

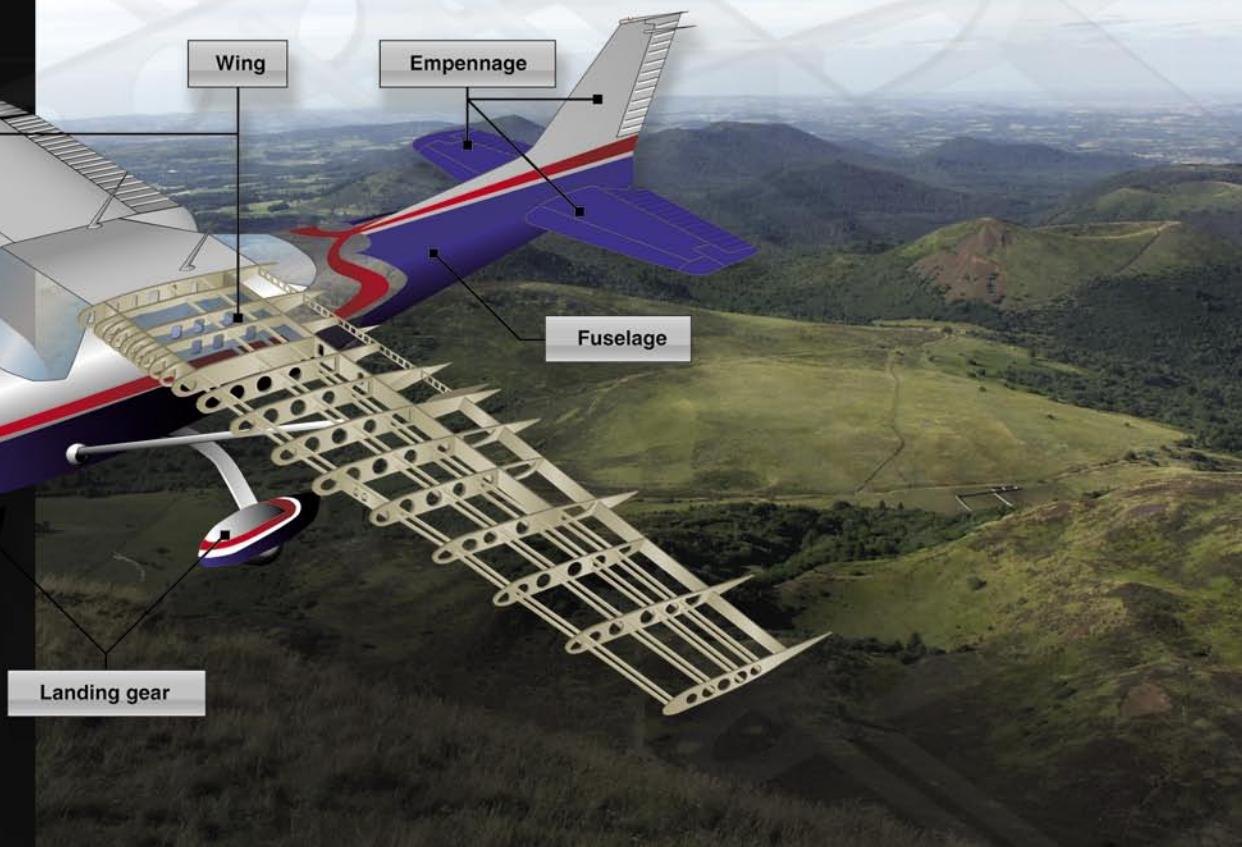


Chapter 2

Aircraft Structure

Introduction

An aircraft is a device that is used, or intended to be used, for flight, according to the current Title 14 of the Code of Federal Regulations (14 CFR) Part 1, Definitions and Abbreviations. Categories of aircraft for certification of airmen include airplane, rotorcraft, glider, lighter-than-air, powered-lift, powered parachute, and weight-shift control. 14 CFR part 1 also defines airplane as an engine-driven, fixed-wing aircraft that is supported in flight by the dynamic reaction of air against its wings. Another term, not yet codified in 14 CFR part 1, is advanced avionics aircraft, which refers to an aircraft that contains a global positioning system (GPS) navigation system with a moving map display, in conjunction with another system, such as an autopilot. This chapter provides a brief introduction to the structure of aircraft and uses an airplane for most illustrations. Light Sport Aircraft (LSA), such as weight-shift control, balloon, glider, powered parachute, and gyroplane have their own handbooks to include detailed information regarding aerodynamics and control.



Lift and Basic Aerodynamics

In order to understand the operation of the major components and subcomponents of an aircraft, it is important to understand basic aerodynamic concepts. This chapter briefly introduces aerodynamics; a more detailed explanation can be found in Chapter 4, Aerodynamics of Flight.

Four forces act upon an aircraft in relation to straight-and-level, unaccelerated flight. These forces are thrust, lift, weight, and drag. [Figure 2-1]

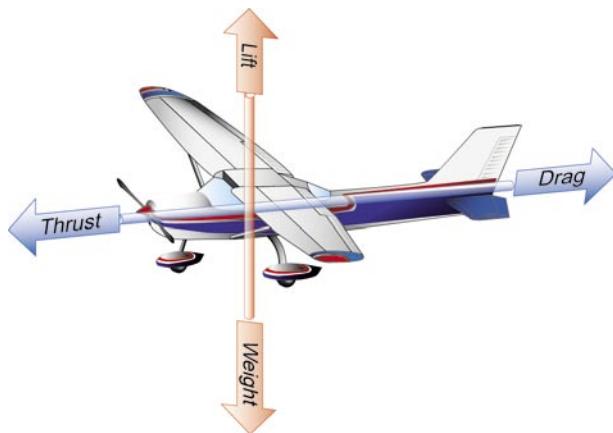


Figure 2-1. The four forces.

Thrust is the forward force produced by the powerplant/propeller. It opposes or overcomes the force of drag. As a general rule, it is said to act parallel to the longitudinal axis. This is not always the case as explained later.

Drag is a rearward, retarding force, and is caused by disruption of airflow by the wing, fuselage, and other protruding objects. Drag opposes thrust, and acts rearward parallel to the relative wind.

Weight is the combined load of the airplane itself, the crew, the fuel, and the cargo or baggage. Weight pulls the airplane downward because of the force of gravity. It opposes lift, and acts vertically downward through the airplane's center of gravity (CG).

Lift opposes the downward force of weight, is produced by the dynamic effect of the air acting on the wing, and acts perpendicular to the flightpath through the wing's center of lift.

An aircraft moves in three dimensions and is controlled by moving it about one or more of its axes. The longitudinal or roll axis extends through the aircraft from nose to tail, with the line passing through the CG. The lateral or pitch axis extends across the aircraft on a line through the wing tips, again passing through the CG. The vertical, or yaw, axis passes through the aircraft vertically, intersecting the CG. All control movements cause the aircraft to move around one or more of these axes, and allows for the control of the airplane in flight. [Figure 2-2]

One of the most significant components of aircraft design is CG. It is the specific point where the mass or weight of an aircraft may be said to center; that is, a point around which, if the aircraft could be suspended or balanced, the aircraft would remain relatively level. The position of the CG of an aircraft determines the stability of the aircraft in flight. As the CG moves rearward (towards the tail) the aircraft becomes more and more dynamically unstable. In aircraft with fuel tanks situated in front of the CG, it is important that the CG is set with the fuel tank empty. Otherwise, as the fuel is used, the aircraft becomes unstable. [Figure 2-3] The CG is computed during initial design and construction, and is further affected by the installation of onboard equipment, aircraft loading, and other factors.

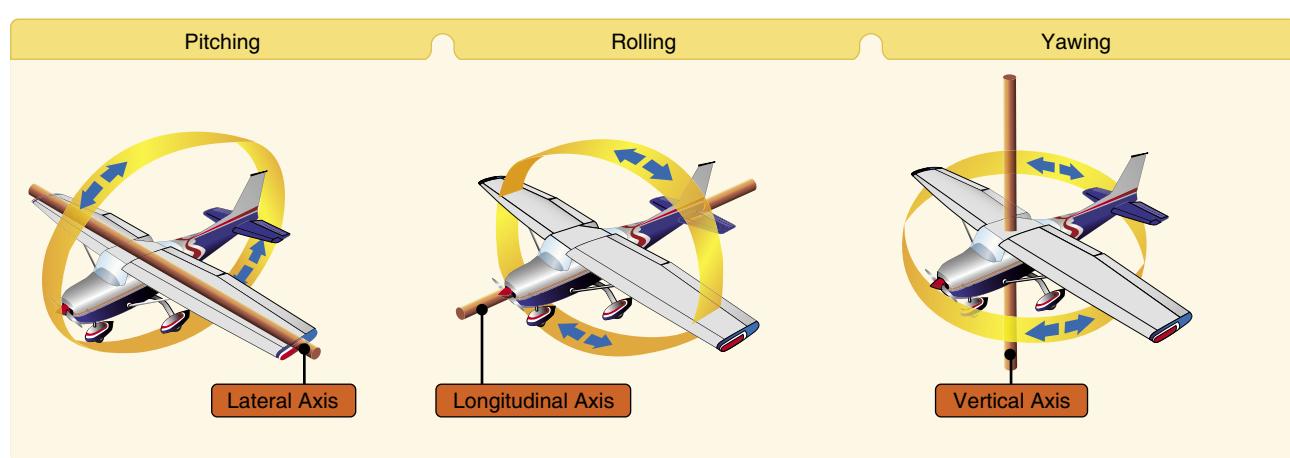


Figure 2-2. Illustrates the pitch, roll, and yaw motion of the aircraft along the lateral, longitudinal, and vertical axes, respectively.

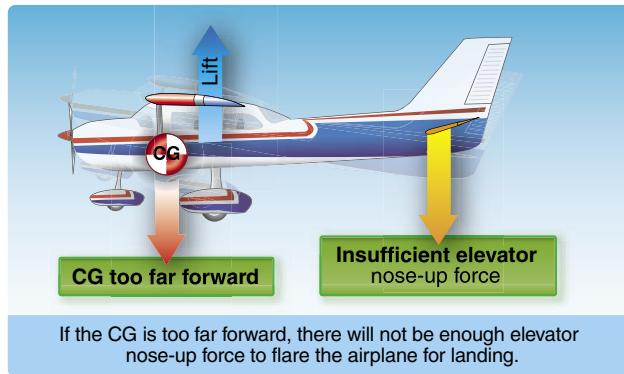
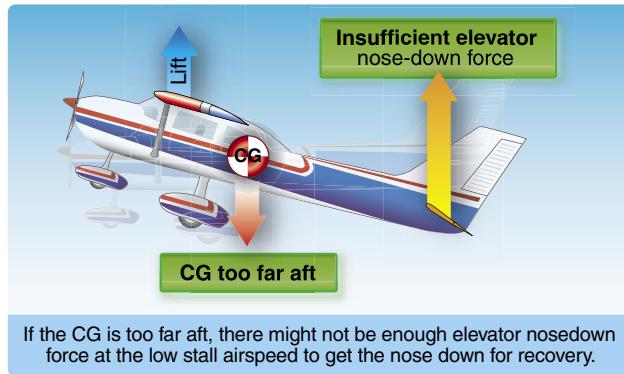
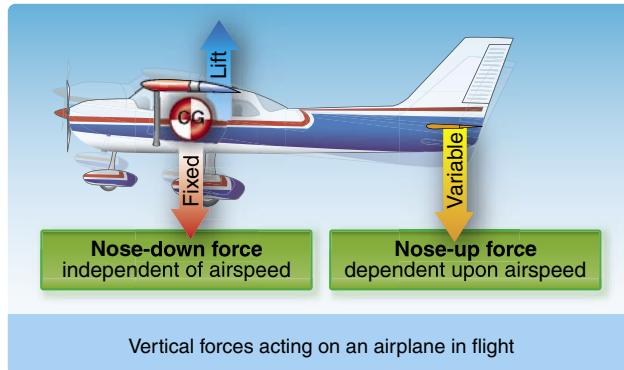


Figure 2-3. Center of gravity (CG).

Major Components

Although airplanes are designed for a variety of purposes, most of them have the same major components. [Figure 2-4] The overall characteristics are largely determined by the original design objectives. Most airplane structures include a fuselage, wings, an empennage, landing gear, and a powerplant.

Fuselage

The fuselage is the central body of an airplane and is designed to accommodate the crew, passengers, and cargo. It also provides the structural connection for the wings and tail assembly. Older types of aircraft design utilized an open truss structure constructed of wood, steel, or aluminum tubing. [Figure 2-5] The most popular types of fuselage structures used in today's aircraft are the monocoque (French for "single shell") and semimonocoque. These structure types

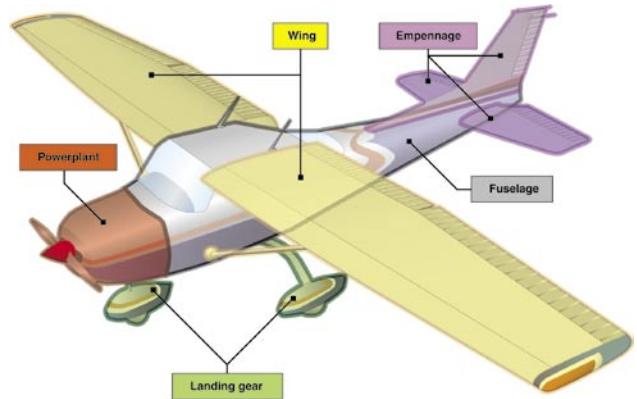


Figure 2-4. Airplane components.

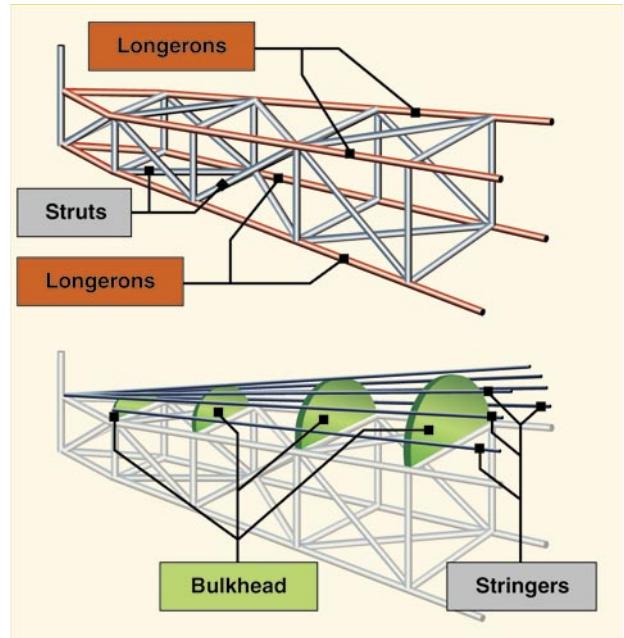


Figure 2-5. Truss-type fuselage structure.

are discussed in more detail under aircraft construction later in the chapter.

Wings

The wings are airfoils attached to each side of the fuselage and are the main lifting surfaces that support the airplane in flight. There are numerous wing designs, sizes, and shapes used by the various manufacturers. Each fulfills a certain need with respect to the expected performance for the particular airplane. How the wing produces lift is explained in Chapter 4, Aerodynamics of Flight.

Wings may be attached at the top, middle, or lower portion of the fuselage. These designs are referred to as high-, mid-, and low-wing, respectively. The number of wings can also vary. Airplanes with a single set of wings are referred to as

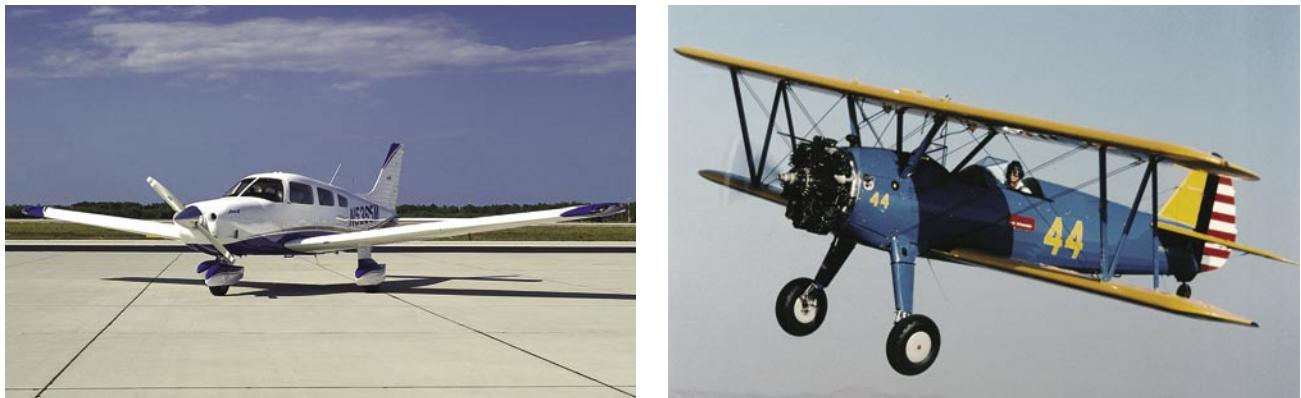


Figure 2-6. Monoplane (left) and biplane (right).

monoplanes, while those with two sets are called biplanes. [Figure 2-6]

Many high-wing airplanes have external braces, or wing struts, which transmit the flight and landing loads through the struts to the main fuselage structure. Since the wing struts are usually attached approximately halfway out on the wing, this type of wing structure is called semi-cantilever. A few high-wing and most low-wing airplanes have a full cantilever wing designed to carry the loads without external struts.

The principal structural parts of the wing are spars, ribs, and stringers. [Figure 2-7] These are reinforced by trusses, I-beams, tubing, or other devices, including the skin. The wing ribs determine the shape and thickness of the wing

(airfoil). In most modern airplanes, the fuel tanks either are an integral part of the wing's structure, or consist of flexible containers mounted inside of the wing.

Attached to the rear or trailing edges of the wings are two types of control surfaces referred to as ailerons and flaps. Ailerons extend from about the midpoint of each wing outward toward the tip, and move in opposite directions to create aerodynamic forces that cause the airplane to roll. Flaps extend outward from the fuselage to near the midpoint of each wing. The flaps are normally flush with the wing's surface during cruising flight. When extended, the flaps move simultaneously downward to increase the lifting force of the wing for takeoffs and landings. [Figure 2-8]

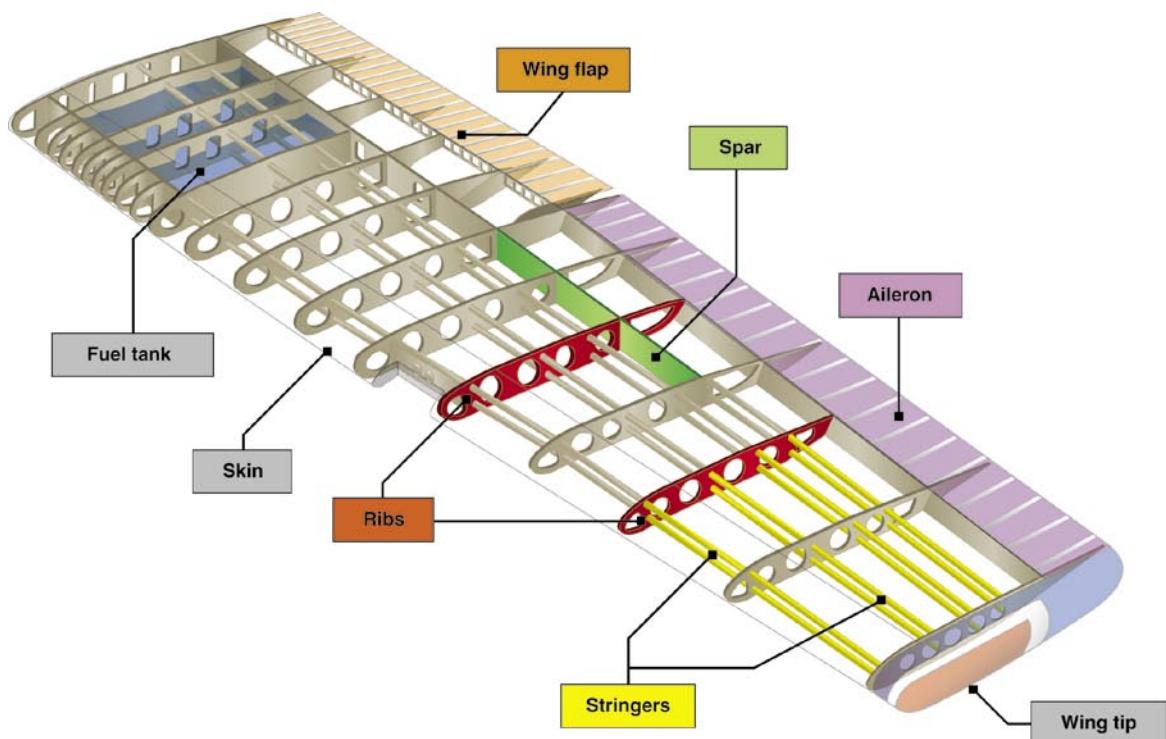


Figure 2-7. Wing components.

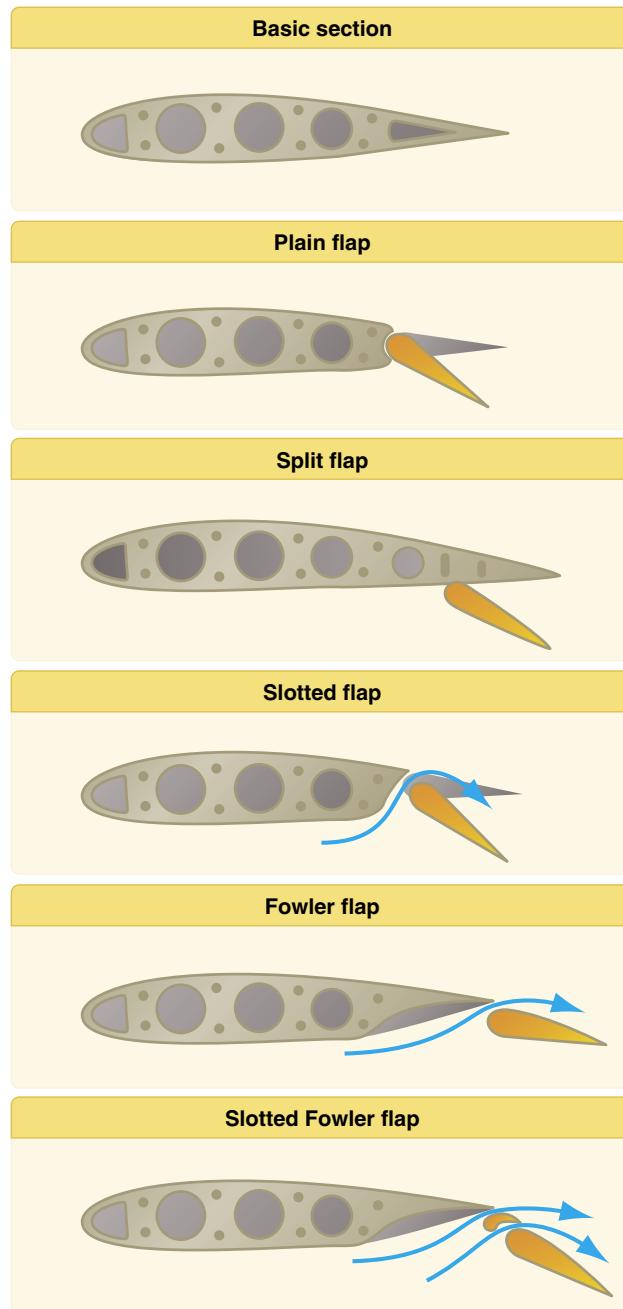


Figure 2-8. Types of flaps.

Alternate Types of Wings

With the Federal Aviation Administration's (FAA) recent addition of the LSA category, various methods are employed to control flight and to produce lift. These methods are discussed in Chapter 4, Aerodynamics of Flight, which provides information on the effect controls have on lifting surfaces from traditional wings to wings that use both flexing (due to billowing) and shifting (through the change of the aircraft's CG). Handbooks specific to each category of LSA are available for the interested pilot. LSA illustrate various lifting surfaces and control methods. For example, the wing

of the weight-shift control aircraft is highly swept, and the shifting of weight to provide controlled flight. [Figure 2-9]



Figure 2-9. Weight-shift control aircraft use the shifting of weight for control.

