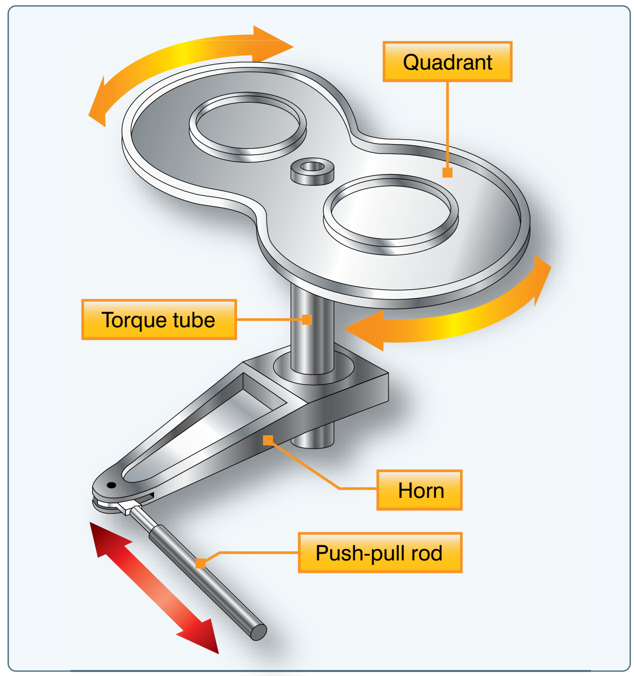


Figure 2-81. *Torque tube.*

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.

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.

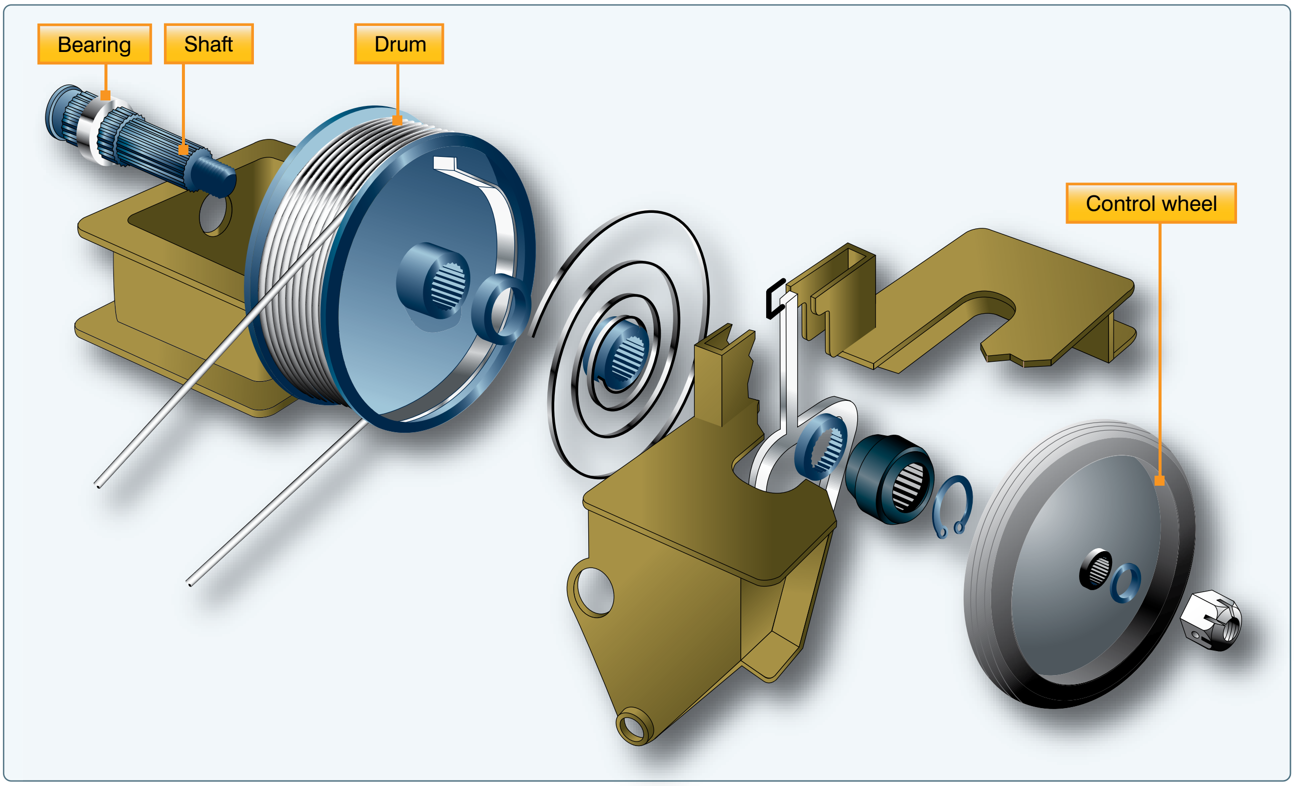


Figure 2-82. *Trim tab cable drum.*

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.

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

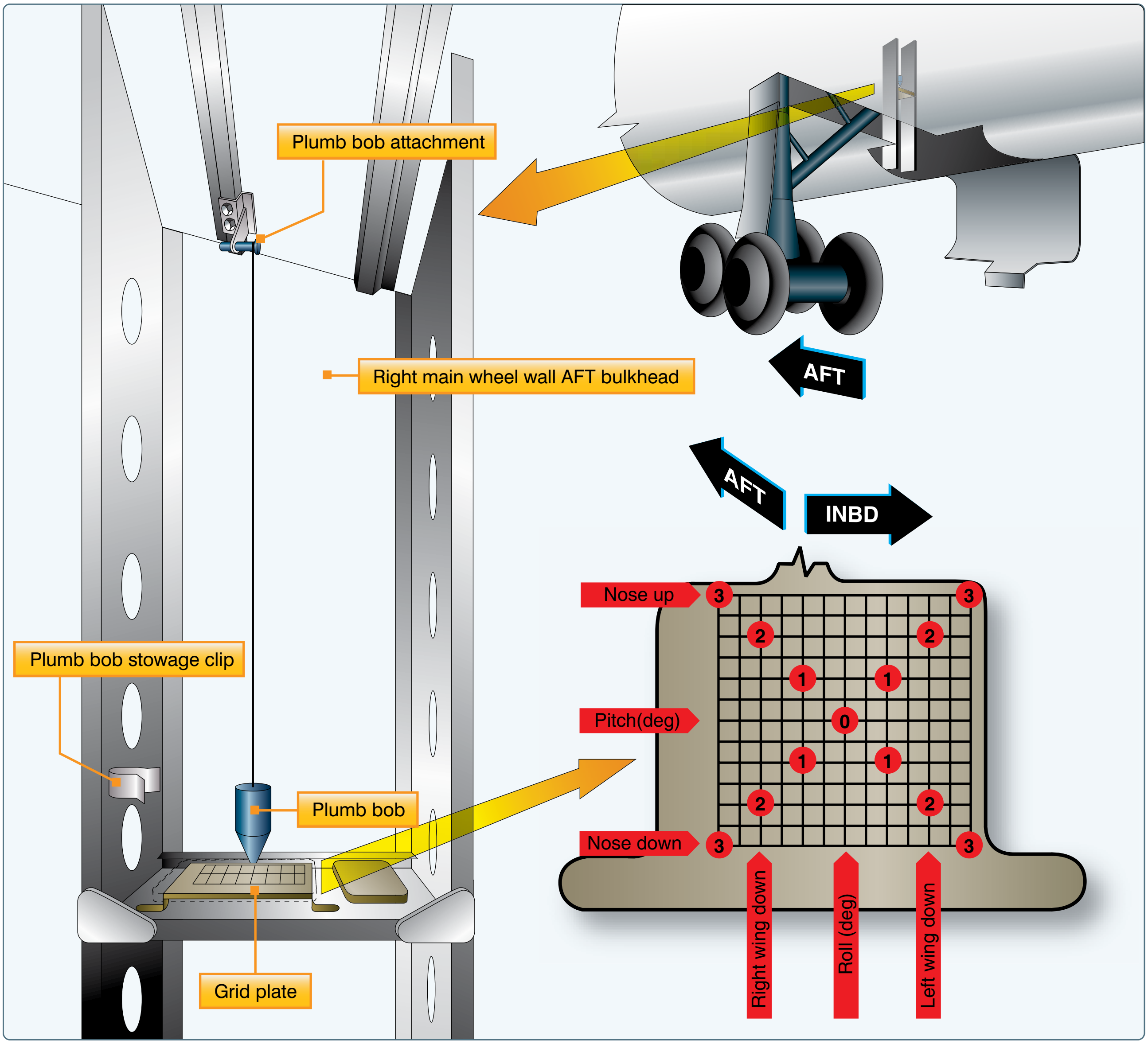


Figure 2-83. *Grid plate installed.*

- 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. 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*.

