Figure 1-67. *Air passing through the slot aft of the slat promotes boundary layer airflow on the upper surface at high angles of attack.*

flight. Dedicated speed brake panels similar to flight spoilers in construction can also be found on the upper surface of the wings of heavy and high-performance aircraft. They are designed specifically to increase drag and reduce the speed of the aircraft when deployed. These speed brake panels do not operate differentially with the ailerons at low speed. The speed brake control in the flight deck can deploy all spoiler and speed brake surfaces fully when operated. Often, these surfaces are also rigged to deploy on the ground automatically when engine thrust reversers are activated.

Figure 1-68. *Spoilers deployed upon landing on a transport category aircraft.*

Tabs

The force of the air against a control surface during the high speed of flight can make it difficult to move and hold that control surface in the deflected position. A control surface might also be too sensitive for similar reasons. Several different tabs are used to aid with these types of problems. The table in *Figure 1-69* summarizes the various tabs and their uses.

While in flight, it is desirable for the pilot to be able to take their hands and feet off of the controls and have the aircraft maintain its flight condition. Trims tabs are designed to allow this. Most trim tabs are small movable surfaces located on the trailing edge of a primary flight control surface. A small movement of the tab in the direction opposite of the direction the flight control surface is deflected, causing air to strike the tab, in turn producing a force that aids in maintaining the flight control surface in the desired position. Through linkage set from the flight deck, the tab can be positioned so that it is actually holding the control surface in position rather than the pilot. Therefore, elevator tabs are used to maintain the speed of the aircraft since they assist in maintaining the selected pitch. Rudder tabs can be set to hold yaw in check and maintain heading. Aileron tabs can help keep the wings level.

Occasionally, a simple light aircraft may have a stationary metal plate attached to the trailing edge of a primary flight control, usually the rudder. This is also a trim tab as shown in *Figure 1-70.* It can be bent slightly on the ground to trim the aircraft in flight to a hands-off condition when flying straight and level. The correct amount of bend can be determined only by flying the aircraft after an adjustment. Note that a small amount of bending is usually sufficient.

The aerodynamic phenomenon of moving a trim tab in one direction to cause the control surface to experience a force moving in the opposite direction is exactly what occurs with the use of balance tabs. *[Figure 1-71]* Often, it is difficult to move a primary control surface due to its surface area and the speed of the air rushing over it. Deflecting a balance tab hinged at the trailing edge of the control surface in the opposite direction of the desired control surface movement causes a force to position the surface in the proper direction with reduced force to do so. Balance tabs are usually linked directly to the control surface linkage so that they move automatically when there is an input for control surface movement. They also can double as trim tabs, if adjustable in the flight deck.

A servo tab is similar to a balance tab in location and effect, but it is designed to operate the primary flight control surface, not just reduce the force needed to do so. It is usually used as

Flight Control Tabs			
Type	**Direction of Motion** (in relation to control surface)	**Activation**	**Effect**
Trim	Opposite	Set by pilot from cockpit. Uses independent linkage.	Statically balances the aircraft in flight. Allows "hands off" maintenance of flight condition.
Balance	Opposite	Moves when pilot moves control surface. Coupled to control surface linkage.	Aids pilot in overcoming the force needed to move the control surface.
Servo	Opposite	Directly linked to flight control input device. Can be primary or back-up means of control.	Aerodynamically positions control surfaces that require too much force to move manually.
Anti-balance or Anti-servo	Same	Directly linked to flight control input device.	Increases force needed by pilot to change flight control position. De-sensitizes flight controls.
Spring	Opposite	Located in line of direct linkage to servo tab. Spring assists when control forces become too high in high-speed flight.	Enables moving control surface when forces are high. Inactive during slow flight.

Figure 1-69. *Various tabs and their uses.*

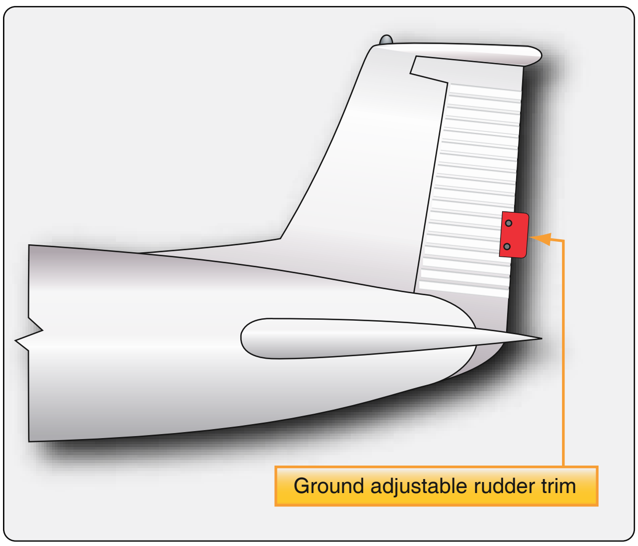

Figure 1-70. *Example of a trim tab.*

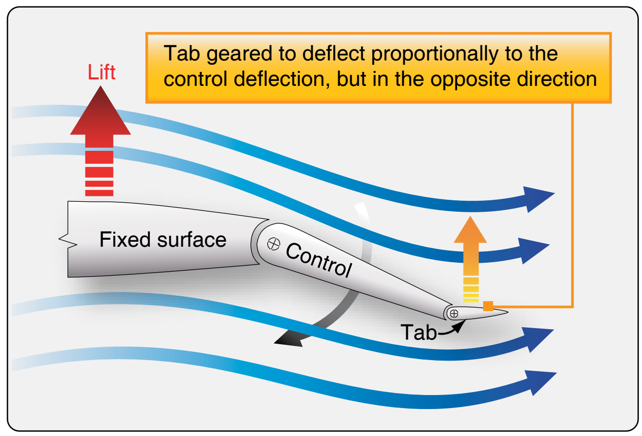

Figure 1-71. *Balance tabs assist with forces needed to position control surfaces.*

a means to back up the primary control of the flight control surfaces. *[Figure 1-72]*

On heavy aircraft, large control surfaces require too much force to be moved manually and are usually deflected out of the neutral position by hydraulic actuators. These power control units are signaled via a system of hydraulic valves connected to the yoke and rudder pedals. On fly-by-wire aircraft, the hydraulic actuators that move the flight control surfaces are signaled by electric input. In the case of hydraulic system failure(s), manual linkage to a servo tab can be used to deflect it. This, in turn, provides an aerodynamic force that moves the primary control surface.

A control surface may require excessive force to move only in the final stages of travel. When this is the case, a spring tab can be used. This is essentially a servo tab that does not activate until an effort is made to move the control surface beyond a certain point. When reached, a spring in line of the control linkage aids in moving the control surface through the remainder of its travel. *[Figure 1-73]*

Figure 1-74 shows another way of assisting the movement of an aileron on a large aircraft. It is called an aileron balance panel. Not visible when approaching the aircraft, it is positioned in the linkage that hinges the aileron to the wing.

Balance panels have been constructed typically of aluminum skin-covered frame assemblies or aluminum honeycomb structures. The trailing edge of the wing just forward of the leading edge of the aileron is sealed to allow controlled airflow

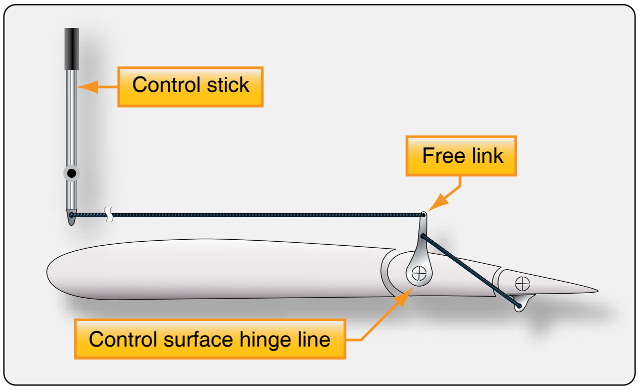

Figure 1-72. *Servo tabs can be used to position flight control surfaces in case of hydraulic failure.*

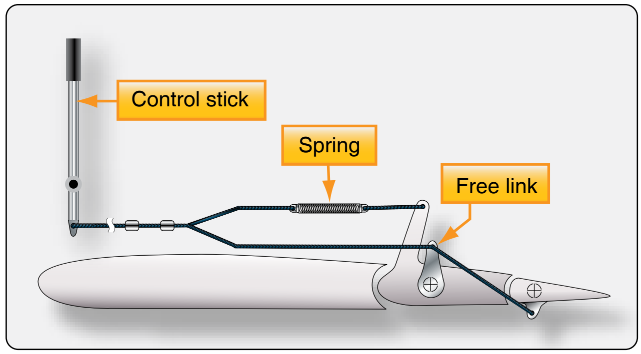

Figure 1-73. *Many tab linkages have a spring tab that kicks in as the forces needed to deflect a control increase with speed and the angle of desired deflection.*

in and out of the hinge area where the balance panel is located. *[Figure 1-75]* When the aileron is moved from the neutral position, differential pressure builds up on one side of the balance panel. This differential pressure acts on the balance panel in a direction that assists the aileron movement. For slight movements, deflecting the control tab at the trailing edge of the aileron is easy enough to not require significant assistance from the balance tab. (Moving the control tab moves the ailerons as desired.) But, as greater deflection is requested, the force resisting control tab and aileron movement becomes greater and augmentation from the balance tab is needed. The seals and mounting geometry allow the differential pressure of airflow on the balance panel to increase as deflection of the ailerons is increased. This makes the resistance felt when moving the aileron controls relatively constant.

Antiservo tabs, as the name suggests, are like servo tabs but move in the same direction as the primary control surface. On some aircraft, especially those with a movable horizontal stabilizer, the input to the control surface can be too sensitive. An antiservo tab tied through the control linkage creates an aerodynamic force that increases the effort needed to move the control surface. This makes flying the aircraft more stable for the pilot. *Figure 1-76* shows an antiservo tab in the near neutral position. Deflected in the same direction as the desired stabilator movement, it increases the required control surface input.

Other Wing Features

There may be other structures visible on the wings of an aircraft that contribute to performance. Winglets, vortex generators, stall fences, and gap seals are all common wing features. Introductory descriptions of each are given in the following paragraphs.

A winglet is an obvious vertical upturn of the wing's tip resembling a vertical stabilizer. It is an aerodynamic device designed to reduce the drag created by wing tip vortices in flight. Usually made from aluminum or composite materials, winglets can be designed to optimize performance at a desired speed. *[Figure 1-77]*

Vortex generators are small airfoil sections usually attached to the upper surface of a wing. *[Figure 1-78]* They are designed to promote smooth, or non-turbulent, airflow over the wing and control surfaces. Usually made of aluminum

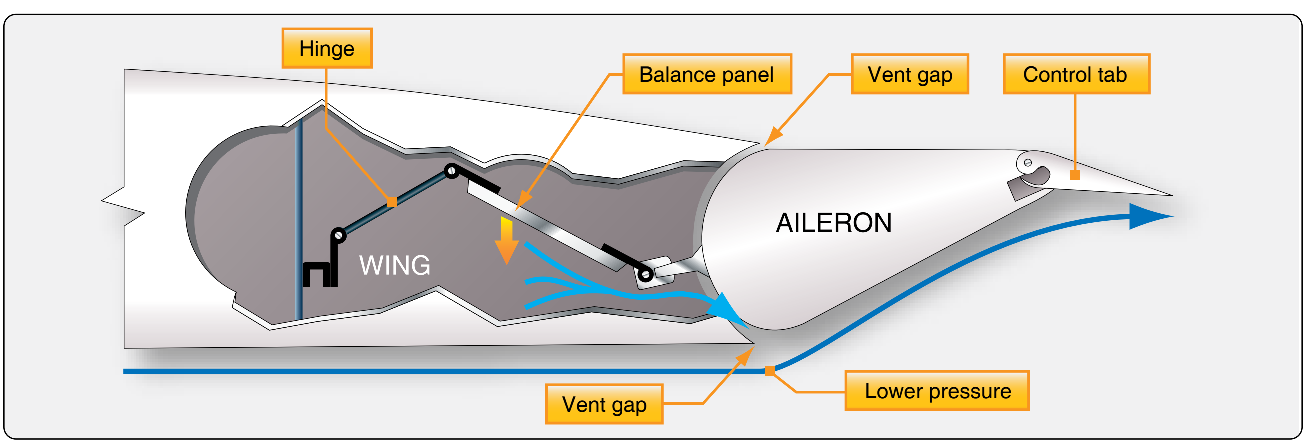

Figure 1-74. *An aileron balance panel and linkage uses varying air pressure to assist in control surface positioning.*

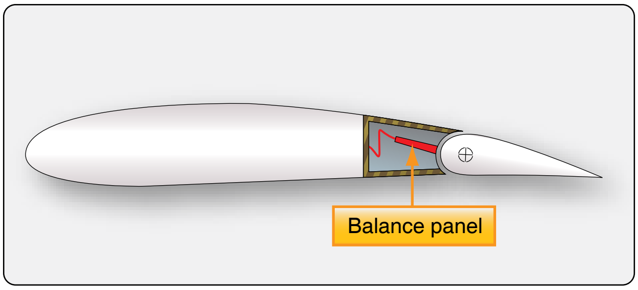

Figure 1-75. *The trailing edge of the wing just forward of the leading edge of the aileron is sealed to allow controlled airflow in and out of the hinge area where the balance panel is located.*

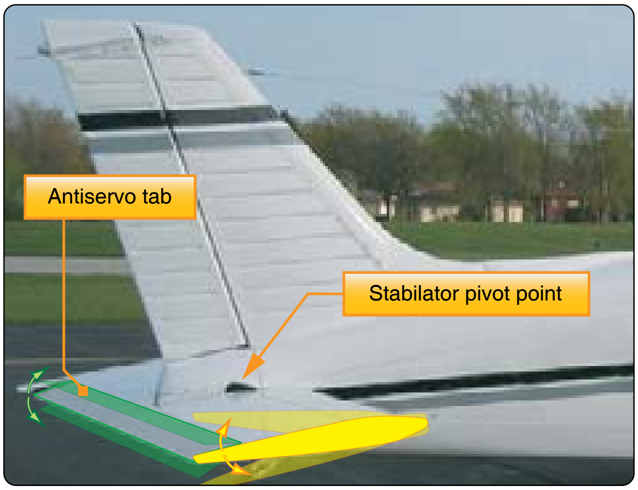

Figure 1-76. *An antiservo tab moves in the same direction as the control tab. Shown here on a stabilator, it desensitizes the pitch control.*

Figure 1-77. *A winglet reduces aerodynamic drag caused by air spilling off of the wing tip.*

Figure 1-78. *Vortex generators.*

Figure 1-79. *The Symphony SA-160 has two unique vortex generators on its wing to ensure aileron effectiveness through the stall.*

and installed in a spanwise line or lines, the vortices created by these devices swirl downward assisting maintenance of the boundary layer of air flowing over the wing. They can also be found on the fuselage and empennage. *Figure 1-79* shows the unique vortex generators on a Symphony SA-160 wing.

A chordwise barrier on the upper surface of the wing, called a stall fence, is used to halt the spanwise flow of air. During low speed flight, this can maintain proper chordwise airflow reducing the tendency for the wing to stall. Usually made of aluminum, the fence is a fixed structure most common on swept wings, which have a natural spanwise tending boundary air flow. *[Figure 1-80]*

Often, a gap can exist between the stationary trailing edge of a wing or stabilizer and the movable control surface(s). At high angles of attack, high pressure air from the lower wing surface can be disrupted at this gap. The result can be turbulent airflow, which increases drag. There is also a tendency for some lower wing boundary air to enter the gap and disrupt the upper wing surface airflow, which in turn reduces lift and control surface responsiveness. The use of gap seals is common to promote smooth airflow in these gap areas. Gap seals can be made of a wide variety of materials ranging from aluminum and impregnated fabric to foam and plastic. *Figure 1-81* shows some gap seals installed on various aircraft.

Landing Gear

The landing gear supports the aircraft during landing and while it is on the ground. Simple aircraft that fly at low speeds generally have fixed gear. This means the gear is stationary and does not retract for flight. Faster, more complex aircraft

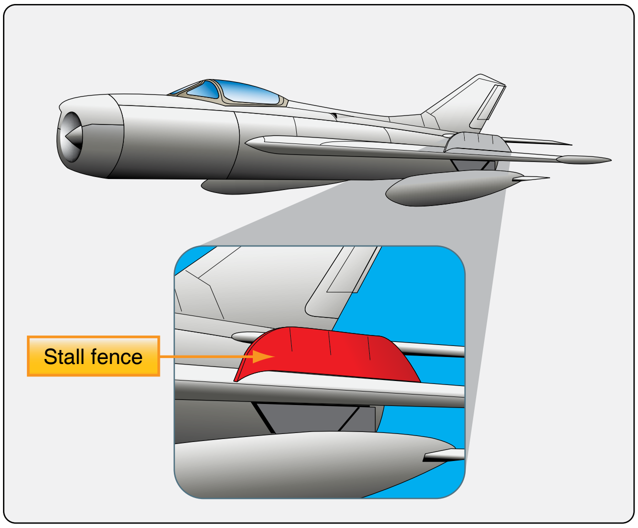

Figure 1-80. *A stall fence aids in maintaining chordwise airflow over the wing.*

have retractable landing gear. After takeoff, the landing gear is retracted into the fuselage or wings and out of the airstream. This is important because extended gear create significant parasite drag which reduces performance. Parasite drag is caused by the friction of the air flowing over the gear. It increases with speed. On very light, slow aircraft, the extra weight that accompanies a retractable landing gear is more of a detriment than the drag caused by the fixed gear. Lightweight fairings and wheel pants can be used to keep drag to a minimum. *Figure 1-82* shows examples of fixed and retractable gear.

Landing gear must be strong enough to withstand the forces of landing when the aircraft is fully loaded. In addition to strength, a major design goal is to have the gear assembly be as light as possible. To accomplish this, landing gear are made from a wide range of materials including steel, aluminum, and magnesium. Wheels and tires are designed specifically for aviation use and have unique operating characteristics. Main wheel assemblies usually have a braking system. To aid with the potentially high impact of landing, most landing gear have a means of either absorbing shock or accepting shock and distributing it so that the structure is not damaged.

Not all aircraft landing gear are configured with wheels. Helicopters, for example, have such high maneuverability and low landing speeds that a set of fixed skids is common and quite functional with lower maintenance. The same is true for free balloons which fly slowly and land on wood skids affixed to the floor of the gondola. Other aircraft landing gear are equipped with pontoons or floats for operation on water. A large amount of drag accompanies this type of gear, but an aircraft that can land and take off on water can be very useful in certain environments. Even skis can be found under some aircraft for operation on snow and ice. *Figure 1-83* shows some of these alternative landing gear, the majority of which are the fixed gear type.

Amphibious aircraft are aircraft than can land either on land or on water. On some aircraft designed for such dual usage, the bottom half of the fuselage acts as a hull. Usually, it is accompanied by outriggers on the underside of the wings near the tips to aid in water landing and taxi. Main gear that retract into the fuselage are only extended when landing on the ground or a runway. This type of amphibious aircraft is sometimes called a flying boat. *[Figure 1-84]*

Many aircraft originally designed for land use can be fitted with floats with retractable wheels for amphibious use. *[Figure 1-85]* Typically, the gear retracts into the float when not needed. Sometimes a dorsal fin is added to the aft underside of the fuselage for longitudinal stability during water operations. It is even possible on some aircraft to direct this type of fin by tying its control into the aircraft's rudder pedals. Skis can also be fitted with wheels that retract to allow landing on solid ground or on snow and ice.

Figure 1-81. *Gap seals promote the smooth flow of air over gaps between fixed and movable surfaces.*

Figure 1-82. *Landing gear can be fixed (top) or retractable (bottom).*

Tail Wheel Gear Configuration

There are two basic configurations of airplane landing gear: conventional gear or tail wheel gear and the tricycle gear. Tail wheel gear dominated early aviation and therefore has become known as conventional gear. In addition to its

Figure 1-84. *An amphibious aircraft is sometimes called a flying boat because the fuselage doubles as a hull.*

two main wheels which are positioned under most of the weight of the aircraft, the conventional gear aircraft also has a smaller wheel located at the aft end of the fuselage. *[Figure 1-86]* Often this tail wheel is able to be steered by rigging cables attached to the rudder pedals. Other conventional gear have no tail wheel at all using just a steel skid plate under the aft fuselage instead. The small tail wheel or skid plate allows the fuselage to incline, thus giving clearance for the long propellers that prevailed in aviation through WWII. It also gives greater clearance between the propeller and loose debris when operating on an unpaved runway. But the inclined fuselage blocks the straight-ahead vision of the pilot during ground operations. Until up to speed where the elevator becomes effective to lift the tail wheel off the ground, the pilot must lean his head out the side of the flight deck to see directly ahead of the aircraft.

The use of tail wheel gear can pose another difficulty. When

Figure 1-83. *Aircraft landing gear without wheels.*

Figure 1-85. *Retractable wheels make this aircraft amphibious.*

landing, tail wheel aircraft can easily ground loop. A ground loop is when the tail of the aircraft swings around and comes forward of the nose of the aircraft. The reason this happens is due to the two main wheels being forward of the aircraft's center of gravity. The tail wheel is aft of the center of gravity. If the aircraft swerves upon landing, the tail wheel can swing out to the side of the intended path of travel. If far enough to the side, the tail can pull the center of gravity out from its desired location slightly aft of but between the main gear. Once the center of gravity is no longer trailing the mains, the tail of the aircraft freely pivots around the main wheels causing the ground loop.

Conventional gear is useful and is still found on certain models of aircraft manufactured today, particularly aerobatic aircraft, crop dusters, and aircraft designed for unpaved runway use. It is typically lighter than tricycle gear which requires a stout, fully shock absorbing nose wheel assembly. The tail wheel configuration excels when operating out of unpaved runways. With the two strong main gear forward providing stability and directional control during takeoff roll, the lightweight tail wheel does little more than keep the aft end of the fuselage from striking the ground. As mentioned, at a certain speed,

Figure 1-86. *An aircraft with tail wheel gear.*

the air flowing over the elevator is sufficient for it to raise the tail off the ground. As speed increases further, the two main wheels under the center of gravity are very stable.