Empennage

The empennage includes the entire tail group and consists of fixed surfaces such as the vertical stabilizer and the horizontal stabilizer. The movable surfaces include the rudder, the elevator, and one or more trim tabs. [Figure 2-10]

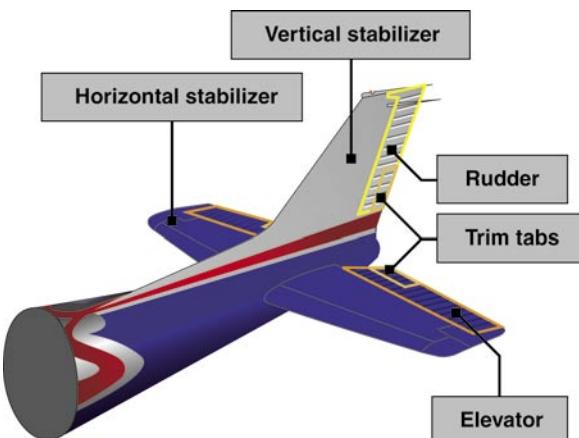


Figure 2-10. Empennage components.

The rudder is attached to the back of the vertical stabilizer. During flight, it is used to move the airplane's nose left and right. The elevator, which is attached to the back of the horizontal stabilizer, is used to move the nose of the airplane up and down during flight. Trim tabs are small, movable portions of the trailing edge of the control surface. These movable trim tabs, which are controlled from the flight deck, reduce control pressures. Trim tabs may be installed on the ailerons, the rudder, and/or the elevator.

A second type of empennage design does not require an elevator. Instead, it incorporates a one-piece horizontal stabilizer that pivots from a central hinge point. This type of

design is called a stabilator, and is moved using the control wheel, just as the elevator is moved. For example, when a pilot pulls back on the control wheel, the stabilator pivots so the trailing edge moves up. This increases the aerodynamic tail load and causes the nose of the airplane to move up. Stabilators have an antiservo tab extending across their trailing edge. [Figure 2-11]

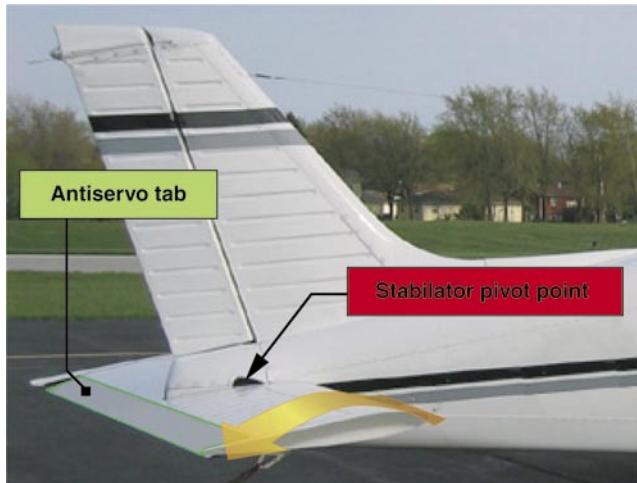


Figure 2-11. Stabilator components.

The antiservo tab moves in the same direction as the trailing edge of the stabilator and helps make the stabilator less sensitive. The antiservo tab also functions as a trim tab to relieve control pressures and helps maintain the stabilator in the desired position.

Landing Gear

The landing gear is the principal support of the airplane when parked, taxiing, taking off, or landing. The most common type of landing gear consists of wheels, but airplanes can also be equipped with floats for water operations, or skis for landing on snow. [Figure 2-12]

The landing gear consists of three wheels—two main wheels and a third wheel positioned either at the front or rear of the airplane. Landing gear with a rear mounted wheel is called conventional landing gear.

Airplanes with conventional landing gear are sometimes referred to as tailwheel airplanes. When the third wheel is located on the nose, it is called a nosewheel, and the design is referred to as a tricycle gear. A steerable nosewheel or tailwheel permits the airplane to be controlled throughout all operations while on the ground. Most aircraft are steered by moving the rudder pedals, whether nosewheel or tailwheel. Additionally, some aircraft are steered by differential braking.



Figure 2-12. Types of landing gear: floats (top), skis (middle), and wheels (bottom).

The Powerplant

The powerplant usually includes both the engine and the propeller. The primary function of the engine is to provide the power to turn the propeller. It also generates electrical power, provides a vacuum source for some flight instruments, and in most single-engine airplanes, provides a source of heat for the pilot and passengers. [Figure 2-13] The engine is covered by a cowling, or a nacelle, which are both types of covered housings. The purpose of the cowling or nacelle

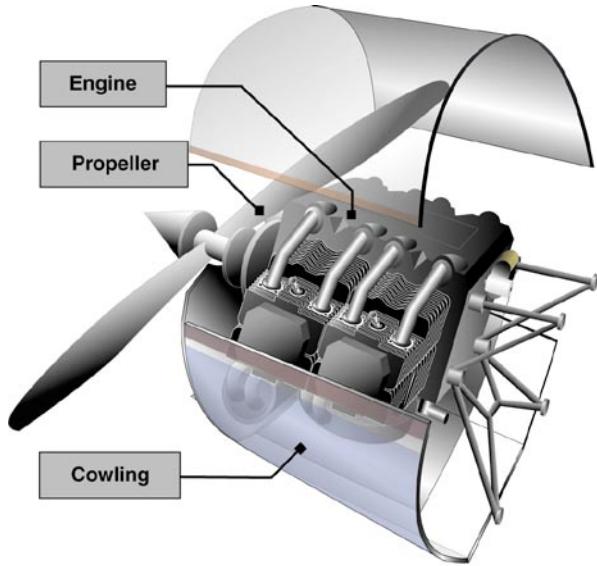


Figure 2-13. Engine compartment.

is to streamline the flow of air around the engine and to help cool the engine by ducting air around the cylinders.

The propeller, mounted on the front of the engine, translates the rotating force of the engine into thrust, a forward acting force that helps move the airplane through the air. The propeller may also be mounted on the rear of the engine as in a pusher-type aircraft. A propeller is a rotating airfoil that produces thrust through aerodynamic action. A low pressure area is formed at the back of the propeller's airfoil, and high pressure is produced at the face of the propeller, similar to the way lift is generated by an airfoil used as a lifting surface or wing. This pressure differential pulls air through the propeller, which in turn pulls the airplane forward.

There are two significant factors involved in the design of a propeller which impact its effectiveness. The angle of a propeller blade, as measured against the hub of the propeller, keeps the angle of attack relatively constant along the span of the propeller blade, reducing or eliminating the possibility of a stall. The pitch is defined as the distance a propeller would travel in one revolution if it were turning in a solid. These two factors combine to allow a measurement of the propeller's efficiency. Propellers are usually matched to a specific aircraft/powerplant combination to achieve the best efficiency at a particular power setting, and they pull or push depending on how the engine is mounted.

Subcomponents

The subcomponents of an airplane include the airframe, electrical system, flight controls, and brakes.

The airframe is the basic structure of an aircraft and is designed to withstand all aerodynamic forces, as well as the stresses imposed by the weight of the fuel, crew, and payload.

The primary function of an aircraft electrical system is to generate, regulate, and distribute electrical power throughout the aircraft. There are several different power sources on aircraft to power the aircraft electrical systems. These power sources include: engine-driven alternating current (AC) generators, auxiliary power units (APUs), and external power. The aircraft's electrical power system is used to operate the flight instruments, essential systems such as anti-icing, etc., and passenger services, such as cabin lighting.

The flight controls are the devices and systems which govern the attitude of an aircraft and, as a result, the flightpath followed by the aircraft. In the case of many conventional airplanes, the primary flight controls utilize hinged, trailing-edge surfaces called elevators for pitch, ailerons for roll, and the rudder for yaw. These surfaces are operated by the pilot in the flight deck or by an automatic pilot.

Airplane brakes consist of multiple pads (called caliper pads) that are hydraulically squeezed toward each other with a rotating disk (called a rotor) between them. The pads place pressure on the rotor which is turning with the wheels. As a result of the increased friction on the rotor, the wheels inherently slow down and stop turning. The disks and brake pads are made either from steel, like those in a car, or from a carbon material that weighs less and can absorb more energy. Because airplane brakes are used principally during landings and must absorb enormous amounts of energy, their life is measured in landings rather than miles.

Types of Aircraft Construction

The construction of aircraft fuselages evolved from the early wood truss structural arrangements to monocoque shell structures to the current semimonocoque shell structures.

Truss Structure

The main drawback of truss structure is its lack of a streamlined shape. In this construction method, lengths of tubing, called longerons, are welded in place to form a well-braced framework. Vertical and horizontal struts are welded to the longerons and give the structure a square or rectangular shape when viewed from the end. Additional struts are needed to resist stress that can come from any direction. Stringers and bulkheads, or formers, are added to shape the fuselage and support the covering.

As technology progressed, aircraft designers began to enclose the truss members to streamline the airplane and improve performance. This was originally accomplished with cloth fabric, which eventually gave way to lightweight metals such as aluminum. In some cases, the outside skin can support all or a major portion of the flight loads. Most modern aircraft use a form of this stressed skin structure known as monocoque or semimonocoque construction. [Figure 2-14]

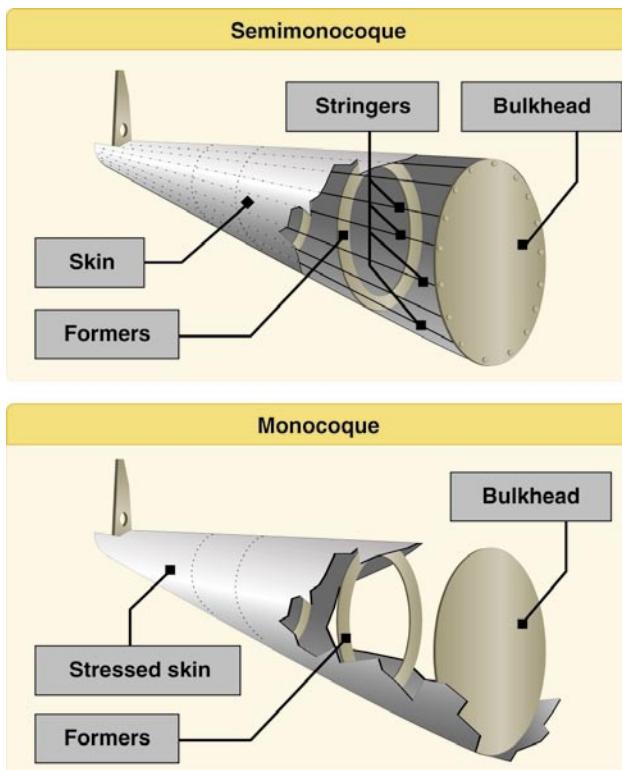


Figure 2-14. Semimonocoque and monocoque fuselage design.

Monocoque

Monocoque construction uses stressed skin to support almost all loads much like an aluminum beverage can. Although very strong, monocoque construction is not highly tolerant to deformation of the surface. For example, an aluminum beverage can supports considerable forces at the ends of the can, but if the side of the can is deformed slightly while supporting a load, it collapses easily.

Because most twisting and bending stresses are carried by the external skin rather than by an open framework, the need for internal bracing was eliminated or reduced, saving weight and maximizing space. One of the notable and innovative methods for using monocoque construction was employed by Jack Northrop. In 1918, he devised a new way to construct a monocoque fuselage used for the Lockheed S-1 Racer. The technique utilized two molded plywood half-shells that were glued together around wooden hoops or stringers. To

construct the half shells, rather than gluing many strips of plywood over a form, three large sets of spruce strips were soaked with glue and laid in a semi-circular concrete mold that looked like a bathtub. Then, under a tightly clamped lid, a rubber balloon was inflated in the cavity to press the plywood against the mold. Twenty-four hours later, the smooth half-shell was ready to be joined to another to create the fuselage. The two halves were each less than a quarter inch thick. Although employed in the early aviation period, monocoque construction would not reemerge for several decades due to the complexities involved. Every day examples of monocoque construction can be found in automobile manufacturing where the unibody is considered standard in manufacturing.

Semimonocoque

Semimonocoque construction, partial or one-half, uses a substructure to which the airplane's skin is attached. The substructure, which consists of bulkheads and/or formers of various sizes and stringers, reinforces the stressed skin by taking some of the bending stress from the fuselage. The main section of the fuselage also includes wing attachment points and a firewall. On single-engine airplanes, the engine is usually attached to the front of the fuselage. There is a fireproof partition between the rear of the engine and the flight deck or cabin to protect the pilot and passengers from accidental engine fires. This partition is called a firewall and is usually made of heat-resistant material such as stainless steel. However, a new emerging process of construction is the integration of composites or aircraft made entirely of composites.

Composite Construction

History

The use of composites in aircraft construction can be dated to World War II aircraft when soft fiberglass insulation was used in B-29 fuselages. By the late 1950s, European high performance sailplane manufacturers were using fiberglass as primary structures. In 1965, the FAA type certified the first all-fiberglass aircraft in the normal category, a Swiss sailplane called a Diamant HBV. Four years later, the FAA certified a four-seat single-engine Windecker Eagle in the normal category. By 2005, over 35 percent of new aircraft were constructed of composite materials.

Composite is a broad term and can mean materials such as fiberglass, carbon fiber cloth, Kevlar[®] cloth, and mixtures of all of the above. Composite construction offers two advantages: extremely smooth skins and the ability to easily form complex curved or streamlined structures. [Figure 2-15]



Figure 2-15. Composite aircraft.

Composite Materials in Aircraft

Composite materials are fiber-reinforced matrix systems. The matrix is the “glue” used to hold the fibers together and, when cured, gives the part its shape, but the fibers carry most of the load. There are many different types of fibers and matrix systems.

In aircraft, the most common matrix is epoxy resin, which is a type of thermosetting plastic. Compared to other choices such as polyester resin, epoxy is stronger and has good high-temperature properties. There are many different types of epoxies available, with a wide range of structural properties, cure times and temperatures, and costs.

The most common reinforcing fibers used in aircraft construction are fiberglass and carbon fiber. Fiberglass has good tensile and compressive strength, good impact resistance, is easy to work with, and is relatively inexpensive and readily available. Its main disadvantage is that it is relatively heavy, and it is difficult to make a fiberglass load-carrying structure lighter than a well designed equivalent aluminum structure.

Carbon fiber is generally stronger in tensile and compressive strength than fiberglass, and has much higher bending stiffness. It is also considerably lighter than fiberglass. However, it is relatively poor in impact resistance; the fibers are brittle and tend to shatter under sharp impact. This can be greatly improved with a “toughened” epoxy resin system, as used in the Boeing 787 horizontal and vertical stabilizers. Carbon fiber is more expensive than fiberglass, but the price has dropped due to innovations driven by the B-2 program in the 1980s, and Boeing 777 work in the 1990s. Very well-designed carbon fiber structures can be significantly lighter than an equivalent aluminum structure, sometimes by 30 percent or so.

Advantages of Composites

Composite construction offers several advantages over metal, wood, or fabric, with its lighter weight being the most frequently cited. Lighter weight is not always automatic. It must be remembered that building an aircraft structure out of composites does not guarantee it will be lighter, it depends on the structure, as well as the type of composite being used.

A more important advantage is that a very smooth, compound curved, aerodynamic structure made from composites reduces drag. This is the main reason sailplane designers switched from metal and wood to composites in the 1960s. In aircraft, the use of composites reduces drag for the Cirrus and Columbia line of production aircraft, leading to their high performance despite their fixed landing gear. Composites also help mask the radar signature of “stealth” aircraft designs, such as the B-2 and the F-22. Today, composites can be found in aircraft as varied as gliders to most new helicopters.

Lack of corrosion is a third advantage of composites. Boeing is designing the 787, with its all-composite fuselage, to have both a higher pressure differential and higher humidity in the cabin than previous airliners. Engineers are no longer as concerned about corrosion from moisture condensation on the hidden areas of the fuselage skins, such as behind insulation blankets. This should lead to lower long-term maintenance costs for the airlines.

Another advantage of composites is their good performance in a flexing environment, such as in helicopter rotor blades. Composites do not suffer from metal fatigue and crack growth as do metals. While it takes careful engineering, composite rotor blades can have considerably higher design lives than metal blades, and most new large helicopter designs have all composite blades, and in many cases, composite rotor hubs.

Disadvantages of Composites

Composite construction comes with its own set of disadvantages, the most important of which is the lack of visual proof of damage. Composites respond differently from other structural materials to impact, and there is often no obvious sign of damage. For example, if a car backs into an aluminum fuselage, it might dent the fuselage. If the fuselage is not dented, there is no damage. If the fuselage is dented, the damage is visible and repairs are made.

In a composite structure, a low energy impact, such as a bump or a tool drop, may not leave any visible sign of the impact on the surface. Underneath the impact site there may be extensive delaminations, spreading in a cone-shaped area from the impact location. The damage on the backside of the structure can be significant and extensive, but it may be hidden from view. Anytime one has reason to think there

may have been an impact, even a minor one, it is best to get an inspector familiar with composites to examine the structure to determine underlying damage. The appearance of “whitish” areas in a fiberglass structure is a good tip-off that delaminations or fiber fracture has occurred.

A medium energy impact (perhaps the car backing into the structure) results in local crushing of the surface, which should be visible to the eye. The damaged area is larger than the visible crushed area, and will need to be repaired. A high energy impact, such as a bird strike or hail while in flight, results in a puncture and a severely damaged structure. In medium and high energy impacts, the damage is visible to the eye, but low energy impact is difficult to detect. [Figure 2-16]

If an impact results in delaminations, crushing of the surface, or a puncture, then a repair is mandatory. While waiting for the repair, the damaged area should be covered and protected from rain. Many composite parts are composed of thin skins over a honeycomb core, creating a “sandwich” structure. While excellent for structural stiffness reasons, such a structure is an easy target for water ingress (entering), leading to further problems later. A piece of “speed tape” over the puncture is a good way to protect it from water, but is not a structural repair. The use of a paste filler to cover up the damage, while acceptable for cosmetic purposes, is not a structural repair, either.

The potential for heat damage to the resin is another disadvantage of using composites. While “too hot” depends on the particular resin system chosen, many epoxies begin to weaken over 150° F. White paint on composites is often used to minimize this issue. For example, the bottom of a wing that is painted black facing a black asphalt ramp on a hot, sunny day, can get as hot as 220 °F. The same structure, painted white, rarely exceeds 140 °F. As a result, composite airplanes often have specific recommendations on allowable paint colors. If the airplane is repainted, these recommendations must be followed. Heat damage can also occur due to a fire. Even a quickly extinguished small brake fire can damage bottom wing skins, composite landing gear legs, or wheel pants.

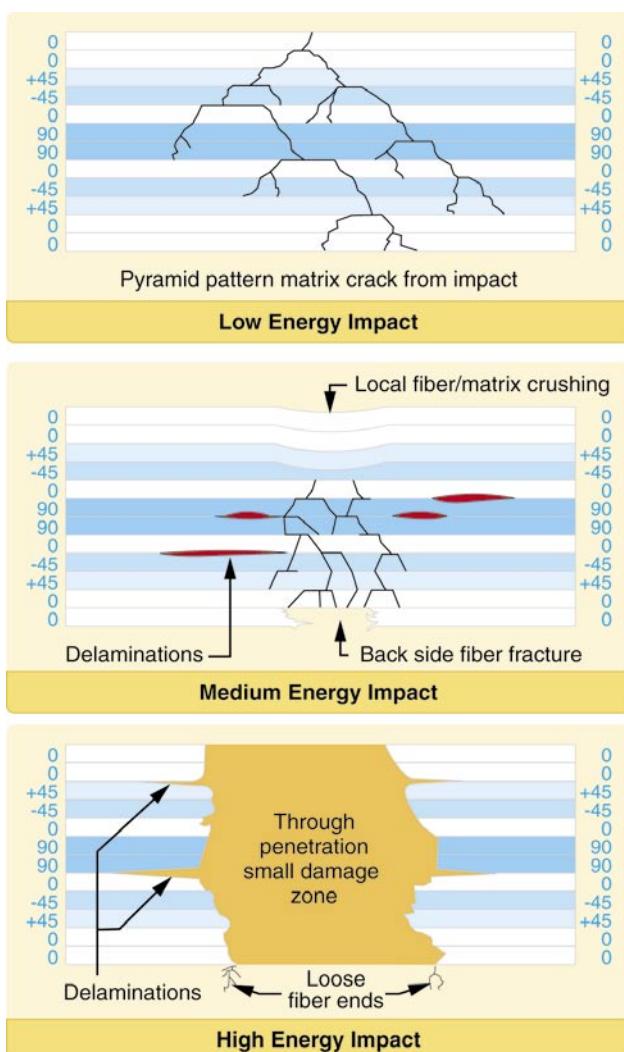


Figure 2-16. Impact energy affects the visibility, as well as the severity, of damage in composite structures. High and medium energy impacts, while severe, are easy to detect. Low energy impacts can easily cause hidden damage.

Also, chemical paint strippers are very harmful to composites, and must not be used on them. If paint needs to be removed from composites, only mechanical methods are allowed, such as gentle grit blasting or sanding. Many expensive composite parts have been ruined by the use of paint stripper, and such damage is generally not repairable.

Fluid Spills on Composites

Some owners are concerned about fuel, oil, or hydraulic fluid spills on composite surfaces. These are generally not a problem with modern composites using epoxy resin. Usually, if the spill doesn't attack the paint, it won't hurt the underlying composite. Some aircraft use fiberglass fuel tanks, for example, in which the fuel rides directly against the composite surface with no sealant being used. If the fiberglass structure is made with some of the more inexpensive types of polyester resin, there can be a problem when using auto gas with ethanol blended into the mixture. The more expensive types of polyester resin, as well as epoxy resin, can be used with auto gas, as well as 100 octane aviation gas (avgas) and jet fuel.

Lightning Strike Protection

Lightning strike protection is an important consideration in aircraft design. When an aircraft is hit by lightning, a very

large amount of energy is delivered to the structure. Whether flying a light general aviation (GA) airplane or a large airliner, the basic principle of lightning strike protection is the same. For any size aircraft, the energy from the strike must be spread over a large surface area to lower the “amps per square inch” to a harmless level.

If lightning strikes an aluminum airplane, the electrical energy naturally conducts easily through the aluminum structure. The challenge is to keep the energy out of avionics, fuel systems, etc., until it can be safely conducted overboard. The outer skin of the aircraft is the path of least resistance.

In a composite aircraft, fiberglass is an excellent electrical insulator, while carbon fiber conducts electricity, but not as easily as aluminum. Therefore, additional electrical conductivity needs to be added to the outside layer of composite skin. This is done typically with fine metal meshes bonded to the skin surfaces. Aluminum and copper mesh are the two most common types, with aluminum used on fiberglass and copper on carbon fiber. Any structural repairs on lightning-strike protected areas must also include the mesh as well as the underlying structure.

For composite aircraft with internal radio antennas, there must be “windows” in the lightning strike mesh in the area of the antenna. Internal radio antennas may be found in fiberglass composites because fiberglass is transparent to radio frequencies, whereas carbon fiber is not.

The Future of Composites

In the decades since World War II, composites have earned an important role in aircraft structure design. Their design flexibility and corrosion resistance, as well as the high strength-to-weight ratios possible, will undoubtedly continue to lead to more innovative aircraft designs in the future. From the Cirrus SR-20 to the Boeing 787, it is obvious that composites have found a home in aircraft construction and are here to stay. [Figure 2-17]

Instrumentation: Moving into the Future

Until recently, most GA aircraft were equipped with individual instruments utilized collectively to safely operate and maneuver the aircraft. With the release of the electronic flight display (EFD) system, conventional instruments have been replaced by multiple liquid crystal display (LCD) screens. The first screen is installed in front of the left seat pilot position and is referred to as the primary flight display (PFD). The second screen, positioned approximately in the center of the instrument panel, is referred to as the multi-function display (MFD). These two screens de-clutter instrument panels while increasing safety. This has been accomplished through the utilization of solid state



Figure 2-17. Composite materials in aircraft, such as Columbia 350 (top), Boeing 787 (middle), and a Coast Guard HH-65 (bottom).

instruments which have a failure rate far less than those of conventional analog instrumentation. [Figure 2-18]

With today's improvements in avionics and the introduction of EFDs, pilots at any level of experience need an astute knowledge of the onboard flight control systems as well as an understanding of how automation melds with Aeronautical Decision-Making (ADM). These subjects are covered in detail in Chapter 17, Aeronautical Decision-Making.