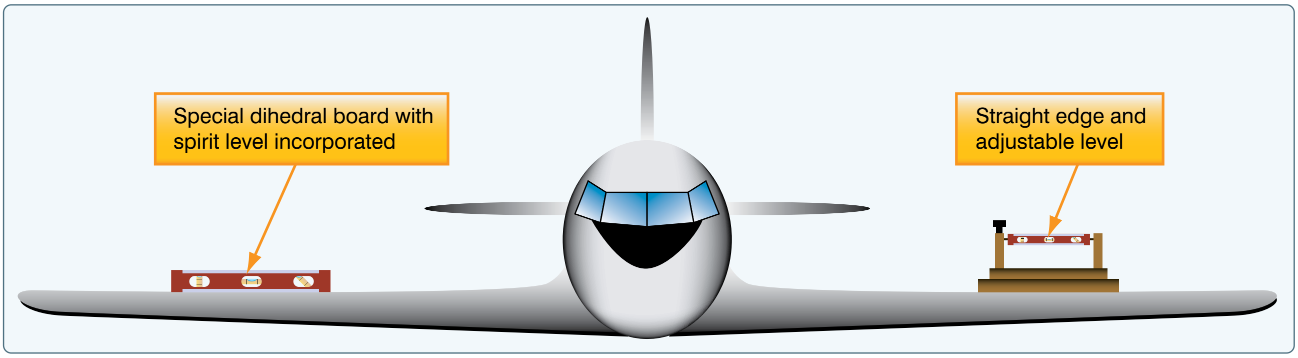


Figure 2-84. *Checking dihedral.*

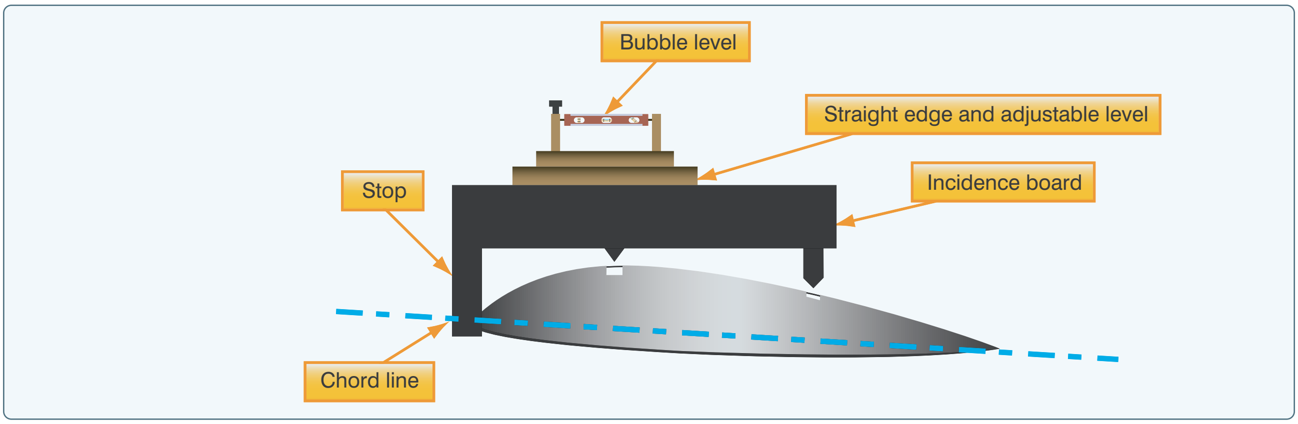


Figure 2-85. *A typical incidence board.*

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

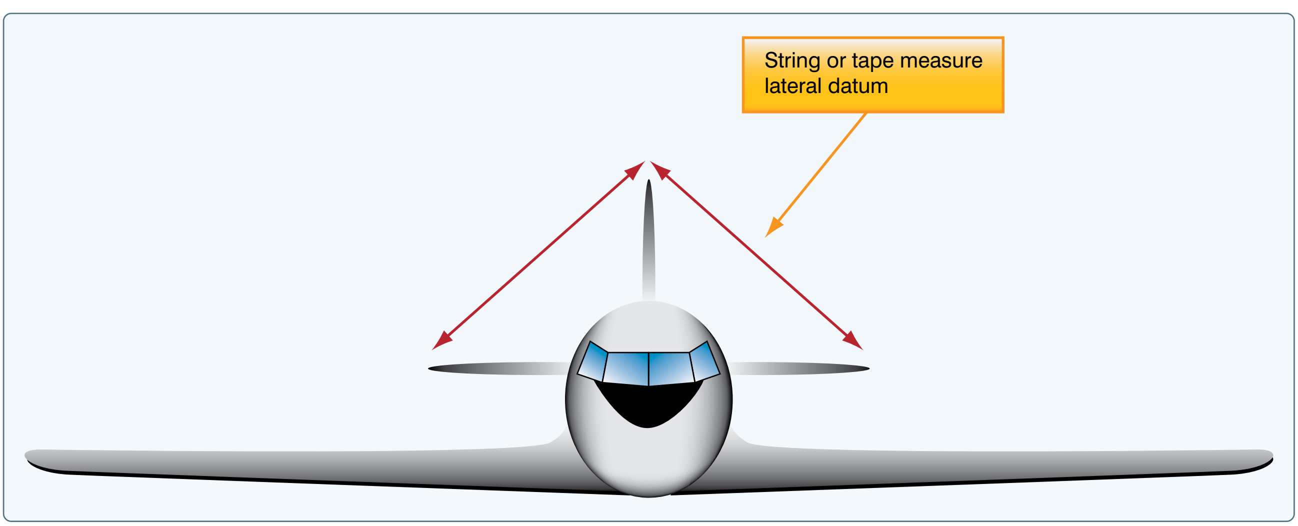


Figure 2-86. *Checking fin verticality.*

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.

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. 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*.

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.

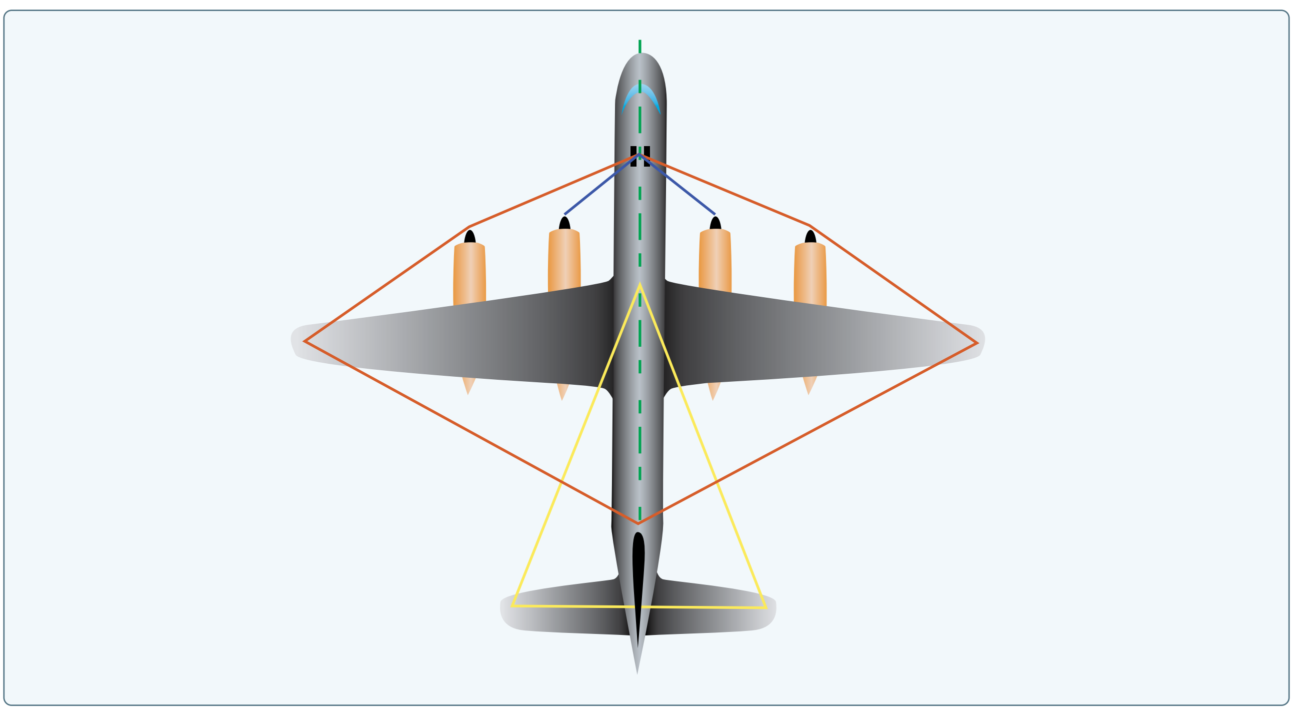
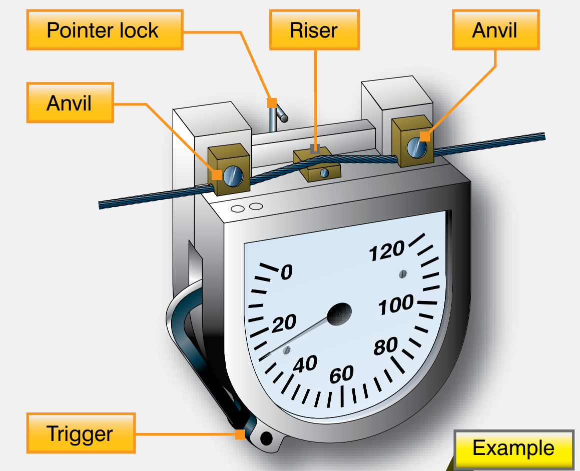


Figure 2-87. *Typical measurements used to check aircraft symmetry.*



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.*

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.