Tricycle Gear Configuration

Tricycle gear is the most prevalent landing gear configuration in aviation. In addition to the main wheels, a shock absorbing nose wheel is at the forward end of the fuselage. Thus, the center of gravity is then forward of the main wheels. The tail of the aircraft is suspended off the ground and clear view straight ahead from the flight deck is given. Ground looping is nearly eliminated since the center of gravity follows the directional nose wheel and remains between the mains.

Light aircraft use tricycle gear, as well as heavy aircraft. Twin nose wheels on the single forward strut and massive multistrut/multiwheel main gear may be found supporting the world's largest aircraft, but the basic configuration is still tricycle. The nose wheel may be steered with the rudder pedals on small aircraft. Larger aircraft often have a nose wheel steering wheel located off to the side of the flight deck. *Figure 1-87* shows aircraft with tricycle gear. Chapter 13, Aircraft Landing Gear Systems, discusses landing gear in detail.

Maintaining the Aircraft

Maintenance of an aircraft is of the utmost importance for safe flight. Certificated technicians are committed to perform timely maintenance functions in accordance with the manufacturer's instructions and under Title 14 of the Code of Federal Regulations (14 CFR). At no time is an act of aircraft maintenance taken lightly or improvised. The consequences of such action could be fatal, and the technician could lose their certificate and face criminal charges.

Airframe, engine, and aircraft component manufacturers are responsible for documenting the maintenance procedures that guide managers and technicians on when and how to perform maintenance on their products. A small aircraft may only require a few manuals, including the aircraft maintenance manual. This volume usually contains the most frequently used information required to maintain the aircraft properly. The Type Certificate Data Sheet (TCDS) for an aircraft also contains critical information. Complex and large aircraft require several manuals to convey correct maintenance procedures adequately. In addition to the maintenance manual, manufacturers may produce such volumes as structural repair manuals, overhaul manuals, wiring diagram manuals, component manuals, and more.

Note that the use of the word "manual" is meant to include electronic as well as printed information. Also, proper maintenance extends to the use of designated tools and fixtures called out in the manufacturer's maintenance documents. In

Figure 1-87. *Tricycle landing gear is the most predominant landing gear configuration in aviation.*

the past, not using the proper tooling has caused damage to critical components, which subsequently failed and led to aircraft crashes and the loss of human life. The technician is responsible for using the correct information, procedures, and tools needed to perform appropriate maintenance or repairs.

Standard aircraft maintenance procedures do exist and can be used by the technician when performing maintenance or a repair. These are found in the Federal Aviation Administration (FAA) approved advisory circulars (AC) 43.13-2, *Acceptable Methods, Techniques, and Practices - Aircraft Alterations* and AC 43.13-1, *Acceptable Methods, Techniques, and Practices - Aircraft Inspection and Repair*. If not addressed by the manufacturer's literature, the technician may use the procedures outlined in these manuals to complete the work in an acceptable manner. These procedures are not specific to any aircraft or component and typically cover methods used during maintenance of all aircraft. Note that the manufacturer's instructions supersede the general procedures found in AC 43.13-2 and AC 43.13-1.

All maintenance related actions on an aircraft or component are required to be documented by the performing technician in the aircraft or component logbook. Light aircraft may have only one logbook for all work performed. Some aircraft may have a separate engine logbook for any work performed on the engine(s). Other aircraft have separate propeller logbooks. Large aircraft require volumes of maintenance documentation comprised of thousands of procedures performed by hundreds of technicians. Electronic dispatch and recordkeeping of maintenance performed on large aircraft such as airliners is common. The importance of correct maintenance recordkeeping should not be overlooked.

Location Numbering Systems

Even on small, light aircraft, a method of precisely locating each structural component is required. Various numbering systems are used to facilitate the location of specific wing frames, fuselage bulkheads, or any other structural members on an aircraft. Most manufacturers use some system of station marking. For example, the nose of the aircraft may be designated "zero station," and all other stations are located at measured distances in inches behind the zero station. Thus, when a blueprint reads "fuselage frame station 137," that particular frame station can be located 137 inches behind the nose of the aircraft.

To locate structures to the right or left of the center line of an aircraft, a similar method is employed. Many manufacturers consider the center line of the aircraft to be a zero station from which measurements can be taken to the right or left to locate an airframe member. This is often used on the horizontal stabilizer and wings.

The applicable manufacturer's numbering system and abbreviated designations or symbols should always be reviewed before attempting to locate a structural member. They are not always the same. The following list includes location designations typical of those used by many manufacturers.

- Fuselage stations (Fus. Sta. or FS) are numbered in inches from a reference or zero point known as the reference datum. *[Figure 1-88]* The reference datum is an imaginary vertical plane at or near the nose of the aircraft from which all fore and aft distances are measured. The distance to a given point is measured in inches parallel to a center line extending through the aircraft from the nose through the center of the tail cone. Some manufacturers may call the fuselage station a body station, abbreviated BS.
- Buttock line or butt line (BL) is a vertical reference plane down the center of the aircraft from which measurements left or right can be made. *[Figure 1-89]*
- Water line (WL) is the measurement of height in inches perpendicular from a horizontal plane usually located at the ground, cabin floor, or some other easily referenced location. *[Figure 1-90]*
- Aileron station (AS) is measured outboard from, and parallel to, the inboard edge of the aileron, perpendicular to the rear beam of the wing.
- Flap station (KS) is measured perpendicular to the rear

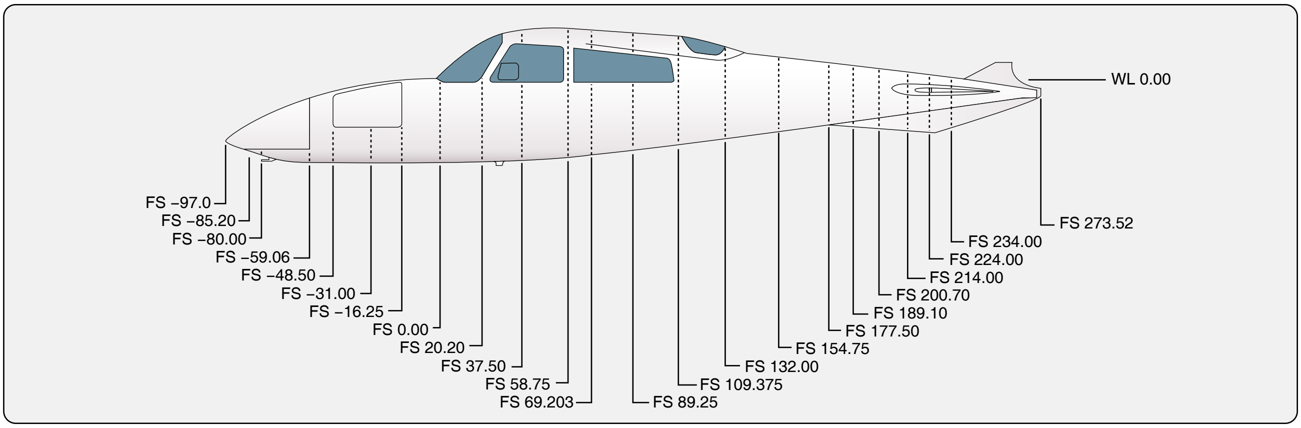

Figure 1-88. *The various fuselage stations relative to a single point of origin illustrated in inches or some other measurement (if of foreign development).*

beam of the wing and parallel to, and outboard from, the inboard edge of the flap.

- Nacelle station (NC or Nac. Sta.) is measured either forward of or behind the front spar of the wing and perpendicular to a designated water line.

In addition to the location stations listed above, other measurements are used, especially on large aircraft. Thus, there may be horizontal stabilizer stations (HSS), vertical stabilizer stations (VSS) or powerplant stations (PPS). *[Figure 1-91]* In every case, the manufacturer's terminology and station location system should be consulted before locating a point on a particular aircraft.

Another method is used to facilitate the location of aircraft components on air transport aircraft. This involves dividing the aircraft into zones. These large areas or major zones are further divided into sequentially numbered zones and subzones. The digits of the zone number are reserved and indexed to indicate the location and type of system of which the component is a part. *Figure 1-92* illustrates these zones and subzones on a transport category aircraft.

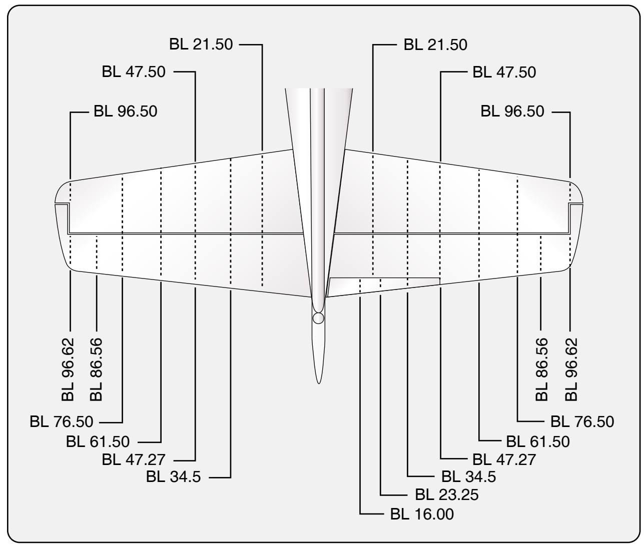

Figure 1-89. *Butt line diagram of a horizontal stabilizer.*

Access & Inspection Panels

Quick access to the accessories and other equipment carried in the fuselage is provided for by numerous access doors, inspection plates, landing wheel wells, and other openings.

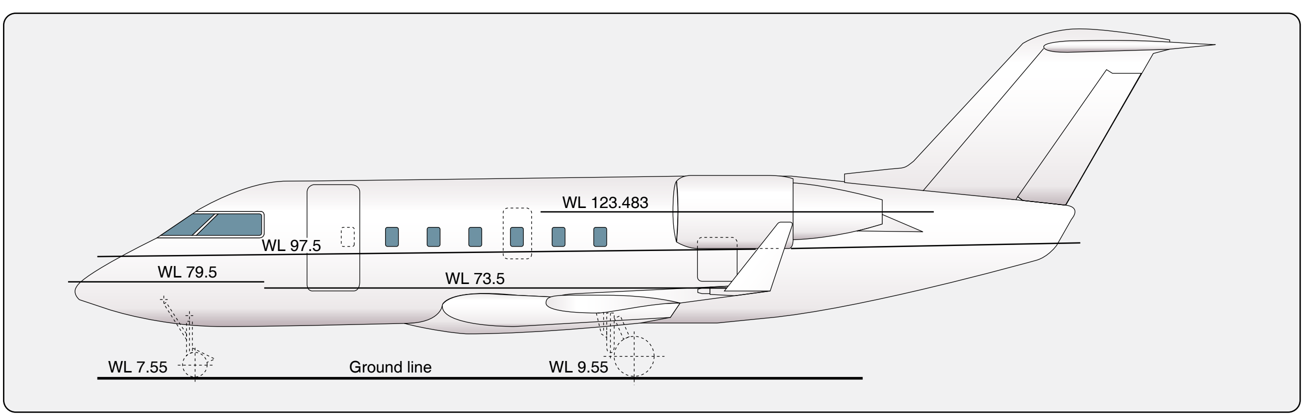

Figure 1-90. *Water line diagram.*

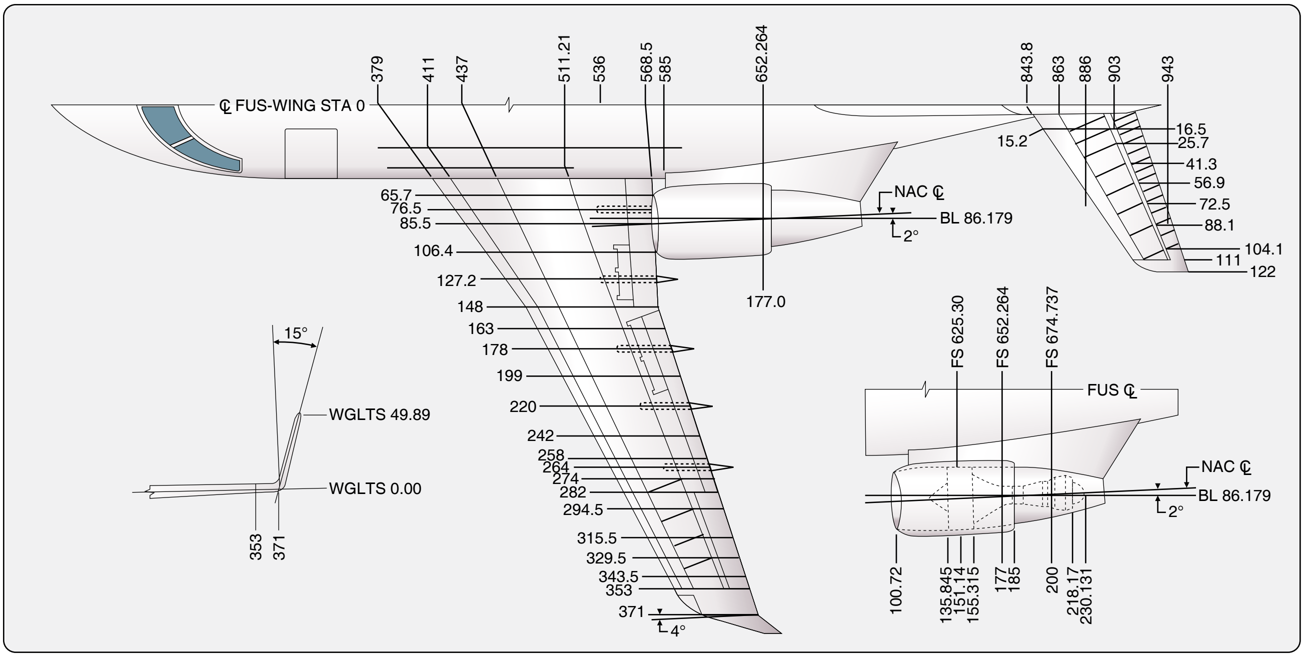

Figure 1-91. *Wing stations are often referenced off the butt line, which bisects the center of the fuselage longitudinally. Horizontal stabilizer stations referenced to the butt line and engine nacelle stations are also shown.*

Servicing diagrams showing the arrangement of equipment and location of access doors are supplied by the manufacturer in the aircraft maintenance manual.

Knowing where a particular structure or component is located on an aircraft needs to be combined with gaining access to that area to perform the required inspections or maintenance. To facilitate this, access and inspection panels are located on most surfaces of the aircraft. Small panels that are hinged or removable allow inspection and servicing. Large panels and doors allow components to be removed and installed, as well as human entry for maintenance purposes.

The underside of a wing, for example, sometimes contains dozens of small panels through which control cable components can be monitored and fittings greased. Various drains and jack points may also be on the underside of the wing. The upper surface of the wings typically have fewer access panels because a smooth surface promotes better laminar airflow, which causes lift. On large aircraft, walkways are sometimes designated on the wing upper surface to permit safe navigation by mechanics and inspectors to critical structures and components located along the wing's leading and trailing edges. Wheel wells and special component bays are places where numerous components and accessories are grouped together for easy maintenance access.

Panels and doors on aircraft are numbered for positive identification. On large aircraft, panels are usually numbered sequentially containing zone and subzone information in the panel number. Designation for a left or right side location on the aircraft is often indicated in the panel number. This could be with an "L" or "R," or panels on one side of the aircraft could be odd numbered and the other side even numbered. The manufacturer's maintenance manual explains the panel numbering system and often has numerous diagrams and tables showing the location of various components and under which panel they may be found. Each manufacturer is entitled to develop its own panel numbering system.

Helicopter Structures

The structures of the helicopter are designed to give the helicopter its unique flight characteristics. A simplified explanation of how a helicopter flies is that the rotors are rotating airfoils that provide lift similar to the way wings provide lift on a fixed-wing aircraft. Air flows faster over the curved upper surface of the rotors, causing a negative pressure and thus, lifting the aircraft. Changing the angle of attack of the rotating blades increases or decreases lift, respectively raising or lowering the helicopter. Tilting the rotor plane of rotation causes the aircraft to move horizontally. *Figure 1-93* shows the major components of a typical helicopter.

Airframe

The airframe, or fundamental structure, of a helicopter can be made of either metal or wood composite materials, or some combination of the two. Typically, a composite component consists of many layers of fiber-impregnated resins, bonded to form a smooth panel. Tubular and sheet metal substructures are usually made of aluminum, though stainless steel or

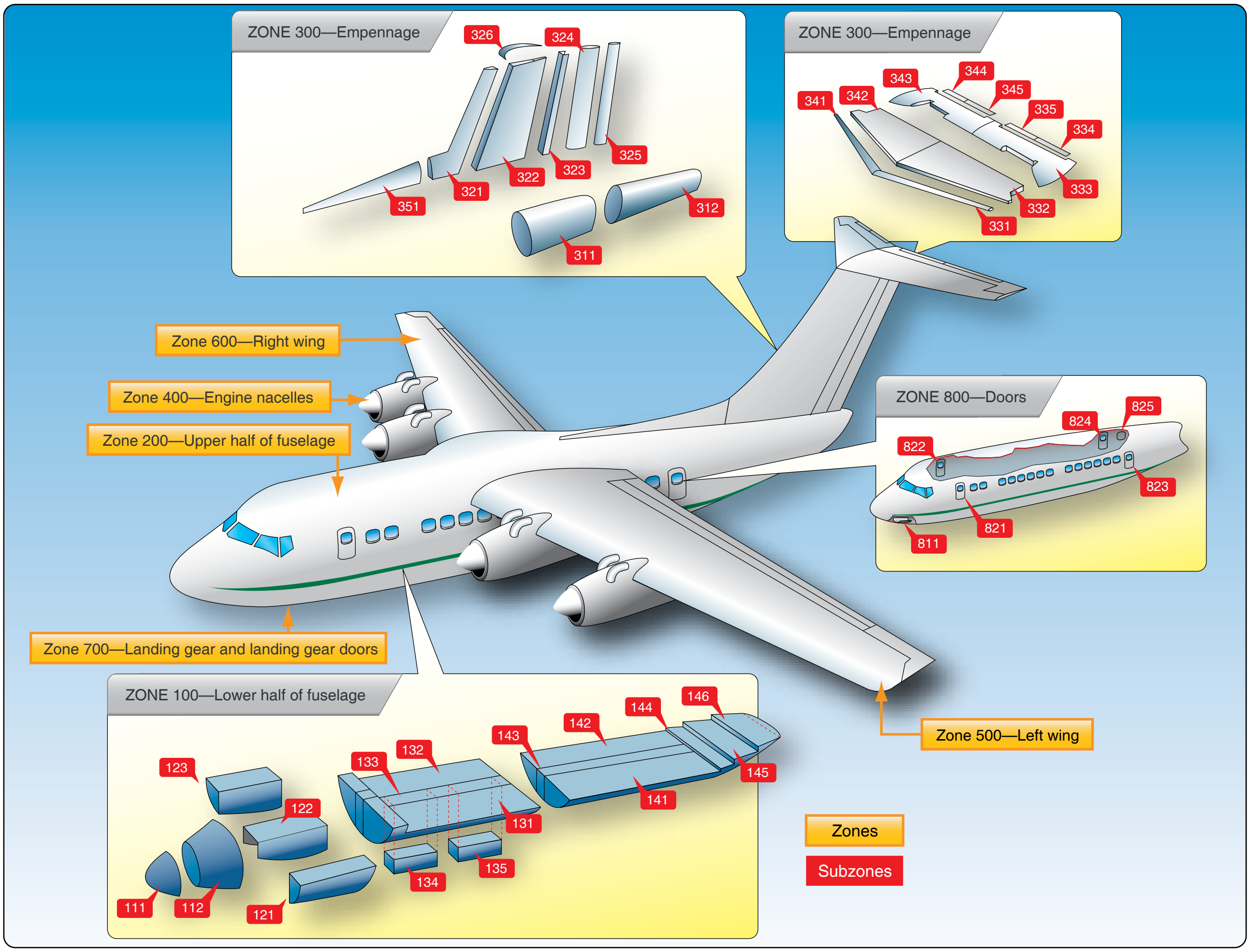

Figure 1-92. *Large aircraft are divided into zones and subzones for identifying the location of various components.*

titanium are sometimes used in areas subject to higher stress or heat. Airframe design encompasses engineering, aerodynamics, materials technology, and manufacturing methods to achieve favorable balances of performance, reliability, and cost.

Fuselage

As with fixed-wing aircraft, helicopter fuselages and tail booms are often truss-type or semimonocoque structures of stress-skin design. Steel and aluminum tubing, formed aluminum, and aluminum skin are commonly used. Modern helicopter fuselage design includes an increasing utilization of advanced composites as well. Firewalls and engine decks are usually stainless steel. Helicopter fuselages vary widely from those with a truss frame, two seats, no doors, and a monocoque shell flight compartment to those with fully enclosed airplane-style cabins as found on larger twin-engine helicopters. The multidirectional nature of helicopter flight makes wide-range visibility from the flight deck essential. Large, formed polycarbonate, glass, or plexiglass windscreens are common.

Landing Gear or Skids

As mentioned, a helicopter's landing gear can be simply a set of tubular metal skids. Many helicopters do have landing gear with wheels, some retractable.