Figure 2-18. Analog display (top) and digital display (bottom) from a Cessna 172.

Whether an aircraft has analog or digital (“glass”) instruments, the instrumentation falls into three different categories: performance, control, and navigation.

Performance Instruments

The performance instruments indicate the aircraft’s actual performance. Performance is determined by reference to the altimeter, airspeed or vertical speed indicator (VSI), heading indicator, and turn-and-slip indicator. The performance instruments directly reflect the performance the aircraft is achieving. The speed of the aircraft can be referenced on the airspeed indicator. The altitude can be referenced on the altimeter. The aircraft’s climb performance can be determined by referencing the VSI. Other performance instruments available are the heading indicator, angle of attack indicator, and the slip-skid indicator. [Figure 2-19]

Control Instruments

The control instruments [Figure 2-20] display immediate attitude and power changes, and are calibrated to permit adjustments in precise increments. The instrument for attitude display is the attitude indicator. The control instruments do not indicate aircraft speed or altitude. In order to determine

these variable and others, a pilot must reference the performance instruments.

Navigation Instruments

The navigation instruments indicate the position of the aircraft in relation to a selected navigation facility or fix. This group of instruments includes various types of course indicators, range indicators, glideslope indicators, and bearing pointers. Newer aircraft with more technologically advanced instrumentation provide blended information, giving the pilot more accurate positional information.

Navigation instruments are comprised of indicators that display GPS, very high frequency (VHF) omni-directional radio range (VOR), nondirectional beacon (NDB), and instrument landing system (ILS) information. The instruments indicate the position of the aircraft relative to a selected navigation facility or fix. They also provide pilotage information so the aircraft can be maneuvered to keep it on a predetermined path. The pilotage information can be in either two or three dimensions relative to the ground-based or space-based navigation information. [Figures 2-21 and 2-22]

Global Positioning System (GPS)

GPS is a satellite-based navigation system composed of a network of satellites placed into orbit by the United States Department of Defense (DOD). GPS was originally intended for military applications, but in the 1980s the government made the system available for civilian use. GPS works in all weather conditions, anywhere in the world, 24 hours a day. A GPS receiver must be locked onto the signal of at least three satellites to calculate a two-dimensional position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user’s three-dimensional position (latitude, longitude, and altitude). Other satellites must also be in view to offset signal loss and signal ambiguity. The use of the GPS is discussed in more detail in Chapter 15, Navigation. Additionally, GPS is discussed in the Aeronautical Information Manual (AIM).

Chapter Summary

This chapter provides an overview of aircraft structures. A more in-depth understanding of aircraft structures and controls can be gained through the use of flight simulation software or interactive programs available online through aviation organizations such as the Aircraft Owners and Pilots Association (AOPA). Pilots are also encouraged to subscribe to or review the various aviation periodicals which contain valuable flying information. As discussed in Chapter 1, the National Air and Space Administration (NASA) and the FAA also offer free information for pilots.

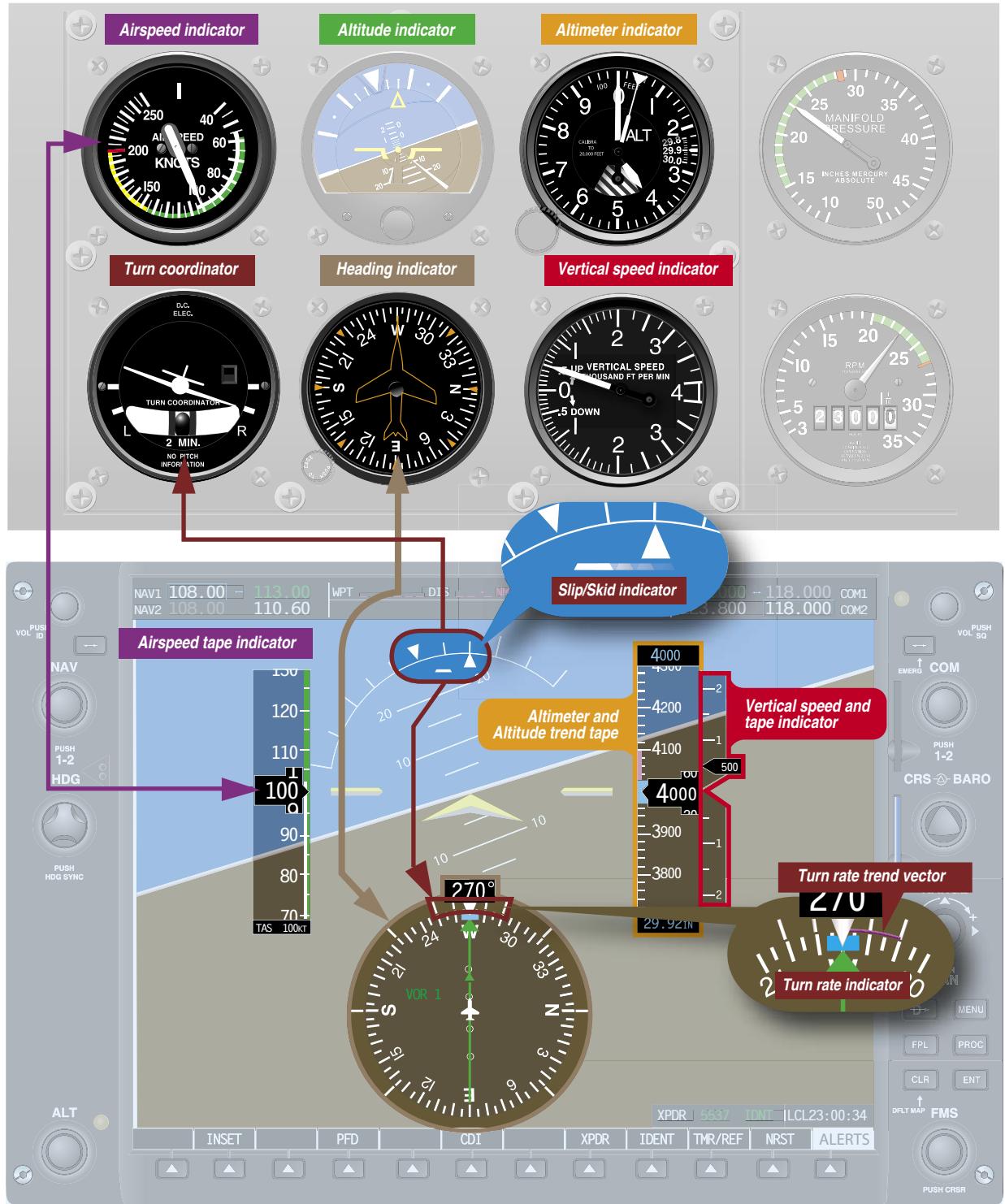


Figure 2-19. Performance instruments.

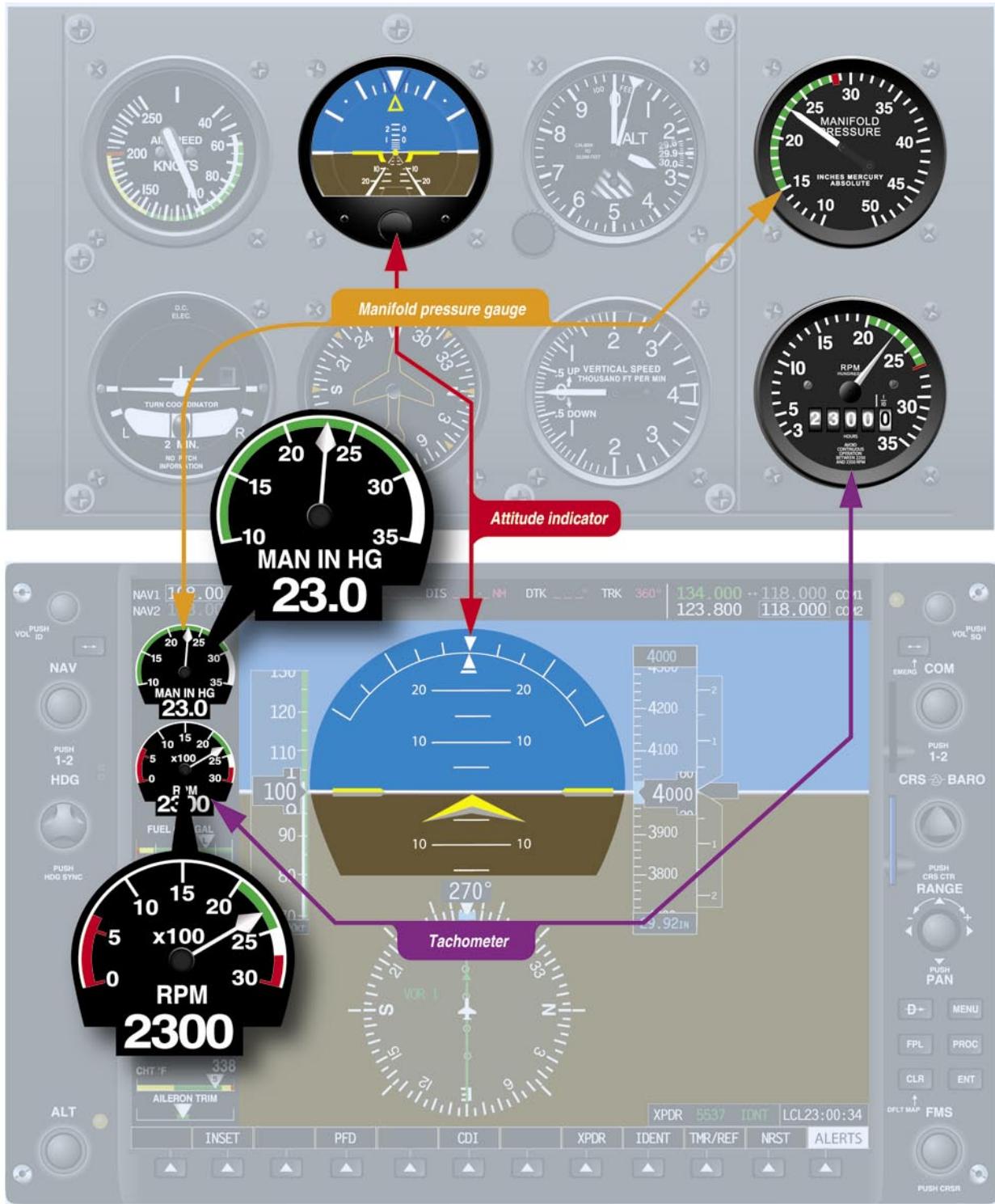


Figure 2-20. Control instruments.

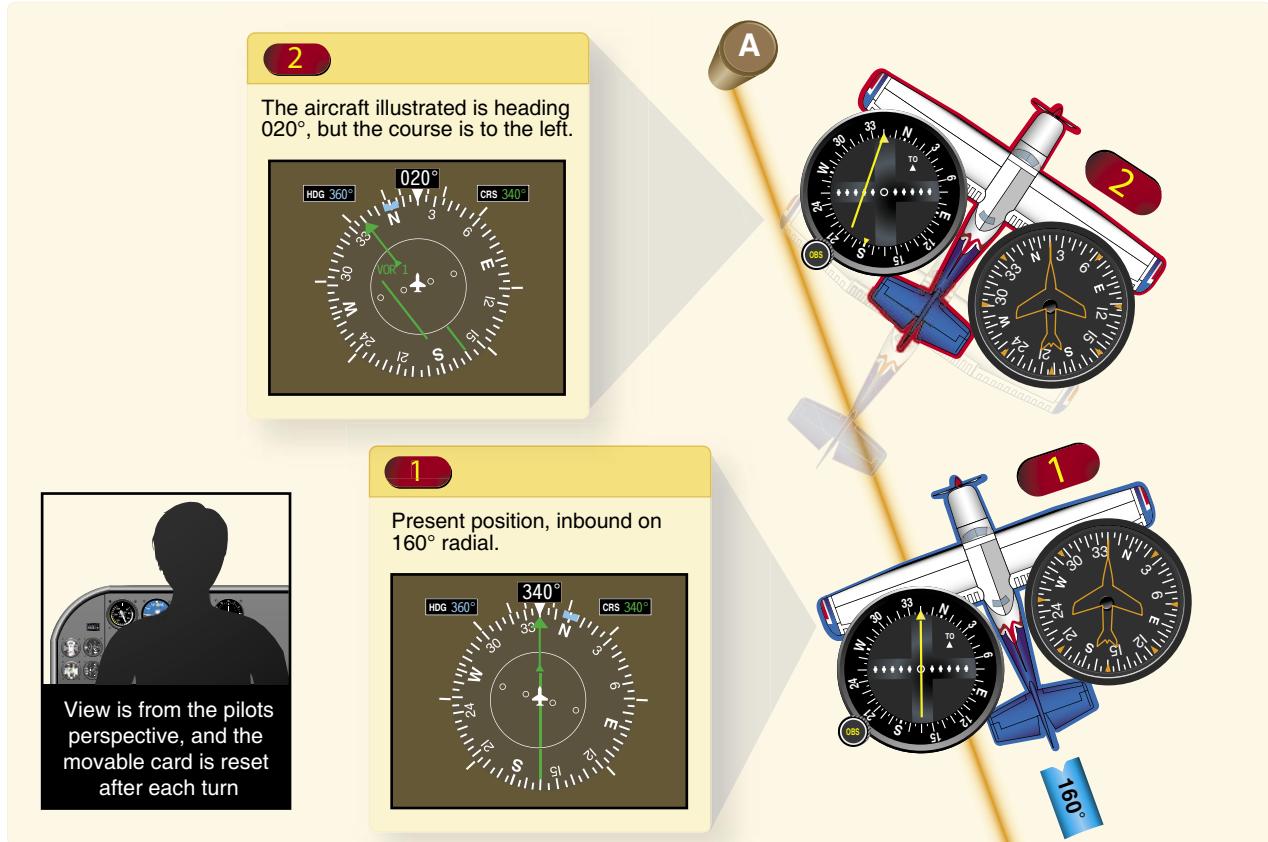


Figure 2-21. A comparison of navigation information as depicted on both analog and digital displays.

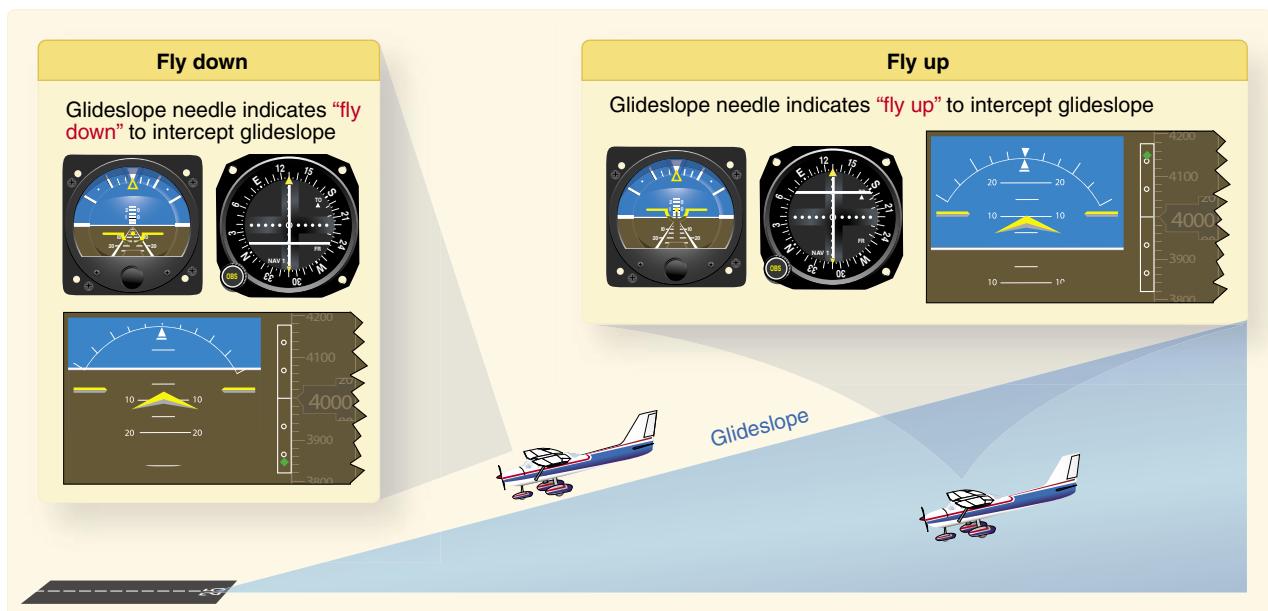


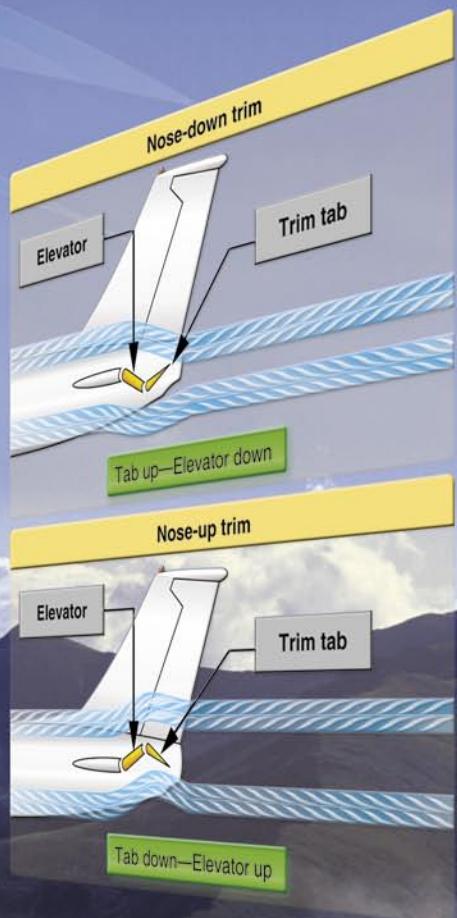
Figure 2-22. Analog and digital indications for glideslope interception.

Chapter 5

Flight Controls

Introduction

This chapter focuses on the flight control systems a pilot uses to control the forces of flight, and the aircraft's direction and attitude. It should be noted that flight control systems and characteristics can vary greatly depending on the type of aircraft flown. The most basic flight control system designs are mechanical and date back to early aircraft. They operate with a collection of mechanical parts such as rods, cables, pulleys, and sometimes chains to transmit the forces of the flight deck controls to the control surfaces. Mechanical flight control systems are still used today in small general and sport category aircraft where the aerodynamic forces are not excessive. [Figure 5-1]



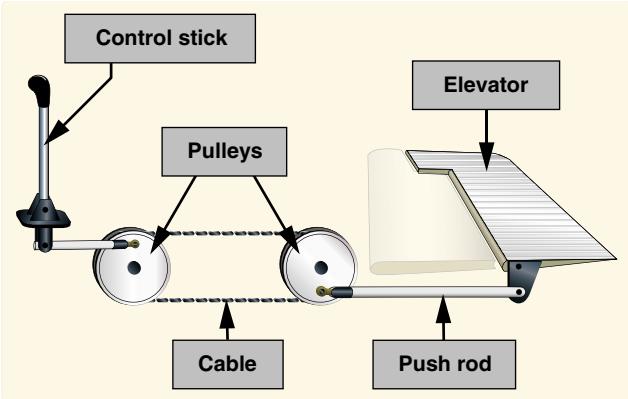


Figure 5-1. Mechanical flight control system.

As aviation matured and aircraft designers learned more about aerodynamics, the industry produced larger and faster aircraft. Therefore, the aerodynamic forces acting upon the control surfaces increased exponentially. To make the control force required by pilots manageable, aircraft engineers designed more complex systems. At first, hydromechanical designs, consisting of a mechanical circuit and a hydraulic circuit, were used to reduce the complexity, weight, and limitations of mechanical flight controls systems. [Figure 5-2]

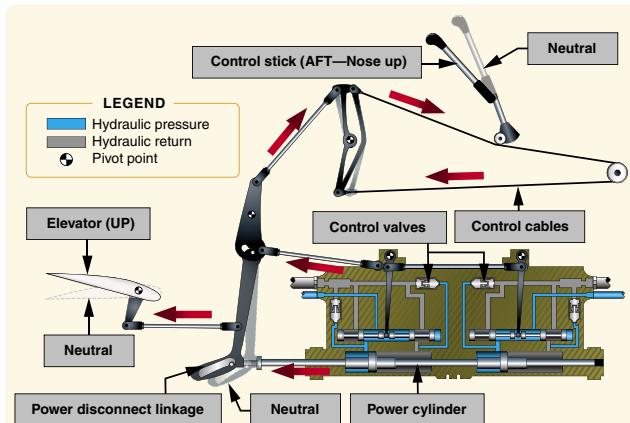


Figure 5-2. Hydromechanical flight control system.

As aircraft became more sophisticated, the control surfaces were actuated by electric motors, digital computers, or fiber optic cables. Called "fly-by-wire," this flight control system replaces the physical connection between pilot controls and the flight control surfaces with an electrical interface. In addition, in some large and fast aircraft, controls are boosted by hydraulically or electrically actuated systems. In both the fly-by-wire and boosted controls, the feel of the control reaction is fed back to the pilot by simulated means.

Current research at the National Aeronautics and Space Administration (NASA) Dryden Flight Research Center involves Intelligent Flight Control Systems (IFCS). The goal

of this project is to develop an adaptive neural network-based flight control system. Applied directly to flight control system feedback errors, IFCS provides adjustments to improve aircraft performance in normal flight as well as with system failures. With IFCS, a pilot is able to maintain control and safely land an aircraft that has suffered a failure to a control surface or damage to the airframe. It also improves mission capability, increases the reliability and safety of flight, and eases the pilot workload.

Today's aircraft employ a variety of flight control systems. For example, some aircraft in the sport pilot category rely on weight-shift control to fly while balloons use a standard burn technique. Helicopters utilize a cyclic to tilt the rotor in the desired direction along with a collective to manipulate rotor pitch and anti-torque pedals to control yaw. [Figure 5-3]

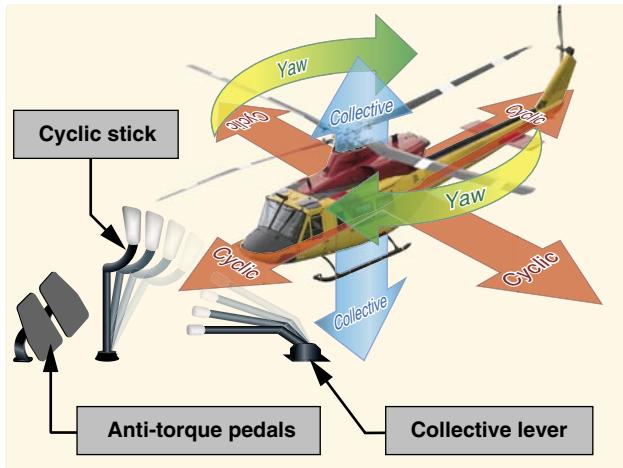


Figure 5-3. Helicopter flight control system.

For additional information on flight control systems, refer to the appropriate handbook for information related to the flight control systems and characteristics of specific types of aircraft.

Flight Control Systems

Flight Controls

Aircraft flight control systems consist of primary and secondary systems. The ailerons, elevator (or stabilator), and rudder constitute the primary control system and are required to control an aircraft safely during flight. Wing flaps, leading edge devices, spoilers, and trim systems constitute the secondary control system and improve the performance characteristics of the airplane or relieve the pilot of excessive control forces.