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

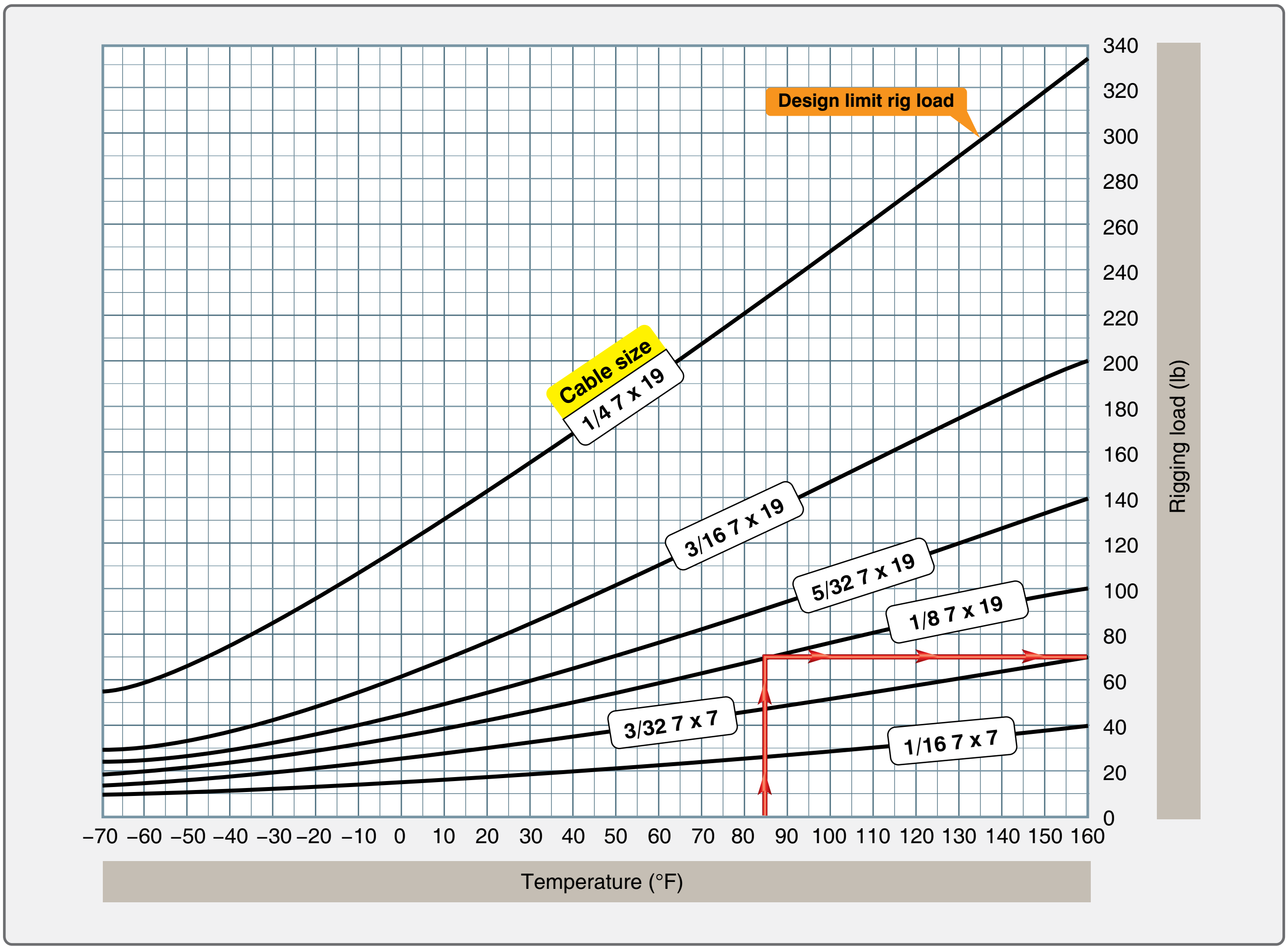


Figure 2-89. *Typical cable rigging chart.*

aileron, elevator, or wing flap travel is the universal propeller protractor shown in *Figure 2-90.*

This protractor is made up of a frame, disk, ring, and two spirit levels. The disk 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 disk when measuring control surface travel. A disk-to-ring lock is provided to secure the disk and ring together when the zero on the ring vernier scale and the zero on the disk degree scale align. The ring-to-frame lock prevents the ring from moving when the disk is moved. Note that they start at 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

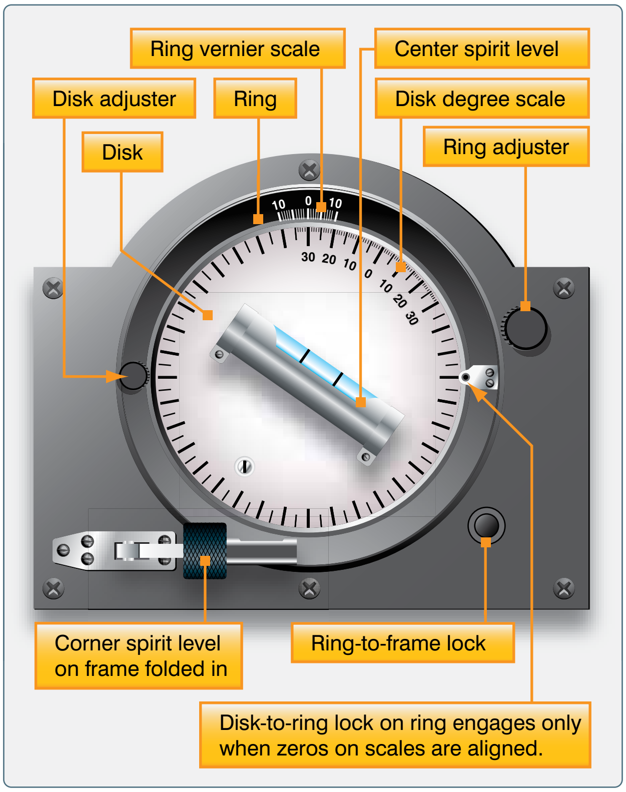


Figure 2-90. *Universal propeller protractor.*

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 and 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 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

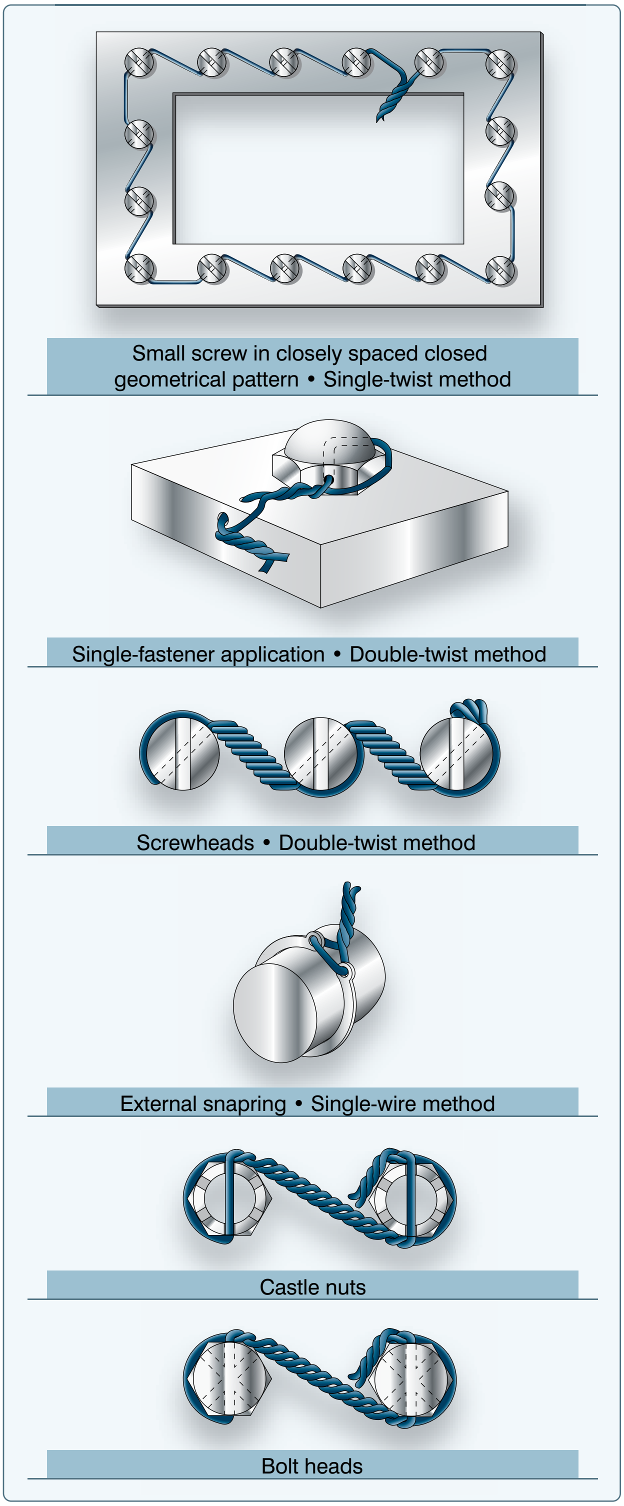


Figure 2-91. *Double-wrap and single safety wire methods for nuts, bolts, and snap rings.*