Powerplant & Transmission

The two most common types of engine 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

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. The turbine engine used in helicopters operates differently than those used in airplane applications. In most applications, the exhaust outlets simply release expended

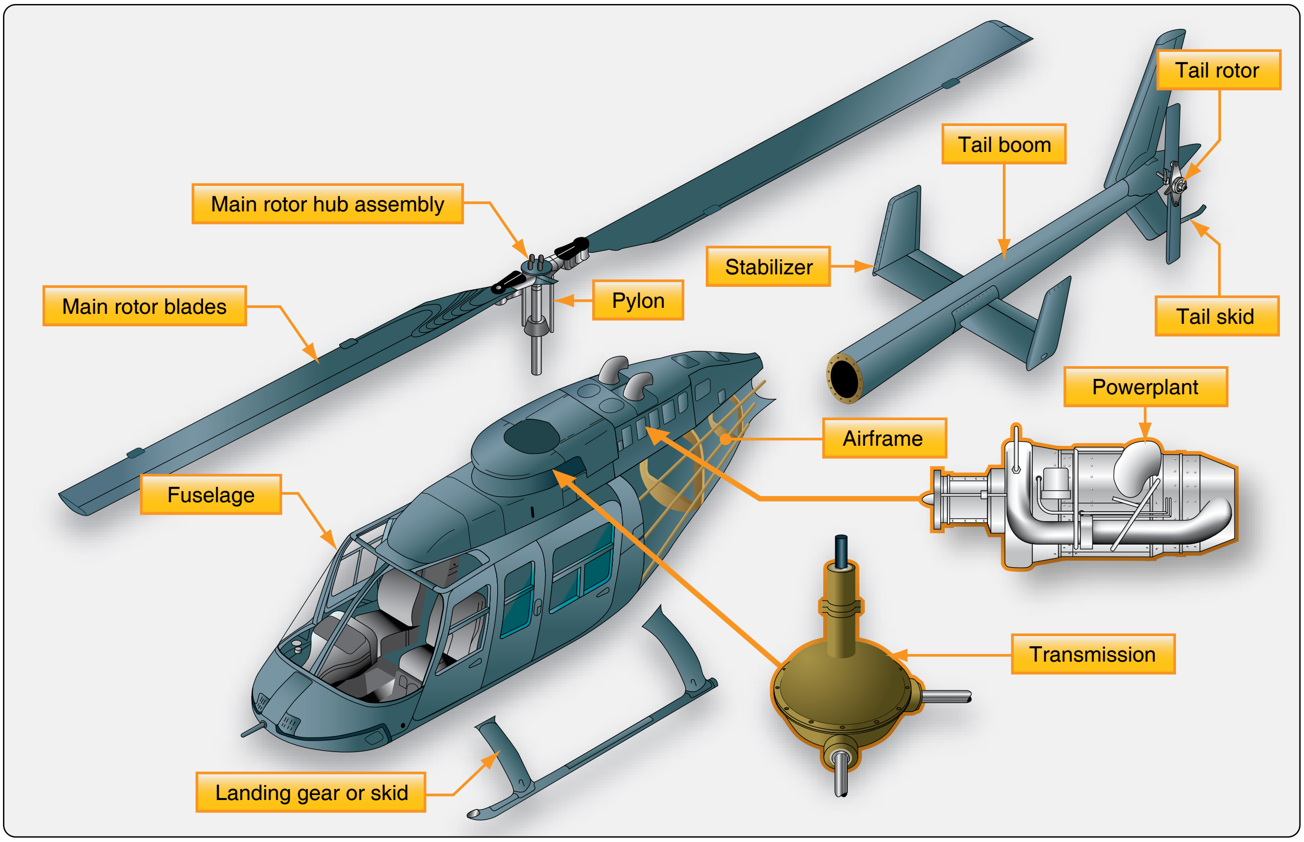

Figure 1-93. *The major components of a helicopter are the airframe, fuselage, landing gear, powerplant/transmission, main rotor system, and antitorque system.*

gases and do not contribute to the forward motion of the helicopter. Because the airflow is not a straight line pass through as in jet engines and is not used for propulsion, the cooling effect of the air is limited. Approximately 75 percent of the incoming airflow is used to cool the 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. Common type filters are centrifugal swirl tubes where debris is ejected outward and blown overboard prior to entering the compressor, or engine barrier filters (EBF), a paper element type filter, encased in a frame with a screen/grill over the inlet, and usually coated with an oil. This design significantly reduces the ingestion of foreign object debris (FOD). The compressed air is directed to the combustion section through discharge tubes where atomized fuel is injected into it. The air-fuel 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. Depending on model and manufacturer, the rpm range can vary from a range low of 20,000 to a range high of 51,600.

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. The temperature of gas is measured at different locations and is referenced differently by each manufacturer. Some common terms are: inter-turbine temperature (ITT), exhaust gas temperature (EGT), or turbine outlet temperature (TOT). TOT is used throughout this discussion for simplicity purposes. *[Figure 1-94]*

Transmission

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

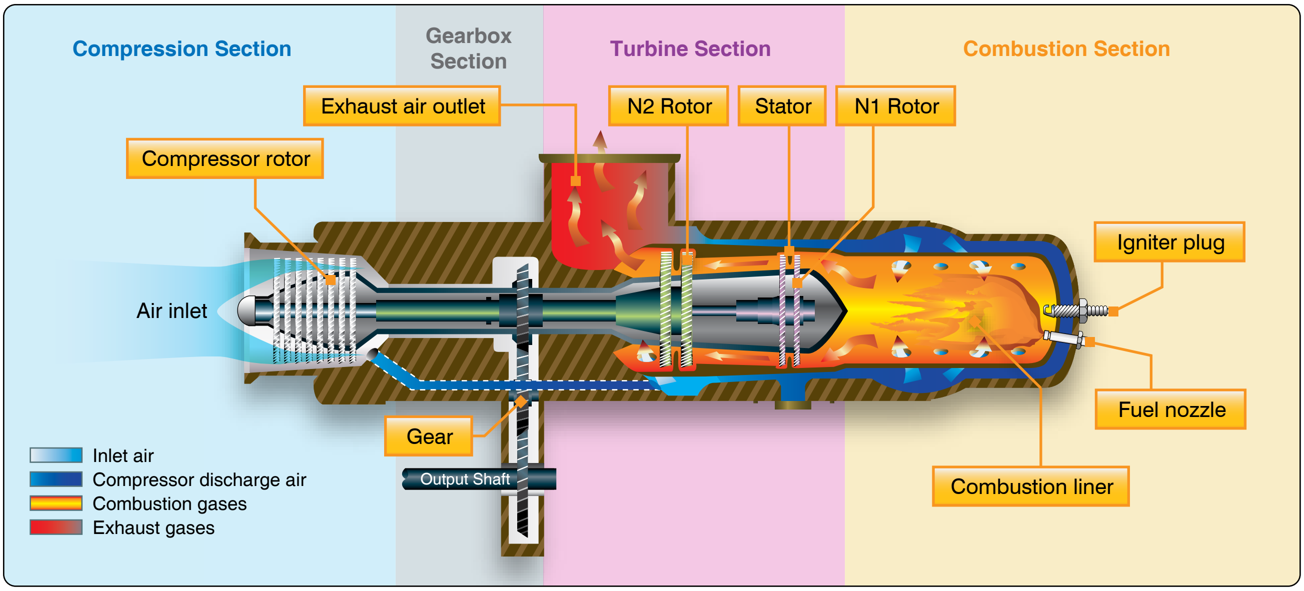

Figure 1-94. *Many helicopters use a turboshaft engine to drive the main transmission and rotor systems. The main difference between a turboshaft and a turbojet engine is that most of the energy produced by the expanding gases is used to drive a turbine rather than producing thrust through the expulsion of exhaust gases.*

on the pilot's instrument panel that illuminate in the event of an internal problem. Some 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 System

The rotor system is the rotating part of a helicopter which generates lift. The rotor consists of a mast, hub, and rotor blades. The mast is a cylindrical metal shaft that extends upwards from and is driven, and sometimes supported, by the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub by any number of different methods. Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: rigid, semirigid, or fully articulated.

Rigid Rotor System

The simplest is the rigid rotor system. In this system, the rotor blades are rigidly attached to the main rotor hub and are not free to slide back and forth (drag) or move up and down (flap). *[Figure 1-95]* The forces tending to make the rotor blades do so are absorbed by the flexible properties of the blade. The pitch of the blades, however, can be adjusted by rotation about the spanwise axis via the feathering hinges.

Semirigid Rotor System

The semirigid rotor system in *Figure 1-96* makes use of a teetering hinge at the blade attach point. While held in check from sliding back and forth, the teetering hinge does allow the blades to flap up and down. With this hinge, when one blade flaps up, the other flaps down.

Flapping is caused by a phenomenon known as dissymmetry of lift. As the plane of rotation of the rotor blades is tilted and the helicopter begins to move forward, an advancing blade and a retreating blade become established (on two-bladed systems). The relative windspeed is greater on an advancing blade than it is on a retreating blade. This causes greater lift to be developed on the advancing blade, causing it to rise up or flap. When blade rotation reaches the point where the blade becomes the retreating blade, the extra lift is lost and the blade flaps downward. *[Figure 1-97]*

Fully Articulated Rotor System

Fully articulated rotor blade systems provide hinges that allow the rotors to move fore and aft, as well as up and down. This lead-lag, drag, or hunting movement as it is called is in response to the Coriolis effect during rotational speed changes. When first starting to spin, the blades lag until centrifugal force is fully developed. Once rotating, a reduction in speed causes the blades to lead the main rotor hub until forces come into balance. Constant fluctuations in rotor blade speeds cause the blades to "hunt." They are free to do so in a fully articulating system due to being mounted on the vertical drag hinge.

One or more horizontal hinges provide for flapping on a fully articulated rotor system. Also, the feathering hinge allows blade pitch changes by permitting rotation about the spanwise axis. Various dampers and stops can be found on

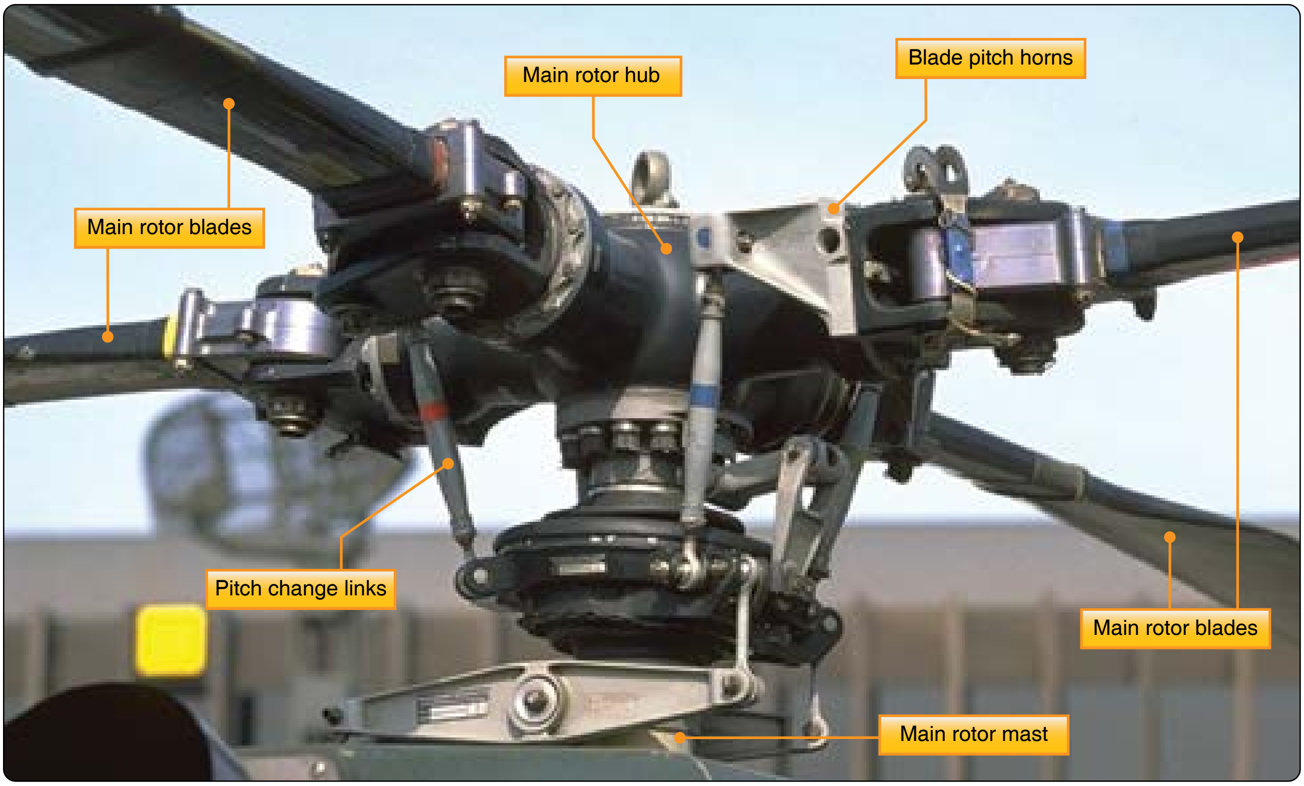

Figure 1-95. *Four-blade hingeless (rigid) main rotor. The hub is a single piece of forged rigid titanium.*

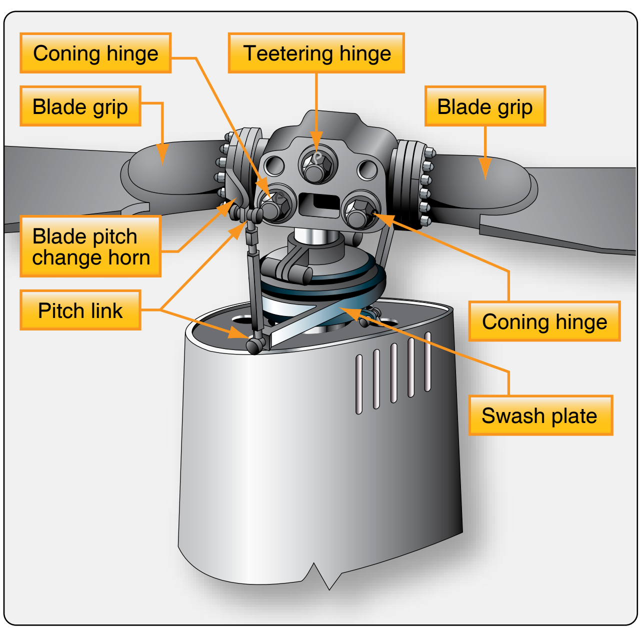

Figure 1-96. *The semirigid rotor system of the Robinson R22.*

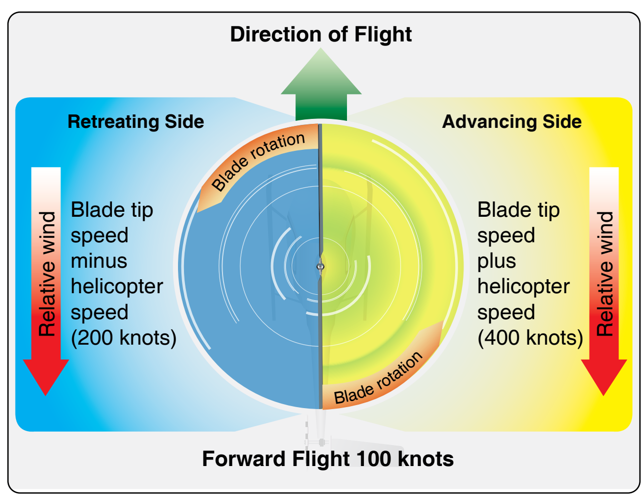

Figure 1-97. *The blade tip speed of this helicopter is approximately 300 knots. If the helicopter is moving forward at 100 knots, the relative windspeed on the advancing side is 400 knots. On the retreating side, it is only 200 knots. This difference in speed causes a dissymmetry of lift.*

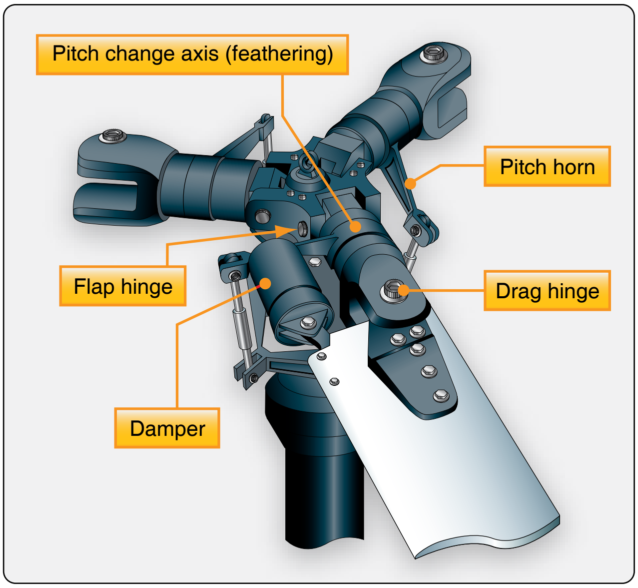

Figure 1-98. *Fully articulated rotor system.*

Figure 1-99. *Five-blade articulated main rotor with elastomeric bearings.*

different designs to reduce shock and limit travel in certain directions. *Figure 1-98* shows a fully articulated main rotor system with the features discussed.

Numerous designs and variations on the three types of main rotor systems exist. Engineers continually search for ways to reduce vibration and noise caused by the rotating parts of the helicopter. Toward that end, the use of elastomeric bearings in main rotor systems is increasing. These polymer bearings have the ability to deform and return to their original shape. As such, they can absorb vibration that would normally be transferred by steel bearings. They also do not require regular lubrication, which reduces maintenance.

Some modern helicopter main rotors have been designed with flextures. These are hubs and hub components that are made out of advanced composite materials. They are designed to take up the forces of blade hunting and dissymmetry of lift by flexing. As such, many hinges and bearings can be eliminated from the traditional main rotor system. The result is a simpler rotor mast with lower maintenance due to fewer moving parts. Often, designs using flextures incorporate elastomeric bearings. *[Figure 1-99]*

Antitorque System

Ordinarily, helicopters have between two and seven main rotor blades. These rotors are usually made of a composite structure. The large rotating mass of the main rotor blades of a helicopter produce torque. This torque increases with engine power and tries to spin the fuselage in the opposite direction. The tail boom and tail rotor, or antitorque rotor, counteract this torque effect. *[Figure 1-100]* Controlled with foot pedals, the countertorque of the tail rotor must be modulated as engine power levels are changed. This is done by changing the pitch of the tail rotor blades. This, in turn, changes the amount of countertorque, and the aircraft can be rotated about its vertical axis, allowing the pilot to control the direction the helicopter is facing.

Similar to a vertical stabilizer on the empennage of an airplane, a fin or pylon is also a common feature on rotorcraft. Normally, it supports the tail rotor assembly, although some tail rotors are mounted on the tail cone of the boom. Additionally, a horizontal member called a stabilizer is often constructed at the tail cone or on the pylon.

A Fenestron® is a unique tail rotor design which is actually a multiblade ducted fan mounted in the vertical pylon. It works the same way as an ordinary tail rotor, providing sideways thrust to counter the torque produced by the main rotors. *[Figure 1-101]*

A NOTAR® antitorque system has no visible rotor mounted

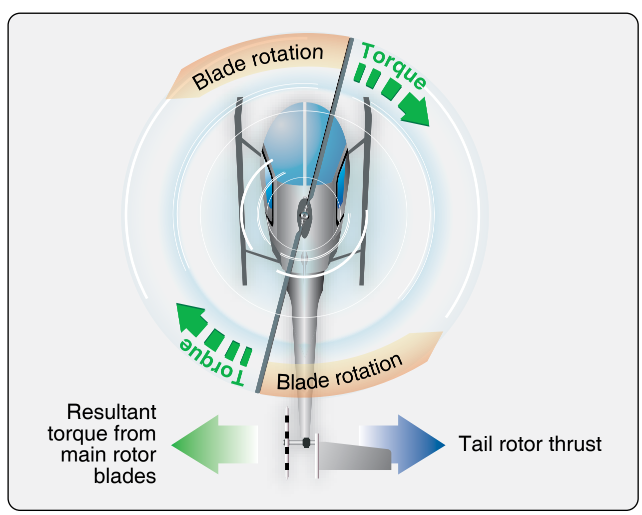

Figure 1-100. *A tail rotor is designed to produce thrust in a direction opposite to that of the torque produced by the rotation of the main rotor blades. It is sometimes called an antitorque rotor.*

Figure 1-101. *A Fenestron or "fan-in-tail" antitorque system. This design provides an improved margin of safety during ground operations.*

on the tail boom. Instead, an engine-driven adjustable fan is located inside the tail boom. NOTAR® is an acronym that stands for "no tail rotor." As the speed of the main rotor changes, the speed of the NOTAR® fan changes. Air is vented out of two long slots on the right side of the tail boom, entraining main rotor wash to hug the right side of the tail boom, in turn causing laminar flow and a low pressure (Coanda Effect). This low pressure causes a force counter to the torque produced by the main rotor. Additionally, the remainder of the air from the fan is sent through the tail boom to a vent on the aft left side of the boom where it is expelled. This action to the left causes an opposite reaction to the right, which is the direction needed to counter the main rotor torque. *[Figure 1-102]*

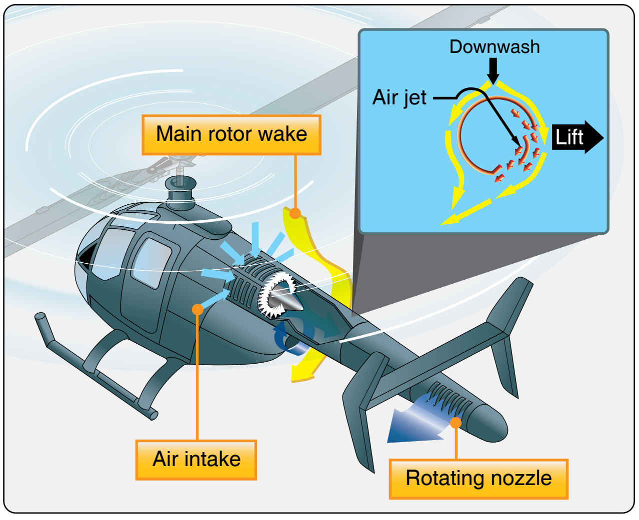

Figure 1-102. *While in a hover, Coanda Effect supplies approximately two-thirds of the lift necessary to maintain directional control. The rest is created by directing the thrust from the controllable rotating nozzle.*

Controls

The controls of a helicopter differ slightly from those found in an aircraft. The collective, operated by the pilot with the left hand, is pulled up or pushed down to increase or decrease the angle of attack on all of the rotor blades simultaneously. This increases or decreases lift and moves the aircraft up or down. The engine throttle control is located on the hand grip at the end of the collective. The cyclic is the control "stick" located between the pilot's legs. It can be moved in any direction to tilt the plane of rotation of the rotor blades. This causes the helicopter to move in the direction that the cyclic is moved. As stated, the foot pedals control the pitch of the tail rotor blades thereby balancing main rotor torque. *Figures 1-103* and *1-104* illustrate the controls found in a typical helicopter.