Primary Flight Controls

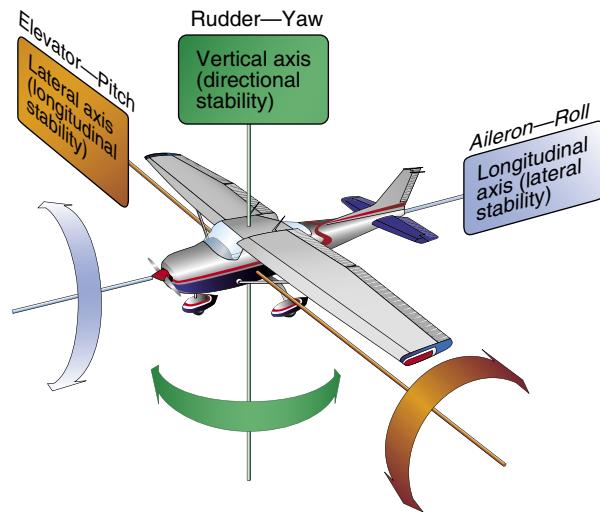
Aircraft control systems are carefully designed to provide adequate responsiveness to control inputs while allowing a

natural feel. At low airspeeds, the controls usually feel soft and sluggish, and the aircraft responds slowly to control applications. At higher airspeeds, the controls become increasingly firm and aircraft response is more rapid.

Movement of any of the three primary flight control surfaces (ailerons, elevator or stabilator, or rudder), changes the airflow and pressure distribution over and around the airfoil. These changes affect the lift and drag produced by the airfoil/control surface combination, and allow a pilot to control the aircraft about its three axes of rotation.

Design features limit the amount of deflection of flight control surfaces. For example, control-stop mechanisms may be incorporated into the flight control linkages, or movement of the control column and/or rudder pedals may be limited. The purpose of these design limits is to prevent the pilot from inadvertently overcontrolling and overstressing the aircraft during normal maneuvers.

A properly designed airplane is stable and easily controlled during normal maneuvering. Control surface inputs cause movement about the three axes of rotation. The types of stability an airplane exhibits also relate to the three axes of rotation. [Figure 5-4]



Primary Control Surface	Airplane Movement	Axes of Rotation	Type of Stability
Aileron	Roll	Longitudinal	Lateral
Elevator/Stabilizer	Pitch	Lateral	Longitudinal
Rudder	Yaw	Vertical	Directional

Figure 5-4. Airplane controls, movement, axes of rotation, and type of stability.

Ailerons

Ailerons control roll about the longitudinal axis. The ailerons are attached to the outboard trailing edge of each wing and move in the opposite direction from each other. Ailerons are connected by cables, bellcranks, pulleys and/or push-pull tubes to a control wheel or control stick.

Moving the control wheel or control stick to the right causes the right aileron to deflect upward and the left aileron to deflect downward. The upward deflection of the right aileron decreases the camber resulting in decreased lift on the right wing. The corresponding downward deflection of the left aileron increases the camber resulting in increased lift on the left wing. Thus, the increased lift on the left wing and the decreased lift on the right wing causes the airplane to roll to the right.

Adverse Yaw

Since the downward deflected aileron produces more lift as evidenced by the wing raising, it also produces more drag. This added drag causes the wing to slow down slightly. This results in the aircraft yawing toward the wing which had experienced an increase in lift (and drag). From the pilot's perspective, the yaw is opposite the direction of the bank. The adverse yaw is a result of differential drag and the slight difference in the velocity of the left and right wings. [Figure 5-5]

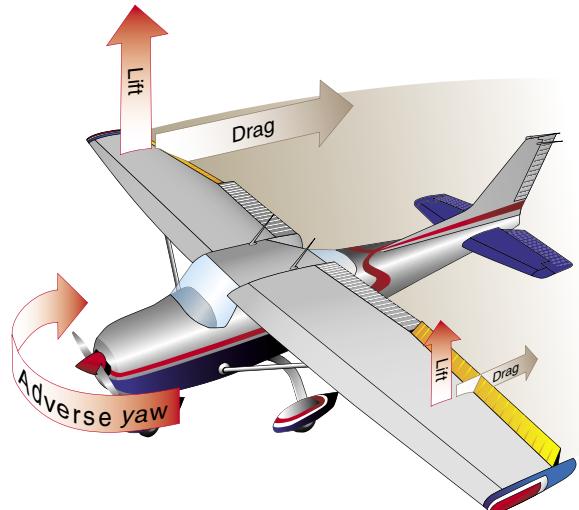


Figure 5-5. Adverse yaw is caused by higher drag on the outside wing, which is producing more lift.

Adverse yaw becomes more pronounced at low airspeeds. At these slower airspeeds aerodynamic pressure on control surfaces are low and larger control inputs are required to effectively maneuver the airplane. As a result, the increase in aileron deflection causes an increase in adverse yaw. The yaw is especially evident in aircraft with long wing spans.

Application of rudder is used to counteract adverse yaw. The amount of rudder control required is greatest at low airspeeds, high angles of attack, and with large aileron deflections. Like all control surfaces at lower airspeeds, the vertical stabilizer/rudder becomes less effective, and magnifies the control problems associated with adverse yaw.

All turns are coordinated by use of ailerons, rudder, and elevator. Applying aileron pressure is necessary to place the aircraft in the desired angle of bank, while simultaneous application of rudder pressure is necessary to counteract the resultant adverse yaw. Additionally, because more lift is required during a turn than when in straight-and-level flight, the angle of attack (AOA) must be increased by applying elevator back pressure. The steeper the turn, the more elevator back pressure is needed.

As the desired angle of bank is established, aileron and rudder pressures should be relaxed. This stops the angle of bank from increasing, because the aileron and rudder control surfaces are in a neutral and streamlined position. Elevator back pressure should be held constant to maintain altitude. The roll-out from a turn is similar to the roll-in, except the flight controls are applied in the opposite direction. Aileron and rudder are applied in the direction of the roll-out or toward the high wing. As the angle of bank decreases, the elevator back pressure should be relaxed as necessary to maintain altitude.

In an attempt to reduce the effects of adverse yaw, manufacturers have engineered four systems: differential ailerons, frise-type ailerons, coupled ailerons and rudder, and flaperons.

Differential Ailerons

With differential ailerons, one aileron is raised a greater distance than the other aileron is lowered for a given movement of the control wheel or control stick. This produces an increase in drag on the descending wing. The greater drag results from deflecting the up aileron on the descending wing to a greater angle than the down aileron on the rising wing. While adverse yaw is reduced, it is not eliminated completely. [Figure 5-6]

Frise-Type Ailerons

With a frise-type aileron, when pressure is applied to the control wheel or control stick, the aileron that is being raised pivots on an offset hinge. This projects the leading edge of the aileron into the airflow and creates drag. It helps equalize the drag created by the lowered aileron on the opposite wing and reduces adverse yaw. [Figure 5-7]

The frise-type aileron also forms a slot so air flows smoothly over the lowered aileron, making it more effective at high

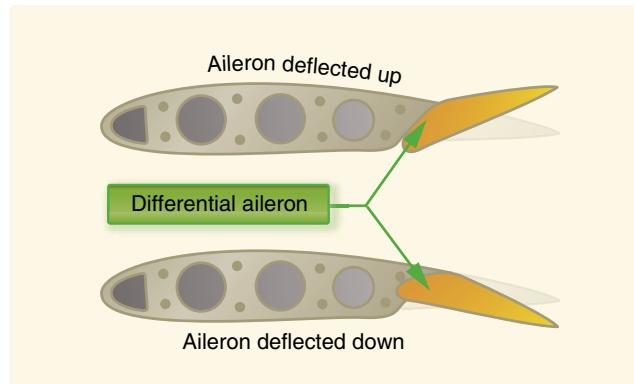


Figure 5-6. Differential ailerons.

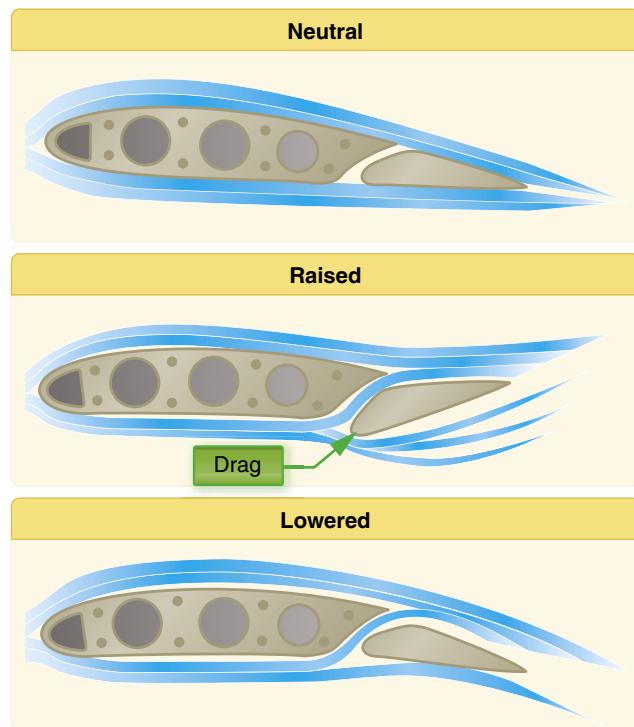


Figure 5-7. Frise-type ailerons.

angles of attack. Frise-type ailerons may also be designed to function differentially. Like the differential aileron, the frise-type aileron does not eliminate adverse yaw entirely. Coordinated rudder application is still needed wherever ailerons are applied.

Coupled Ailerons and Rudder

Coupled ailerons and rudder are linked controls. This is accomplished with rudder-aileron interconnect springs, which help correct for aileron drag by automatically deflecting the rudder at the same time the ailerons are deflected. For example, when the control wheel or control stick is moved to produce a left roll, the interconnect cable and spring pulls forward on the left rudder pedal just enough to prevent the nose of the aircraft from yawing to the right. The force applied

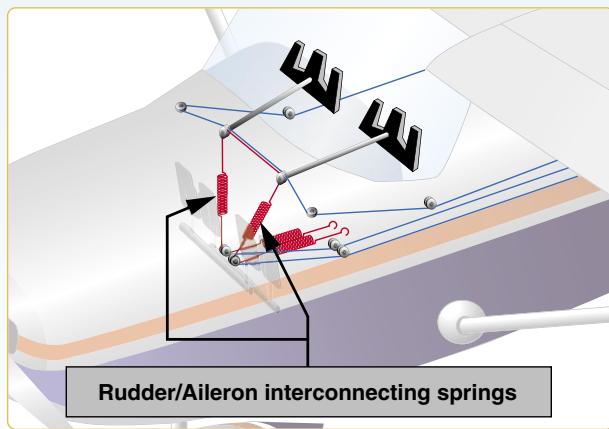
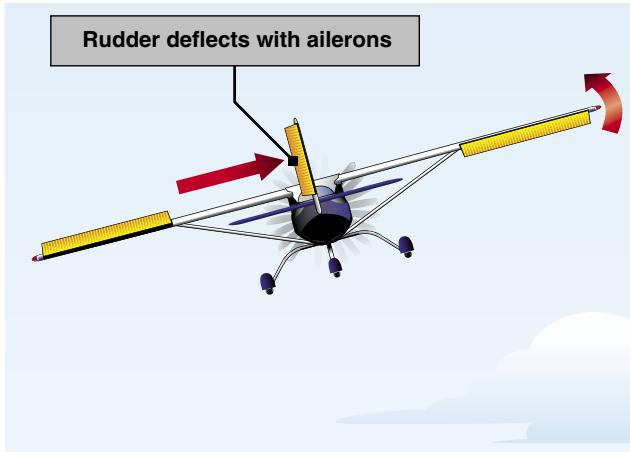


Figure 5-8. Coupled ailerons and rudder.

to the rudder by the springs can be overridden if it becomes necessary to slip the aircraft. [Figure 5-8]

Flaperons

Flaperons combine both aspects of flaps and ailerons. In addition to controlling the bank angle of an aircraft like conventional ailerons, flaperons can be lowered together to function much the same as a dedicated set of flaps. The pilot retains separate controls for ailerons and flaps. A mixer is used to combine the separate pilot inputs into this single set of control surfaces called flaperons. Many designs that incorporate flaperons mount the control surfaces away from the wing to provide undisturbed airflow at high angles of attack and/or low airspeeds. [Figure 5-9]

Elevator

The elevator controls pitch about the lateral axis. Like the ailerons on small aircraft, the elevator is connected to the control column in the flight deck by a series of mechanical linkages. Aft movement of the control column deflects the trailing edge of the elevator surface up. This is usually referred to as up “elevator.” [Figure 5-10]



Figure 5-9. Flaperons on a Skystar Kitfox MK 7.

The up-elevator position decreases the camber of the elevator and creates a downward aerodynamic force, which is greater than the normal tail-down force that exists in straight-and-level flight. The overall effect causes the tail of the aircraft to move down and the nose to pitch up. The pitching moment occurs about the center of gravity (CG). The strength of the pitching moment is determined by the distance between the CG and the horizontal tail surface, as well as by the aerodynamic effectiveness of the horizontal tail surface. Moving the control column forward has the opposite effect. In this case, elevator camber increases, creating more lift (less tail-down force) on the horizontal stabilizer/elevator. This moves the tail upward and pitches the nose down. Again, the pitching moment occurs about the CG.

As mentioned earlier in the coverage on stability, power, thrustline, and the position of the horizontal tail surfaces on the empennage are factors in elevator effectiveness controlling pitch. For example, the horizontal tail surfaces may be attached near the lower part of the vertical stabilizer, at the midpoint, or at the high point, as in the T-tail design.

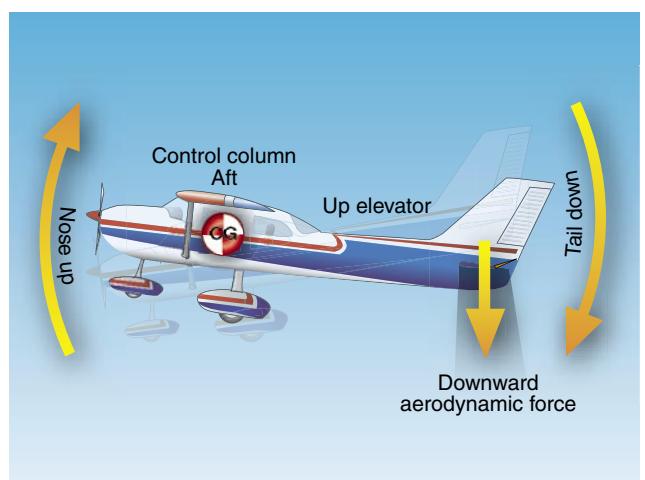


Figure 5-10. The elevator is the primary control for changing the pitch attitude of an airplane.

T-Tail

In a T-tail configuration, the elevator is above most of the effects of downwash from the propeller as well as airflow around the fuselage and/or wings during normal flight conditions. Operation of the elevators in this undisturbed air allows control movements that are consistent throughout most flight regimes. T-tail designs have become popular on many light and large aircraft, especially those with aft fuselage-mounted engines because the T-tail configuration removes the tail from the exhaust blast of the engines. Seaplanes and amphibians often have T-tails in order to keep the horizontal surfaces as far from the water as possible. An additional benefit is reduced vibration and noise inside the aircraft.

At slow speeds, the elevator on a T-tail aircraft must be moved through a larger number of degrees of travel to raise the nose a given amount than on a conventional-tail aircraft. This is because the conventional-tail aircraft has the downwash from the propeller pushing down on the tail to assist in raising the nose.

Since controls on aircraft are rigged so that increasing control forces are required for increased control travel, the forces required to raise the nose of a T-tail aircraft are greater than those for a conventional-tail aircraft. Longitudinal stability of a trimmed aircraft is the same for both types of configuration, but the pilot must be aware that the required control forces are greater at slow speeds during takeoffs, landings, or stalls than for similar size aircraft equipped with conventional tails.

T-tail airplanes also require additional design considerations to counter the problem of flutter. Since the weight of the horizontal surfaces is at the top of the vertical stabilizer, the moment arm created causes high loads on the vertical stabilizer which can result in flutter. Engineers must compensate for this by increasing the design stiffness of the vertical stabilizer, usually resulting in a weight penalty over conventional tail designs.

When flying at a very high AOA with a low airspeed and an aft CG, the T-tail aircraft may be susceptible to a deep stall. In a deep stall, the airflow over the horizontal tail is blanketed by the disturbed airflow from the wings and fuselage. In these circumstances, elevator or stabilator control could be diminished, making it difficult to recover from the stall. It should be noted that an aft CG is often a contributing factor in these incidents, since similar recovery problems are also found with conventional tail aircraft with an aft CG. [Figure 5-11]

Since flight at a high AOA with a low airspeed and an aft CG position can be dangerous, many aircraft have systems to compensate for this situation. The systems range from

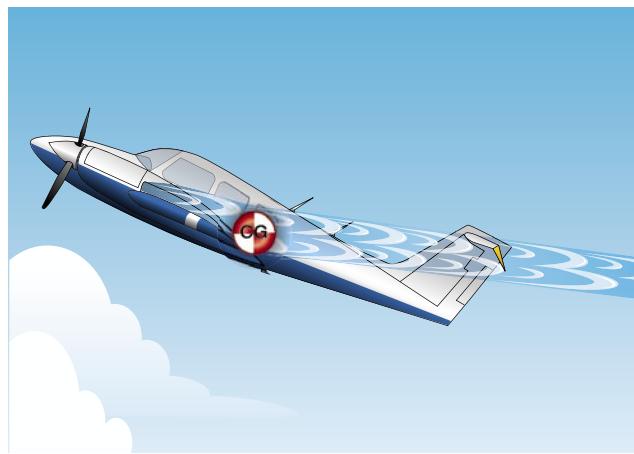


Figure 5-11. Airplane with a T-tail design at a high AOA and an aft CG.

control stops to elevator down springs. An elevator down spring assists in lowering the nose of the aircraft to prevent a stall caused by the aft CG position. The stall occurs because the properly trimmed airplane is flying with the elevator in a trailing edge down position, forcing the tail up and the nose down. In this unstable condition, if the aircraft encounters turbulence and slows down further, the trim tab no longer positions the elevator in the nose-down position. The elevator then streamlines, and the nose of the aircraft pitches upward, possibly resulting in a stall.

The elevator down spring produces a mechanical load on the elevator, causing it to move toward the nose-down position if not otherwise balanced. The elevator trim tab balances the elevator down spring to position the elevator in a trimmed position. When the trim tab becomes ineffective, the down spring drives the elevator to a nose-down position. The nose of the aircraft lowers, speed builds up, and a stall is prevented. [Figure 5-12]

The elevator must also have sufficient authority to hold the nose of the aircraft up during the roundout for a landing. In this case, a forward CG may cause a problem. During the landing flare, power is usually reduced, which decreases the airflow over the empennage. This, coupled with the reduced landing speed, makes the elevator less effective.

As this discussion demonstrates, pilots must understand and follow proper loading procedures, particularly with regard to the CG position. More information on aircraft loading, as well as weight and balance, is included in Chapter 9, Weight and Balance.

Stabilator

As mentioned in Chapter 2, Aircraft Structure, a stabilator is essentially a one-piece horizontal stabilizer that pivots

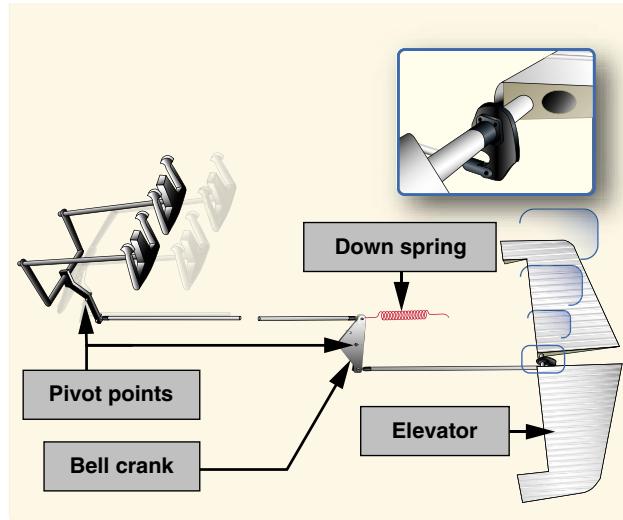


Figure 5-12. When the aerodynamic efficiency of the horizontal tail surface is inadequate due to an aft CG condition, an elevator down spring may be used to supply a mechanical load to lower the nose.

from a central hinge point. When the control column is pulled back, it raises the stabilator's trailing edge, pulling the airplane's nose up. Pushing the control column forward lowers the trailing edge of the stabilator and pitches the nose of the airplane down.

Because stabilators pivot around a central hinge point, they are extremely sensitive to control inputs and aerodynamic loads. Antiservo tabs are incorporated on the trailing edge to decrease sensitivity. They deflect in the same direction as the stabilator. This results in an increase in the force required to move the stabilator, thus making it less prone to pilot-induced overcontrolling. In addition, a balance weight is usually incorporated in front of the main spar. The balance weight may project into the empennage or may be incorporated on the forward portion of the stabilator tips. [Figure 5-13]

Canard

The canard design utilizes the concept of two lifting surfaces, the canard functioning as a horizontal stabilizer located in front of the main wings. In effect, the canard is an airfoil similar to the horizontal surface on a conventional aft-tail design. The difference is that the canard actually creates lift and holds the nose up, as opposed to the aft-tail design which exerts downward force on the tail to prevent the nose from rotating downward. [Figure 5-14]

The canard design dates back to the pioneer days of aviation, most notably used on the Wright Flyer. Recently, the canard configuration has regained popularity and is appearing on newer aircraft. Canard designs include two types—one with a horizontal surface of about the same size as a normal aft-tail

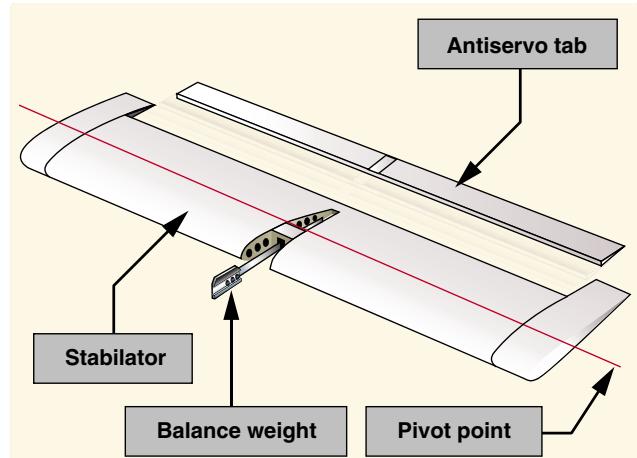


Figure 5-13. The stabilator is a one-piece horizontal tail surface that pivots up and down about a central hinge point.

design, and the other with a surface of the same approximate size and airfoil of the aft-mounted wing known as a tandem wing configuration. Theoretically, the canard is considered more efficient because using the horizontal surface to help lift the weight of the aircraft should result in less drag for a given amount of lift.

Rudder

The rudder controls movement of the aircraft about its vertical axis. This motion is called yaw. Like the other primary control surfaces, the rudder is a movable surface hinged to a fixed surface, in this case to the vertical stabilizer, or fin. Moving the left or right rudder pedal controls the rudder.

When the rudder is deflected into the airflow, a horizontal force is exerted in the opposite direction. [Figure 5-15] By pushing the left pedal, the rudder moves left. This alters the airflow around the vertical stabilizer/rudder, and creates a



Figure 5-14. The Piaggio P180 includes a variable-sweep canard design, which provides longitudinal stability about the lateral axis.

sideward lift that moves the tail to the right and yaws the nose of the airplane to the left. Rudder effectiveness increases with speed; therefore, large deflections at low speeds and small deflections at high speeds may be required to provide the desired reaction. In propeller-driven aircraft, any slipstream flowing over the rudder increases its effectiveness.