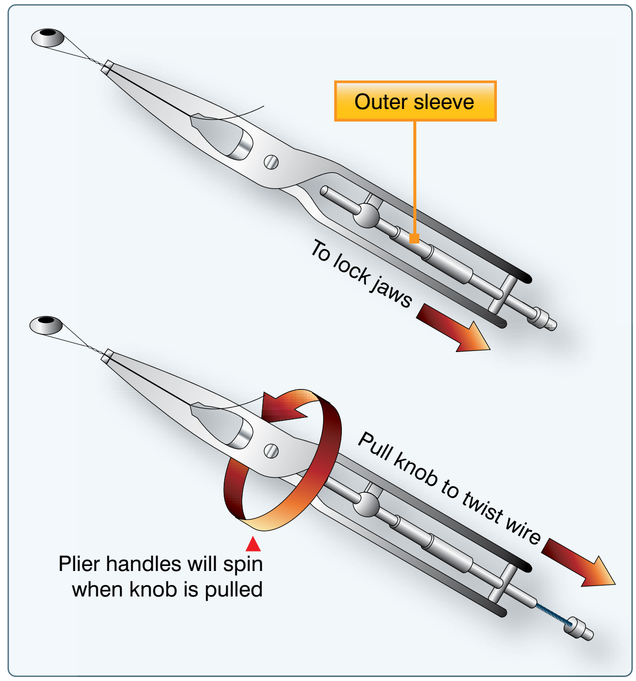


Figure 2-92. *Use of safety-wire pliers or wire twisters.*

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]*

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]*

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]*

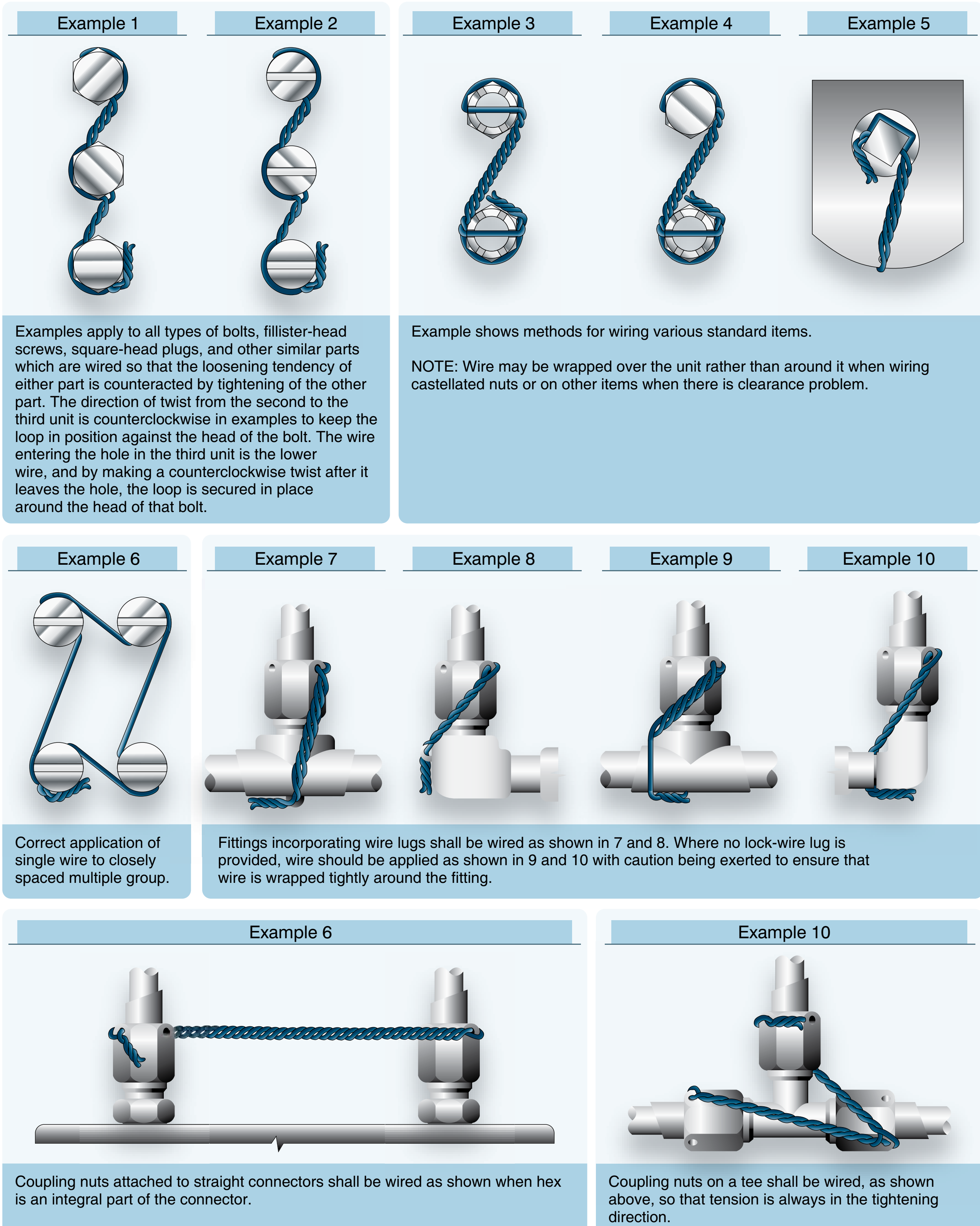


Figure 2-93. *Examples of various fasteners and methods of safetying.*

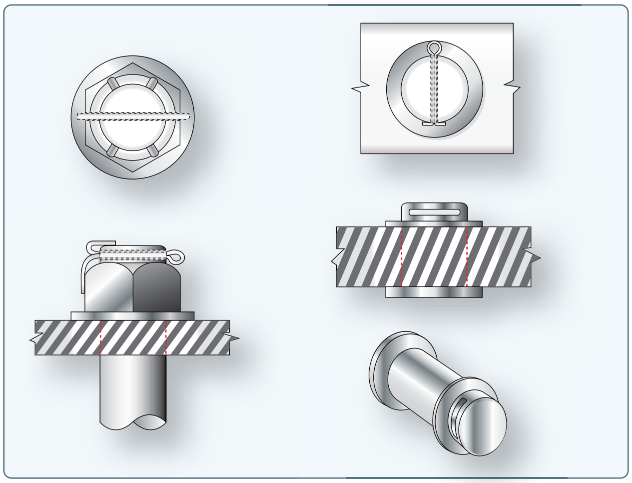


Figure 2-94. *Securing hardware with cotter pins.*

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 unts.*

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 and 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 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