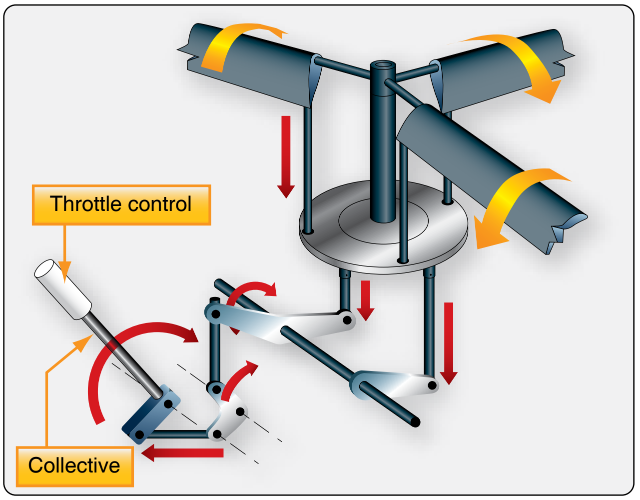

Figure 1-103. *The collective changes the pitch of all of the rotor blades simultaneously and by the same amount, thereby increasing or decreasing lift.*

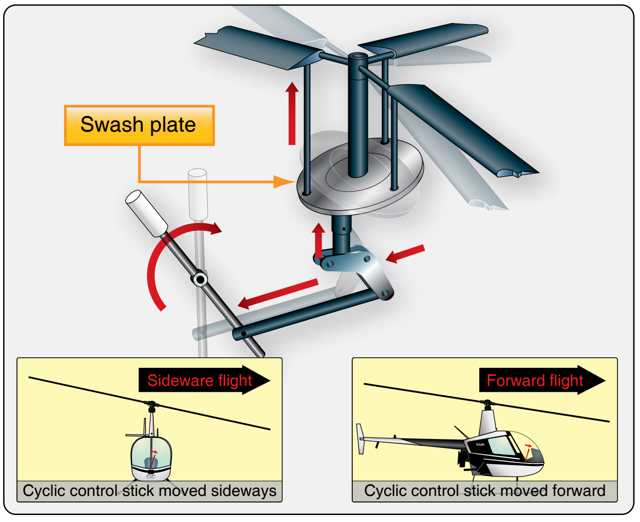

Figure 1-104. *The cyclic changes the angle of the swash plate which changes the plane of rotation of the rotor blades. This moves the aircraft horizontally in any direction depending on the positioning of the cyclic.*

Chapter 2

Aerodynamics, Aircraft Assembly, & 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

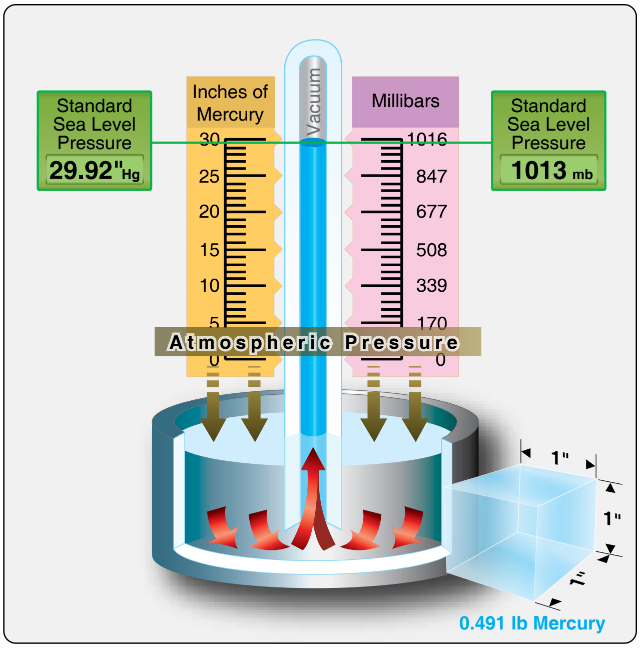

Figure 2-1. *Barometer used to measure atmospheric pressure.*

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

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

Density

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

The density of gases is governed by the following rules:

1. Density varies in direct proportion with the pressure.
2. Density varies inversely with the temperature.

Thus, air at high altitudes is less dense than air at low altitudes, and a mass of hot air is less dense than a mass of cool air.

Changes in density affect the aerodynamic performance of aircraft with the same horsepower. An aircraft can fly faster at a high altitude where the density is low than at a low altitude where the density is greater. This is because air offers less resistance to the aircraft when it contains a smaller number of air particles per unit of volume.

Humidity

Humidity is the amount of water vapor in the air. The maximum amount of water vapor that air can hold varies with the temperature. The higher the temperature of the air, the more water vapor it can absorb.

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

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

By itself, water vapor weighs approximately five-eighths as much as an equal amount of perfectly dry air. Therefore, when air contains water vapor, it is not as heavy as dry air containing no moisture.

Aerodynamics & the Laws of Physics

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

Motion is the act or process of changing place or position. An object may be in motion with respect to one object and motionless with respect to another. For example, a person sitting quietly in an aircraft flying at 200 knots is at rest or motionless with respect to the aircraft; however, the person and the aircraft are in motion with respect to the air and to the earth.

Air has no force or power, except pressure, unless it is in motion. When it is moving, however, its force becomes apparent. A moving object in motionless air has a force exerted on it as a result of its own motion. It makes no difference in the effect then, whether an object is moving with respect to the air or the air is moving with respect to the object. The flow of air around an object caused by the movement of either the air or the object, or both, is called the relative wind.

Velocity & Acceleration

The terms "speed" and "velocity" are often used interchangeably, but they do not have the same meaning. Speed is the rate of motion in relation to time, and velocity is the rate of motion in a particular direction in relation to time.

An aircraft starts from New York City and flies 10 hours at an average speed of 260 miles per hour (mph). At the end of this time, the aircraft may be over the Atlantic Ocean, Pacific Ocean, Gulf of Mexico, or, if its flight were in a circular path, it may even be back over New York City. If this same aircraft flew at a velocity of 260 mph in a southwestward direction, it would arrive in Los Angeles in about 10 hours. Only the rate of motion is indicated in the first example and denotes the speed of the aircraft. In the last example, the particular direction is included with the rate of motion, thus, denoting the velocity of the aircraft.

Acceleration is defined as the rate of change of velocity. An aircraft increasing in velocity is an example of positive acceleration, while another aircraft reducing its velocity is an example of negative acceleration, or deceleration.

Newton's Laws of Motion

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

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

According to Newton's law, since air has mass, it is a body. When an aircraft is on the ground with its engines off, inertia keeps the aircraft at rest. An aircraft is moved from its state of rest by the thrust force created by a propeller, or by the expanding exhaust, or both. When an aircraft is flying at uniform speed in a straight line, inertia tends to keep the aircraft moving. Some external force is required to change the aircraft from its path of flight.

Newton's second law states that if a body moving with uniform speed is acted upon by an external force, the change of motion is proportional to the amount of the force, and motion takes place in the direction in which the force acts. This law may be stated mathematically as follows:

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 & Subsonic Flow

Bernoulli's principle states that when a fluid (air) flowing through a tube reaches a constriction, or narrowing, of the tube, the speed of the fluid flowing through that constriction is increased and its pressure is decreased. The cambered (curved) surface of an airfoil (wing) affects the airflow exactly as a constriction in a tube affects airflow. *[Figure 2-2]* Diagram A of *Figure 2-2* illustrates the effect of air passing through a constriction in a tube. In Diagram B, air is flowing past a cambered surface, such as an airfoil, and the effect is similar to that of air passing through a restriction.

As the air flows over the upper surface of an airfoil, its velocity increases and its pressure decreases; an area of low pressure is formed. There is an area of greater pressure on the lower surface of the airfoil, and this greater pressure tends to move the wing upward. The difference in pressure between the upper and lower surfaces of the wing is called lift. Three-fourths of the total lift of an airfoil is the result of the decrease in pressure over the upper surface. The impact of air on the under surface of an airfoil produces the other one-fourth of the total lift.

Airfoil

An airfoil is a surface designed to obtain lift from the air through which it moves. Thus, it can be stated that any part of the aircraft that converts air resistance into lift is an airfoil. The profile of a conventional wing is an excellent example of an airfoil. *[Figure 2-3]* Notice that the top surface of the wing profile has greater curvature than the lower surface.

The difference in curvature of the upper and lower surfaces of the wing builds up the lift force. Air flowing over the top surface of the wing must reach the trailing edge of the wing in the same amount of time as the air flowing under the wing. To do this, the air passing over the top surface moves at a

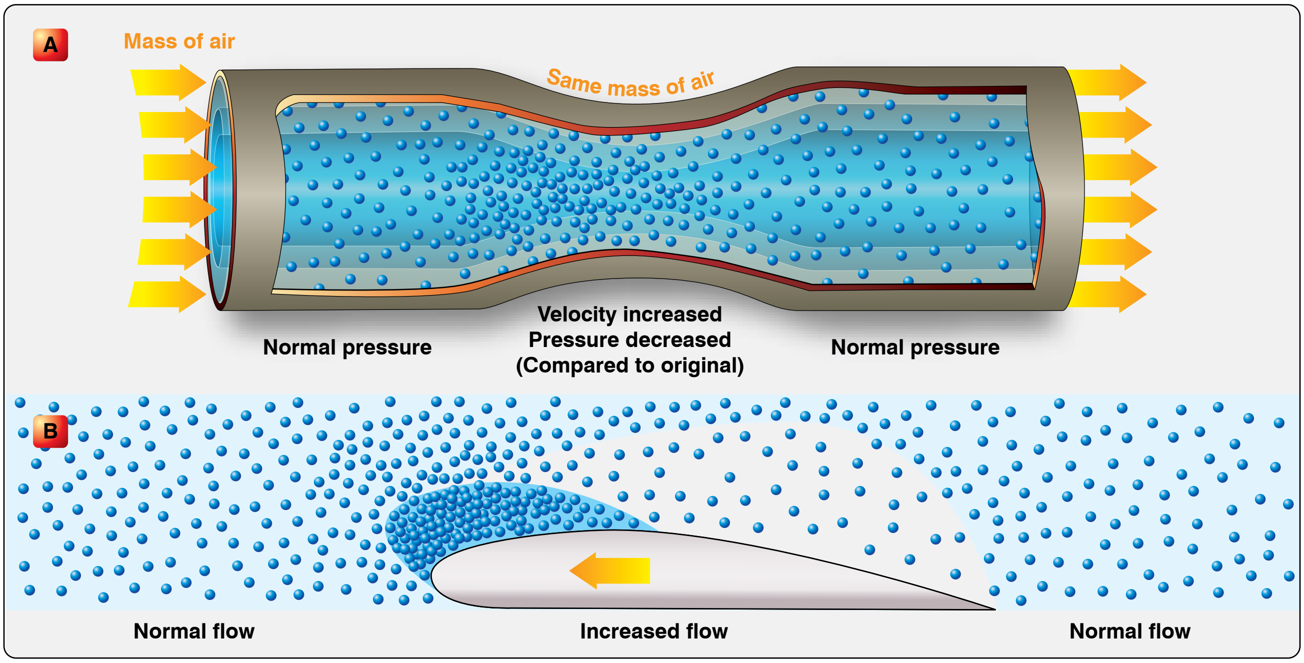

Figure 2-2. *Bernoulli's Principle.*

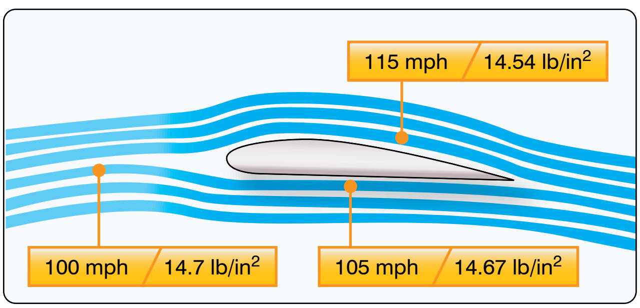

Figure 2-3. *Airflow over a wing section.*

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

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

Shape of the Airfoil

Individual airfoil section properties differ from those properties of the wing or aircraft as a whole because of the effect of the wing planform. A wing may have various airfoil sections from root to tip, with taper, twist, and sweepback. The resulting aerodynamic properties of the wing are determined by the action of each section along the span.

The shape of the airfoil determines the amount of turbulence or skin friction that it produces, consequently affecting the efficiency of the wing. Turbulence and skin friction are controlled mainly by the fineness ratio, which is defined as the ratio of the chord of the airfoil to the maximum thickness. If the wing has a high fineness ratio, it is a very thin wing. A thick wing has a low fineness ratio. A wing with a high fineness ratio produces a large amount of skin friction. A wing with a low fineness ratio produces a large amount of turbulence. The best wing is a compromise between these two extremes to hold both turbulence and skin friction to a minimum.

The efficiency of a wing is measured in terms of the lift to drag ratio (L/D). This ratio varies with the AOA but reaches a definite maximum value for a particular AOA. At this angle, the wing has reached its maximum efficiency. The shape of the airfoil is the factor that determines the AOA at which the wing is most efficient; it also determines the degree of efficiency. Research has shown that the most efficient airfoils for general use have the maximum thickness occurring about one-third of the way back from the leading edge of the wing.

High-lift wings and high-lift devices for wings have been developed by shaping the airfoils to produce the desired effect. The amount of lift produced by an airfoil increases with an increase in wing camber. Camber refers to the curvature of an airfoil above and below the chord line surface. Upper camber refers to the upper surface, lower camber to the lower surface, and mean camber to the mean line of the section. Camber is positive when departure from the chord line is outward and negative when it is inward. Thus, high-lift wings have a large positive camber on the upper surface and a slightly negative camber on the lower surface. Wing flaps cause an ordinary wing to approximate this same condition by increasing the upper camber and by creating a negative lower camber.

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

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

Angle of Incidence

The acute angle the wing chord makes with the longitudinal axis of the aircraft is called the angle of incidence, or the angle of wing setting. *[Figure 2-4]* The angle of incidence in most cases is a fixed, built-in angle. When the leading edge of the wing is higher than the trailing edge, the angle of incidence is said to be positive. The angle of incidence is negative when the leading edge is lower than the trailing edge of the wing.

Angle of Attack (AOA)

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

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

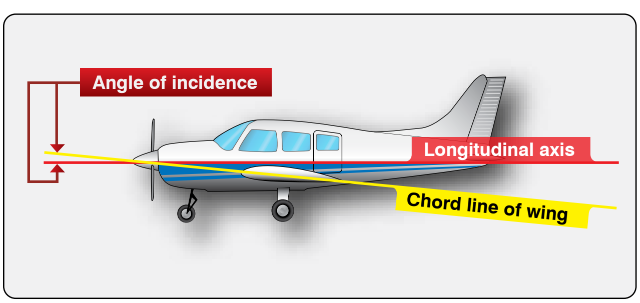

Figure 2-4. *Angle of incidence.*

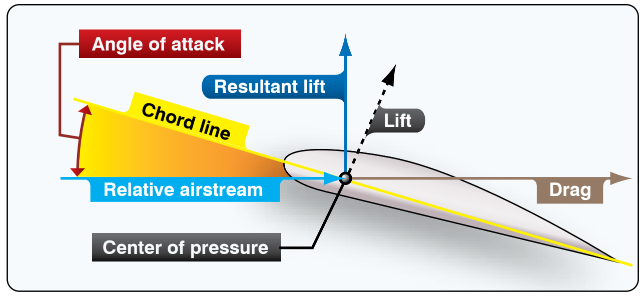

Figure 2-5. *Airflow over a wing section.*

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

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

When the AOA increases to the angle of maximum lift, the burble point is reached. This is known as the critical angle. When the critical angle is reached, the air ceases to flow smoothly over the top surface of the airfoil and begins to burble or eddy. This means that air breaks away from the upper camber line of the wing. What was formerly the area of decreased pressure is now filled by this burbling air. When this occurs, the amount of lift drops and drag becomes excessive. The force of gravity exerts itself, and the nose of the aircraft drops. This is a stall. Thus, the burble point is the stalling angle.

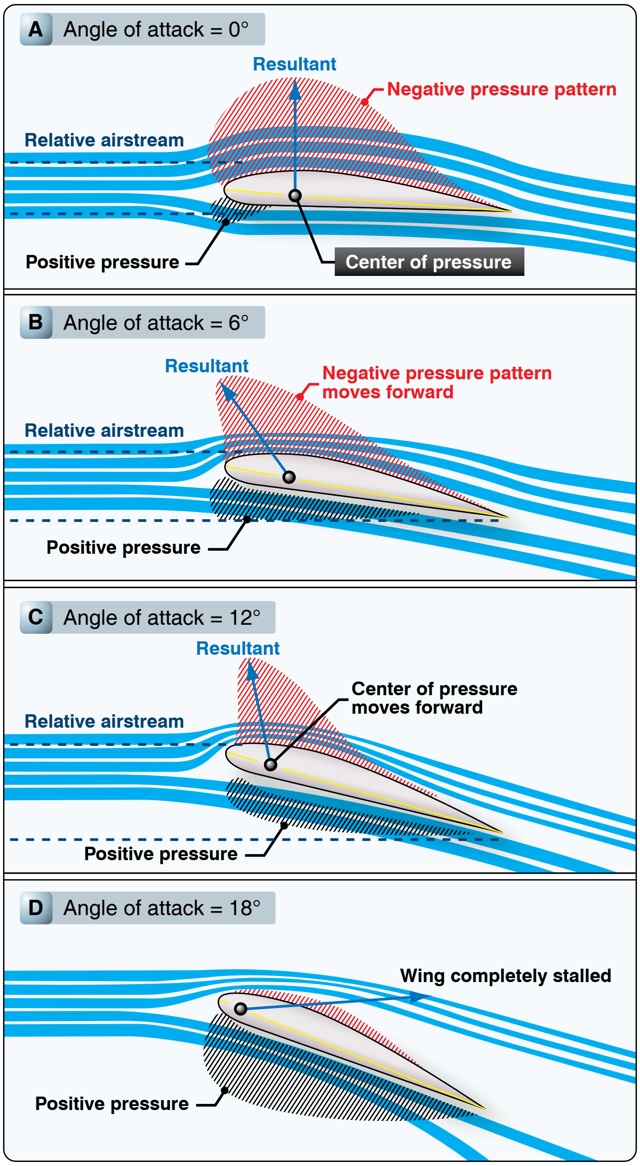

Figure 2-6. *Effect on increasing angle of attack.*

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

Boundary Layer

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

Thrust & Drag

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

An aircraft in flight is acted upon by four forces:

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

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

The forces of lift and drag are the direct result of the relationship between the relative wind and the aircraft. The force of lift always acts perpendicular to the relative wind, and the force of drag always acts parallel to and in the same direction as the relative wind. These forces are actually the components that produce a resultant lift force on the wing. *[Figure 2-8]*

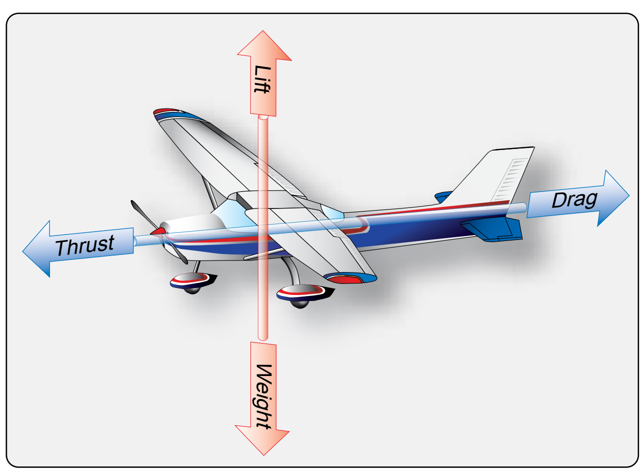

Figure 2-7. *Forces in action during flight.*

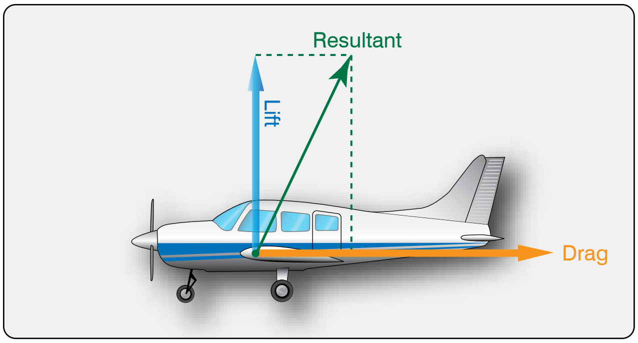

Figure 2-8. *Resultant of lift and drag.*

Weight has a definite relationship with lift, and thrust with drag. These relationships are quite simple, but very important in understanding the aerodynamics of flying. As stated previously, lift is the upward force on the wing perpendicular to the relative wind. Lift is required to counteract the aircraft's weight, caused by the force of gravity acting on the mass of the aircraft. This weight force acts downward through a point called the center of gravity (CG). The CG is the point at which all the weight of the aircraft is considered to be concentrated. When the lift force is in equilibrium with the weight force, the aircraft neither gains nor loses altitude. If lift becomes less than weight, the aircraft loses altitude. When the lift is greater than the weight, the aircraft gains altitude.

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

Drag must be overcome for the aircraft to move, and movement is essential to obtain lift. To overcome drag and move the aircraft forward, another force is essential. This force is thrust. Thrust is derived from jet propulsion or from a propeller and engine combination. Jet propulsion theory is based on Newton's third law of motion *(page 2-3)*. The turbine engine causes a mass of air to be moved backward at high velocity causing a reaction that moves the aircraft forward.