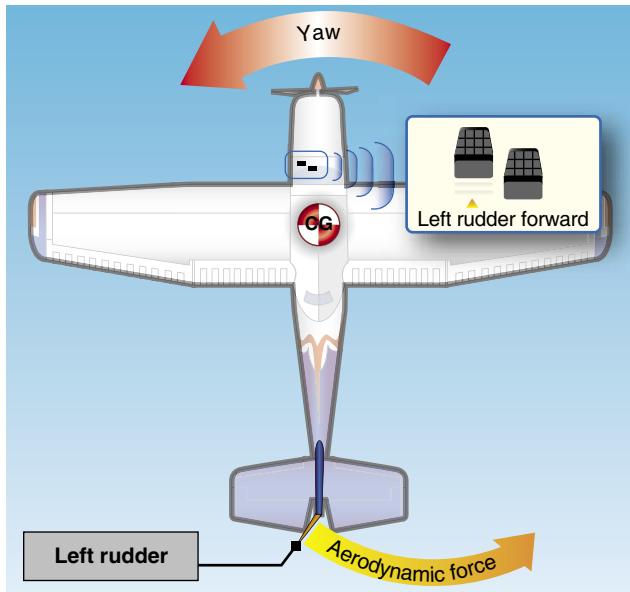


Figure 5-15. The effect of left rudder pressure.

V-Tail

The V-tail design utilizes two slanted tail surfaces to perform the same functions as the surfaces of a conventional elevator and rudder configuration. The fixed surfaces act as both horizontal and vertical stabilizers. [Figure 5-16]



Figure 5-16. Beechcraft Bonanza V35.

The movable surfaces, which are usually called ruddervators, are connected through a special linkage that allows the control wheel to move both surfaces simultaneously. On the other hand, displacement of the rudder pedals moves the surfaces differentially, thereby providing directional control.

When both rudder and elevator controls are moved by the pilot, a control mixing mechanism moves each surface the appropriate amount. The control system for the V-tail is more complex than that required for a conventional tail. In addition, the V-tail design is more susceptible to Dutch roll tendencies than a conventional tail, and total reduction in drag is minimal.

Secondary Flight Controls

Secondary flight control systems may consist of wing flaps, leading edge devices, spoilers, and trim systems.

Flaps

Flaps are the most common high-lift devices used on aircraft. These surfaces, which are attached to the trailing edge of the wing, increase both lift and induced drag for any given AOA. Flaps allow a compromise between high cruising speed and low landing speed, because they may be extended when needed, and retracted into the wing's structure when not needed. There are four common types of flaps: plain, split, slotted, and Fowler flaps. [Figure 5-17]

The plain flap is the simplest of the four types. It increases the airfoil camber, resulting in a significant increase in the coefficient of lift (C_L) at a given AOA. At the same time, it greatly increases drag and moves the center of pressure (CP) aft on the airfoil, resulting in a nose-down pitching moment.

The split flap is deflected from the lower surface of the airfoil and produces a slightly greater increase in lift than the plain flap. More drag is created because of the turbulent air pattern produced behind the airfoil. When fully extended, both plain and split flaps produce high drag with little additional lift.

The most popular flap on aircraft today is the slotted flap. Variations of this design are used for small aircraft, as well as for large ones. Slotted flaps increase the lift coefficient significantly more than plain or split flaps. On small aircraft, the hinge is located below the lower surface of the flap, and when the flap is lowered, a duct forms between the flap well in the wing and the leading edge of the flap. When the slotted flap is lowered, high energy air from the lower surface is ducted to the flap's upper surface. The high energy air from the slot accelerates the upper surface boundary layer and delays airflow separation, providing a higher C_L . Thus, the slotted flap produces much greater increases in maximum coefficient of lift (C_{L-MAX}) than the plain or split flap. While there are many types of slotted flaps, large aircraft often have double- and even triple-slotted flaps. These allow the maximum increase in drag without the airflow over the flaps separating and destroying the lift they produce.

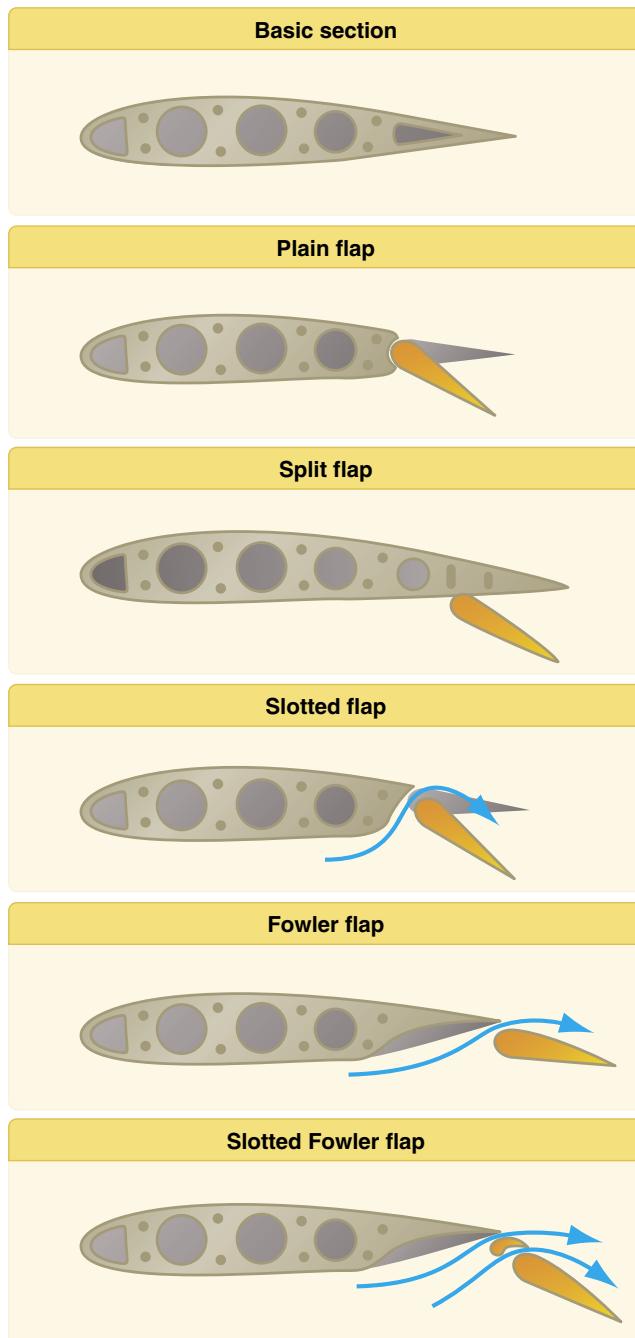


Figure 5-17. Five common types of flaps.

Fowler flaps are a type of slotted flap. This flap design not only changes the camber of the wing, it also increases the wing area. Instead of rotating down on a hinge, it slides backwards on tracks. In the first portion of its extension, it increases the drag very little, but increases the lift a great deal as it increases both the area and camber. As the extension continues, the flap deflects downward. During the last portion of its travel, the flap increases the drag with little additional increase in lift.

Leading Edge Devices

High-lift devices also can be applied to the leading edge of the airfoil. The most common types are fixed slots, movable slats, leading edge flaps, and cuffs. [Figure 5-18]

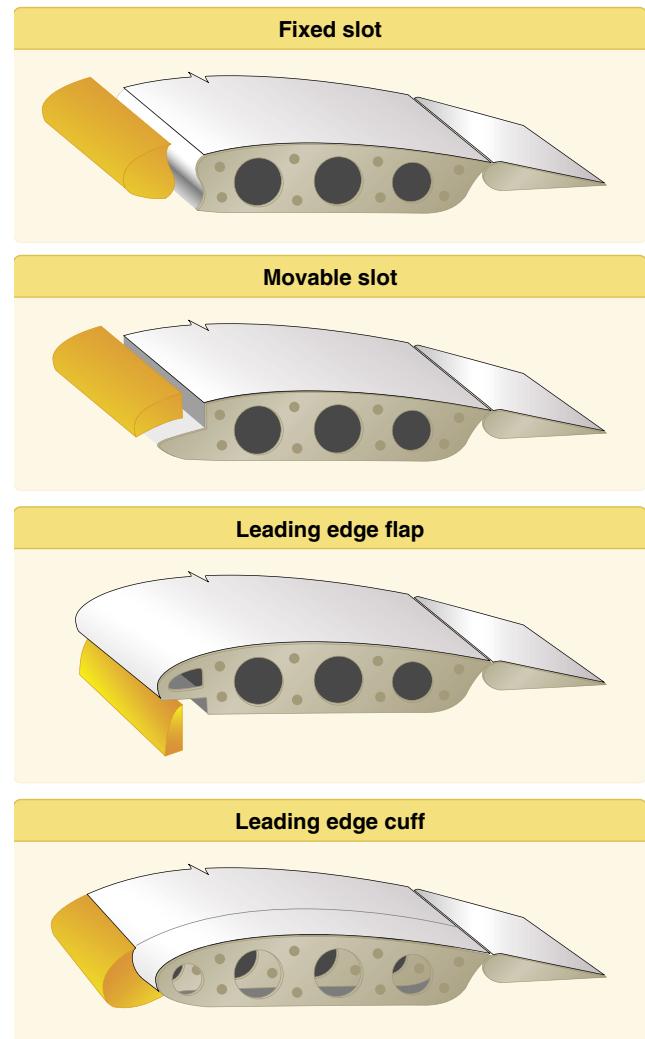


Figure 5-18. Leading edge high lift devices.

Fixed slots direct airflow to the upper wing surface and delay airflow separation at higher angles of attack. The slot does not increase the wing camber, but allows a higher maximum C_L because the stall is delayed until the wing reaches a greater AOA.

Movable slats consist of leading edge segments, which move on tracks. At low angles of attack, each slat is held flush against the wing's leading edge by the high pressure that forms at the wing's leading edge. As the AOA increases, the high-pressure area moves aft below the lower surface of the wing, allowing the slats to move forward. Some slats, however, are

pilot operated and can be deployed at any AOA. Opening a slat allows the air below the wing to flow over the wing's upper surface, delaying airflow separation.

Leading edge flaps, like trailing edge flaps, are used to increase both C_{L-MAX} and the camber of the wings. This type of leading edge device is frequently used in conjunction with trailing edge flaps and can reduce the nose-down pitching movement produced by the latter. As is true with trailing edge flaps, a small increment of leading edge flaps increases lift to a much greater extent than drag. As greater amounts of flaps are extended, drag increases at a greater rate than lift.

Leading edge cuffs, like leading edge flaps and trailing edge flaps are used to increase both C_{L-MAX} and the camber of the wings. Unlike leading edge flaps and trailing edge flaps, leading edge cuffs are fixed aerodynamic devices. In most cases leading edge cuffs extend the leading edge down and forward. This causes the airflow to attach better to the upper surface of the wing at higher angles of attack, thus lowering an aircraft's stall speed. The fixed nature of leading edge cuffs extracts a penalty in maximum cruise airspeed, but recent advances in design and technology have reduced this penalty.

Spoilers

Found on many gliders and some aircraft, high drag devices called spoilers are deployed from the wings to spoil the smooth airflow, reducing lift and increasing drag. On gliders, spoilers are most often used to control rate of descent for accurate landings. On other aircraft, spoilers are often used for roll control, an advantage of which is the elimination of adverse yaw. To turn right, for example, the spoiler on the right wing is raised, destroying some of the lift and creating more drag on the right. The right wing drops, and the aircraft banks and yaws to the right. Deploying spoilers on both wings at the same time allows the aircraft to descend without gaining speed. Spoilers are also deployed to help reduce ground roll after landing. By destroying lift, they transfer weight to the wheels, improving braking effectiveness. [Figure 5-19]

Trim Systems

Although an aircraft can be operated throughout a wide range of attitudes, airspeeds, and power settings, it can be designed to fly hands-off within only a very limited combination of these variables. Trim systems are used to relieve the pilot of the need to maintain constant pressure on the flight controls, and usually consist of flight deck controls and small hinged devices attached to the trailing edge of one or more of the primary flight control surfaces. Designed to help minimize a pilot's workload, trim systems aerodynamically assist movement and position of the flight control surface to which they are attached. Common types of trim systems include trim



Figure 5-19. Spoilers reduce lift and increase drag during descent and landing.

tabs, balance tabs, antiservo tabs, ground adjustable tabs, and an adjustable stabilizer.

Trim Tabs

The most common installation on small aircraft is a single trim tab attached to the trailing edge of the elevator. Most trim tabs are manually operated by a small, vertically mounted control wheel. However, a trim crank may be found in some aircraft. The flight deck control includes a trim tab position indicator. Placing the trim control in the full nose-down position moves the trim tab to its full up position. With the trim tab up and into the airstream, the airflow over the horizontal tail surface tends to force the trailing edge of the elevator down. This causes the tail of the airplane to move up, and the nose to move down. [Figure 5-20]

If the trim tab is set to the full nose-up position, the tab moves to its full down position. In this case, the air flowing under the horizontal tail surface hits the tab and forces the trailing edge of the elevator up, reducing the elevator's AOA. This causes the tail of the airplane to move down, and the nose to move up.

In spite of the opposing directional movement of the trim tab and the elevator, control of trim is natural to a pilot. If the pilot needs to exert constant back pressure on a control column, the need for nose-up trim is indicated. The normal trim procedure is to continue trimming until the aircraft is balanced and the nose-heavy condition is no longer apparent. Pilots normally establish the desired power, pitch attitude, and configuration first, and then trim the aircraft to relieve control pressures that may exist for that flight condition. Any time power, pitch attitude, or configuration is changed, expect that retrimming will be necessary to relieve the control pressures for the new flight condition.

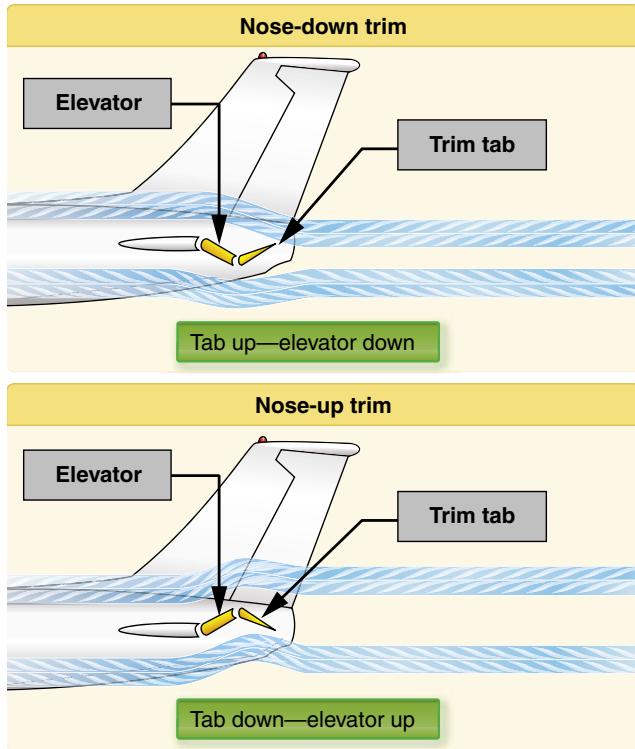


Figure 5-20. The movement of the elevator is opposite to the direction of movement of the elevator trim tab.

Balance Tabs

The control forces may be excessively high in some aircraft, and, in order to decrease them, the manufacturer may use balance tabs. They look like trim tabs and are hinged in approximately the same places as trim tabs. The essential difference between the two is that the balancing tab is coupled to the control surface rod so that when the primary control surface is moved in any direction, the tab automatically moves in the opposite direction. The airflow striking the tab counterbalances some of the air pressure against the primary control surface, and enables the pilot to move more easily and hold the control surface in position.

If the linkage between the balance tab and the fixed surface is adjustable from the flight deck, the tab acts as a combination trim and balance tab that can be adjusted to any desired deflection.

Antiservo Tabs

Antiservo tabs work in the same manner as balance tabs except, instead of moving in the opposite direction, they move in the same direction as the trailing edge of the stabilator. In addition to decreasing the sensitivity of the stabilator, an antiservo tab also functions as a trim device to relieve control pressure and maintain the stabilator in the desired position. The fixed end of the linkage is on the opposite side of the surface from the horn on the tab; when the trailing edge of the

stabilator moves up, the linkage forces the trailing edge of the tab up. When the stabilator moves down, the tab also moves down. Conversely, trim tabs on elevators move opposite of the control surface. [Figure 5-21]

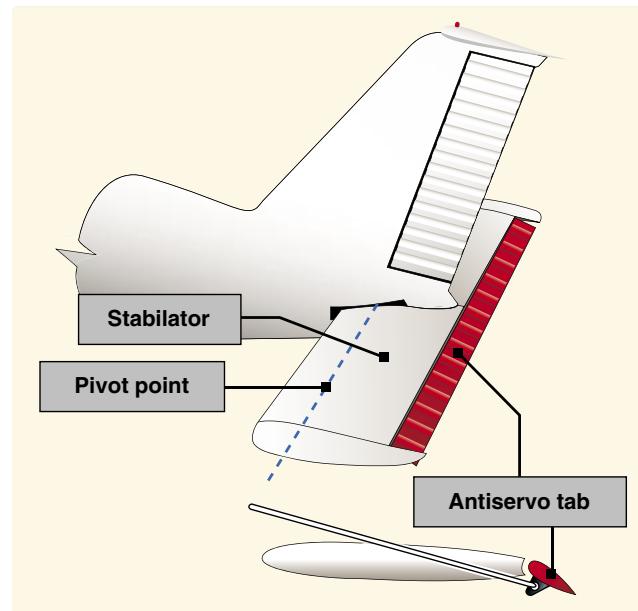


Figure 5-21. An antiservo tab attempts to streamline the control surface and is used to make the stabilator less sensitive by opposing the force exerted by the pilot.

Ground Adjustable Tabs

Many small aircraft have a nonmovable metal trim tab on the rudder. This tab is bent in one direction or the other while on the ground to apply a trim force to the rudder. The correct displacement is determined by trial and error. Usually, small adjustments are necessary until the aircraft no longer skids left or right during normal cruising flight. [Figure 5-22]



Figure 5-22. A ground adjustable tab is used on the rudder of many small airplanes to correct for a tendency to fly with the fuselage slightly misaligned with the relative wind.

Adjustable Stabilizer

Rather than using a movable tab on the trailing edge of the elevator, some aircraft have an adjustable stabilizer. With this arrangement, linkages pivot the horizontal stabilizer about its rear spar. This is accomplished by use of a jackscrew mounted on the leading edge of the stabilator. [Figure 5-23]

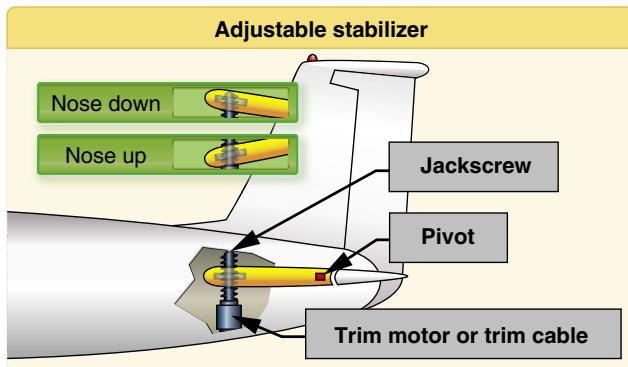


Figure 5-23. Some airplanes, including most jet transports, use an adjustable stabilizer to provide the required pitch trim forces.

On small aircraft, the jackscrew is cable operated with a trim wheel or crank. On larger aircraft, it is motor driven. The trimming effect and flight deck indications for an adjustable stabilizer are similar to those of a trim tab.

Autopilot

Autopilot is an automatic flight control system that keeps an aircraft in level flight or on a set course. It can be directed by the pilot, or it may be coupled to a radio navigation signal. Autopilot reduces the physical and mental demands on a pilot and increases safety. The common features available on an autopilot are altitude and heading hold.

The simplest systems use gyroscopic attitude indicators and magnetic compasses to control servos connected to the flight control system. [Figure 5-24] The number and location of these servos depends on the complexity of the system. For example, a single-axis autopilot controls the aircraft about the longitudinal axis and a servo actuates the ailerons. A three-axis autopilot controls the aircraft about the longitudinal, lateral, and vertical axes. Three different servos actuate ailerons, elevator, and rudder. More advanced systems often include a vertical speed and/or indicated airspeed hold mode. Advanced autopilot systems are coupled to navigational aids through a flight director.

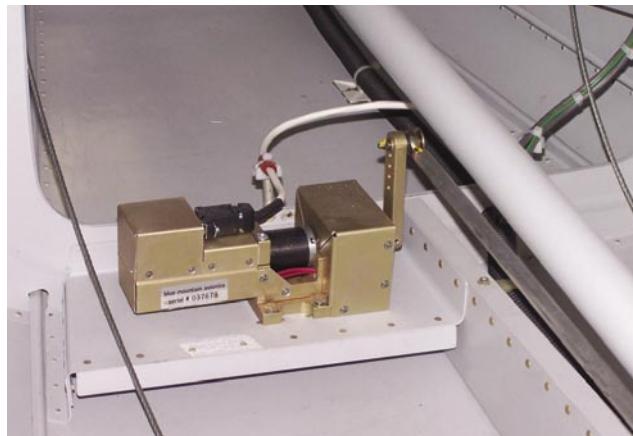


Figure 5-24. Basic autopilot system integrated into the flight control system.

The autopilot system also incorporates a disconnect safety feature to disengage the system automatically or manually. These autopilots work with inertial navigation systems, global positioning systems (GPS), and flight computers to control the aircraft. In fly-by-wire systems, the autopilot is an integrated component.

Additionally, autopilots can be manually overridden. Because autopilot systems differ widely in their operation, refer to the autopilot operating instructions in the Airplane Flight Manual (AFM) or the Pilot's Operating Handbook (POH).

Chapter Summary

Because flight control systems and aerodynamic characteristics vary greatly between aircraft, it is essential that a pilot become familiar with the primary and secondary flight control systems of the aircraft being flown. The primary source of this information is the AFM or the POH. Various manufacturer and owner group websites can also be a valuable source of additional information.

Chapter 6

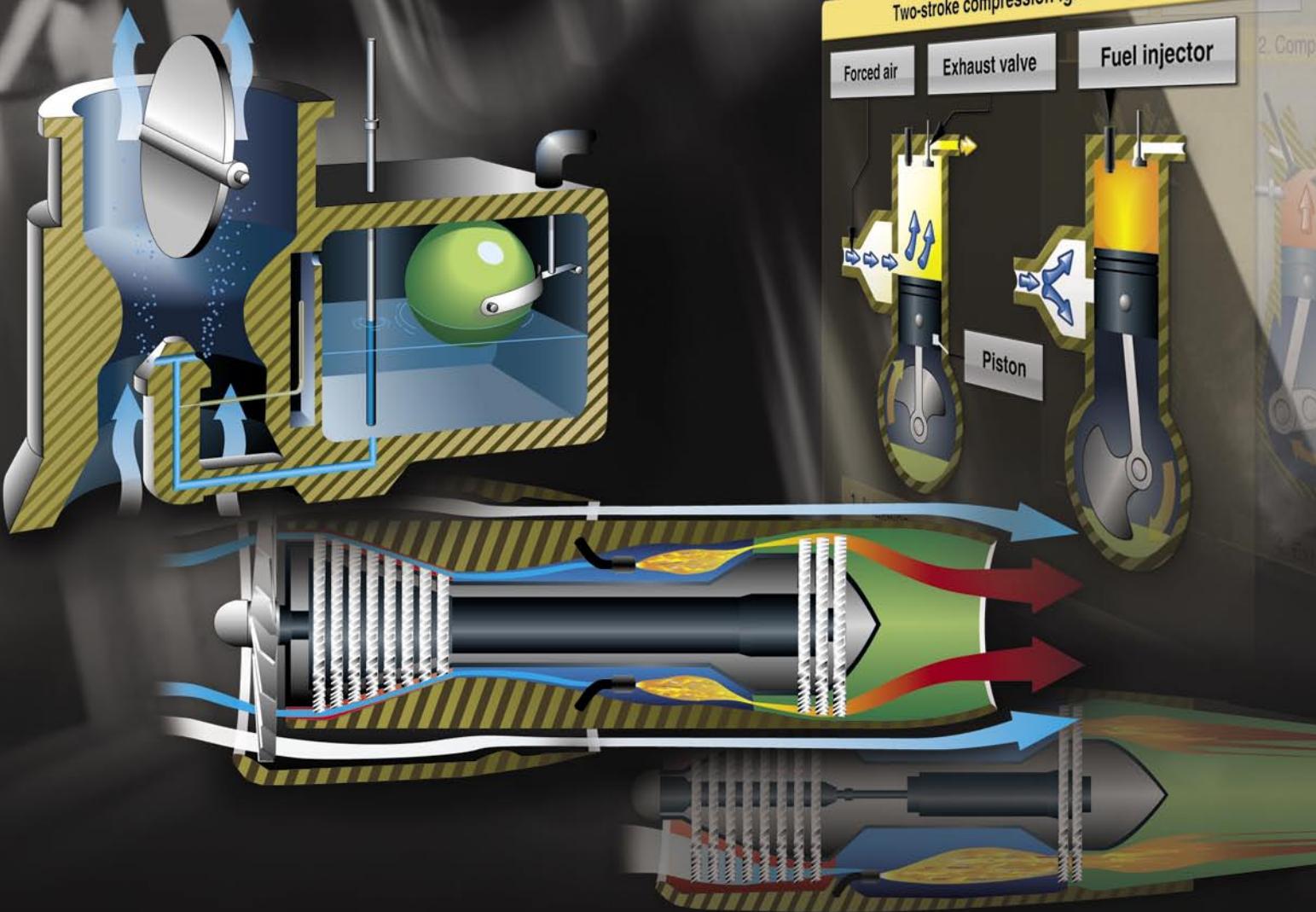
Aircraft Systems

Introduction

This chapter covers the primary systems found on most aircraft. These include the engine, propeller, induction, ignition, as well as the fuel, lubrication, cooling, electrical, landing gear, and environmental control systems.