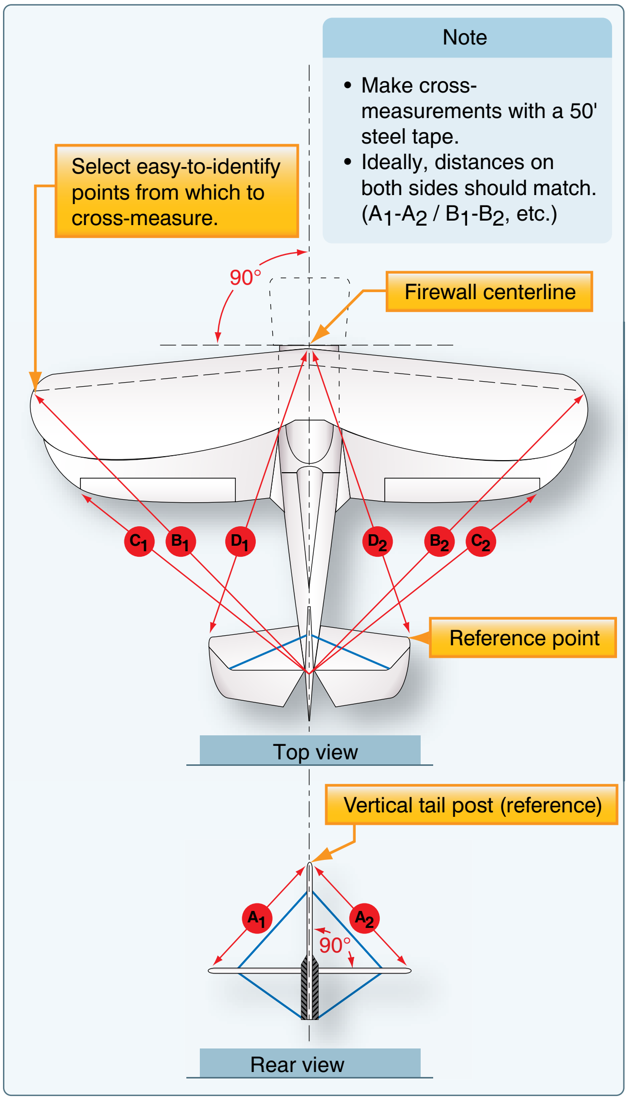


Figure 2-96. *Checking aircraft symmetry.*

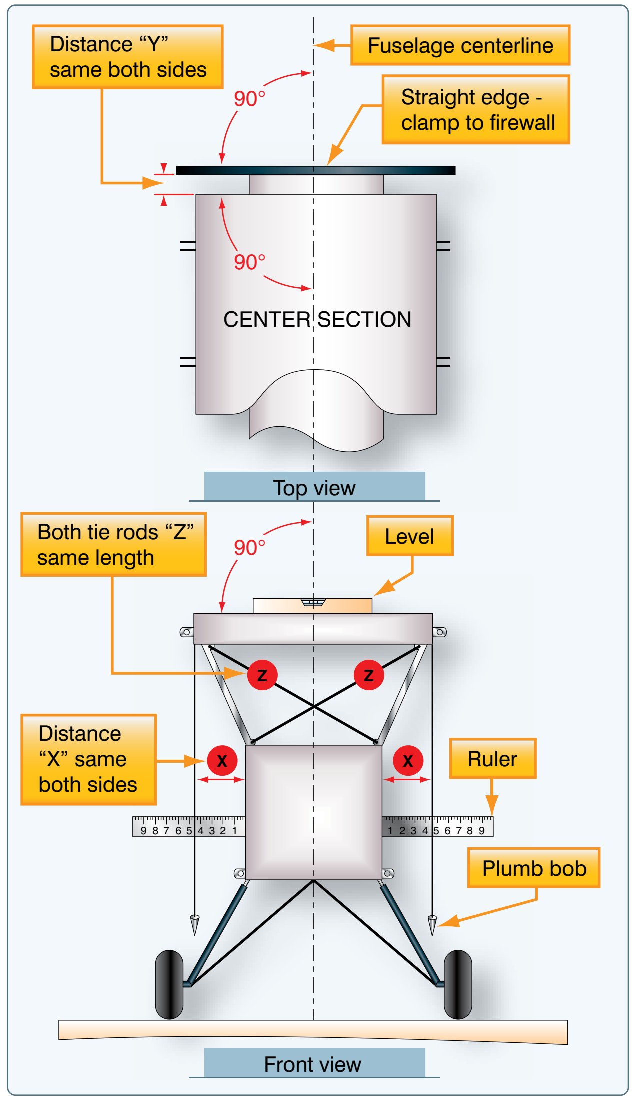


Figure 2-97. *Center section alignment.*

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*.

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.

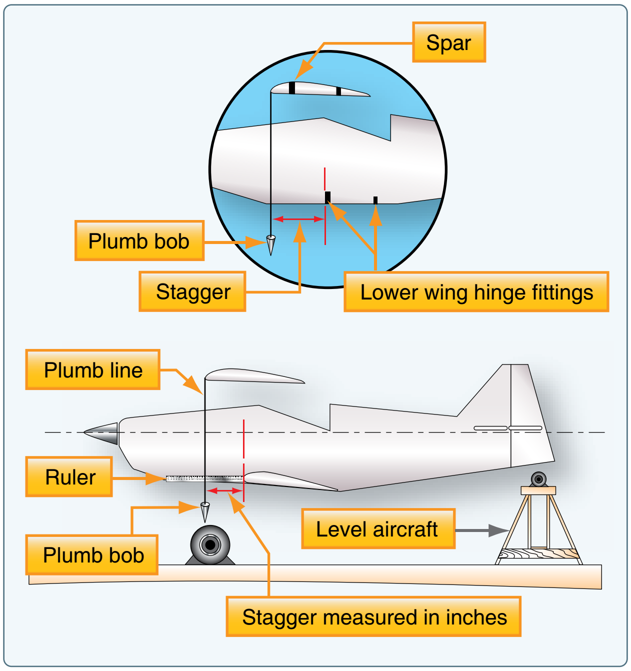


Figure 2-98. *Measuring stagger.*

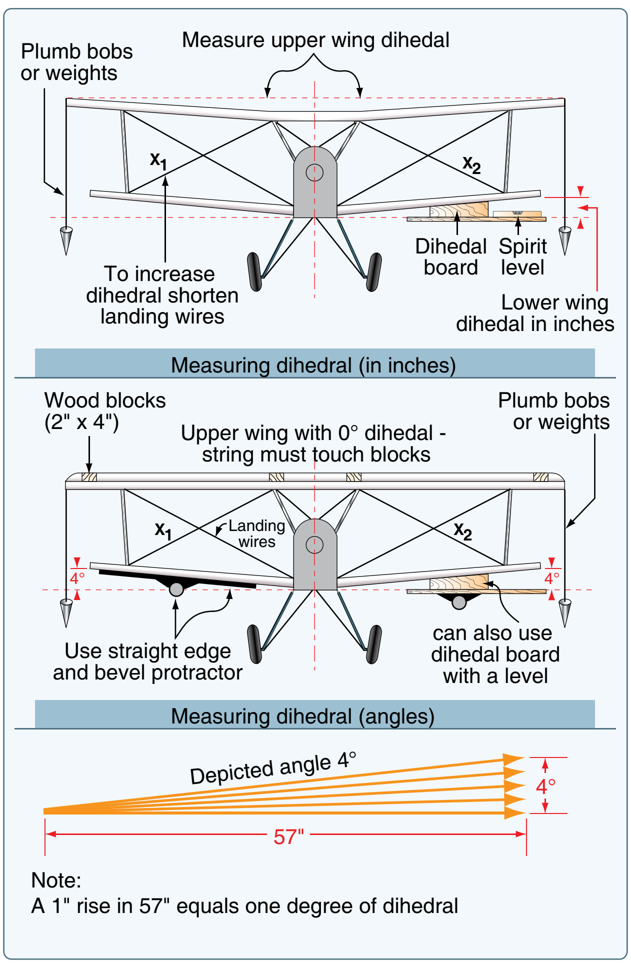


Figure 2-99. *Measuring dihedral.*

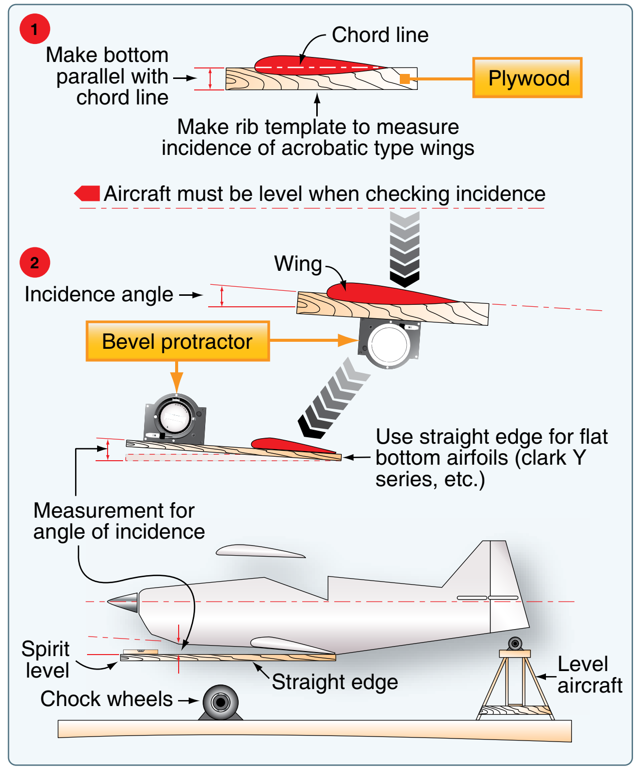


Figure 2-100. *Checking incidence.*

Aircraft Inspection

Purpose of Inspection Programs

The purpose of an aircraft inspection program is to ensure that the aircraft is airworthy. The term airworthy is not defined in the 14 CFR. However, case law relating to the term and regulations for the issuance of a standard airworthiness certificate reveal two conditions that must be met for the aircraft to be considered airworthy:

1. *The aircraft must conform to its type certificate (TC).* Conformity to type design is considered attained when the aircraft configuration and the components installed are consistent with the drawings, specifications, and other data that are part of the TC, which includes any supplemental type certificate (STC) and field approved alterations incorporated into the aircraft.
2. *The aircraft must be in a condition for safe operation.* This refers to the condition of the aircraft relative to wear and deterioration (e.g., skin corrosion, window delamination/crazing, fluid leaks, and tire wear beyond specified limits).

When flight hours and calendar time are accumulated into the life of an aircraft, some components wear out and others deteriorate. Inspections are developed to find these items, and repair or replace them before they affect the airworthiness of the aircraft.

Perform an Airframe Conformity and Airworthiness Inspection

To establish conformity of an aircraft product, start with a Type Certificate Data Sheet (TCDS). This document is a formal description of the aircraft, the engine, or the propeller. It is issued by the Federal Aviation Administration (FAA) when they find that the product meets the applicable requirements for certification under 14 CFR.

The TCDS lists the limitations and information required for type certification of aircraft. It includes the certification basis and eligible serial numbers for the product. It lists airspeed limits, weight limits, control surface movements, engine make and models, minimum crew, fuel type, etc.; the horsepower and rpm limits, thrust limitations, size and weight for engines; and blade diameter, pitch, etc., for propellers. Additionally, it provides all the various components by make and model, eligible for installation on the applicable product.

A manufacturer's maintenance information may be in the form of service instructions, service bulletins, or service letters that the manufacturer publishes to provide instructions for product improvement or to revise and update maintenance manuals. Service bulletins are not regulatory unless:

1. All or a portion of a service bulletin is incorporated as part of an airworthiness directive.
2. The service bulletins are part of the FAA-approved airworthiness limitations section of the manufacturer's manual or part of the type certificate.
3. The service bulletins are incorporated directly or by reference into an FAA-approved inspection program, such as an approved aircraft inspection program (AAIP) or continuous aircraft maintenance program (CAMP).
4. The service bulletins are listed as an additional maintenance requirement in a certificate holder's operations specifications (Op Specs).

Airworthiness directives (ADs) are published by the FAA as amendments to 14 CFR part 39, section 39.13. They apply to the following products: aircraft, aircraft engines, propellers, and appliances. The FAA issues airworthiness directives when an unsafe condition exists in a product, and the condition is likely to exist or develop in other products of the same type design.

To perform the airframe conformity and verify the airworthiness of the aircraft, records must be checked and the aircraft inspected. The data plate on the airframe is inspected to verify its make, model, serial number, type certificate, or production certificate. Check the registration and airworthiness certificate to verify they are correct and reflect the "N" number on the aircraft.