In a propeller/engine combination, the propeller is actually two or more revolving airfoils mounted on a horizontal shaft. The motion of the blades through the air produces lift similar to the lift on the wing, but acts in a horizontal direction, pulling the aircraft forward.

Before the aircraft begins to move, thrust must be exerted. The aircraft continues to move and gain speed until thrust and drag are equal. In order to maintain a steady speed, thrust and drag must remain equal, just as lift and weight must be equal for steady, horizontal flight. Increasing the lift means that the aircraft moves upward, whereas decreasing the lift so that it is less than the weight causes the aircraft to lose altitude. A similar rule applies to the two forces of thrust and drag. If the revolutions per minute (rpm) of the engine is reduced, the thrust is lessened, and the aircraft slows down. As long as the thrust is less than the drag, the aircraft travels more and more slowly until its speed is insufficient to support it in the air.

Likewise, if the rpm of the engine is increased, thrust becomes greater than drag, and the speed of the aircraft increases. As long as the thrust continues to be greater than the drag, the aircraft continues to accelerate. When drag equals thrust, the aircraft flies at a steady speed.

The relative motion of the air over an object that produces lift also produces drag. Drag is the resistance of the air to objects moving through it. If an aircraft is flying on a level course, the lift force acts vertically to support it while the drag force acts horizontally to hold it back. The total amount of drag on an aircraft is made up of many drag forces, but this handbook considers three: parasite drag, profile drag, and induced drag.

Parasite drag is made up of a combination of many different drag forces. Any exposed object on an aircraft offers some resistance to the air, and the more objects in the airstream, the more parasite drag. While parasite drag can be reduced by reducing the number of exposed parts to as few as practical and streamlining their shape, skin friction is the type of parasite drag most difficult to reduce. No surface is perfectly smooth. Even machined surfaces have a ragged uneven appearance when inspected under magnification. These ragged surfaces deflect the air near the surface causing resistance to smooth airflow. Skin friction can be reduced by using glossy smooth finishes and eliminating protruding rivet heads, roughness, and other irregularities.

Profile drag may be considered the parasite drag of the airfoil. The various components of parasite drag are all of the same nature as profile drag.

The action of the airfoil that creates lift also causes induced drag. Remember, the pressure above the wing is less than atmospheric pressure, and the pressure below the wing is equal to or greater than atmospheric pressure. Since fluids always move from high pressure toward low pressure, there is a spanwise movement of air from the bottom of the wing outward from the fuselage and upward around the wing tip. This flow of air results in spillage over the wing tip, thereby setting up a whirlpool of air called a "vortex." *[Figure 2-9]*

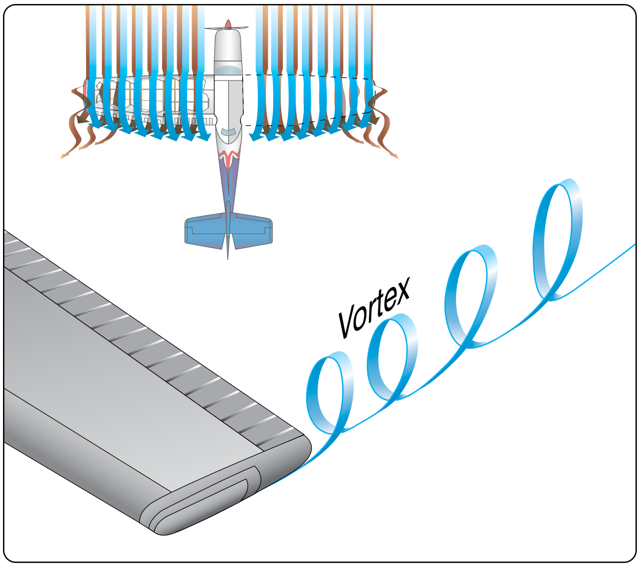

Figure 2-9. *Wingtip vortices.*

The air on the upper surface has a tendency to move in toward the fuselage and off the trailing edge. This air current forms a similar vortex at the inner portion of the trailing edge of the wing. These vortices increase drag because of the turbulence produced, and constitute induced drag.

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

Center of Gravity (CG)

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

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

The Axes of an Aircraft

Whenever an aircraft changes its attitude in flight, it must turn about one or more of three axes. *Figure 2-10* shows the three axes, which are imaginary lines passing through the center of the aircraft.

The axes of an aircraft can be considered as imaginary axles around which the aircraft turns like a wheel. At the center, where all three axes intersect, each is perpendicular to the other two. The axis that extends lengthwise through the fuselage from the nose to the tail is called the longitudinal axis. The axis that extends crosswise from wing tip to wing tip is the lateral, or pitch, axis. The axis that passes through the center, from top to bottom, is called the vertical, or yaw, axis. Roll, pitch, and yaw are controlled by three control surfaces. Roll is produced by the ailerons, which are located at the trailing edges of the wings. Pitch is affected by the elevators, the rear portion of the horizontal tail assembly. Yaw is controlled by the rudder, the rear portion of the vertical tail assembly.

Stability & Control

An aircraft must have sufficient stability to maintain a uniform flightpath and recover from the various upsetting forces. Also, to achieve the best performance, the aircraft must have the proper response to the movement of the controls. Control is the pilot action of moving the flight controls, providing the aerodynamic force that induces the aircraft to follow a desired flightpath. When an aircraft is said to be controllable, it means that the aircraft responds easily and promptly to movement of the controls. Different control surfaces are used to control the aircraft about each of the three axes. Moving the control surfaces on an aircraft changes the airflow over the aircraft's surface. This, in turn, creates changes in the balance of forces acting to keep the aircraft flying straight and level.

Three terms that appear in any discussion of stability and control are: stability, maneuverability, and controllability. Stability is the characteristic of an aircraft that tends to cause it to fly (hands off) in a straight-and-level flightpath. Maneuverability is the characteristic of an aircraft to be directed along a desired flightpath and to withstand the stresses imposed. Controllability is the quality of the response of an aircraft to the pilot's commands while maneuvering the aircraft.

Static Stability

An aircraft is in a state of equilibrium when the sum of all the forces acting on the aircraft and all the moments is equal to zero. An aircraft in equilibrium experiences no accelerations, and the aircraft continues in a steady condition of flight. A gust of wind or a deflection of the controls disturbs the equilibrium, and the aircraft experiences acceleration due to the unbalance of moment or force.

The three types of static stability are defined by the character

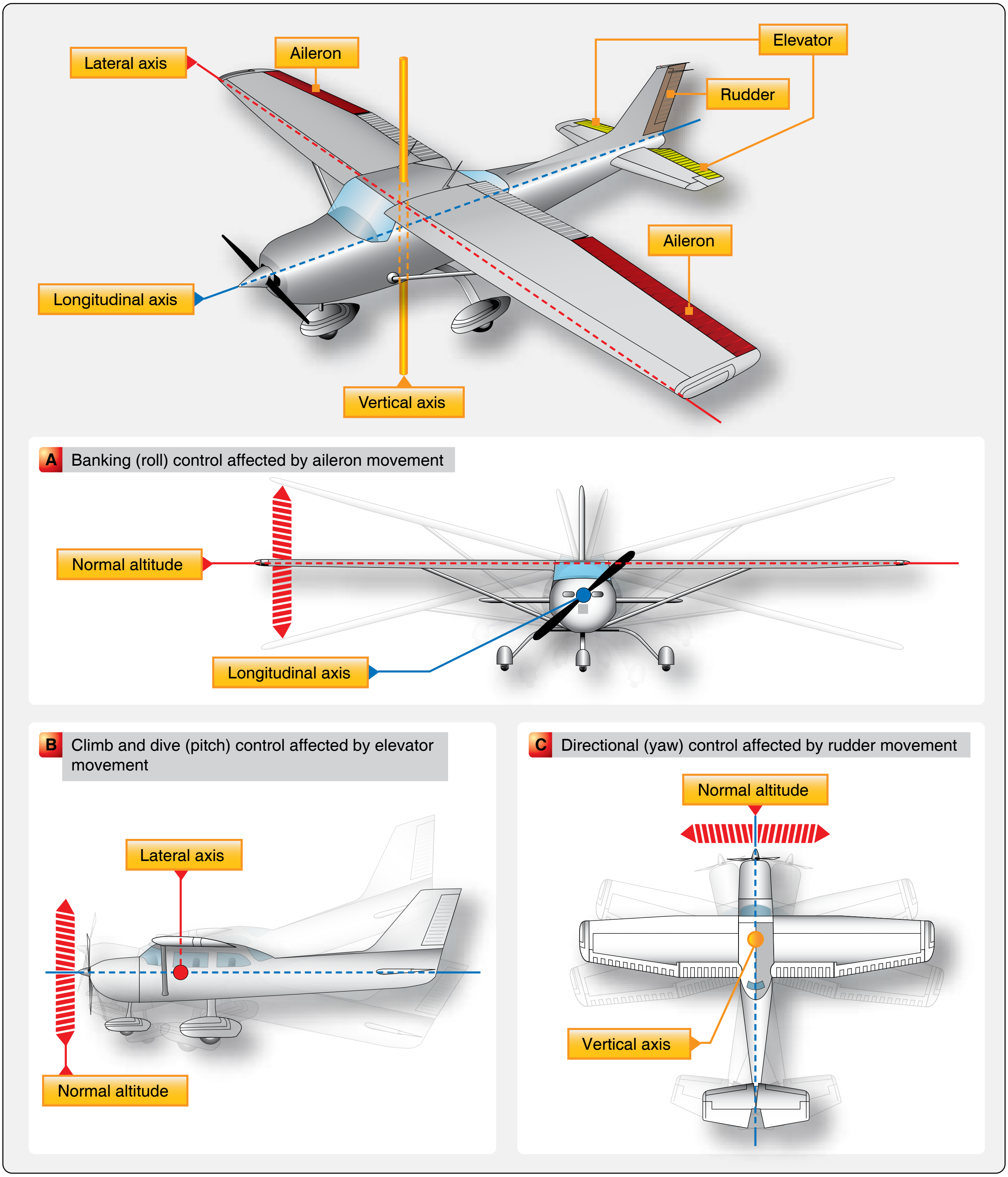

Figure 2-10. *Motion of an aircraft about its axes.*

of movement following some disturbance from equilibrium. Positive static stability exists when the disturbed object tends to return to equilibrium. Negative static stability, or static instability, exists when the disturbed object tends to continue in the direction of disturbance. Neutral static stability exists when the disturbed object has neither tendency, but remains in equilibrium in the direction of disturbance. These three types of stability are illustrated in *Figure 2-11*.

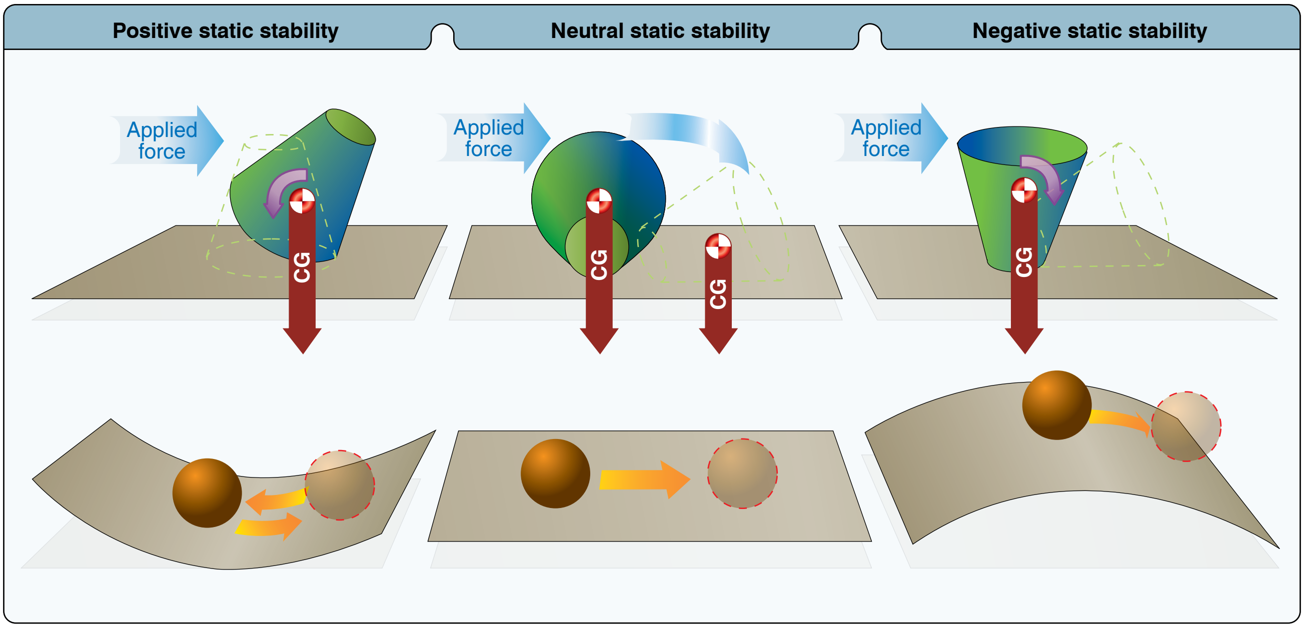

Figure 2-11. *Three types of stability.*

Dynamic Stability

While static stability deals with the tendency of a displaced body to return to equilibrium, dynamic stability deals with the resulting motion with time. If an object is disturbed from equilibrium, the time history of the resulting motion defines the dynamic stability of the object. In general, an object demonstrates positive dynamic stability if the amplitude of motion decreases with time. If the amplitude of motion increases with time, the object is said to possess dynamic instability.

Any aircraft must demonstrate the required degrees of static and dynamic stability. If an aircraft were designed with static instability and a rapid rate of dynamic instability, the aircraft would be very difficult, if not impossible, to fly. Usually, positive dynamic stability is required in an aircraft design to prevent objectionable continued oscillations of the aircraft.

Longitudinal Stability

When an aircraft has a tendency to keep a constant AOA with reference to the relative wind (i.e., it does not tend to put its nose down and dive or lift its nose and stall); it is said to have longitudinal stability. Longitudinal stability refers to motion in pitch. The horizontal stabilizer is the primary surface which controls longitudinal stability. The action of the stabilizer depends upon the speed and AOA of the aircraft.

Directional Stability

Stability about the vertical axis is referred to as directional stability. The aircraft should be designed so that when it is in straight-and-level flight it remains on its course heading even though the pilot takes their hands and feet off the controls. If an aircraft recovers automatically from a skid, it has been well designed for directional balance. The vertical stabilizer is the primary surface that controls directional stability. Directional stability can be designed into an aircraft, where appropriate, by using a large dorsal fin, a long fuselage, and sweptback wings.

Lateral Stability

Motion about the aircraft's longitudinal (fore and aft) axis is a lateral, or rolling, motion. The tendency to return to the original attitude from such motion is called lateral stability.

Dutch Roll

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

Primary Flight Controls

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

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

Trim Controls

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

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

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

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

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

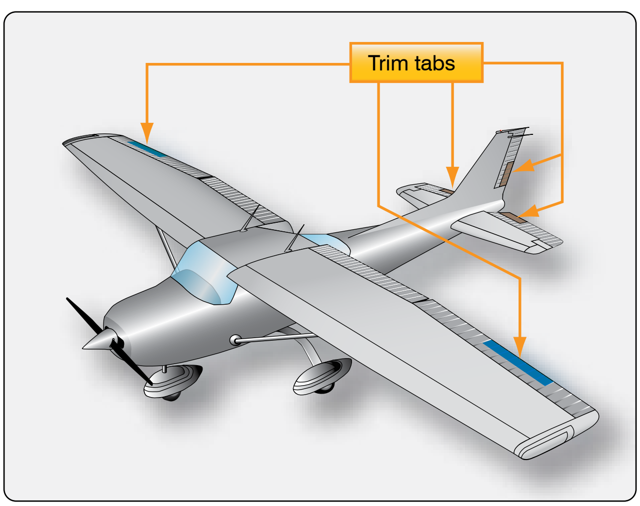

Figure 2-12. *Trim tabs.*

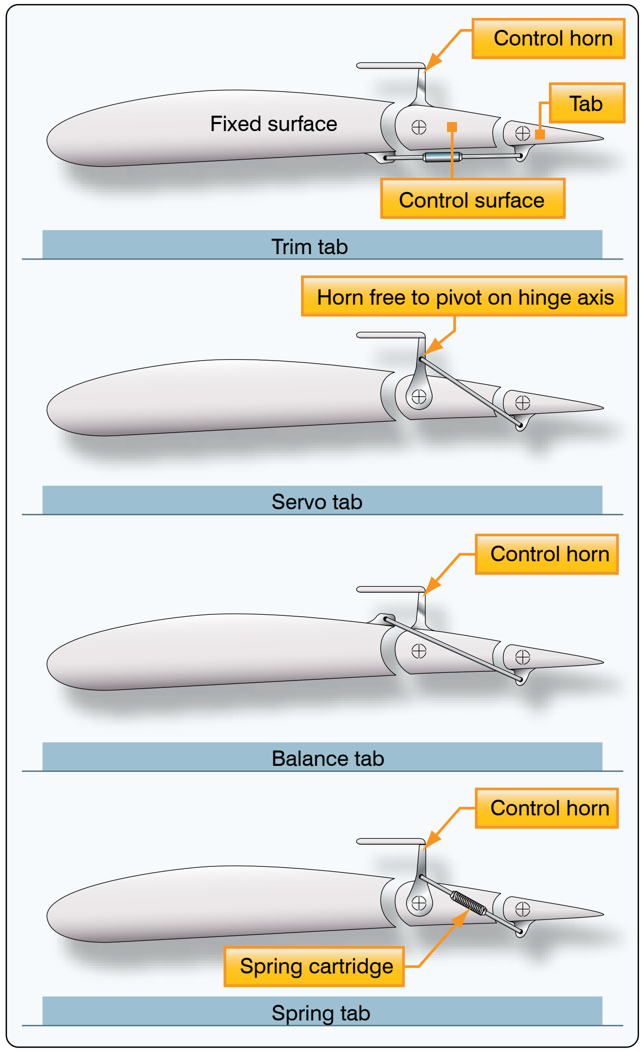

Figure 2-13. *Types of trim tabs.*

Auxiliary Lift Devices

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

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

Lift Augmenting

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

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

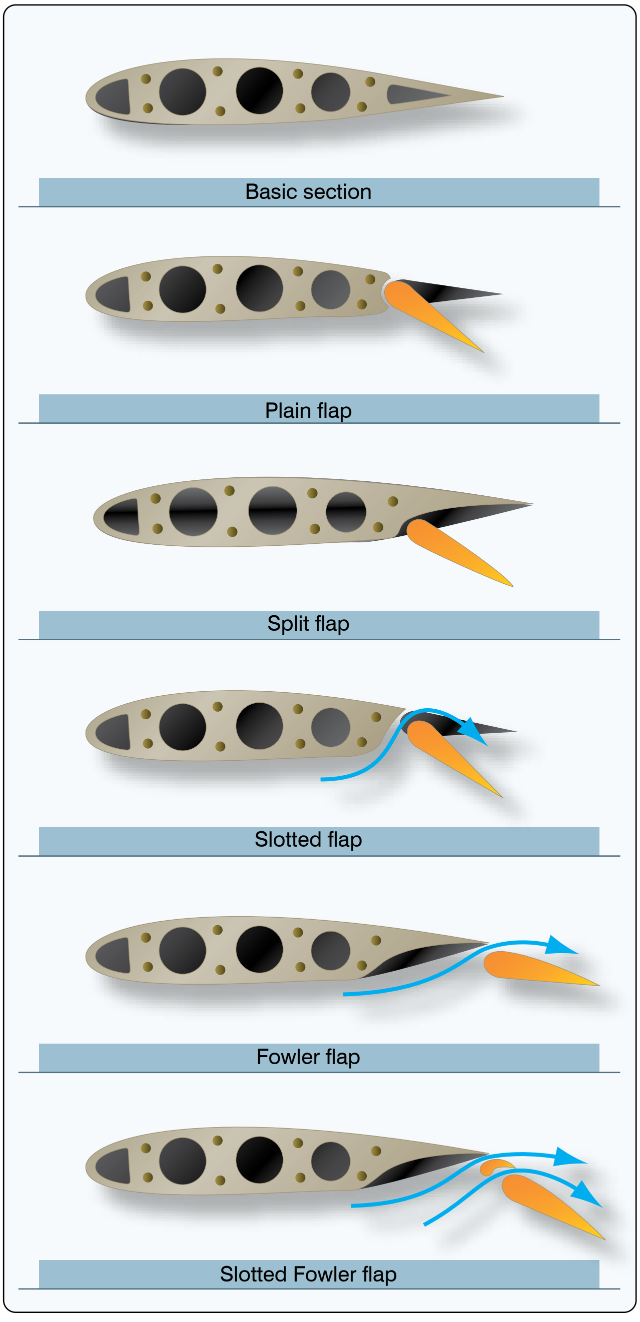

Figure 2-14. *Types of wing flaps.*

Lift Decreasing

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

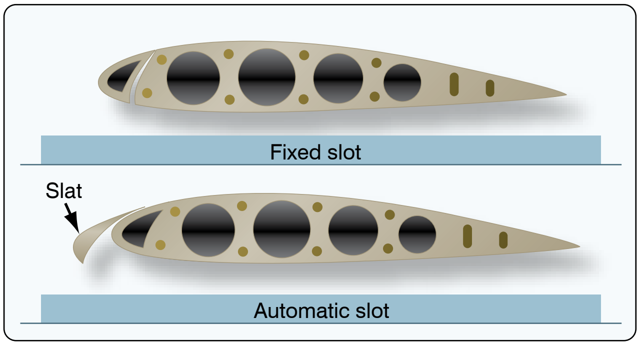

Figure 2-15. *Wing slots.*

Figure 2-16. *Speed brake.*

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

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

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

Control Systems for Large Aircraft

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

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

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

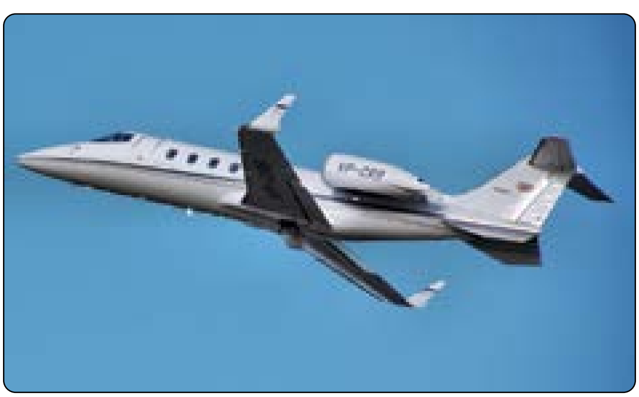

Figure 2-17. *Winglets on a Bombardier Learjet 60.*

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

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

Figure 2-20. *Aircraft stall fence.*

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

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

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

Fly-By-Wire Control

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

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

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

High-Speed Aerodynamics

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

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

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

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

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

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

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

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

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

Rotary-Wing Aircraft Assembly & 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.