Powerplant

An aircraft engine, or powerplant, produces thrust to propel an aircraft. Reciprocating engines and turboprop engines work in combination with a propeller to produce thrust. Turbojet and turbofan engines produce thrust by increasing the velocity of air flowing through the engine. All of these powerplants also drive the various systems that support the operation of an aircraft.



Reciprocating Engines

Most small aircraft are designed with reciprocating engines. The name is derived from the back-and-forth, or reciprocating, movement of the pistons which produces the mechanical energy necessary to accomplish work.

Driven by a revitalization of the general aviation (GA) industry and advances in both material and engine design, reciprocating engine technology has improved dramatically over the past two decades. The integration of computerized engine management systems has improved fuel efficiency, decreased emissions, and reduced pilot workload.

Reciprocating engines operate on the basic principle of converting chemical energy (fuel) into mechanical energy. This conversion occurs within the cylinders of the engine through the process of combustion. The two primary reciprocating engine designs are the spark ignition and the compression ignition. The spark ignition reciprocating engine has served as the powerplant of choice for many years. In an effort to reduce operating costs, simplify design, and improve reliability, several engine manufacturers are turning to compression ignition as a viable alternative. Often referred to as jet fuel piston engines, compression ignition engines have the added advantage of utilizing readily available and lower cost diesel or jet fuel.

The main mechanical components of the spark ignition and the compression ignition engine are essentially the same. Both use cylindrical combustion chambers and pistons that travel the length of the cylinders to convert linear motion into the rotary motion of the crankshaft. The main difference between spark ignition and compression ignition is the process of igniting the fuel. Spark ignition engines use a spark plug to ignite a pre-mixed fuel/air mixture. (Fuel/air mixture is the ratio of the “weight” of fuel to the “weight” of air in the mixture to be burned.) A compression ignition engine first compresses the air in the cylinder, raising its temperature to a degree necessary for automatic ignition when fuel is injected into the cylinder.

These two engine designs can be further classified as:

1. Cylinder arrangement with respect to the crankshaft—radial, in-line, v-type, or opposed.
2. Operating cycle—two or four.
3. Method of cooling—liquid or air.

Radial engines were widely used during World War II and many are still in service today. With these engines, a row or rows of cylinders are arranged in a circular pattern around the crankcase. The main advantage of a radial engine is the favorable power-to-weight ratio. [Figure 6-1]

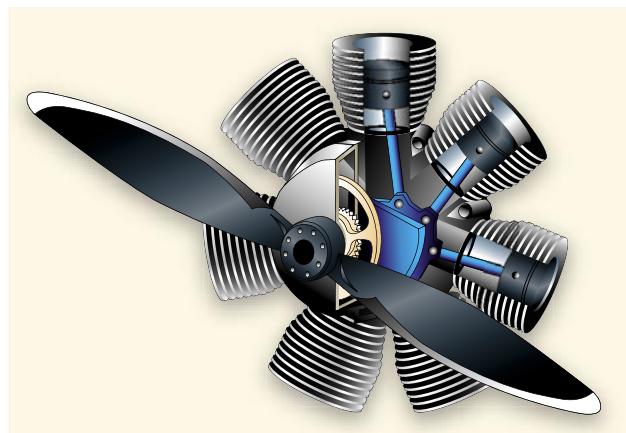


Figure 6-1. Radial engine.

In-line engines have a comparatively small frontal area, but their power-to-weight ratios are relatively low. In addition, the rearmost cylinders of an air-cooled, in-line engine receive very little cooling air, so these engines are normally limited to four or six cylinders. V-type engines provide more horsepower than in-line engines and still retain a small frontal area.

Continued improvements in engine design led to the development of the horizontally-opposed engine which remains the most popular reciprocating engines used on smaller aircraft. These engines always have an even number of cylinders, since a cylinder on one side of the crankcase “opposes” a cylinder on the other side. [Figure 6-2] The majority of these engines are air cooled and usually are mounted in a horizontal position when installed on fixed-wing airplanes. Opposed-type engines have high power-to-weight ratios because they have a comparatively small, lightweight crankcase. In addition, the compact cylinder arrangement reduces the engine’s frontal area and allows a streamlined installation that minimizes aerodynamic drag.

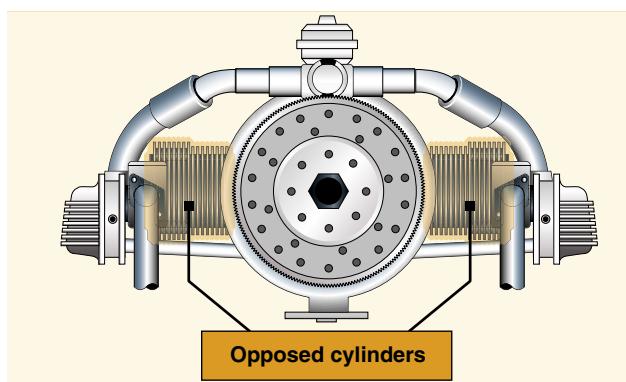


Figure 6-2. Horizontally opposed engine.

Depending on the engine manufacturer, all of these arrangements can be designed to utilize spark or compression ignition, and operate on either a two- or four-stroke cycle.

In a two-stroke engine, the conversion of chemical energy into mechanical energy occurs over a two-stroke operating cycle. The intake, compression, power, and exhaust processes occur in only two strokes of the piston rather than the more common four strokes. Because a two-stroke engine has a power stroke each revolution of the crankshaft, it typically has higher power-to-weight ratio than a comparable four-stroke engine. Due to the inherent inefficiency and disproportionate emissions of the earliest designs, use of the two-stroke engine has been limited in aviation.

Recent advances in material and engine design have reduced many of the negative characteristics associated with two-stroke engines. Modern two-stroke engines often use conventional oil sumps, oil pumps and full pressure fed lubrication systems. The use of direct fuel injection and pressurized air, characteristic of advanced compression ignition engines, make two-stroke compression ignition engines a viable alternative to the more common four-stroke spark ignition designs. [Figure 6-3]

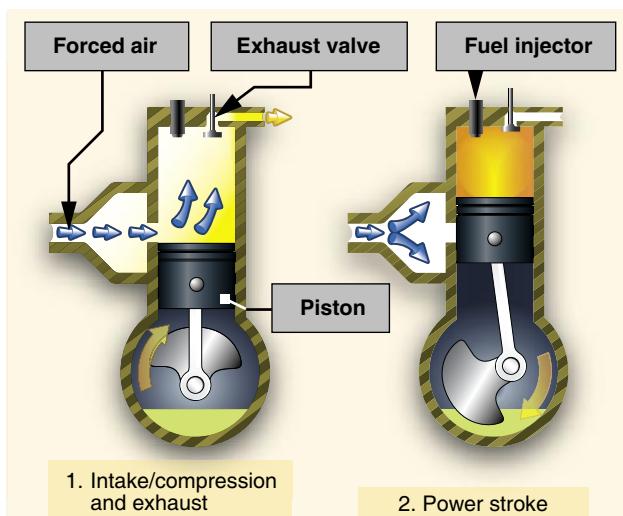


Figure 6-3. Two-stroke compression ignition.

Spark ignition four-stroke engines remain the most common design used in general aviation today. [Figure 6-4] The main parts of a spark ignition reciprocating engine include the cylinders, crankcase, and accessory housing. The intake/exhaust valves, spark plugs, and pistons are located in the cylinders. The crankshaft and connecting rods are located in the crankcase. The magnetos are normally located on the engine accessory housing.

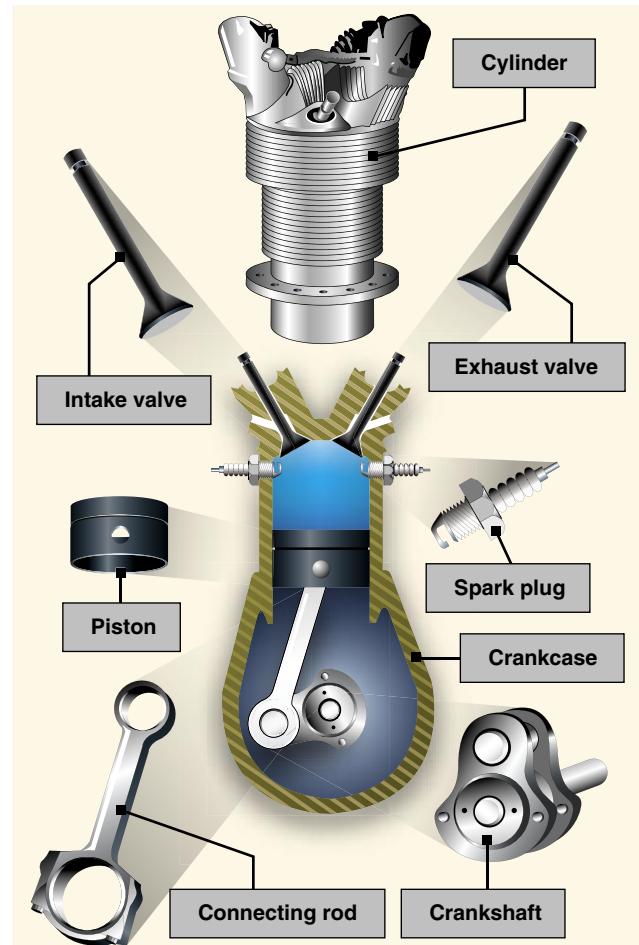


Figure 6-4. Main components of a spark ignition reciprocating engine.

In a four-stroke engine the conversion of chemical energy into mechanical energy occurs over a four stroke operating cycle. The intake, compression, power, and exhaust processes occur in four separate strokes of the piston.

1. The intake stroke begins as the piston starts its downward travel. When this happens, the intake valve opens and the fuel/air mixture is drawn into the cylinder.
2. The compression stroke begins when the intake valve closes and the piston starts moving back to the top of the cylinder. This phase of the cycle is used to obtain a much greater power output from the fuel/air mixture once it is ignited.
3. The power stroke begins when the fuel/air mixture is ignited. This causes a tremendous pressure increase in the cylinder, and forces the piston downward away from the cylinder head, creating the power that turns the crankshaft.

- The exhaust stroke is used to purge the cylinder of burned gases. It begins when the exhaust valve opens and the piston starts to move toward the cylinder head once again.

Even when the engine is operated at a fairly low speed, the four-stroke cycle takes place several hundred times each minute. [Figure 6-5] 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. Continuous operation of the engine depends on the simultaneous function of auxiliary systems, including the induction, ignition, fuel, oil, cooling, and exhaust systems.

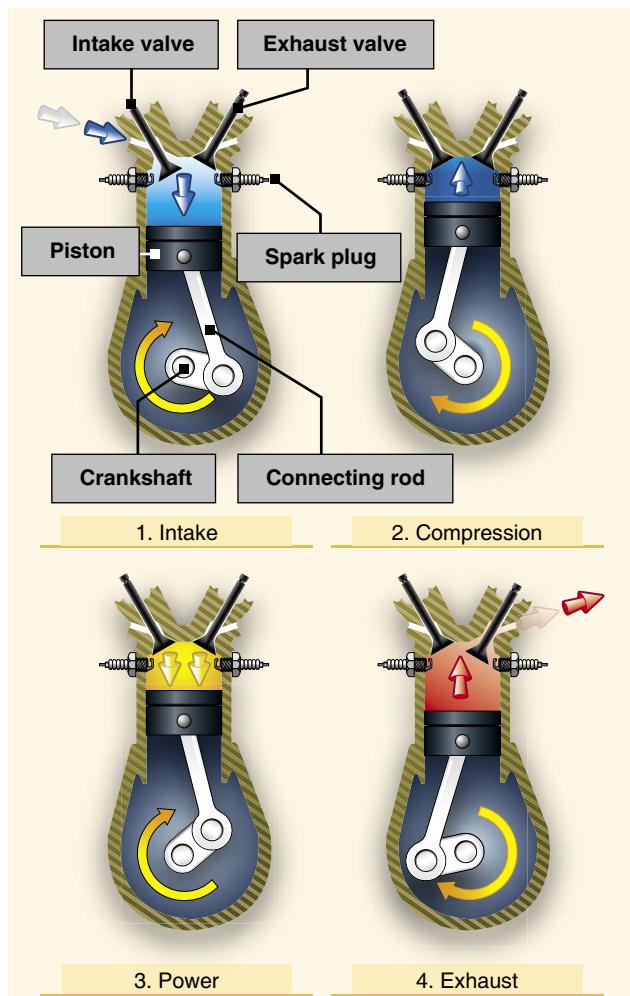


Figure 6-5. The arrows in this illustration indicate the direction of motion of the crankshaft and piston during the four-stroke cycle.

The latest advance in aircraft reciprocating engines was pioneered in the mid-1960s by Frank Thielert, who looked to the automotive industry for answers on how to integrate diesel technology into an aircraft engine. The advantage

of a diesel-fueled reciprocating engine lies in the physical similarity of diesel and kerosene. Aircraft equipped with a diesel piston engine runs on standard aviation fuel kerosene which provides more independence, higher reliability, lower consumption, and operational cost saving.

In 1999, Thielert formed Thielert Aircraft Engines (TAE) to design, develop, certify, and manufacture a brand-new Jet-A-burning diesel cycle engine (also known as jet-fueled piston engine) for the GA industry. By March 2001, the first prototype engine became the first certified diesel engine since World War II. TAE continues to design and develop diesel cycle engines and other engine manufacturers such as Société de Motorisations Aéronautiques (SMA) now offer jet-fueled piston engines as well. TAE engines can be found on the Diamond DA40 single and the DA42 Twin Star, the first diesel engine to be part of the type certificate of a new original equipment manufacturer (OEM) aircraft.

These engines have also gained a toehold in the retrofit market with a supplemental type certificate (STC) to re-engine the Cessna 172 models and the Piper PA-28 family. The jet-fueled piston engines technology has continued to progress and a full authority digital engine control (FADEC, discussed more fully later in the chapter) is standard on such equipped aircraft which minimizes complication of engine control. By 2007, various jet-fueled piston aircraft had logged well over 600,000 hours of service.

Propeller

The propeller is a rotating airfoil, subject to induced drag, stalls, and other aerodynamic principles that apply to any airfoil. It provides the necessary thrust to pull, or in some cases push, the aircraft through the air. The engine power is used to rotate the propeller, which in turn generates thrust very similar to the manner in which a wing produces lift. The amount of thrust produced depends on the shape of the airfoil, the angle of attack of the propeller blade, and the revolutions per minute (rpm) of the engine. The propeller itself is twisted so the blade angle changes from hub to tip. The greatest angle of incidence, or the highest pitch, is at the hub while the smallest angle of incidence or smallest pitch is at the tip. [Figure 6-6]

The reason for the twist is to produce uniform lift from the hub to the tip. As the blade rotates, there is a difference in the actual speed of the various portions of the blade. The tip of the blade travels faster than the part near the hub, because the tip travels a greater distance than the hub in the same length of time. [Figure 6-7] Changing the angle of incidence (pitch) from the hub to the tip to correspond with the speed produces uniform lift throughout the length of the blade. A

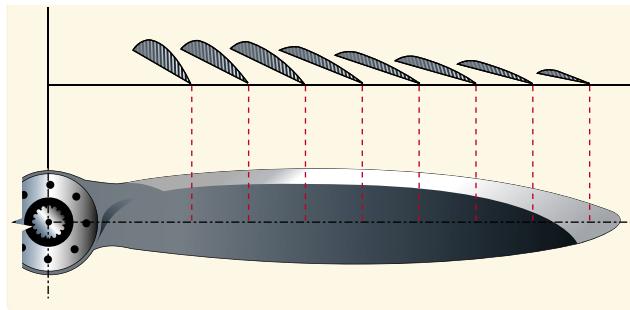


Figure 6-6. Changes in propeller blade angle from hub to tip.

propeller blade designed with the same angle of incidence throughout its entire length would be inefficient because as airspeed increases in flight, the portion near the hub would have a negative angle of attack while the blade tip would be stalled.

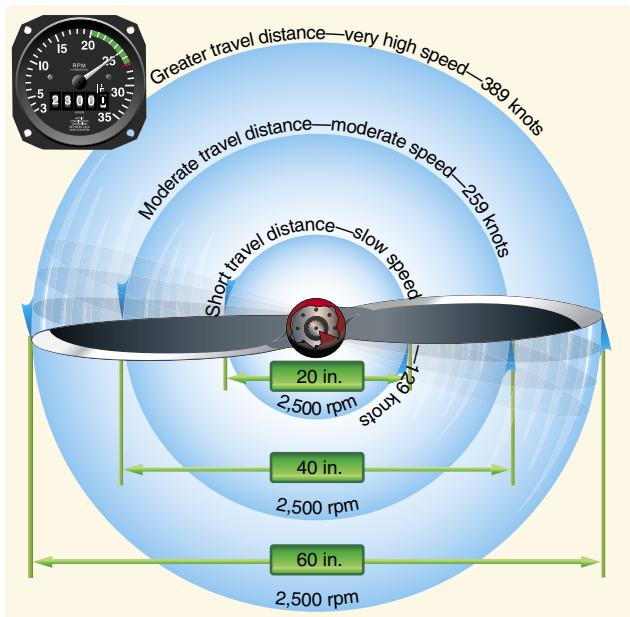


Figure 6-7. Relationship of travel distance and speed of various portions of propeller blade.

Small aircraft are equipped with either one of two types of propellers. One is the fixed pitch, and the other is the adjustable pitch.

Fixed-Pitch Propeller

A propeller with fixed blade angles is a fixed-pitch propeller. The pitch of this propeller is set by the manufacturer and cannot be changed. Since a fixed-pitch propeller achieves the best efficiency only at a given combination of airspeed and rpm, the pitch setting is ideal for neither cruise nor climb. Thus, the aircraft suffers a bit in each performance category. The fixed-pitch propeller is used when low weight, simplicity, and low cost are needed.

There are two types of fixed-pitch propellers: climb and cruise. Whether the airplane has a climb or cruise propeller installed depends upon its intended use. The climb propeller has a lower pitch, therefore less drag. Less drag results in higher rpm and more horsepower capability, which increases performance during takeoffs and climbs, but decreases performance during cruising flight.

The cruise propeller has a higher pitch, therefore more drag. More drag results in lower rpm and less horsepower capability, which decreases performance during takeoffs and climbs, but increases efficiency during cruising flight.

The propeller is usually mounted on a shaft, which may be an extension of the engine crankshaft. In this case, the rpm of the propeller would be the same as the crankshaft rpm. On some engines, the propeller is mounted on a shaft geared to the engine crankshaft. In this type, the rpm of the propeller is different than that of the engine.

In a fixed-pitch propeller, the tachometer is the indicator of engine power. [Figure 6-8] A tachometer is calibrated in hundreds of rpm and gives a direct indication of the engine and propeller rpm. The instrument is color coded, with a green arc denoting the maximum continuous operating rpm. Some tachometers have additional markings to reflect engine and/or propeller limitations. The manufacturer's recommendations should be used as a reference to clarify any misunderstanding of tachometer markings.



Figure 6-8. Engine rpm is indicated on the tachometer.

The rpm is regulated by the throttle, which controls the fuel/air flow to the engine. At a given altitude, the higher the tachometer reading, the higher the power output of the engine.

When operating altitude increases, the tachometer may not show correct power output of the engine. For example, 2,300

rpm at 5,000 feet produces less horsepower than 2,300 rpm at sea level because power output depends on air density. Air density decreases as altitude increases and a decrease in air density (higher density altitude) decreases the power output of the engine. As altitude changes, the position of the throttle must be changed to maintain the same rpm. As altitude is increased, the throttle must be opened further to indicate the same rpm as at a lower altitude.

Adjustable-Pitch Propeller

The adjustable-pitch propeller was the forerunner of the constant-speed propeller. It is a propeller with blades whose pitch can be adjusted on the ground with the engine not running, but which cannot be adjusted in flight. It is also referred to as a ground adjustable propeller. By the 1930s, pioneer aviation inventors were laying the ground work for automatic pitch-change mechanisms, which is why the term sometimes refers to modern constant-speed propellers that are adjustable in flight.

The first adjustable-pitch propeller systems provided only two pitch settings: low and high. Today, most adjustable-pitch propeller systems are capable of a range of pitch settings.

A constant-speed propeller is a controllable-pitch propeller whose pitch is automatically varied in flight by a governor maintaining constant rpm despite varying air loads. It is the most common type of adjustable-pitch propeller. The main advantage of a constant-speed propeller is that it converts a high percentage of brake horsepower (BHP) into thrust horsepower (THP) over a wide range of rpm and airspeed combinations. A constant-speed propeller is more efficient than other propellers because it allows selection of the most efficient engine rpm for the given conditions.

An aircraft with a constant-speed propeller has two controls: the throttle and the propeller control. The throttle controls power output and the propeller control regulates engine rpm. This in turn regulates propeller rpm which is registered on the tachometer.

Once a specific rpm is selected, a governor automatically adjusts the propeller blade angle as necessary to maintain the selected rpm. For example, after setting the desired rpm during cruising flight, an increase in airspeed or decrease in propeller load will cause the propeller blade angle to increase as necessary to maintain the selected rpm. A reduction in airspeed or increase in propeller load will cause the propeller blade angle to decrease.

The propeller's constant-speed range, defined by the high and low pitch stops, is the range of possible blade angles for a constant-speed propeller. As long as the propeller blade

angle is within the constant-speed range and not against either pitch stop, a constant engine rpm will be maintained. If the propeller blades contact a pitch stop, the engine rpm will increase or decrease as appropriate, with changes in airspeed and propeller load. For example, once a specific rpm has been selected, if aircraft speed decreases enough to rotate the propeller blades until they contact the low pitch stop, any further decrease in airspeed will cause engine rpm to decrease the same way as if a fixed-pitch propeller were installed. The same holds true when an aircraft equipped with a constant-speed propeller accelerates to a faster airspeed. As the aircraft accelerates, the propeller blade angle increases to maintain the selected rpm until the high pitch stop is reached. Once this occurs, the blade angle cannot increase any further and engine rpm increases.