Inspect aircraft records. Check current inspection status of aircraft, by verifying:

- The date of the last inspection and aircraft total time in service.
- The type of inspection and if it includes manufacturer's bulletins.
- The signature, certificate number, and the type of certificate of the person who returned the aircraft to service.

Identify if any major alterations or major repairs have been performed and recorded on an FAA Form 337, Major Repair and Alteration. If any STC have been added, check for flight manual supplements (FMS) in the Pilot's Operating Handbook (POH).

Check for a current weight and balance report, and the current equipment list, current status of airworthiness directives for airframe, engine, propeller, and appliances. Also, check the limitations section of the manufacturer's manual to verify the status of any life-limited components.

Obtain the latest revision of the airframe TCDS and use it as a verification document to inspect and ensure the correct engines, propellers, and components are installed on the airframe.

Required Inspections

Preflight

Preflight for the aircraft is described in the POH for that specific aircraft and should be followed with the same attention given to the checklists for takeoff, inflight, and landing checklists.

Periodic Maintenance Inspections:

Annual Inspection

With few exceptions, no person may operate an aircraft unless, within the preceding 12 calendar months, it has had an annual inspection in accordance with 14 CFR part 43 and was approved for return to service by a person authorized under section 43.7. (A certificated mechanic with an Airframe and Powerplant (A&P) rating must hold an inspection authorization (IA) to perform an annual inspection.) A checklist must be used and include as a minimum, the scope and detail of items (as applicable to the particular aircraft) in 14 CFR part 43, Appendix D.

100-hour Inspection

This inspection is required when an aircraft is operated under 14 CFR part 91 and used for hire, such as flight training. It is required to be performed every 100 hours of service in addition to the annual inspection. (The inspection may be performed by a certificated mechanic with an A & P rating.) A checklist must be used and as a minimum, the inspection must include the scope and detail of items (as applicable to the particular aircraft) in 14 CFR part 43, Appendix D.

Progressive Inspection

This inspection program can be performed under 14 CFR part 91, section 91.409(d), as an alternative to an annual inspection. However, the program requires that a written request be submitted by the registered owner or operator of an aircraft desiring to use a progressive inspection to the local FAA Flight Standards District Office (FSDO). It shall provide:

1. The name of a certificated mechanic holding an inspection authorization, a certificated airframe repair station, or the manufacturer of the aircraft to supervise or conduct the inspection.
2. A current inspection procedures manual available and readily understandable to the pilot and maintenance personnel containing in detail:
    - An explanation of the progressive inspection, including the continuity of inspection responsibility, the making of reports, and the keeping of records and technical reference material.
    - An inspection schedule, specifying the intervals in hours or days when routine and detailed inspections will be performed, and including instructions for exceeding an inspection interval by not more than 10 hours while en route, and for changing an inspection interval because of service experience.
    - Sample routine and detailed inspection forms and instructions for their use.
    - Sample reports and records and instructions for their use.
3. Enough housing and equipment for necessary disassembly and proper inspection of the aircraft.
4. Appropriate current technical information for the aircraft.

The frequency and detail of the progressive inspection program shall provide for the complete inspection of the aircraft within each 12 calendar months and be consistent with the manufacturer's recommendations and kind of operation in which the aircraft is engaged. The progressive inspection schedule must ensure that the aircraft will be airworthy at all times. A certificated A&P mechanic may perform a progressive inspection, as long as he or she is being supervised by a mechanic holding an Inspection Authorization.

If the progressive inspection is discontinued, the owner or operator must immediately notify the local FAA FSDO in writing. After discontinuance, the first annual inspection will be due within 12 calendar months of the last complete inspection of the aircraft under the progressive inspection.

Large Airplanes (over 12,500 lb)

Inspection requirements of 14 CFR part 91, section 91.409, to include paragraphs (e) and (f).

Paragraph (e) applies to large airplanes (to which 14 CFR part 125 is not applicable), turbojet multiengine airplanes, turbo propeller powered multiengine airplanes, and turbine-powered rotorcraft. Paragraph (f) lists the inspection programs that can be selected under paragraph (e).

The additional inspection requirements for these aircraft are placed on the operator because the larger aircraft typically are more complex and require a more detailed inspection program than is provided for in 14 CFR part 43, Appendix D.

An inspection program must be selected from one of the following four options by the owner or operator of the aircraft:

1. A continuous airworthiness inspection program that is part of a continuous airworthiness maintenance program currently in use by a person holding an air carrier operating certificate or an operating certificate issued under 14 CFR part 121 or 135.
2. An approved aircraft inspection program approved under 14 CFR part 135, section 135.419, and currently in use by a person holding an operating certificate issued under 14 CFR part 135.
3. A current inspection program recommended by the manufacturer.
4. Any other inspection program established by the registered owner or operator of the airplane or turbine-powered rotorcraft and approved by the FAA. This program must be submitted to the local FAA FSDO having jurisdiction of the area in which the aircraft is based. The program must be in writing and include at least the following information:
    (a) Instructions and procedures for the conduct of inspections for the particular make and model

airplane or turbine-powered rotorcraft, including the necessary tests and checks. The instructions and procedures must set forth in detail the parts and areas of the airframe, engines, propellers, rotors, and appliances, including survival and emergency equipment, required to be inspected.

(b) A schedule for performing the inspections that must be performed under the program expressed in terms of the time in service, calendar time, number of system operations (cycles), or any combination of these.

This FAA approved owner/operator program can be revised at a future date by the FAA, if they find that revisions are necessary for the continued adequacy of the program. The owner/operator can petition the FAA within 30 days of notification to reconsider the notice to make changes.

Manufacturer's Inspection Program

This is a program developed by the manufacturer for their product. It is contained in the "Instructions for Continued Airworthiness" required under 14 CFR part 23, section 23.1529 and part 25, section 25.1529. It is in the form of a manual, or manuals as appropriate, for the quantity of data to be provided and including, but not limited to, the following content:

- A description of the airplane and its systems and installations, including its engines, propellers, and appliances.
- Basic information describing how the airplane components and systems are controlled and operated, including any special procedures and limitations that apply.
- Servicing information that covers servicing points, capacities of tanks, reservoirs, types of fluids to be used, pressures applicable to the various systems, lubrication points, lubricants to be used, equipment required for servicing, tow instructions, mooring, jacking, and leveling information.
- Maintenance instructions with scheduling information for the airplane and each component that provides the recommended periods at which they should be cleaned, inspected, adjusted, tested, and lubricated, and the degree of inspection and work recommended at these periods.
- The recommended overhaul periods and necessary cross references to the airworthiness limitations section of the manual.
- The inspection program that details the frequency and extent of the inspections necessary to provide for the continued airworthiness of the airplane.
- Diagrams of structural access plates and information needed to gain access for inspections when access plates are not provided.
- Details for the application of special inspection techniques, including radiographic and ultrasonic testing where such processes are specified.
- A list of special tools needed.
- An Airworthiness Limitations section that is segregated and clearly distinguishable from the rest of the document. This section must set forth—
    1. Each mandatory replacement time, structural inspection interval, and related structural inspection procedures required for type certification or approved under 14 CFR part 25, section 25.571.
    2. Each mandatory replacement time, inspection interval, related inspection procedure, and all critical design configuration control limitations approved under 14 CFR part 25, section 25.981, for the fuel tank system.

The Airworthiness Limitations section must contain a legible statement in a prominent location that reads: "The Airworthiness Limitations section is FAA approved and specifies maintenance required under 14 CFR part 43, sections 43.16 and part 91, section 91.403, unless an alternative program has been FAA-approved."

Any operator who wishes to adopt a manufacturers' inspection program should first contact their local FAA Flight Standards District Office, for further guidance.

Altimeter and Static System Inspections

Any person operating an airplane or helicopter in controlled airspace under instrument flight rules (IFR) must have had, within the preceding 24 calendar months, each static pressure system, each altimeter instrument, and each automatic pressure altitude reporting system tested and inspected and found to comply with 14 CFR part 43, Appendix E. Those test and inspections must be conducted by appropriately rated persons under 14 CFR.

Air Traffic Control (ATC) Transponder Inspections

Any person using an air traffic control (ATC) transponder must have had, within the preceding 24 calendar months, that transponder tested and inspected and found to comply with 14 CFR part 43, Appendix F. Additionally, following any installation or maintenance on an ATC transponder where data correspondence error could be introduced, the integrated system must be tested and inspected and found to comply with 14 CFR part 43, Appendix E, by an appropriately person under 14 CFR.

Emergency Locator Transmitter (ELT) Operational and Maintenance Practices in Accordance With Advisory Circular (AC) 91-44

This AC combined and updated several ACs on the subject of ELTs and receivers for airborne service.

Under the operating rules of 14 CFR part 91, most small U.S. registered civil airplanes equipped to carry more than one person must have an ELT attached to the airplane. 14 CFR part 91, section 91.207 defines the requirements of what type aircraft and when the ELT must be installed. It also states that an ELT that meets the requirements of Technical Standard Order (TSO)-C91 may not be used for new installations.* (This is the ELT that smaller general aviation aircraft have installed and they transmit on 121.5 MHz.)

The pilot in command of an aircraft equipped with an ELT is responsible for its operation and, prior to engine shutdown at the end of each flight, should tune the VHF receiver to 121.5 MHz and listen for ELT activations. Maintenance personnel are responsible for accidental activation during the actual period of their work.