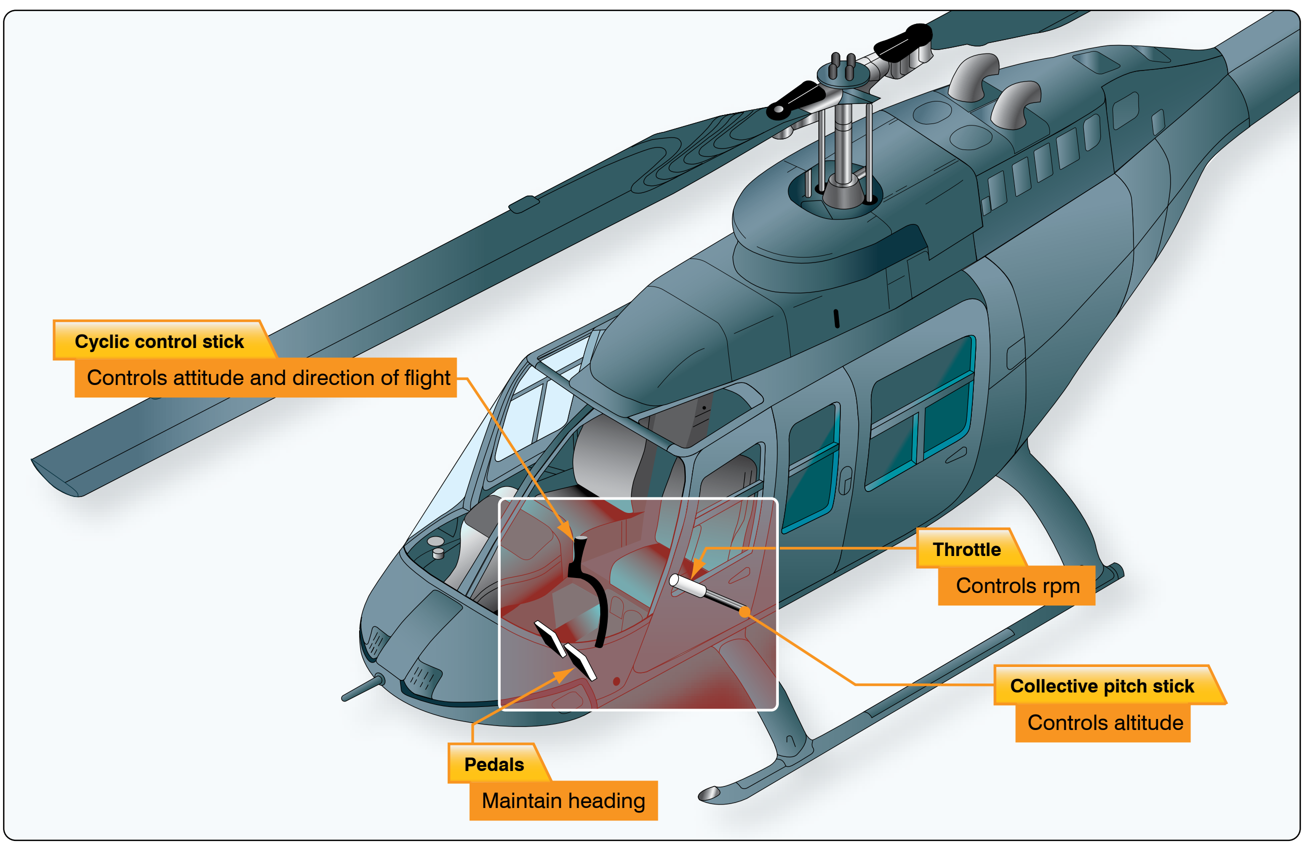

Figure 2-22. *Controls of a helicopter and the principal function of each.*

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.
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.

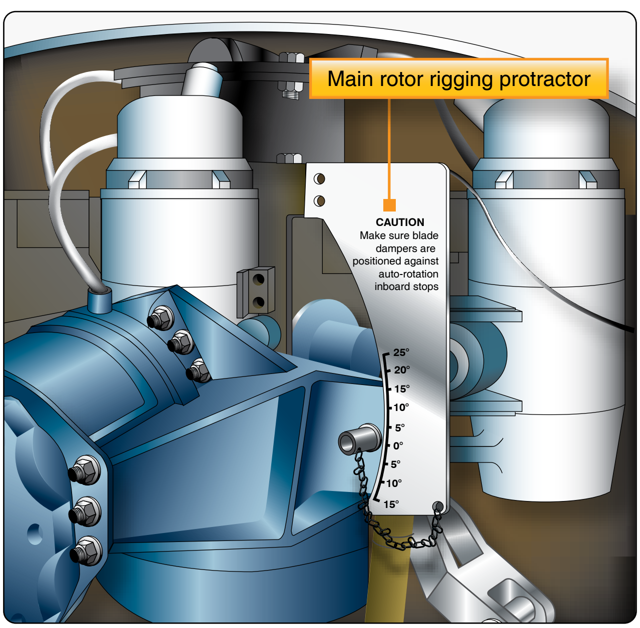

Figure 2-23. *A typical rigging protractor.*

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]*

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

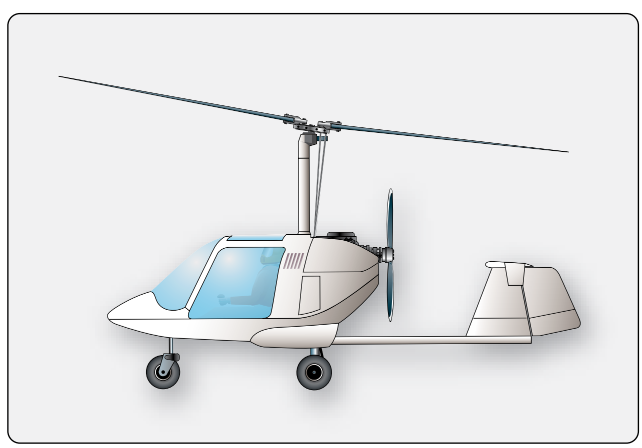

Figure 2-24. *An autogyro.*

the rotational force (torque) of the main rotor to correct yaw of the fuselage. *[Figure 2-25]*

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]*

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]*

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.

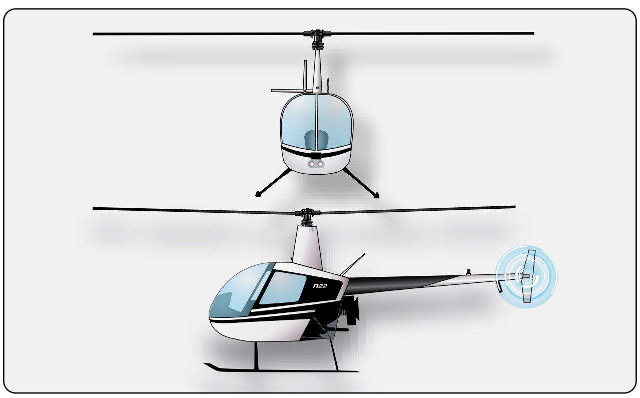

Figure 2-25. *Single rotor helicopter.*

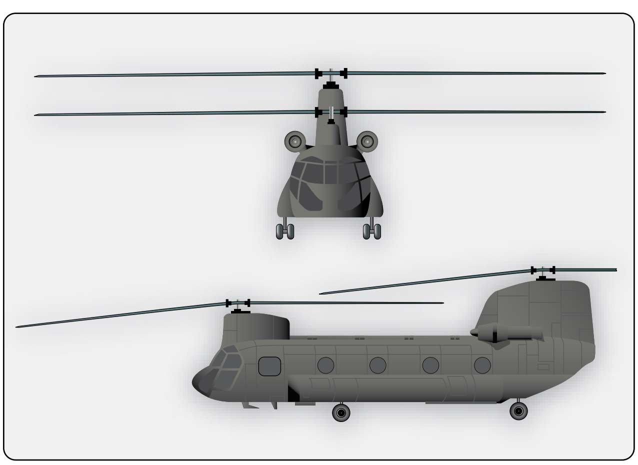

Figure 2-26. *Dual rotor helicopter.*

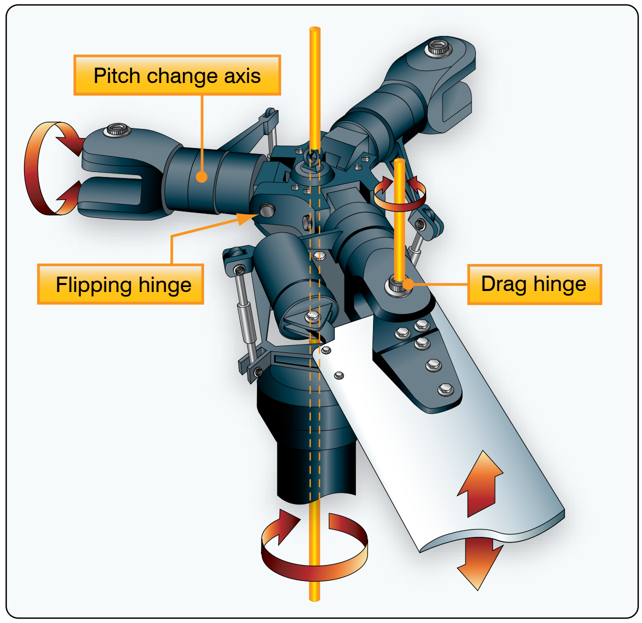

Figure 2-27. *Articulated rotor head.*

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 McDonnell Douglas design with no tail rotor, employs air directed through a series of slots in the tail boom, with the balance

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

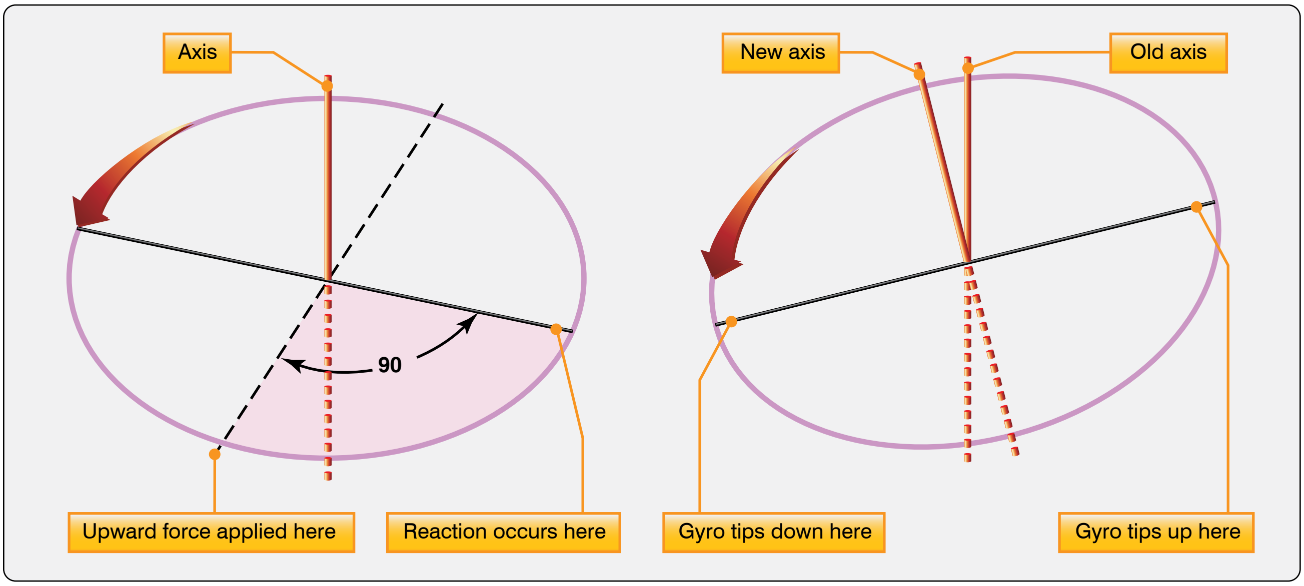

Figure 2-29. *Gyroscopic precession principle.*

exiting through a 90° duct located at the rear of the tail boom. *[Figure 2-28]*

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 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 decreased AOA tends to flap down. Because the rotor disc 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.

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

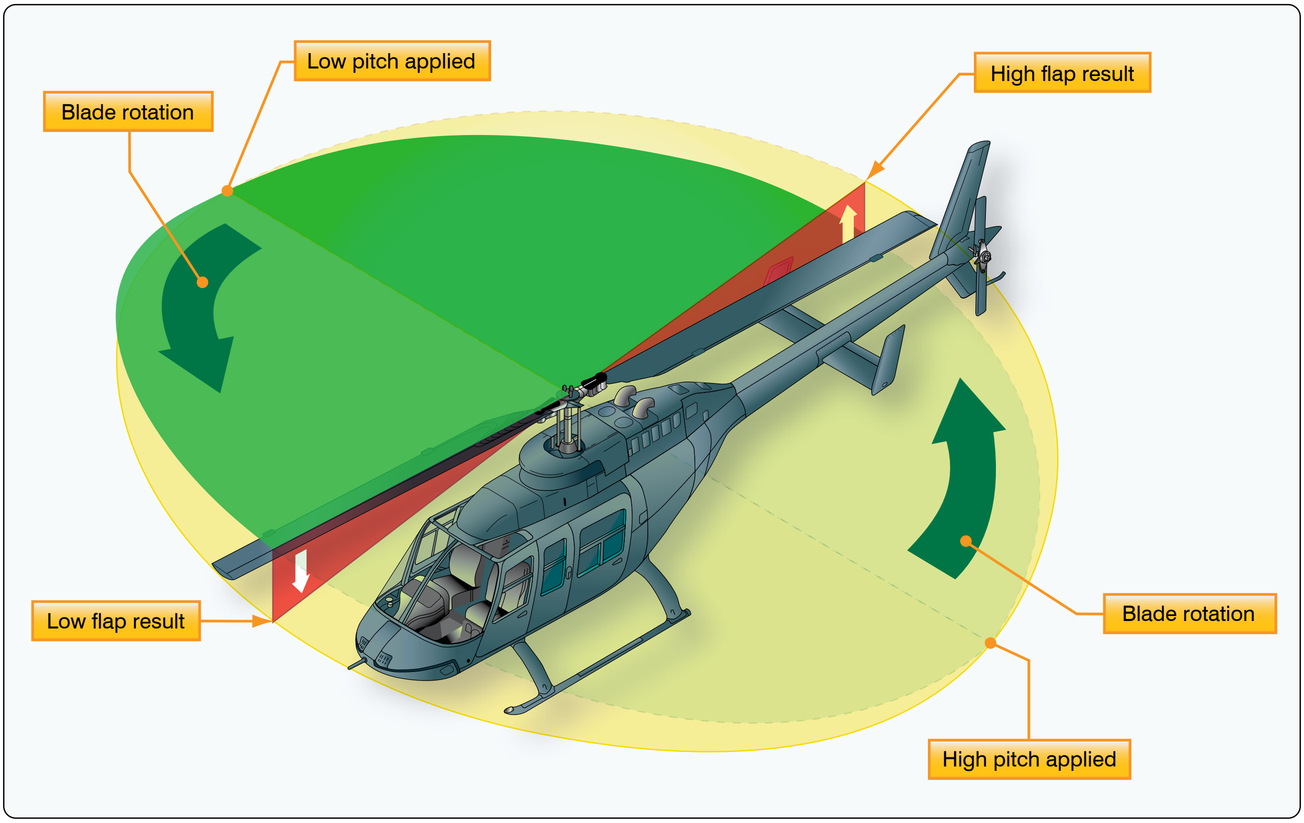

Figure 2-30. *Gyroscopic precession.*

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.

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.

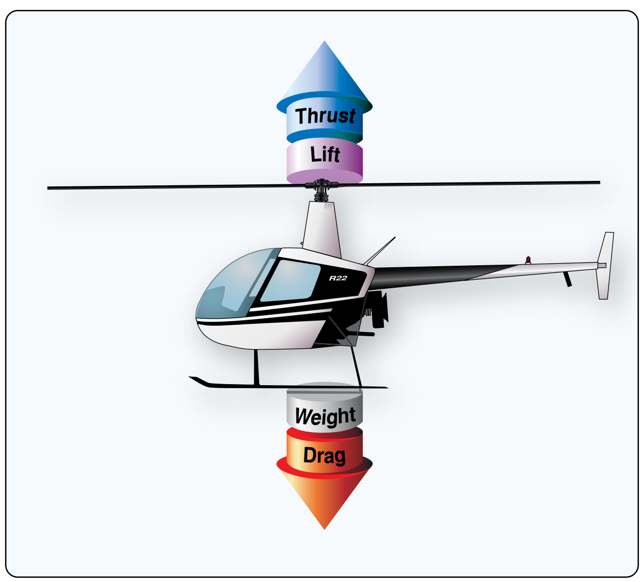

Figure 2-31. *To maintain a hover at a constant altitude, enough lift and thrust must be generated to equal the weight of the helicopter and the drag produced by the rotor blades.*

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]*

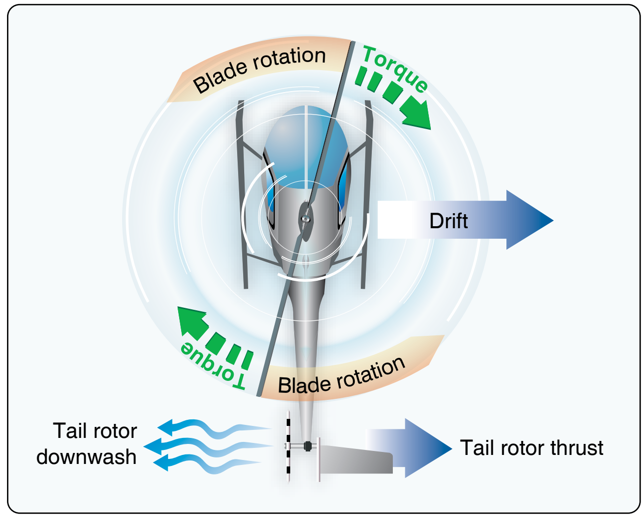

Figure 2-32. *A tail rotor is designed to produce thrust in a direction opposite torque. The thrust produced by the tail rotor is sufficient to move the helicopter laterally.*

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 disc 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 that 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 disc 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 disc 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 disc 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 disc flattens out from the loss of G-load induced coning, the blade tips 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 disc 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.