On aircraft equipped with a constant-speed propeller, power output is controlled by the throttle and indicated by a manifold pressure gauge. The gauge measures the absolute pressure of the fuel/air mixture inside the intake manifold and is more correctly a measure of manifold absolute pressure (MAP). At a constant rpm and altitude, the amount of power produced is directly related to the fuel/air flow being delivered to the combustion chamber. As the throttle setting is increased, more fuel and air flows to the engine and MAP increases. When the engine is not running, the manifold pressure gauge indicates ambient air pressure (i.e., 29.92 inches mercury (29.92 "Hg)). When the engine is started, the manifold pressure indication will decrease to a value less than ambient pressure (i.e., idle at 12 "Hg). Engine failure or power loss is indicated on the manifold gauge as an increase in manifold pressure to a value corresponding to the ambient air pressure at the altitude where the failure occurred. [Figure 6-9]



Figure 6-9. Engine power output is indicated on the manifold pressure gauge.

The manifold pressure gauge is color coded to indicate the engine's operating range. The face of the manifold pressure gauge contains a green arc to show the normal operating range, and a red radial line to indicate the upper limit of manifold pressure.

For any given rpm, there is a manifold pressure that should not be exceeded. If manifold pressure is excessive for a given rpm, the pressure within the cylinders could be exceeded, placing undue stress on the cylinders. If repeated too frequently, this stress can weaken the cylinder components and eventually cause engine failure. As a general rule, manifold pressure (inches) should be less than the rpm.

A pilot can avoid conditions that overstress the cylinders by being constantly aware of the rpm, especially when increasing the manifold pressure. Conform to the manufacturer's recommendations for power settings of a particular engine to maintain the proper relationship between manifold pressure and rpm.

When both manifold pressure and rpm need to be changed, avoid engine overstress by making power adjustments in the proper order:

- When power settings are being decreased, reduce manifold pressure before reducing rpm. If rpm is reduced before manifold pressure, manifold pressure will automatically increase, possibly exceeding the manufacturer's tolerances.
- When power settings are being increased, reverse the order—increase rpm first, then manifold pressure.
- To prevent damage to radial engines, minimize operating time at maximum rpm and manifold pressure, and avoid operation at maximum rpm and low manifold pressure.

The engine and/or airframe manufacturer's recommendations should be followed to prevent severe wear, fatigue, and damage to high-performance reciprocating engines.

Induction Systems

The induction system brings in air from the outside, mixes it with fuel, and delivers the fuel/air mixture to the cylinder where combustion occurs. Outside air enters the induction system through an intake port on the front of the engine cowling. This port normally contains an air filter that inhibits the entry of dust and other foreign objects. Since the filter may occasionally become clogged, an alternate source of air must be available. Usually, the alternate air comes from inside the engine cowling, where it bypasses a clogged air filter. Some alternate air sources function automatically, while others operate manually.

Two types of induction systems are commonly used in small aircraft engines:

1. The carburetor system, which mixes the fuel and air in the carburetor before this mixture enters the intake manifold
2. The fuel injection system, which mixes the fuel and air immediately before entry into each cylinder or injects fuel directly into each cylinder

Carburetor Systems

Carburetors are classified as either float type or pressure type. The float type of carburetor, complete with idling, accelerating, mixture control, idle cutoff, and power enrichment systems is probably the most common of all carburetor types. Pressure carburetors are usually not found on small aircraft. The basic difference between a float-type and a pressure-type carburetor is the delivery of fuel. The pressure-type carburetor delivers fuel under pressure by a fuel pump.

In the operation of the float-type carburetor system, the outside air first flows through an air filter, usually located at an air intake in the front part of the engine cowling. This filtered air flows into the carburetor and through a venturi, a narrow throat in the carburetor. When the air flows through the venturi, a low-pressure area is created, which forces the fuel to flow through a main fuel jet located at the throat. The fuel then flows into the airstream where it is mixed with the flowing air. [Figure 6-10]

The fuel/air mixture is then drawn through the intake manifold and into the combustion chambers where it is ignited. The float-type carburetor acquires its name from a float, which rests on fuel within the float chamber. A needle attached to the float opens and closes an opening at the bottom of the carburetor bowl. This meters the correct amount of fuel into the carburetor, depending upon the position of the float, which is controlled by the level of fuel in the float chamber. When the level of the fuel forces the float to rise, the needle valve closes the fuel opening and shuts off the fuel flow to the carburetor. The needle valve opens again when the engine requires additional fuel. The flow of the fuel/air mixture to the combustion chambers is regulated by the throttle valve, which is controlled by the throttle in the flight deck.

The float-type carburetor has several distinct disadvantages. In the first place, imagine the effect that abrupt maneuvers have on the float action. In the second place, the fact that its fuel must be discharged at low pressure leads to incomplete vaporization and difficulty in discharging fuel into some types of supercharged systems. The chief disadvantage of the float carburetor, however, is its icing tendency. Since the float carburetor must discharge fuel at a point of low

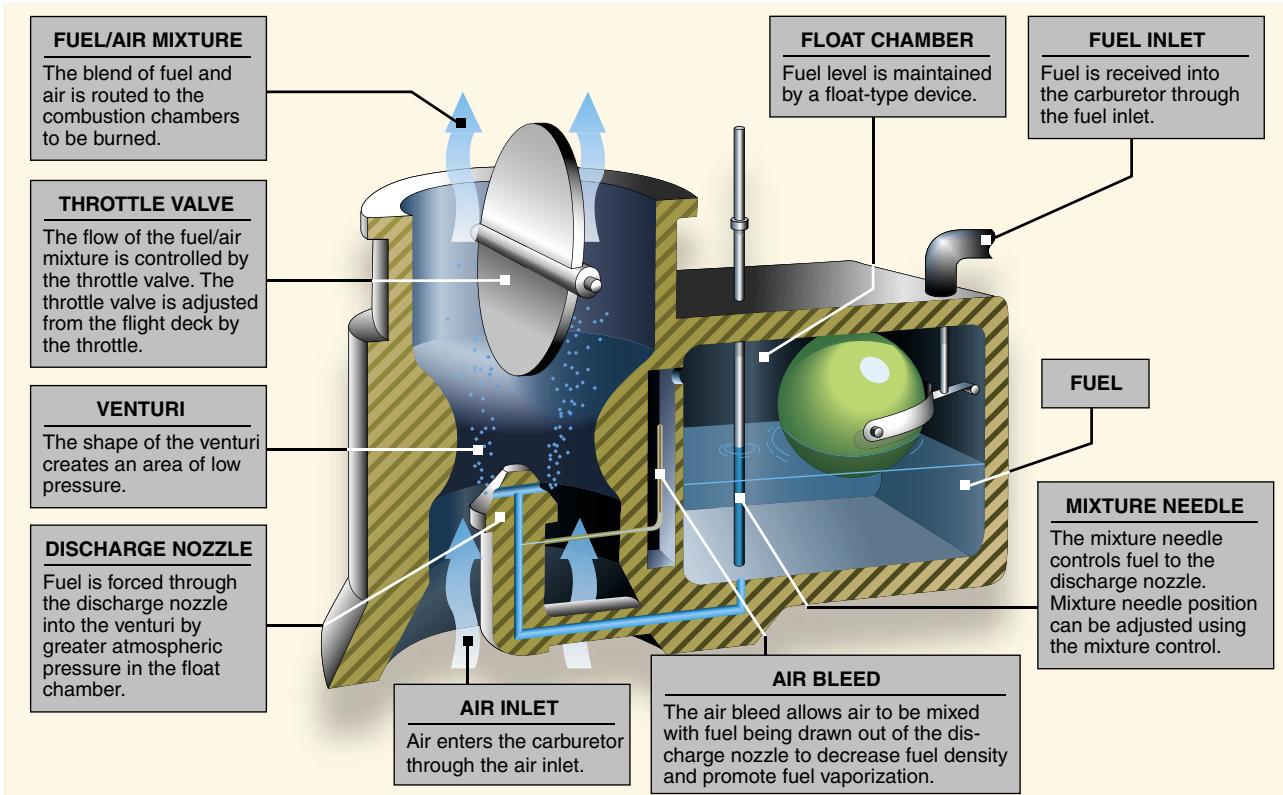


Figure 6-10. Float-type carburetor.

pressure, the discharge nozzle must be located at the venturi throat, and the throttle valve must be on the engine side of the discharge nozzle. This means the drop in temperature due to fuel vaporization takes place within the venturi. As a result, ice readily forms in the venturi and on the throttle valve.

A pressure-type carburetor discharges fuel into the airstream at a pressure well above atmospheric. This results in better vaporization and permits the discharge of fuel into the airstream on the engine side of the throttle valve. With the discharge nozzle located at this point, the drop in temperature due to fuel vaporization takes place after the air has passed the throttle valve and at a point where engine heat tends to offset it. Thus, the danger of fuel vaporization icing is practically eliminated. The effects of rapid maneuvers and rough air on the pressure-type carburetors are negligible since their fuel chambers remain filled under all operating conditions.

Mixture Control

Carburetors are normally calibrated at sea-level pressure, where the correct fuel-to-air mixture ratio is established with the mixture control set in the FULL RICH position. However, as altitude increases, the density of air entering the carburetor decreases, while the density of the fuel remains the same. This creates a progressively richer mixture, which can result in engine roughness and an appreciable loss of power. The roughness normally is due to spark plug fouling

from excessive carbon buildup on the plugs. Carbon buildup occurs because the rich mixture lowers the temperature inside the cylinder, inhibiting complete combustion of the fuel. This condition may occur during the pretakeoff runup at high-elevation airports and during climbs or cruise flight at high altitudes. To maintain the correct fuel/air mixture, the mixture must be leaned using the mixture control. Leaning the mixture decreases fuel flow, which compensates for the decreased air density at high altitude.

During a descent from high altitude, the mixture must be enriched, or it may become too lean. An overly lean mixture causes detonation, which may result in rough engine operation, overheating, and a loss of power. The best way to maintain the proper mixture is to monitor the engine temperature and enrich the mixture as needed. Proper mixture control and better fuel economy for fuel-injected engines can be achieved by use of an exhaust gas temperature (EGT) gauge. Since the process of adjusting the mixture can vary from one aircraft to another, it is important to refer to the airplane flight manual (AFM) or the pilot's operating handbook (POH) to determine the specific procedures for a given aircraft.

Carburetor Icing

As mentioned earlier, one disadvantage of the float-type carburetor is its icing tendency. Carburetor ice occurs due

to the effect of fuel vaporization and the decrease in air pressure in the venturi, which causes a sharp temperature drop in the carburetor. If water vapor in the air condenses when the carburetor temperature is at or below freezing, ice may form on internal surfaces of the carburetor, including the throttle valve. [Figure 6-11]

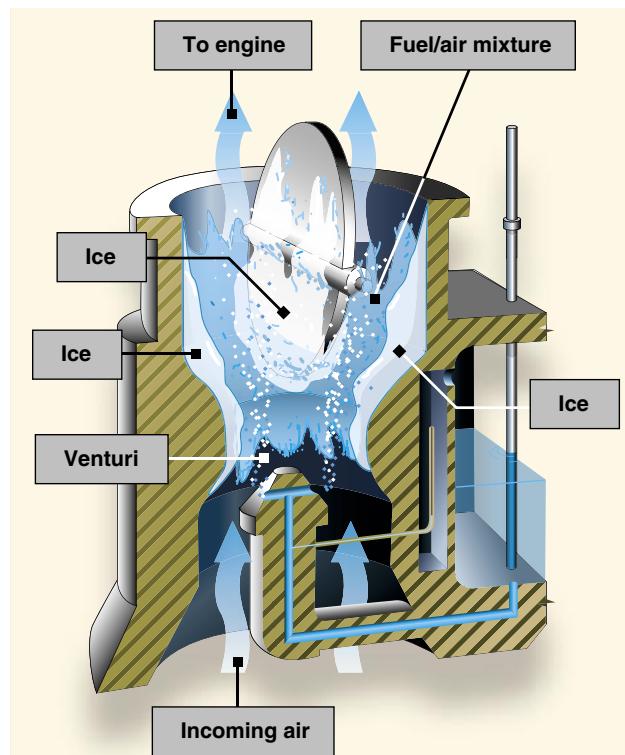


Figure 6-11. The formation of carburetor ice may reduce or block fuel/air flow to the engine.

The reduced air pressure, as well as the vaporization of fuel, contributes to the temperature decrease in the carburetor. Ice generally forms in the vicinity of the throttle valve and in the venturi throat. This restricts the flow of the fuel/air mixture and reduces power. If enough ice builds up, the engine may cease to operate. Carburetor ice is most likely to occur when temperatures are below 70 degrees Fahrenheit ($^{\circ}\text{F}$) or 21 degrees Celsius ($^{\circ}\text{C}$) and the relative humidity is above 80 percent. Due to the sudden cooling that takes place in the carburetor, icing can occur even with temperatures as high as 100 $^{\circ}\text{F}$ (38 $^{\circ}\text{C}$) and humidity as low as 50 percent. This temperature drop can be as much as 60 to 70 $^{\circ}\text{F}$ (15 to 21 $^{\circ}\text{C}$). Therefore, at an outside air temperature of 100 $^{\circ}\text{F}$ (37 $^{\circ}\text{C}$), a temperature drop of 70 $^{\circ}\text{F}$ (21 $^{\circ}\text{C}$) results in an air temperature in the carburetor of 30 $^{\circ}\text{F}$ (-1 $^{\circ}\text{C}$). [Figure 6-12]

The first indication of carburetor icing in an aircraft with a fixed-pitch propeller is a decrease in engine rpm, which may be followed by engine roughness. In an aircraft with a constant-speed propeller, carburetor icing is usually indicated

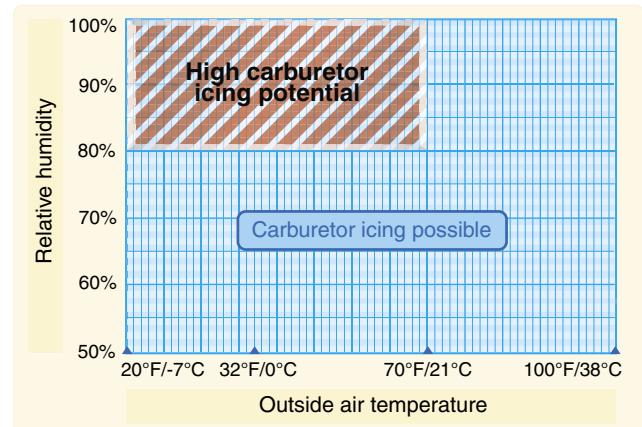


Figure 6-12. Although carburetor ice is most likely to form when the temperature and humidity are in ranges indicated by this chart, carburetor ice is possible under conditions not depicted.

by a decrease in manifold pressure, but no reduction in rpm. Propeller pitch is automatically adjusted to compensate for loss of power. Thus, a constant rpm is maintained. Although carburetor ice can occur during any phase of flight, it is particularly dangerous when using reduced power during a descent. Under certain conditions, carburetor ice could build unnoticed until power is added. To combat the effects of carburetor ice, engines with float-type carburetors employ a carburetor heat system.

Carburetor Heat

Carburetor heat is an anti-icing system that preheats the air before it reaches the carburetor, and is intended to keep the fuel/air mixture above the freezing temperature to prevent the formation of carburetor ice. Carburetor heat can be used to melt ice that has already formed in the carburetor if the accumulation is not too great, but using carburetor heat as a preventative measure is the better option. Additionally, the use of carburetor heat as an alternate air source can be used if the intake filter clogs such as in sudden or unexpected airframe icing conditions. The carburetor heat should be checked during the engine runup. When using carburetor heat, follow the manufacturer's recommendations.

When conditions are conducive to carburetor icing during flight, periodic checks should be made to detect its presence. If detected, full carburetor heat should be applied immediately, and it should be left in the ON position until the pilot is certain all the ice has been removed. If ice is present, applying partial heat or leaving heat on for an insufficient time might aggravate the situation. In extreme cases of carburetor icing, even after the ice has been removed, full carburetor heat should be used to prevent further ice formation. If installed, a carburetor temperature gauge is useful in determining when to use carburetor heat.

Whenever the throttle is closed during flight, the engine cools rapidly and vaporization of the fuel is less complete than if the engine is warm. Also, in this condition, the engine is more susceptible to carburetor icing. If carburetor icing conditions are suspected and closed-throttle operation anticipated, adjust the carburetor heat to the full ON position before closing the throttle and leave it on during the closed-throttle operation. The heat will aid in vaporizing the fuel and help prevent the formation of carburetor ice. Periodically, open the throttle smoothly for a few seconds to keep the engine warm; otherwise, the carburetor heater may not provide enough heat to prevent icing.

The use of carburetor heat causes a decrease in engine power, sometimes up to 15 percent, because the heated air is less dense than the outside air that had been entering the engine. This enriches the mixture. When ice is present in an aircraft with a fixed-pitch propeller and carburetor heat is being used, there is a decrease in rpm, followed by a gradual increase in rpm as the ice melts. The engine also should run more smoothly after the ice has been removed. If ice is not present, the rpm will decrease and then remain constant. When carburetor heat is used on an aircraft with a constant-speed propeller and ice is present, a decrease in the manifold pressure will be noticed, followed by a gradual increase. If carburetor icing is not present, the gradual increase in manifold pressure will not be apparent until the carburetor heat is turned off.

It is imperative for a pilot to recognize carburetor ice when it forms during flight because a loss of power, altitude, and/or airspeed will occur. These symptoms may sometimes be accompanied by vibration or engine roughness. Once a power loss is noticed, immediate action should be taken to eliminate ice already formed in the carburetor, and to prevent further ice formation. This is accomplished by applying full carburetor heat, which will cause a further reduction in power, and possibly engine roughness as melted ice goes through the engine. These symptoms may last from 30 seconds to several minutes, depending on the severity of the icing. During this period, the pilot must resist the temptation to decrease the carburetor heat usage. Carburetor heat must remain in the full-hot position until normal power returns.

Since the use of carburetor heat tends to reduce the output of the engine and to increase the operating temperature, carburetor heat should not be used when full power is required (as during takeoff) or during normal engine operation, except to check for the presence or to remove carburetor ice.

Carburetor Air Temperature Gauge

Some aircraft are equipped with a carburetor air temperature gauge, which is useful in detecting potential icing conditions.

Usually, the face of the gauge is calibrated in degrees Celsius, with a yellow arc indicating the carburetor air temperatures where icing may occur. This yellow arc typically ranges between -15 °C and +5 °C (5 °F and 41 °F). If the air temperature and moisture content of the air are such that carburetor icing is improbable, the engine can be operated with the indicator in the yellow range with no adverse effects. If the atmospheric conditions are conducive to carburetor icing, the indicator must be kept outside the yellow arc by application of carburetor heat.

Certain carburetor air temperature gauges have a red radial, which indicates the maximum permissible carburetor inlet air temperature recommended by the engine manufacturer. If present, a green arc indicates the normal operating range.

Outside Air Temperature Gauge

Most aircraft are also equipped with an outside air temperature (OAT) gauge calibrated in both degrees Celsius and Fahrenheit. It provides the outside or ambient air temperature for calculating true airspeed, and also is useful in detecting potential icing conditions.

Fuel Injection Systems

In a fuel injection system, the fuel is injected directly into the cylinders, or just ahead of the intake valve. The air intake for the fuel injection system is similar to that used in a carburetor system, with an alternate air source located within the engine cowling. This source is used if the external air source is obstructed. The alternate air source is usually operated automatically, with a backup manual system that can be used if the automatic feature malfunctions.

A fuel injection system usually incorporates six basic components: an engine-driven fuel pump, a fuel/air control unit, fuel manifold (fuel distributor), discharge nozzles, an auxiliary fuel pump, and fuel pressure/flow indicators. *[Figure 6-13]*

The auxiliary fuel pump provides fuel under pressure to the fuel/air control unit for engine starting and/or emergency use. After starting, the engine-driven fuel pump provides fuel under pressure from the fuel tank to the fuel/air control unit.

This control unit, which essentially replaces the carburetor, meters fuel based on the mixture control setting, and sends it to the fuel manifold valve at a rate controlled by the throttle. After reaching the fuel manifold valve, the fuel is distributed to the individual fuel discharge nozzles. The discharge nozzles, which are located in each cylinder head, inject the fuel/air mixture directly into each cylinder intake port.

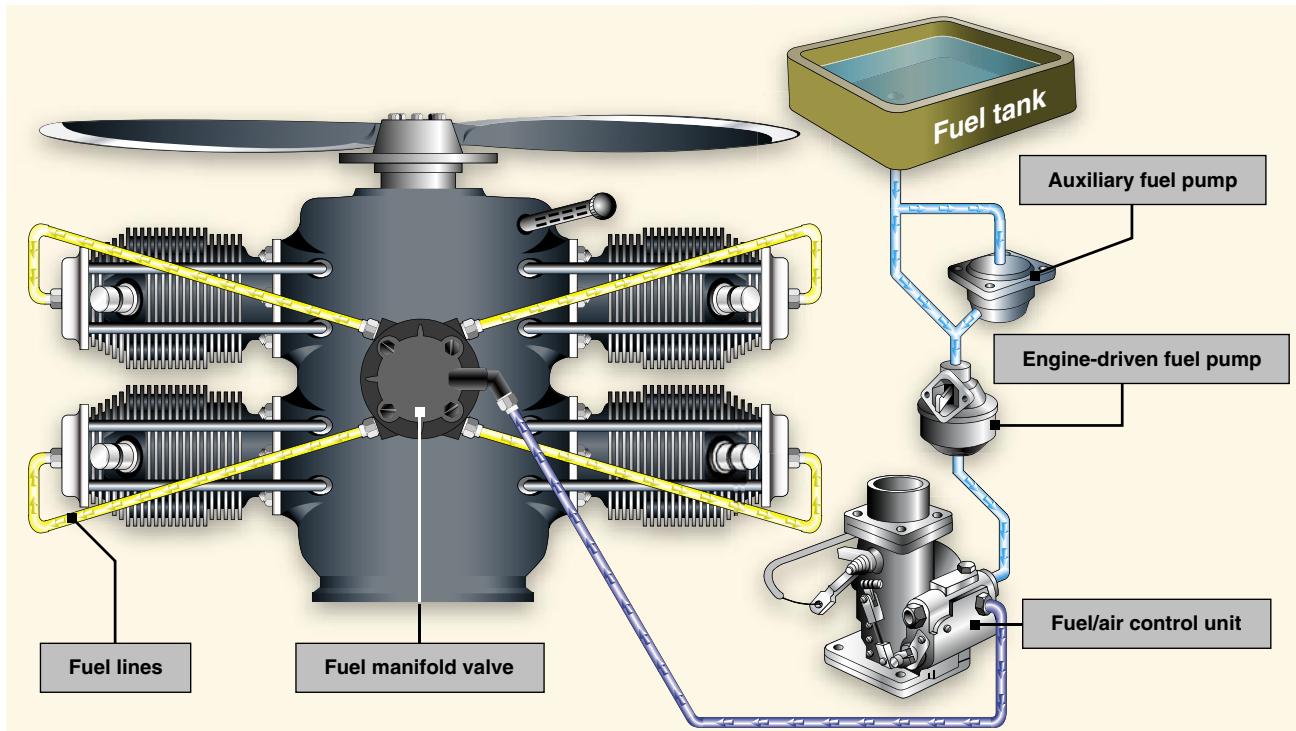


Figure 6-13. Fuel injection system.

A fuel injection system is considered to be less susceptible to icing than the carburetor system, but impact icing on the air intake is a possibility in either system. Impact icing occurs when ice forms on the exterior of the aircraft, and blocks openings such as the air intake for the injection system.

Advantages of fuel injection:

- Reduction in evaporative icing
- Better fuel flow
- Faster throttle response
- Precise control of mixture
- Better fuel distribution
- Easier cold weather starts

Disadvantages:

- Difficulty in starting a hot engine
- Vapor locks during ground operations on hot days
- Problems associated with restarting an engine that quits because of fuel starvation

Superchargers and Turbosuperchargers

To increase an engine's horsepower, manufacturers have developed forced induction systems called supercharger and turbosupercharger systems. They both compress the intake air to increase its density. The key difference lies in

the power supply. A supercharger relies on an engine-driven air pump or compressor, while a turbocharger gets its power from the exhaust stream that runs through a turbine, which in turn spins the compressor. Aircraft with these systems have a manifold pressure gauge, which displays MAP within the engine's intake manifold.