Maintenance of ELTs is subject to 14 CFR part 43 and should be included in the required inspections. It is essential that the impact switch operation and the transmitter output be checked using the manufacturer's instructions. Testing of an ELT prior to installation or for maintenance reasons, should be conducted in a metal enclosure in order to avoid outside radiation by the transmitter. If this is not possible, the test should be conducted only within the first 5 minutes after any hour.

Manufacturers of ELTs are required to mark the expiration date of the battery, based on 50 percent of the useful life, on the outside of the transmitter. The batteries are required to be replaced on that date or when the transmitter has been in use for more than 1 cumulative hour. Water activated batteries, have virtually unlimited shelf life. They are not usually marked with an expiration date. They must be replaced after activation regardless of how long they were in service.

The battery replacement can be accomplished by a pilot on a portable type ELT that is readily accessible and can be removed and reinstalled in the aircraft by a simple operation. That would be considered preventive maintenance under 14 CFR part 43, section 43.3(g). Replacement batteries should be approved for the specific model of ELT and the installation performed in accordance with section 43.13.

AC 91-44 also contains additional information on:

- Airborne homing and alerting equipment for use with ELTs.
- Search and rescue responsibility.
- Alert and search procedures including various flight procedures for locating an ELT.
- The FAA Frequency Management Offices, for contacting by manufacturers when they are demonstrating and testing ELTs.

*The reason; as of January 31, 2009, the 121.5/243 MHz frequency will no longer be monitored by the COSPAS-SARSAT (Search and Rescue Satellite-Aided Tracking) search and rescue satellites.

NOTE: All new installations must be a 406 MHz digital ELT. It must meet the standards of TSO C126. When installed, the new 406 MHz ELT should be registered so that if the aircraft were to go down, search and rescue could take full advantage of the benefits the system offers. The digital circuitry of the 406 ELT can be coded with information about the aircraft type, base location, ownership, etc. This coding allows the search and rescue (SAR) coordinating centers to contact the registered owner or operator if a signal is detected to determine if the aircraft is flying or parked. This type of identification permits a rapid SAR response in the event of an accident, and will save valuable resources from a false alarm search.

Annual and 100-Hour Inspections

Preparation

An owner/operator bringing an aircraft into a maintenance facility for an annual or 100-hour inspection may not know what is involved in the process. This is the point at which the person who performs the inspection sits down with the customer to review the records and discuss any maintenance issues, repairs needed, or additional work the customer may want done. Moreover, the time spent on these items before starting the inspection usually saves time and money before the work is completed.

The work order describes the work that will be performed and the fee that the owner pays for the service. It is a contract that includes the parts, materials, and labor to complete the inspection. It may also include additional maintenance and repairs requested by the owner or found during the inspection.

Additional materials such as ADs, manufacturer's service bulletins and letters, and vendor service information must be researched to include the avionics and emergency equipment on the aircraft. The TCDS provides all the components eligible for installation on the aircraft.

The review of the aircraft records is one of the most important parts of any inspection. Those records provide the history of the aircraft. The records to be kept and how they are to be maintained are listed in 14 CFR part 91, section 91.417. Among those records that must be tracked are records of maintenance, preventive maintenance, and alteration, records of the last 100-hour, annual, or other required or approved inspections for the airframe, engine propeller, rotor, and appliances of an aircraft. The records must include:

- A description (or reference to data acceptable to the FAA) of the work performed.
- The date of completion of the work performed and the signature and certificate number of the person approving the aircraft for return to service.
- The total time in service and the current status of life-limited parts of the airframe, each engine, each propeller, and each rotor.
- The time since last overhaul of all items installed on the aircraft which are required to be overhauled on a specified time basis.
- The current inspection status of the aircraft, including the time since last inspection required by the program under which the aircraft and its appliances are maintained.
- The current status of applicable ADs including for each, the method of compliance, the AD number, and revision date. If the AD involves recurring action, the time and date when the next action is required.
- Copies of the forms prescribed by 14 CFR part 43, section 43.9, for each major alteration to the airframe and currently installed components.

The owner/operator is required to retain the records of inspection until the work is repeated, or for 1 year after the work is performed. Most of the other records that include total times and current status of life-limited parts, overhaul times, and AD status must be retained and transferred with the aircraft when it is sold.

14 CFR part 43, part 43.15, requires that each person performing a 100-hour or annual inspection shall use a checklist while performing the inspection. The checklist may be one developed by the person, one provided by the manufacturer of the equipment being inspected, or one obtained from another source. The checklist must include the scope and detail of the items contained in part 43, Appendix D.

The inspection checklist provided by the manufacturer is the preferred one to use. The manufacturer separates the areas to inspect such as engine, cabin, wing, empennage and landing gear. They typically list Service Bulletins and Service Letters for specific areas of the aircraft and the appliances that are installed.

Initial run-up provides an assessment to the condition of the engine prior to performing the inspection. The run-up should include full power and idle rpm, magneto operation, including positive switch grounding, fuel mixture check, oil and fuel pressure, and cylinder head and oil temperatures. After the engine run, check it for fuel, oil, and hydraulic leaks.

Following the checklist, the entire aircraft shall be opened by removing all necessary inspection plates, access doors, fairings, and cowling. The entire aircraft must then be cleaned to uncover hidden cracks or defects that may have been missed because of the dirt.

Following in order and using the checklist visually inspect each item, or perform the checks or tests necessary to verify the condition of the component or system. Record discrepancies when they are found. The entire aircraft should be inspected and a list of discrepancies be presented to the owner.

A typical inspection following a checklist, on a small single-engine airplane may include in part, as applicable:

- The fuselage for damage, corrosion, and attachment of fittings, antennas, and lights; for "smoking rivets" especially in the landing gear area indicating the possibility of structural movement or hidden failure.
- The flight deck and cabin area for loose equipment that could foul the controls; seats and seat belts for defects; windows and windshields for deterioration; instruments for condition, markings, and operation; flight and engine controls for proper operation.
- The engine and attached components for visual evidence of leaks; studs and nuts for improper torque and obvious defects; engine mount and vibration dampeners for cracks, deterioration, and looseness; engine controls for defects, operation, and safetying; the internal engine for cylinder compression; spark plugs for operation; oil screens and filters for metal particles or foreign matter; exhaust stacks and mufflers for leaks, cracks, and missing hardware; cooling baffles for deterioration, damage, and missing seals; and engine cowling for cracks and defects.
- The landing gear group for condition and attachment; shock absorbing devices for leaks and fluid levels; retracting and locking mechanism for defects, damage, and operation; hydraulic lines for leakage; electrical system for chafing and switches for operation; wheels and bearings for condition; tires for wear and cuts; and brakes for condition and adjustment.
- The wing and center section assembly for condition, skin deterioration, distortion, structural failure, and attachment.

- The empennage assembly for condition, distortion, skin deterioration, evidence of failure (smoking rivets), secure attachment, and component operation and installation.
- The propeller group and system components for torque and proper safetying; the propeller for nicks, cracks, and oil leaks; the anti-icing devices for defects and operation; and the control mechanism for operation, mounting, and restricted movement.
- The radios and electronic equipment for improper installation and mounting; wiring and conduits for improper routing, insecure mounting, and obvious defects; bonding and shielding for installation and condition; and all antennas for condition, mounting, and operation. Additionally, if not already inspected and serviced, the main battery inspected for condition, mounting, corrosion, and electrical charge.
- Any and all installed miscellaneous items and components that are not otherwise covered by this listing for condition and operation.

With the aircraft inspection checklist completed, the list of discrepancies should be transferred to the work order. As part of the annual and 100-hour inspections, the engine oil is drained and replaced because new filters and/or clean screens have been installed in the engine. The repairs are then completed and all fluid systems serviced.

Before approving the aircraft for return to service after the annual or 100-hour inspection, 14 CFR states that the engine must be run to determine satisfactory performance in accordance with the manufacturers recommendations. The run must include:

- Power output (static and idle rpm)
- Magnetos (for drop and switch ground)
- Fuel and oil pressure
- Cylinder and oil temperature

After the run, the engine is inspected for fluid leaks and the oil level is checked a final time before close up of the cowling.

With the aircraft inspection completed, all inspections plates, access doors, fairing and cowling that were removed, must be reinstalled. It is a good practice to visually check inside the inspection areas for tools, shop rags, etc., prior to close up. Using the checklist and discrepancy list to review areas that were repaired will help ensure the aircraft is properly returned to service.

Upon completion of the inspection, the records for each airframe, engine, propeller, and appliance must be signed off. The record entry in accordance with 14 CFR part 43, section 43.11, must include the following information:

- The type inspection and a brief description of the extent of the inspection.
- The date of the inspection and aircraft total time in service.
- The signature, the certificate number, and kind of certificate held by the person approving or disapproving for return to service the aircraft, airframe, aircraft engine, propeller, appliance, component part, or portions thereof.
- For the annual and 100-hour inspection, if the aircraft is found to be airworthy and approved for return to service, enter the following statement: "I certify that this aircraft has been inspected in accordance with a (insert type) inspection and was determined to be in airworthy condition."
- If the aircraft is not approved for return to service because of necessary maintenance, noncompliance with applicable specifications, airworthiness directives, or other approved data, enter the following statement: "I certify that this aircraft has been inspected in accordance with a (insert type) inspection and a list of discrepancies and unairworthy items has been provided to the aircraft owner or operator."