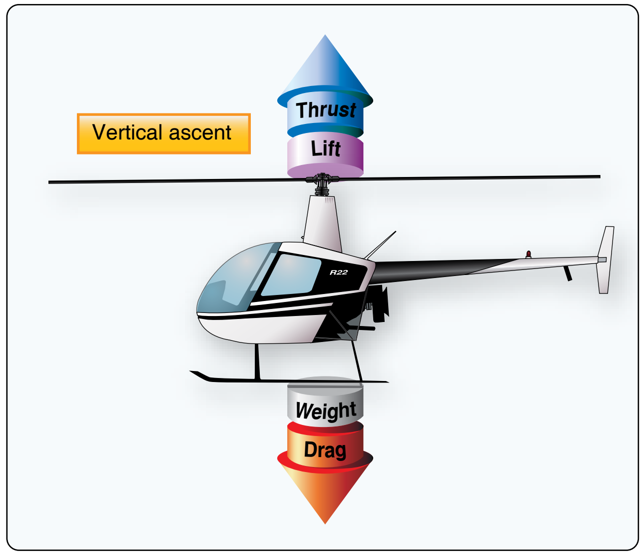

Figure 2-34. *To ascend vertically, more lift and thrust must be generated to overcome the forces of weight and drag.*

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]*

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]*

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

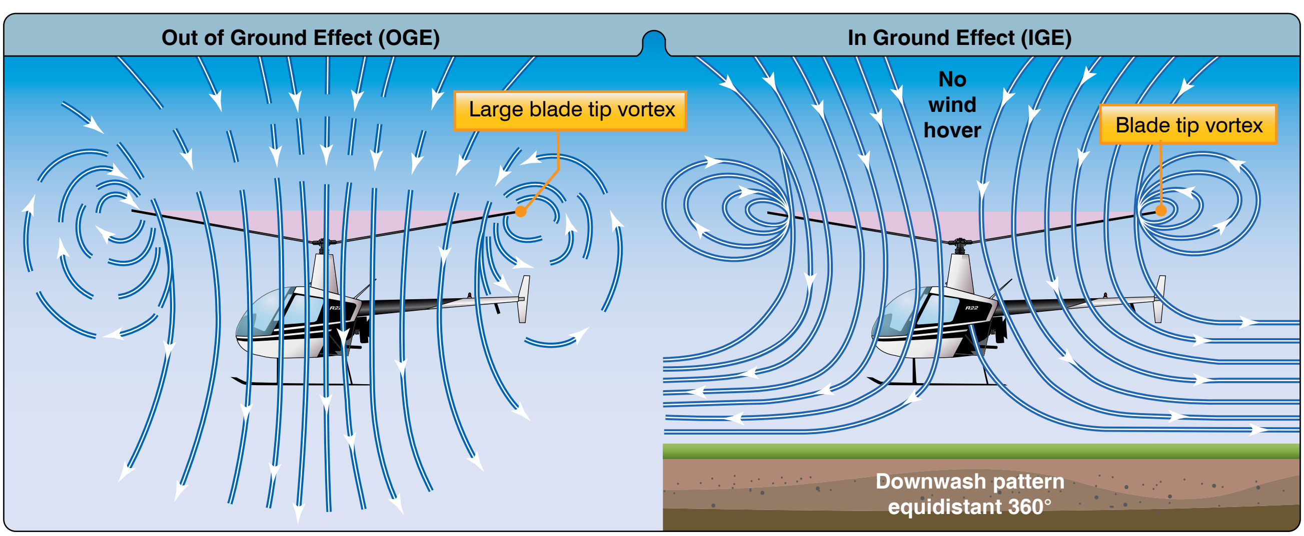

Figure 2-33. *Air circulation patterns change when hovering out of ground effect (OGE) and when hovering in ground effect (IGE).*

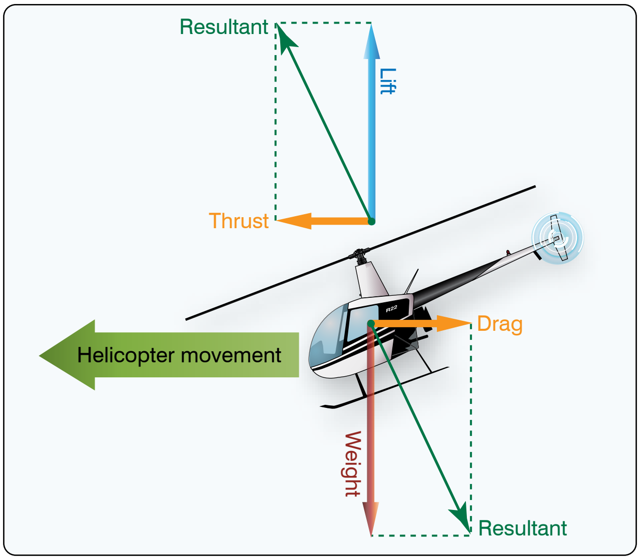

Figure 2-35. *The power required to maintain a straight-and-level flight and a stabilized airspeed.*

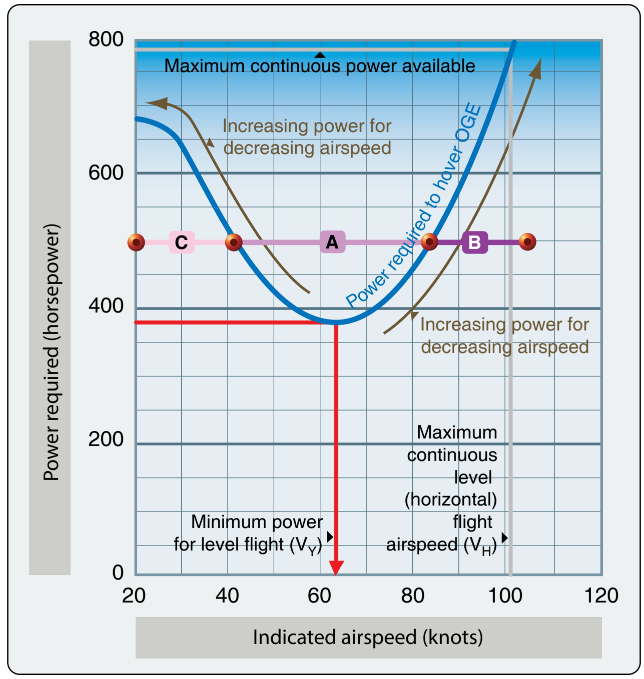

Figure 2-36. *Changing force vectors results in aircraft movement.*

hover. Continued acceleration causes an even larger increase in airflow through the rotor disc 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 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-disc attitude. *[Figure 2-39]*

Dissymmetry of Lift

Dissymmetry of lift is the differential (unequal) lift between advancing and retreating halves of the rotor disc 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

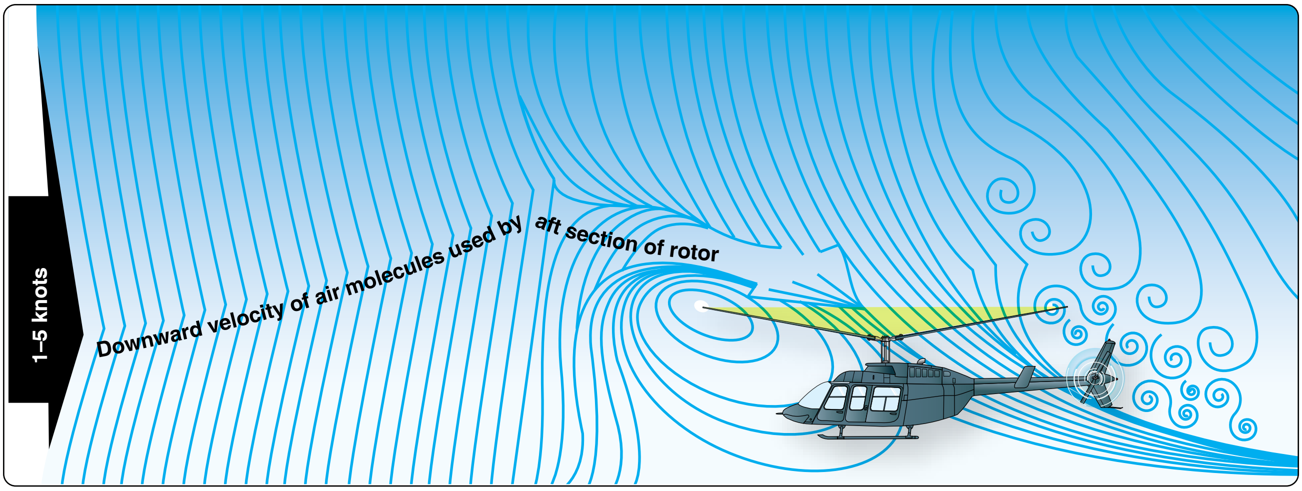

Figure 2-37. *The airflow pattern for 1–5 knots of forward airspeed. Note how the downwind vortex is beginning to dissipate and induced flow down through the rear of the rotor system is more horizontal.*

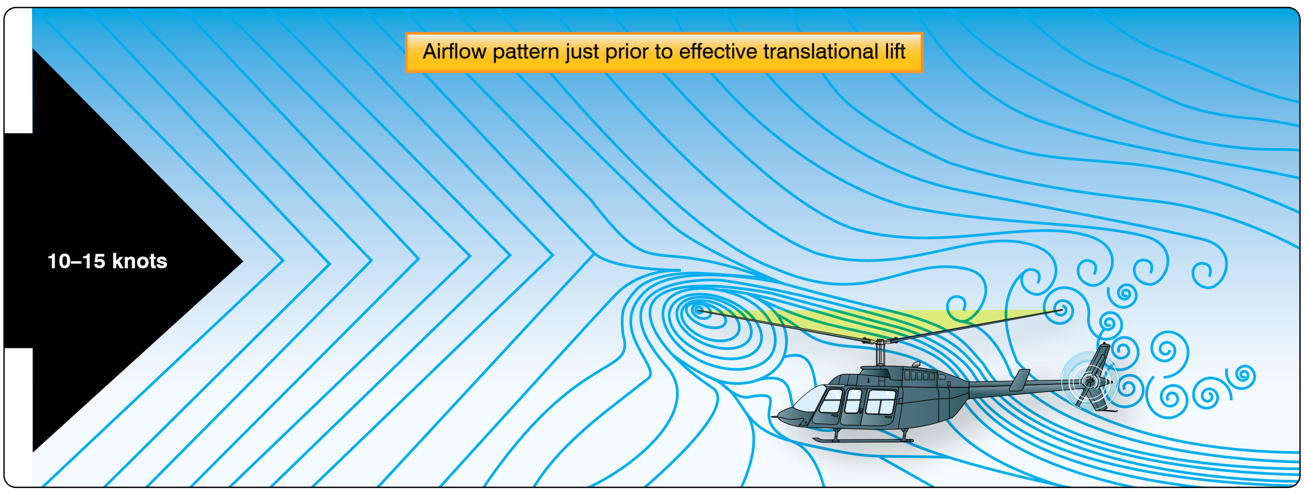

Figure 2-38. *An airflow pattern at a speed of 10–15 knots. At this increased airspeed, the airflow continues to become more horizontal. The leading edge of the downwash pattern is being overrun and is well back under the nose of the helicopter.*

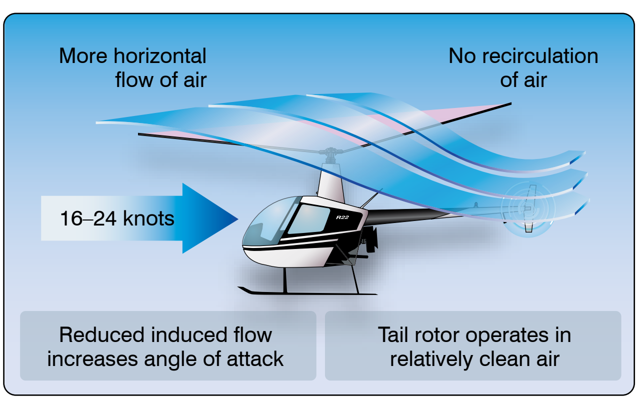

Figure 2-39. *Effective translational lift is easily recognized in actual flight by a transient induced aerodynamic vibration and increased performance of the helicopter.*

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 disc 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 disc 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 disc. Articulated rotor systems, usually with three or

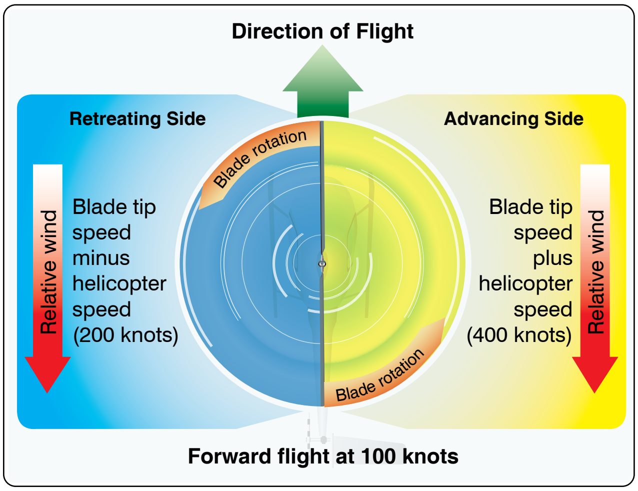

Figure 2-40. *The blade tip speed of this helicopter is approximately 300 knots. If the helicopter is moving forward at 100 knots, the relative windspeed on the advancing side is 400 knots. On the retreating side, it is only 200 knots. This difference in speed causes a dissymmetry of lift.*

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 disc, 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

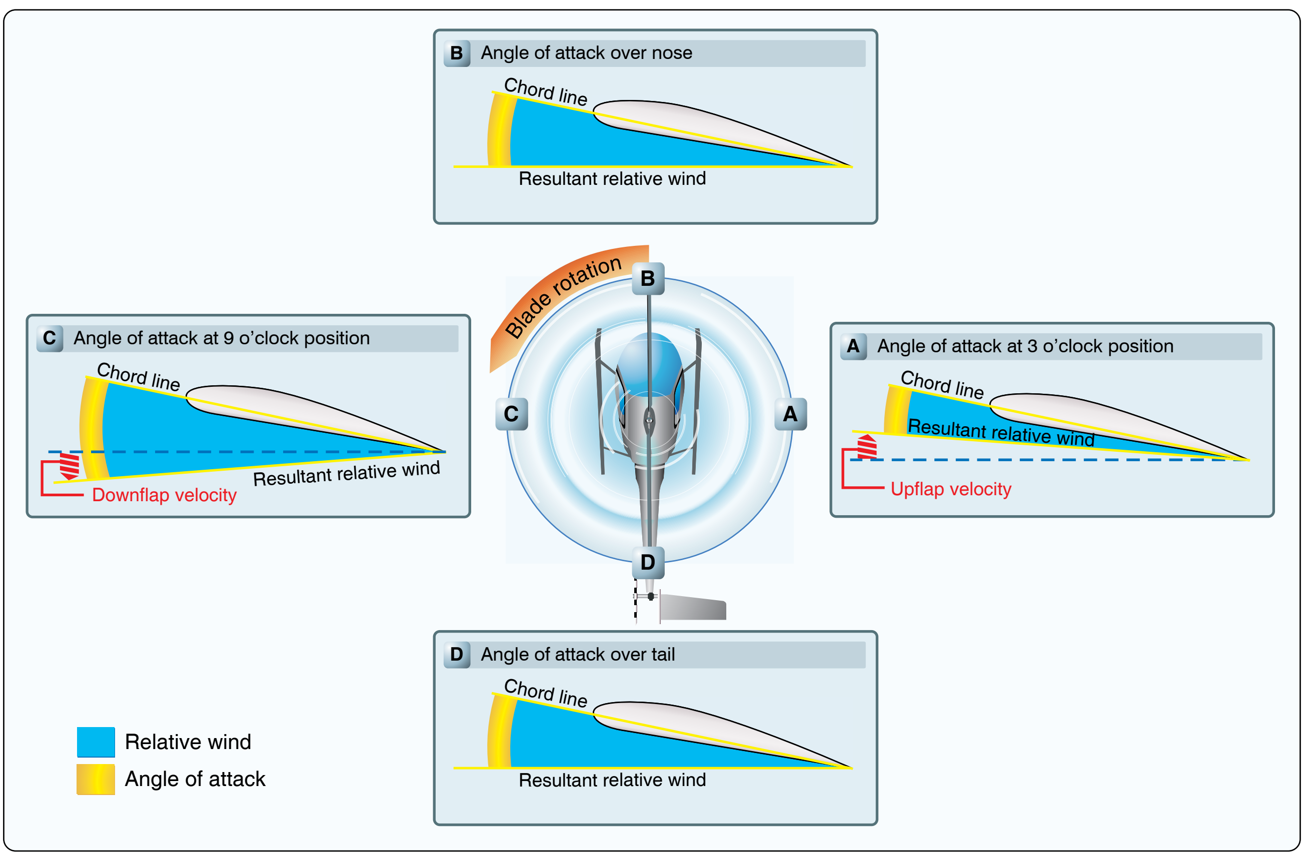

Figure 2-41. *The combined upward flapping (reduced lift) of the advancing blade and downward flapping (increased lift) of the retreating blade equalizes lift across the main rotor disc counteracting dissymmetry of lift.*

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 disc 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 disc comes up, and the back of the disc goes down. This reorientation of the rotor disc 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 them to control the attitude of the rotor disc.

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 disc 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 disc 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.

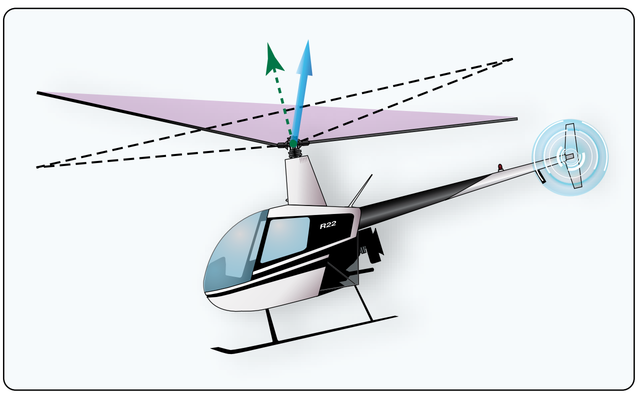

Figure 2-42. *To compensate for blowback, move the cyclic forward. Blowback is more pronounced with higher airspeeds.*

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. *[Figure 2-43]* 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

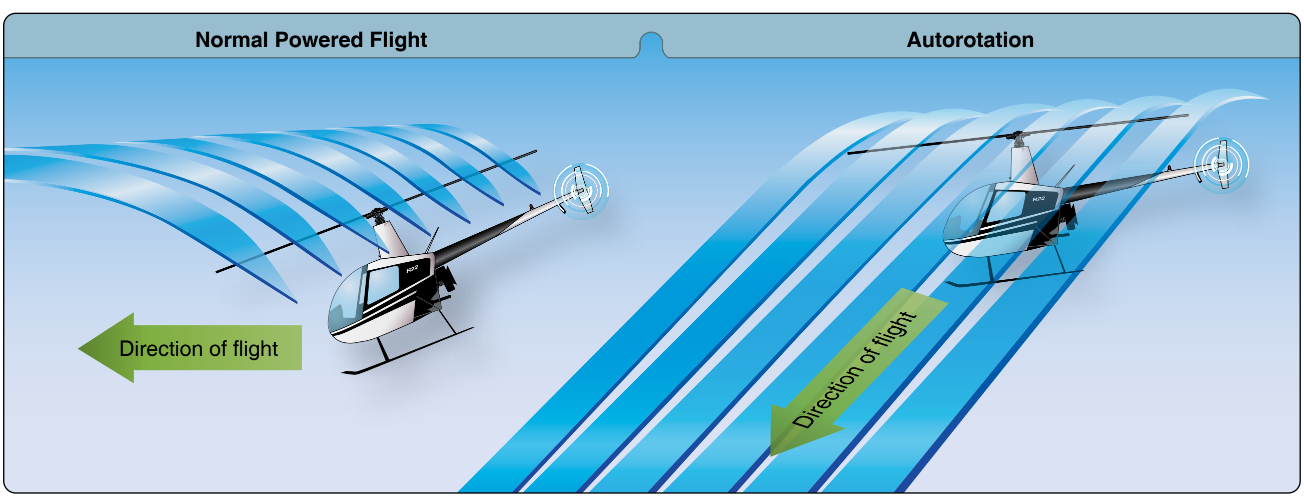

Figure 2-43. *During an autorotation, the upward flow of relative wind permits the main rotor blades to rotate at their normal speed. In effect, the blades are "gliding" in their rotational plane.*

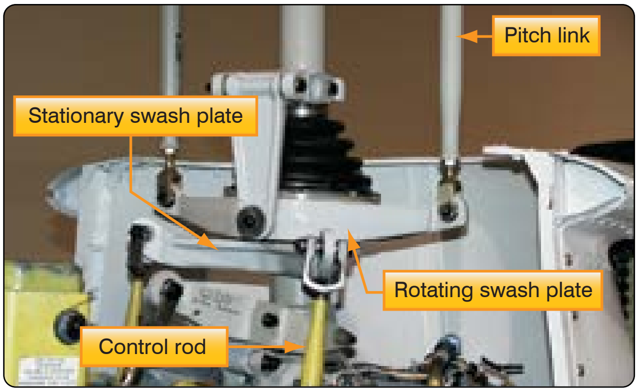

Figure 2-44. *Stationary and rotating swash plate.*

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.

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]*

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. *[Figure 2-45]* This is done through a series of mechanical linkages, and the amount

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

of movement in the collective lever determines the amount of blade pitch change. An adjustable friction control helps prevent inadvertent collective pitch movement.

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]*

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.

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 flight deck.*

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.

Cyclic Pitch Control

The cyclic pitch control is mounted vertically from the flight deck 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 disc tilts in the same direction the cyclic pitch control is moved. If the cyclic is moved forward, the rotor disc tilts forward; if the cyclic is moved aft, the disc tilts aft, and so on. Because the rotor disc 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 of the

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.*

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.*

rotor blade in front of the helicopter and maximum upward deflection behind it, causing the rotor disc 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.

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

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

flight, as well as while taxiing with the forward gear off the ground. With the right pedal displaced forward, the forward rotor disc tilts to the right, while the aft rotor disc tilts to the left. The opposite occurs when the left pedal is pushed forward; the forward rotor disc inclines to the left, and the aft rotor disc 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 disc 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.

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.

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.*

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. A high frequency vibration typically occurs when the tail rotor gears, tail drive shaft or the tail rotor engine, fan or shaft assembly vibrates or rotates at an equal or greater speed than the tail rotor.

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 below.

Flag & 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.

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

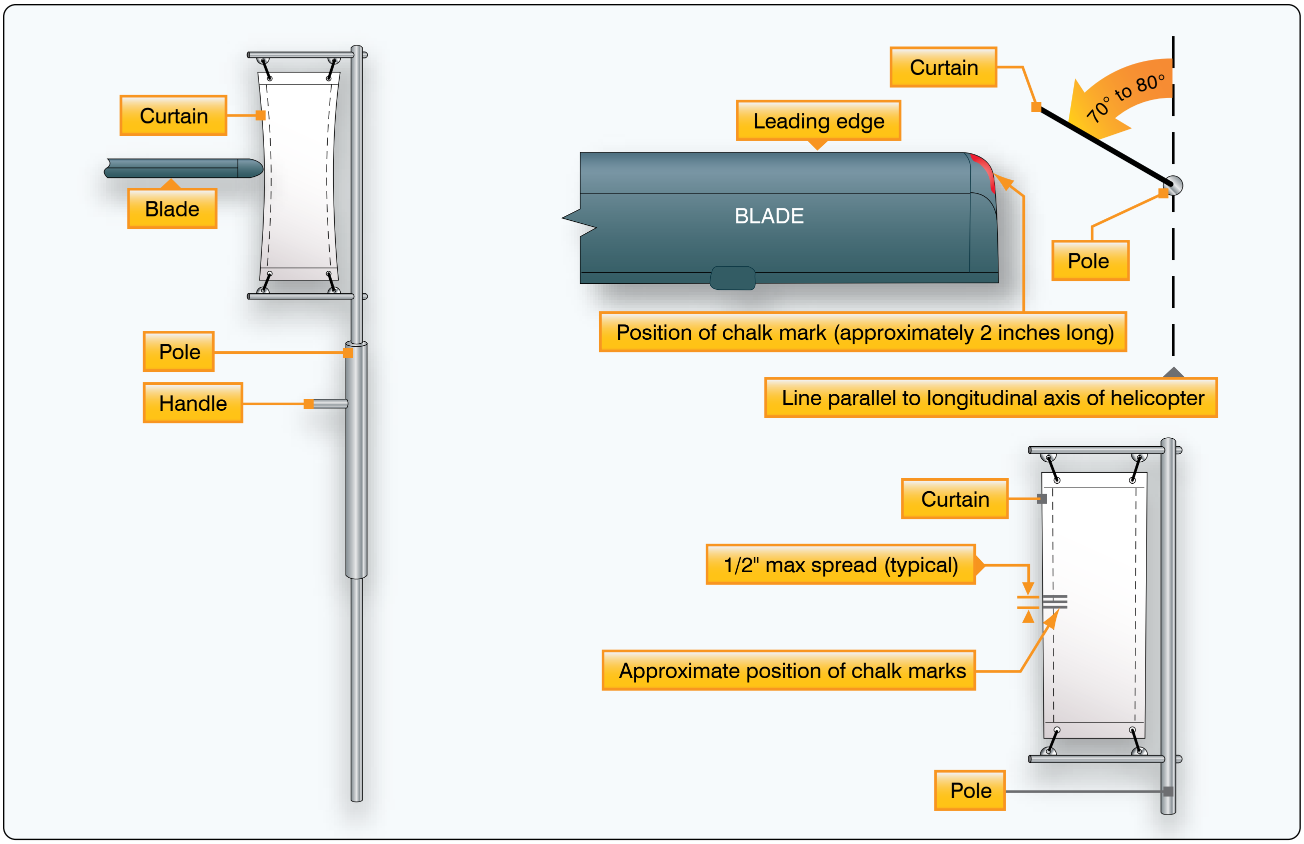

Figure 2-51. *Flag and pole blade tracking.*

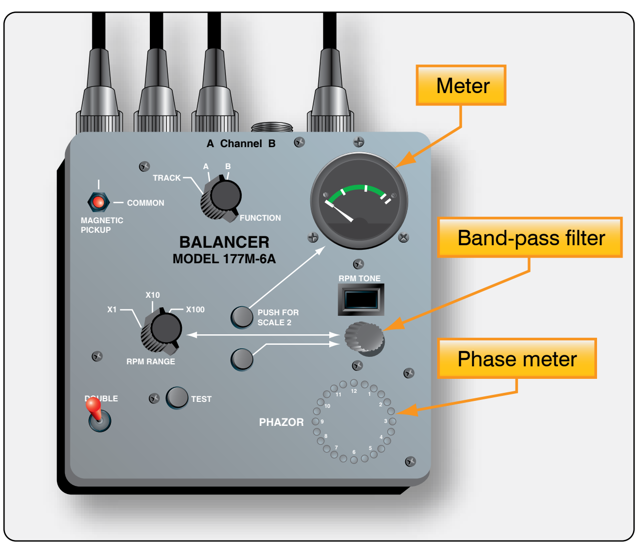

Figure 2-52. *Balancer/Phazor.*

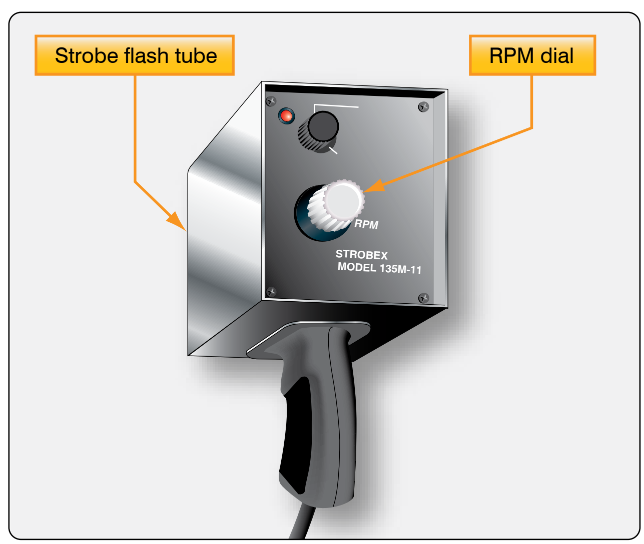

Figure 2-53. *Strobex tracker.*

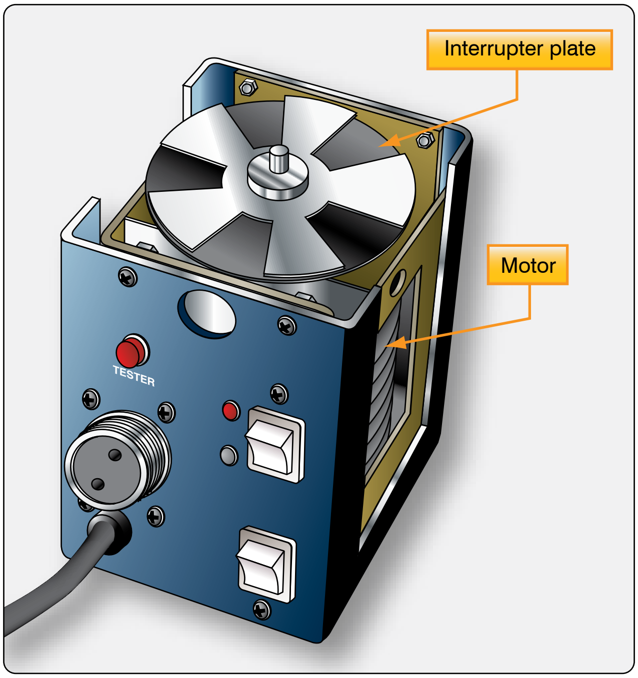

Figure 2-54. *Vibrex tracker.*

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 autorotation rpm adjustment.

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.

- 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 disc 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.

Figure 2-55. *Tail rotor tracking.*

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 & 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. Annotate the blade model, part number (P/N) 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]*

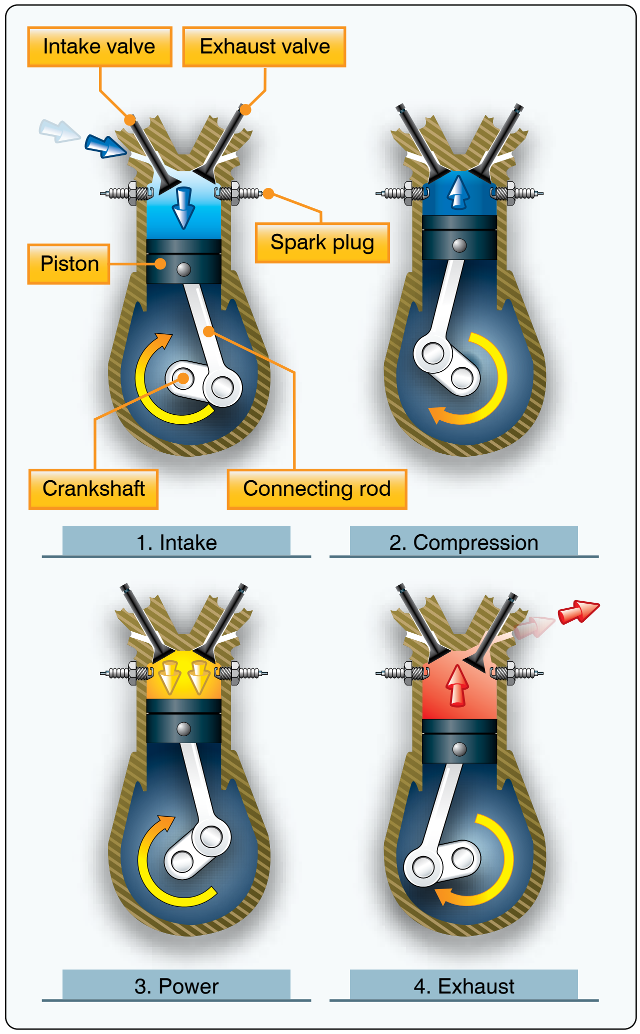

Figure 2-56. *The arrows indicate the direction of motion of the crankshaft and piston during the four-stroke cycle.*

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 air-fuel 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 air-fuel 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 air-fuel 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]*

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]*

Clutch

In a conventional airplane, the engine and propeller are directly 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

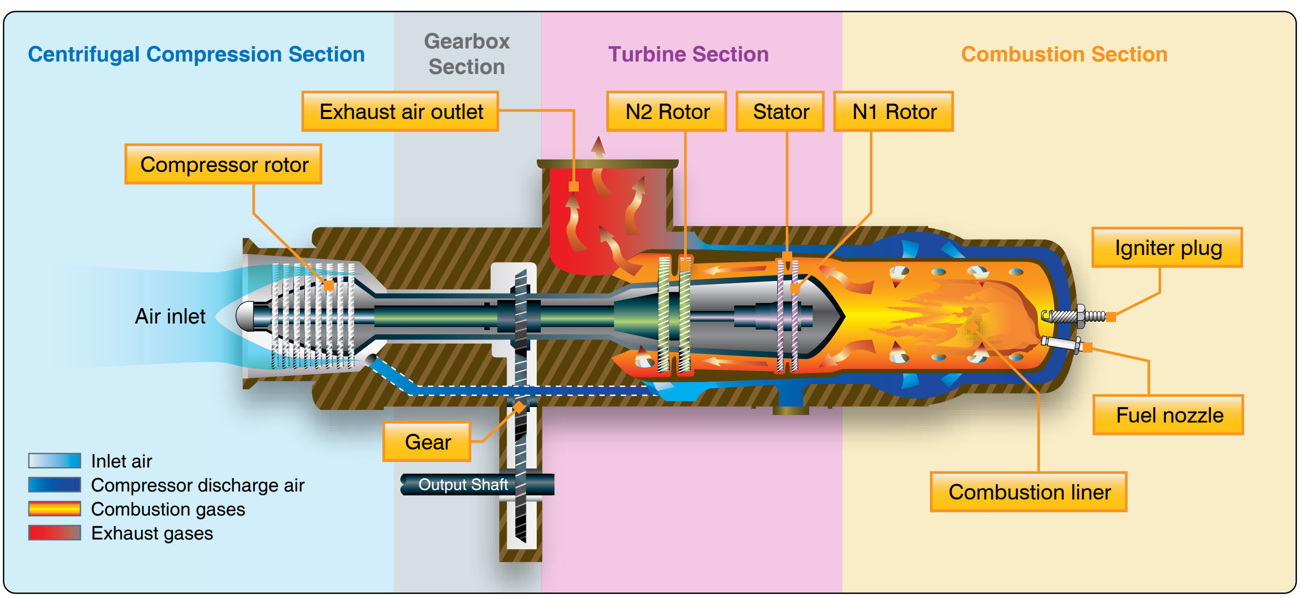

Figure 2-57. *Many helicopters use a turboshaft engine as shown above to drive the main transmission and rotor systems. The main difference between a turboshaft and a turbojet engine is that most of the energy produced by the expanding gases is used to drive a turbine rather than producing thrust through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

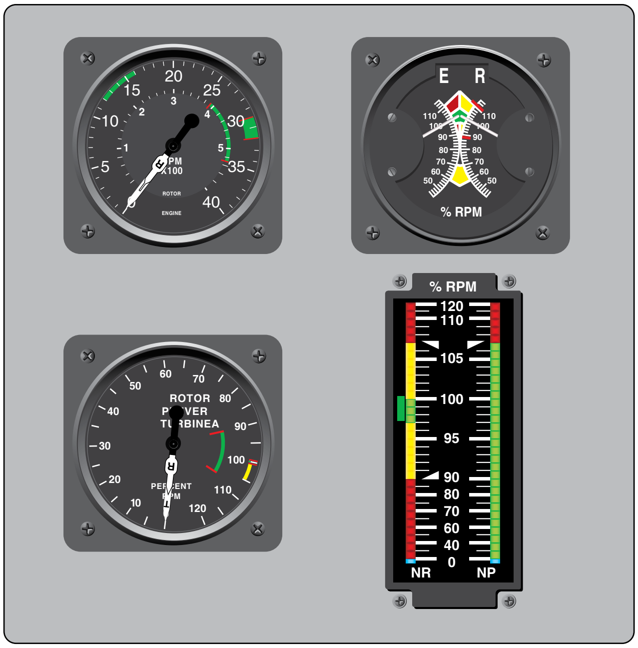

Figure 2-58. *There are various types of dual-needle tachometers; however, when the needles are superimposed, or married, the ratio of the engine rpm is the same as the gear reduction ratio.*

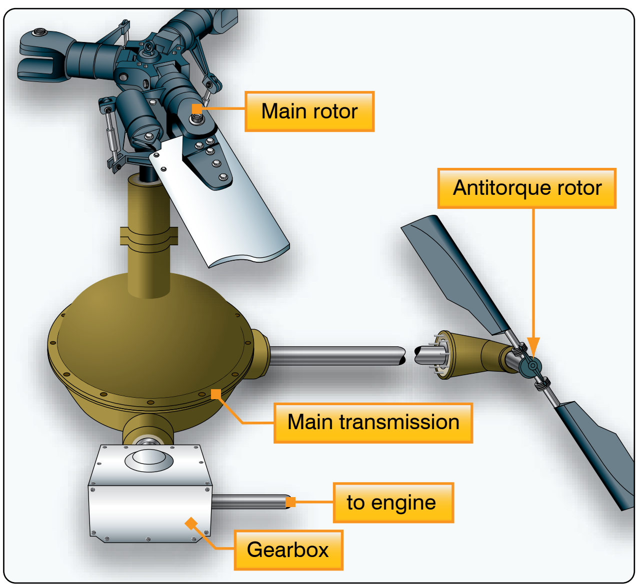

Figure 2-59. *The main rotor transmission and gearbox reduce engine output rpm to optimum rotor rpm and change the axis of rotation of the engine output shaft to the vertical axis for the rotor shaft.*

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 & Rigging

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

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

Rebalancing of Control Surfaces

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

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

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

Static Balance

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

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

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

Dynamic Balance

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

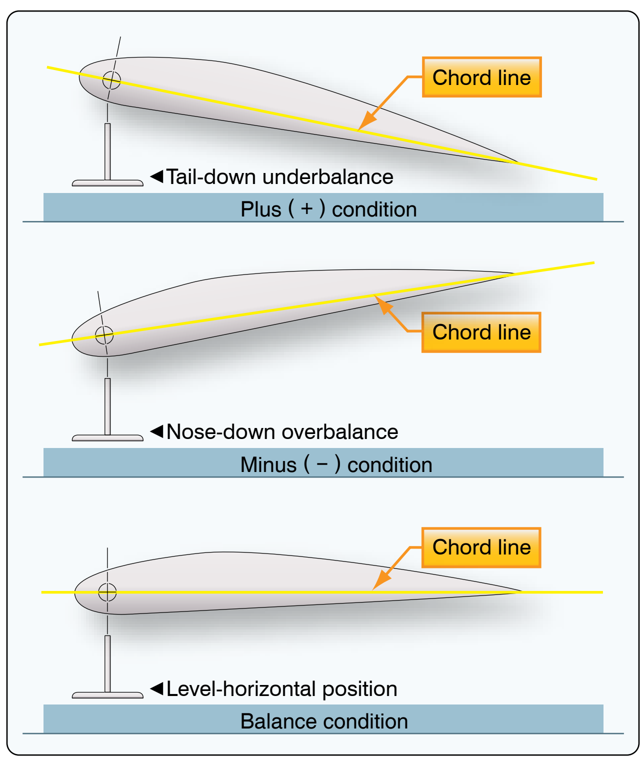

Figure 2-60. *Control surface static balance.*

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

Rebalancing Procedures

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

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

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

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

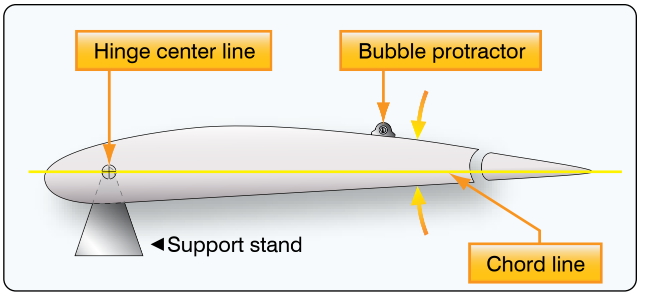

Figure 2-62. *Establishing a neutral position of the control surface.*

Rebalancing Methods

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

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

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

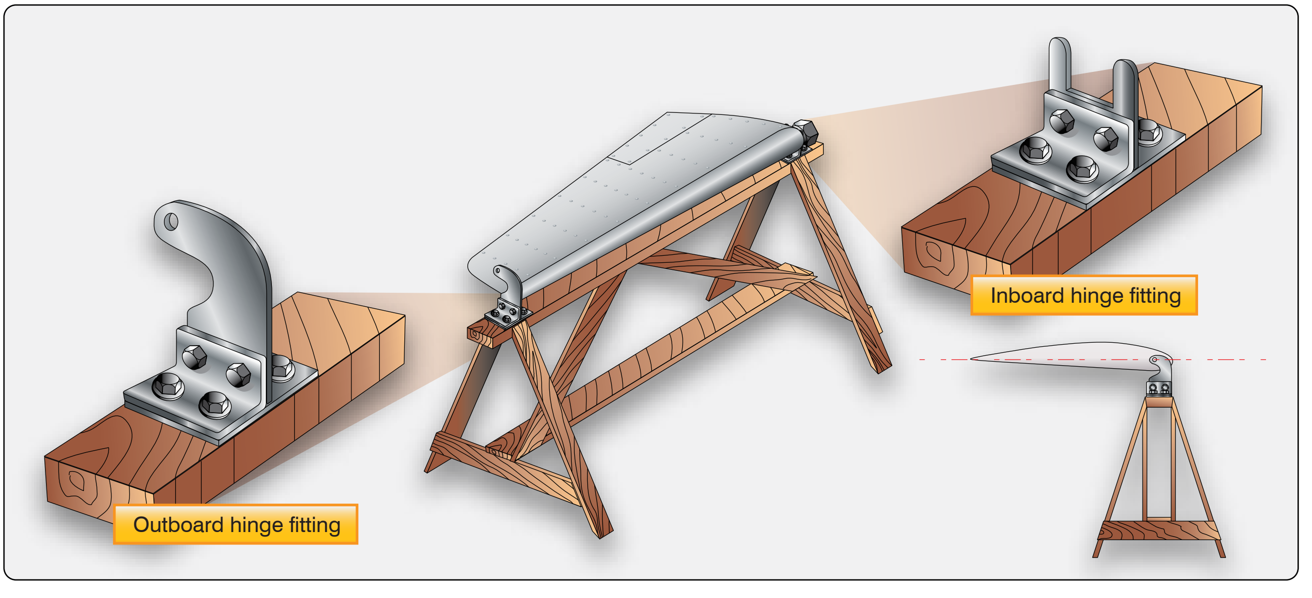

Figure 2-61. *Locally fabricated balancing fixture.*

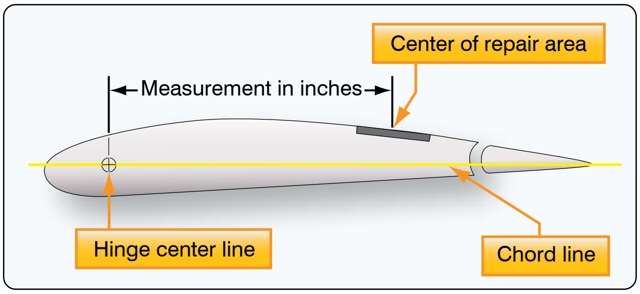

Figure 2-63. *Calculation method measurement.*

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

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

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

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

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

Aircraft Rigging

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

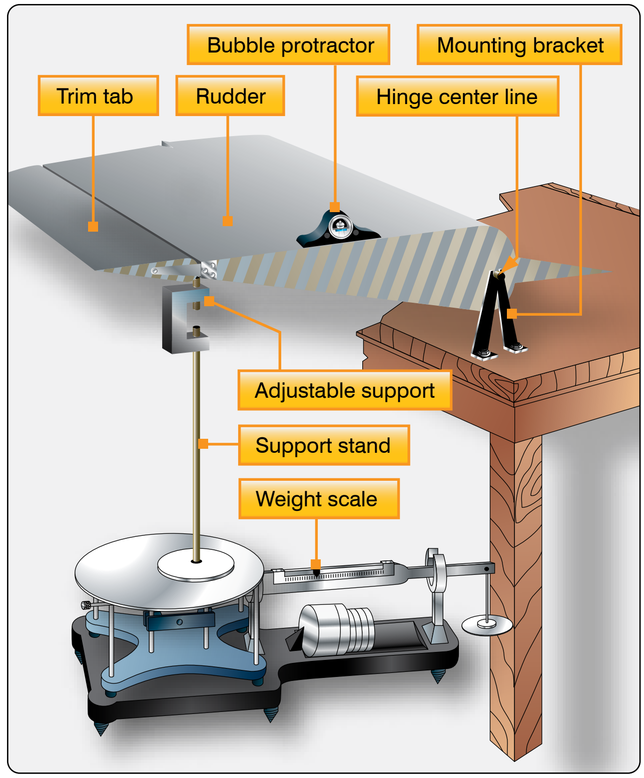

Figure 2-64. *Balancing setup.*

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

Rigging Specifications

Type Certificate Data Sheet

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

Maintenance Manual

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

Structural Repair Manual (SRM)

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

Manufacturer's Service Information

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

Airplane Assembly

Aileron Installation

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

Flap Installation

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

Empennage Installation

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

Control Operating Systems

Cable Systems

There are various types of cable:

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

Types of control cable termination include:

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

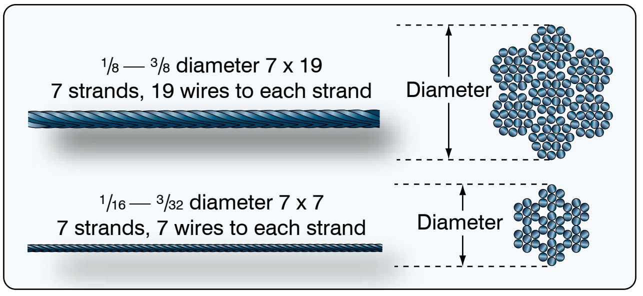

Figure 2-65. *Cable construction and cross-section.*