If the owner or operator did not want the discrepancies and/or unairworthy items repaired at the location where the inspection was accomplished, they may have the option of flying the aircraft to another location with a Special Flight Permit (Ferry Permit). An application for a Special Flight Permit can be made at the local FAA FSDO.

Other Aircraft Inspection and Maintenance Programs

Aircraft operating under 14 CFR part 135, Commuter and On Demand, have additional rules for maintenance that must be followed beyond those in 14 CFR parts 43 and 91.

14 CFR part 135, section 135.411(a)(1) applies to aircraft that are type certificated for a passenger seating configuration, excluding any pilot seat, of nine seats or less. The additional rules include:

- Section 135.415—requires each certificate holder to submit a Service Difficulty Report, whenever they have an occurrence, failure, malfunction, or defect in an aircraft concerning the list detailed in this section of the regulation.
- Section 135.417—requires each certificate holder to mail or deliver a Mechanical Interruption Report, for occurrences in multi-engine aircraft, concerning

unscheduled flight interruptions, and the number of propeller featherings in flight, as detailed in this section of the regulation.

- Section 135.421—requires each certificate holder to comply with the manufacturer's recommended maintenance programs, or a program approved by the FAA for each aircraft, engine, propeller, rotor, and each item of emergency required by 14 CFR part 135. This section also details requirements for single-engine IFR passenger-carrying operations.
- Section 135.422—this section applies to multi-engine airplanes and details requirements for Aging Airplane Inspections and Records review. It excludes airplanes in schedule operations between any point within the State of Alaska.
- Sections 135.423 through 135.443—the listed regulations are numerous and complex, and compliance is required; however, they are not summarized in this handbook.

Any certificated operator using aircraft with ten or more passenger seats must have the required organization and maintenance programs, along with competent and knowledgeable people to ensure a safe operation. It is their responsibility to know and comply with these and all other applicable Federal Aviation Regulations, and should contact their local FAA FSDO for further guidance.

The AAIP is an FAA-approved inspection program for aircraft of nine or less passenger seats operated under 14 CFR part 135. The AAIP is an operator developed program tailored to their particular needs to satisfy aircraft inspection requirements. This program allows operators to develop procedures and time intervals for the accomplishment of inspection tasks in accordance with the needs of the aircraft, rather than repeat all the tasks at each 100-hour interval.

The operator is responsible for the AAIP. The program must encompass the total aircraft; including all avionics equipment, emergency equipment, cargo provisions, etc. FAA Advisory Circular 135-10A provides detailed guidance to develop an approved aircraft inspection program. The following is a summary, in part, of elements that the program should include:

- A schedule of individual tasks (inspections) or groups of tasks, as well as the frequency for performing those tasks.
- Work forms designating those tasks with a signoff provision for each. The forms may be developed by the operator or obtained from another source.
- Instructions for accomplishing each task. These tasks must satisfy 14 CFR part 43, section 43.13(a), regarding methods, techniques, practices, tools, and equipment. The instructions should include adequate information in a form suitable for use by the person performing the work.
- Provisions for operator-developed revisions to referenced instructions should be incorporated in the operator's manual.
- A system for recording discrepancies and their correction.
- A means for accounting for work forms upon completion of the inspection. These forms are used to satisfy the requirements of 14 CFR part 91, section 91.417, so they must be complete, legible, and identifiable as to the aircraft and specific inspection to which they relate.
- Accommodation for variations in equipment and configurations between aircraft in the fleet.
- Provisions for transferring an aircraft from another program to the AAIP.

The development of the AAIP may come from one of the following sources:

- An adoption of an aircraft manufacturer's inspection in its entirety. However, many aircraft manufacturers' programs do not encompass avionics, emergency equipment, appliances, and related installations that must be incorporated into the AAIP. The inspection of these items and systems will require additions to the program to ensure they comply with the air carrier's operation specifications and as applicable to 14 CFR.
- A modified manufacturer's program. The operator may modify a manufacturer's inspection program to suit its needs. Modifications should be clearly identified and provide an equivalent level of safety to those in the manufacturer's approved program.
- An operator-developed program. This type of program is developed in its entirety by the operator. It should include methods, techniques, practices, and standards necessary for proper accomplishment of the program.
- An existing progressive inspection program (14 CFR part 91.409(d)) may be used as a basis for the development of an AAIP.

As part of this inspection program, the FAA strongly recommends that a Corrosion Protection Control Program and a supplemental structural inspection type program be included.

A program revision procedure should be included so that an evaluation of any revision can be made by the operator prior to submitting them to the FAA for approval.

Procedures for administering the program should be established. These should include: defining the duties and responsibilities for all personnel involved in the program, scheduling inspections, recording their accomplishment, and maintaining a file of completed work forms.

The operator's manual should include a section that clearly describes the complete program, including procedures for program scheduling, recording, and accountability for continuing accomplishment of the program. This section serves to facilitate administration of the program by the certificate holder and to direct its accomplishment by mechanics or repair stations. The operator's manual should include instructions to accomplish the maintenance/inspections tasks. It should also contain a list of the necessary tools and equipment needed to perform the maintenance and inspections.

The FAA FSDO will provide each operator with computer-generated Operations Specifications when they approve the program.

Continuous Airworthiness Maintenance Program (CAMP)

The definition of maintenance in 14 CFR part 1 includes inspection. The inspection program required for 14 CFR part 121 and part 135 air carriers is part of the Continuous Airworthiness Maintenance Program (CAMP). It is a complex program that requires an organization of experienced and knowledgeable aviation personnel to implement it.

The FAA has developed an Advisory Circular, AC 120-16D Air Carrier Aircraft Maintenance Programs, which explains the background as well as the FAA regulatory requirements for these programs. The AC applies to air carriers subject to 14 CFR parts 119, 121, and 135. For part 135, it applies only to aircraft type certificated with ten or more passenger seats.

Any person wanting to place their aircraft on this type of program should contact their local FAA FSDO for guidance.

Title 14 CFR part 125, section 125.247, Inspection Programs and Maintenance

This regulation applies to airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 pounds or more. Inspection programs which may be approved for use under this 14 CFR part include, but are not limited to:

1. A continuous inspection program which is part of a current continuous airworthiness program approved for use by a certificate holder under 14 CFR part 121 or part 135;
2. Inspection programs currently recommended by the manufacturer of the airplane, airplane engines, propellers, appliances, or survival and emergency equipment; or
3. An inspection program developed by a certificate holder under 14 CFR part 125.

   The airplane subject to this part may not be operated unless:

   - The replacement times for life-limited parts specified in the aircraft type certificate data sheets, or other documents approved by the FAA are complied with;
   - Defects disclosed between inspections, or as a result of inspection, have been corrected in accordance with 14 CFR part 43; and
   - The airplane, including airframe, aircraft engines, propellers, appliances, and survival and emergency equipment, and their component parts, is inspected in accordance with an inspection program approved by the FAA. These inspections must include at least the following:
     - Instructions, procedures and standards for the particular make and model of airplane, including tests and checks. The instructions and procedures must set forth in detail the parts and areas of the airframe, aircraft engines, propellers, appliances, and survival and emergency equipment required to be inspected.
     - A schedule for the performance of the inspections that must be performed under the program, expressed in terms of the time in service, calendar time, number of system operations, or any combination of these.
     - The person used to perform the inspections required by 14 CFR part 125, must be authorized to perform maintenance under 14 CFR part 43. The airplane subject to part 125 may not be operated unless the installed engines have been maintained in accordance with the overhaul periods

recommended by the manufacturer or a program approved by the FAA; the engine overhaul periods are specified in the inspection programs required by 14 CFR part 125, section 125.247.

Helicopter Inspections, Piston-Engine and Turbine-Powered

A piston-engine helicopter can be inspected in accordance with the scope and detail of 14 CFR part 43, Appendix D for an Annual Inspection. However, there are additional performance rules for inspections under 14 CFR part 43, section 43.15, requiring that each person performing an inspection under 14 CFR part 91 on a rotorcraft shall inspect these additional components in accordance with the maintenance manual or Instructions for Continued Airworthiness of the manufacturer concerned:

1. The drive shaft or similar systems
2. The main rotor transmission gear box for obvious defects
3. The main rotor and center section (or the equivalent area)
4. The auxiliary rotor

The operator of a turbine-powered helicopter can elect to have it inspected under 14 CFR part 91, section 91.409:

1. Annual inspection
2. 100-hour inspection
3. Applies to turbine-powered rotorcraft when operator elects to inspect in accordance with paragraph section 91.409(e), at which time (a) and (b) do not apply.
4. A progressive inspection

When performing any of the above inspections, the additional performance rules under 14 CFR part 43, section 43.15, for rotorcraft must be complied with.

Light-Sport Aircraft, Powered Parachute, and Weight-Shift Control Aircraft

When operating under an Experimental certificate issued for the purpose of Operating Light Sport Aircraft, these aircraft must have a condition inspection performed once every 12 months.

The inspection must be performed by a certificated repairman (light-sport aircraft) with a maintenance rating, an appropriately rated mechanic, or an appropriately rated repair station in accordance with the inspection procedures developed by the aircraft manufacturer or a person acceptable to the FAA. Additionally, if the aircraft is used for compensation or hire to tow a glider or unpowered ultralight vehicle, or is used by a person to conduct flight training for compensation or hire, it must have been inspected within the preceding 100 hours and returned to service in accordance with 14 CFR part 43, by one of the persons listed above.