On a standard day at sea level with the engine shut down, the manifold pressure gauge will indicate the ambient absolute air pressure of 29.92 "Hg. Because atmospheric pressure decreases approximately 1 "Hg per 1,000 feet of altitude increase, the manifold pressure gauge will indicate approximately 24.92 "Hg at an airport that is 5,000 feet above sea level with standard day conditions.

As a normally aspirated aircraft climbs, it eventually reaches an altitude where the MAP is insufficient for a normal climb. That altitude limit is the aircraft's service ceiling, and it is directly affected by the engine's ability to produce power. If the induction air entering the engine is pressurized, or boosted, by either a supercharger or a turbosupercharger, the aircraft's service ceiling can be increased. With these systems, an aircraft can fly at higher altitudes with the advantage of higher true airspeeds and the increased ability to circumnavigate adverse weather.

Superchargers

A supercharger is an engine-driven air pump or compressor that provides compressed air to the engine to provide additional pressure to the induction air so the engine can produce additional power. It increases manifold pressure and forces the fuel/air mixture into the cylinders. The higher the manifold pressure, the more dense the fuel/air mixture, and the more power an engine can produce. With a normally aspirated engine, it is not possible to have manifold pressure higher than the existing atmospheric pressure. A supercharger is capable of boosting manifold pressure above 30 "Hg.

For example, at 8,000 feet a typical engine may be able to produce 75 percent of the power it could produce at mean sea level (MSL) because the air is less dense at the higher altitude. The supercharger compresses the air to a higher density allowing a supercharged engine to produce the same manifold pressure at higher altitudes as it could produce at sea level. Thus, an engine at 8,000 feet MSL could still produce 25 "Hg of manifold pressure whereas without a supercharger it could produce only 22 "Hg. Superchargers are especially valuable at high altitudes (such as 18,000 feet) where the air density is 50 percent that of sea level. The use of a supercharger in many cases will supply air to the engine at the same density it did at sea level. With a normally aspirated engine, it is not possible to have manifold pressure higher than the existing atmospheric pressure. A supercharger is capable of boosting manifold pressure above 30 "Hg.

The components in a supercharged induction system are similar to those in a normally aspirated system, with the addition of a supercharger between the fuel metering device and intake manifold. A supercharger is driven by the engine through a gear train at one speed, two speeds, or variable speeds. In addition, superchargers can have one or more stages. Each stage also provides an increase in pressure and superchargers may be classified as single stage, two stage, or multistage, depending on the number of times compression occurs.

An early version of a single-stage, single-speed supercharger may be referred to as a sea-level supercharger. An engine equipped with this type of supercharger is called a sea-level engine. With this type of supercharger, a single gear-driven impeller is used to increase the power produced by an engine at all altitudes. The drawback with this type of supercharger is a decrease in engine power output with an increase in altitude.

Single-stage, single-speed superchargers are found on many high-powered radial engines and use an air intake that faces forward so the induction system can take full advantage of the ram air. Intake air passes through ducts to a carburetor, where fuel is metered in proportion to the airflow. The fuel/air charge is then ducted to the supercharger, or blower impeller, which

accelerates the fuel/air mixture outward. Once accelerated, the fuel/air mixture passes through a diffuser, where air velocity is traded for pressure energy. After compression, the resulting high pressure fuel/air mixture is directed to the cylinders.

Some of the large radial engines developed during World War II have a single-stage, two-speed supercharger. With this type of supercharger, a single impeller may be operated at two speeds. The low impeller speed is often referred to as the low blower setting, while the high impeller speed is called the high blower setting. On engines equipped with a two-speed supercharger, a lever or switch in the flight deck activates an oil-operated clutch that switches from one speed to the other.

Under normal operations, takeoff is made with the supercharger in the low blower position. In this mode, the engine performs as a ground-boosted engine, and the power output decreases as the aircraft gains altitude. However, once the aircraft reaches a specified altitude, a power reduction is made, and the supercharger control is switched to the high blower position. The throttle is then reset to the desired manifold pressure. An engine equipped with this type of supercharger is called an altitude engine. [Figure 6-14]

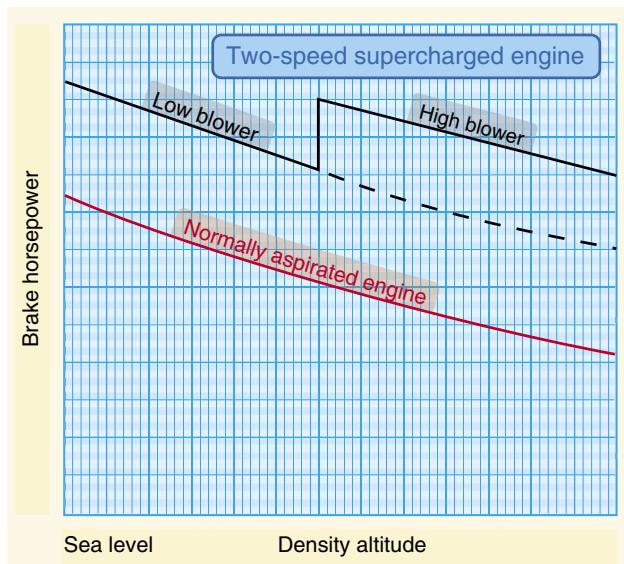


Figure 6-14. Power output of normally aspirated engine compared to a single-stage, two-speed supercharged engine.

Turbosuperchargers

The most efficient method of increasing horsepower in an engine is by use of a turbosupercharger or turbocharger. Installed on an engine, this booster uses the engine's exhaust gases to drive an air compressor to increase the pressure of the air going into the engine through the carburetor or fuel injection system to boost power at higher altitude.

The major disadvantage of the gear-driven supercharger—use of a large amount of the engine's power output for the amount of power increase produced—is avoided with a turbocharger, because turbochargers are powered by an engine's exhaust gases. This means a turbocharger recovers energy from hot exhaust gases that would otherwise be lost.

A second advantage of turbochargers over superchargers is the ability to maintain control over an engine's rated sea-level horsepower from sea level up to the engine's critical altitude. Critical altitude is the maximum altitude at which a turbocharged engine can produce its rated horsepower. Above the critical altitude, power output begins to decrease like it does for a normally aspirated engine.

Turbochargers increase the pressure of the engine's induction air, which allows the engine to develop sea level or greater horsepower at higher altitudes. A turbocharger is comprised of two main elements: a compressor and turbine. The compressor section houses an impeller that turns at a high rate of speed. As induction air is drawn across the impeller blades, the impeller accelerates the air, allowing a large volume of air to be drawn into the compressor housing. The impeller's action subsequently produces high-pressure, high-density air, which is delivered to the engine. To turn the impeller, the engine's exhaust gases are used to drive a turbine wheel that is mounted on the opposite end of the impeller's drive

shaft. By directing different amounts of exhaust gases to flow over the turbine, more energy can be extracted, causing the impeller to deliver more compressed air to the engine. The waste gate, essentially an adjustable butterfly valve installed in the exhaust system, is used to vary the mass of exhaust gas flowing into the turbine. When closed, most of the exhaust gases from the engine are forced to flow through the turbine. When open, the exhaust gases are allowed to bypass the turbine by flowing directly out through the engine's exhaust pipe. [Figure 6-15]

Since the temperature of a gas rises when it is compressed, turbocharging causes the temperature of the induction air to increase. To reduce this temperature and lower the risk of detonation, many turbocharged engines use an intercooler. This small heat exchanger uses outside air to cool the hot compressed air before it enters the fuel metering device.

System Operation

On most modern turbocharged engines, the position of the waste gate is governed by a pressure-sensing control mechanism coupled to an actuator. Engine oil directed into or away from this actuator moves the waste gate position. On these systems, the actuator is automatically positioned to produce the desired MAP simply by changing the position of the throttle control.

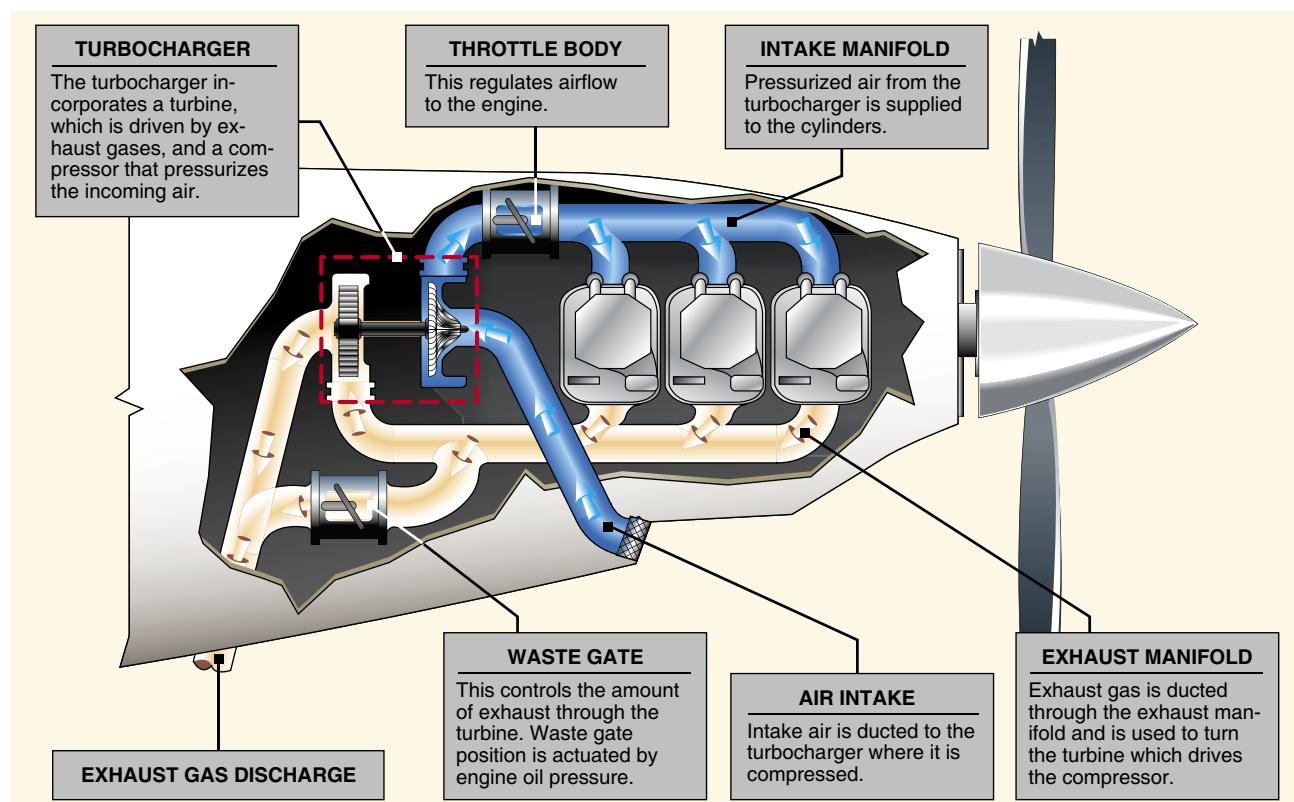


Figure 6-15. Turbocharger components.

Other turbocharging system designs use a separate manual control to position the waste gate. With manual control, the manifold pressure gauge must be closely monitored to determine when the desired MAP has been achieved. Manual systems are often found on aircraft that have been modified with aftermarket turbocharging systems. These systems require special operating considerations. For example, if the waste gate is left closed after descending from a high altitude, it is possible to produce a manifold pressure that exceeds the engine's limitations. This condition, called an overboost, may produce severe detonation because of the leaning effect resulting from increased air density during descent.

Although an automatic waste gate system is less likely to experience an overboost condition, it can still occur. If takeoff power is applied while the engine oil temperature is below its normal operating range, the cold oil may not flow out of the waste gate actuator quickly enough to prevent an overboost. To help prevent overboosting, advance the throttle cautiously to prevent exceeding the maximum manifold pressure limits.

A pilot flying an aircraft with a turbocharger should be aware of system limitations. For example, a turbocharger turbine and impeller can operate at rotational speeds in excess of 80,000 rpm while at extremely high temperatures. To achieve high rotational speed, the bearings within the system must be constantly supplied with engine oil to reduce the frictional forces and high temperature. To obtain adequate lubrication, the oil temperature should be in the normal operating range before high throttle settings are applied. In addition, allow the turbocharger to cool and the turbine to slow down before shutting the engine down. Otherwise, the oil remaining in the bearing housing will boil, causing hard carbon deposits to form on the bearings and shaft. These deposits rapidly deteriorate the turbocharger's efficiency and service life. For further limitations, refer to the AFM/POH.

High Altitude Performance

As an aircraft equipped with a turbocharging system climbs, the waste gate is gradually closed to maintain the maximum allowable manifold pressure. At some point, the waste gate will be fully closed and further increases in altitude will cause the manifold pressure to decrease. This is the critical altitude, which is established by the aircraft or engine manufacturer. When evaluating the performance of the turbocharging system, be aware that if the manifold pressure begins decreasing before the specified critical altitude, the engine and turbocharging system should be inspected by a qualified aviation maintenance technician to verify the system's proper operation.

Ignition System

In a spark ignition engine the ignition system provides a spark that ignites the fuel/air mixture in the cylinders and is made up of magnetos, spark plugs, high-tension leads, and the ignition switch. [Figure 6-16]

A magneto uses a permanent magnet to generate an electrical current completely independent of the aircraft's electrical system. The magneto generates sufficiently high voltage to jump a spark across the spark plug gap in each cylinder. The system begins to fire when the starter is engaged and the crankshaft begins to turn. It continues to operate whenever the crankshaft is rotating.

Most standard certificated aircraft incorporate a dual ignition system with two individual magnetos, separate sets of wires, and spark plugs to increase reliability of the ignition system. Each magneto operates independently to fire one of the two spark plugs in each cylinder. The firing of two spark plugs improves combustion of the fuel/air mixture and results in a slightly higher power output. If one of the magnetos fails, the other is unaffected. The engine will continue to operate normally, although a slight decrease in engine power can be expected. The same is true if one of the two spark plugs in a cylinder fails.

The operation of the magneto is controlled in the flight deck by the ignition switch. The switch has five positions:

1. OFF
2. R (right)
3. L (left)
4. BOTH
5. START

With RIGHT or LEFT selected, only the associated magneto is activated. The system operates on both magnetos with BOTH selected.

A malfunctioning ignition system can be identified during the pretakeoff check by observing the decrease in rpm that occurs when the ignition switch is first moved from BOTH to RIGHT, and then from BOTH to LEFT. A small decrease in engine rpm is normal during this check. The permissible decrease is listed in the AFM or POH. If the engine stops running when switched to one magneto or if the rpm drop exceeds the allowable limit, do not fly the aircraft until the problem is corrected. The cause could be fouled plugs, broken or shorted wires between the magneto and the plugs, or improperly timed firing of the plugs. It should be noted

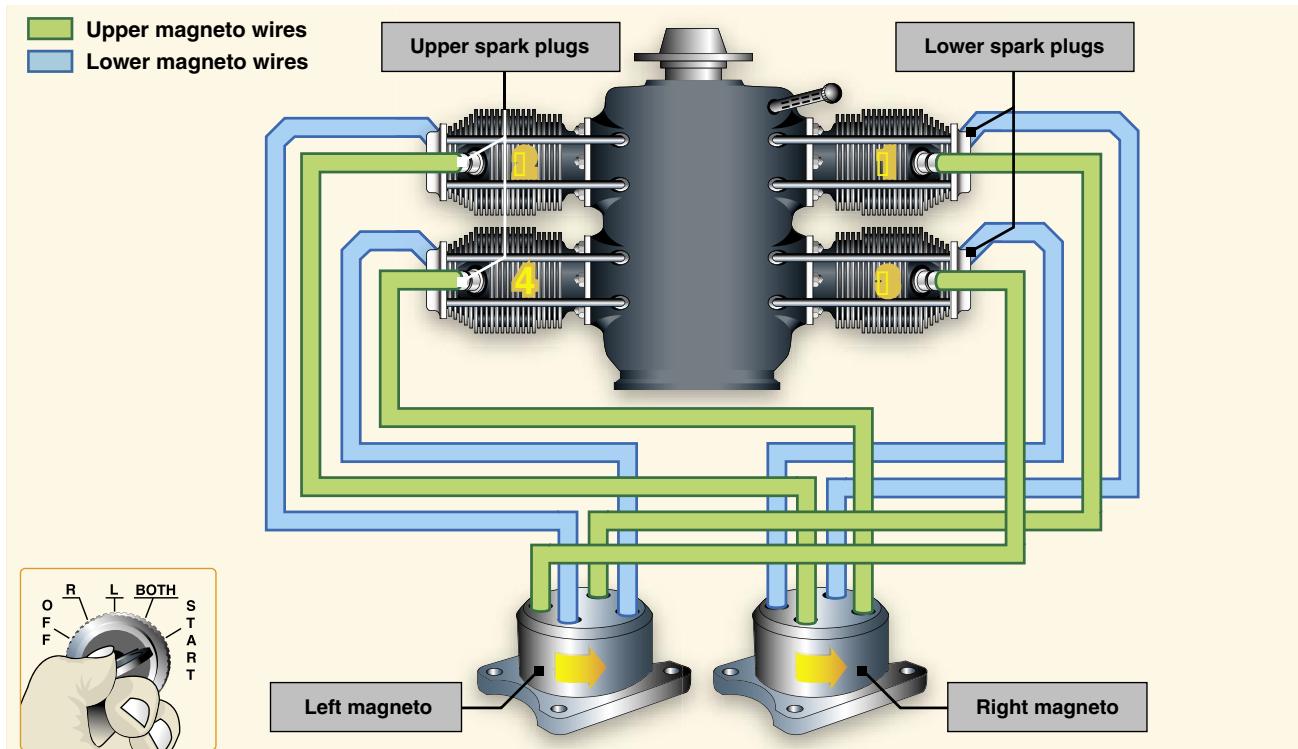


Figure 6-16. Ignition system components.

that “no drop” in rpm is not normal, and in that instance, the aircraft should not be flown.

Following engine shutdown, turn the ignition switch to the OFF position. Even with the battery and master switches OFF, the engine can fire and turn over if the ignition switch is left ON and the propeller is moved because the magneto requires no outside source of electrical power. Be aware of the potential for serious injury in this situation.

Even with the ignition switch in the OFF position, if the ground wire between the magneto and the ignition switch becomes disconnected or broken, the engine could accidentally start if the propeller is moved with residual fuel in the cylinder. If this occurs, the only way to stop the engine is to move the mixture lever to the idle cutoff position, then have the system checked by a qualified aviation maintenance technician.

Oil Systems

The engine oil system performs several important functions:

- Lubrication of the engine’s moving parts
- Cooling of the engine by reducing friction
- Removing heat from the cylinders
- Providing a seal between the cylinder walls and pistons
- Carrying away contaminants

Reciprocating engines use either a wet-sump or a dry-sump oil system. In a wet-sump system, the oil is located in a sump, which is an integral part of the engine. In a dry-sump system, the oil is contained in a separate tank, and circulated through the engine by pumps. [Figure 6-17]

The main component of a wet-sump system is the oil pump, which draws oil from the sump and routes it to the engine. After the oil passes through the engine, it returns to the sump. In some engines, additional lubrication is supplied by the rotating crankshaft, which splashes oil onto portions of the engine.

An oil pump also supplies oil pressure in a dry-sump system, but the source of the oil is located external to the engine in a separate oil tank. After oil is routed through the engine, it is pumped from the various locations in the engine back to the oil tank by scavenge pumps. Dry-sump systems allow for a greater volume of oil to be supplied to the engine, which makes them more suitable for very large reciprocating engines.

The oil pressure gauge provides a direct indication of the oil system operation. It ensures the pressure in pounds per square inch (psi) of the oil supplied to the engine. Green indicates the normal operating range, while red indicates the minimum and maximum pressures. There should be an indication of oil pressure during engine start. Refer to the AFM/POH for manufacturer limitations.

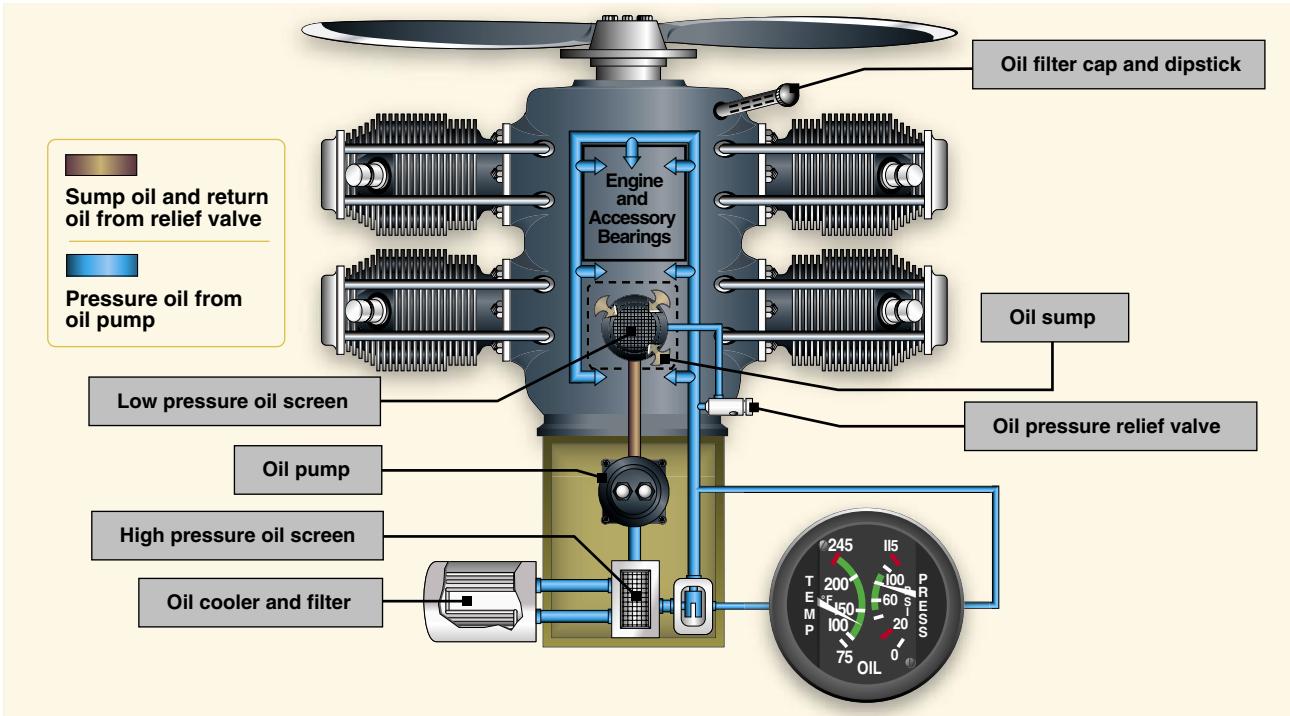


Figure 6-17. Wet-sump oil system.

The oil temperature gauge measures the temperature of oil. A green area shows the normal operating range and the red line indicates the maximum allowable temperature. Unlike oil pressure, changes in oil temperature occur more slowly. This is particularly noticeable after starting a cold engine, when it may take several minutes or longer for the gauge to show any increase in oil temperature.

Check oil temperature periodically during flight especially when operating in high or low ambient air temperature. High oil temperature indications may signal a plugged oil line, a low oil quantity, a blocked oil cooler, or a defective temperature gauge. Low oil temperature indications may signal improper oil viscosity during cold weather operations.

The oil filler cap and dipstick (for measuring the oil quantity) are usually accessible through a panel in the engine cowling. If the quantity does not meet the manufacturer's recommended operating levels, oil should be added. The AFM/POH or placards near the access panel provide information about the correct oil type and weight, as well as the minimum and maximum oil quantity. [Figure 6-18]

Engine Cooling Systems

The burning fuel within the cylinders produces intense heat, most of which is expelled through the exhaust system. Much of the remaining heat, however, must be removed, or at least dissipated, to prevent the engine from overheating. Otherwise, the extremely high engine temperatures can lead



Figure 6-18. Always check the engine oil level during the preflight inspection.

to loss of power, excessive oil consumption, detonation, and serious engine damage.

While the oil system is vital to the internal cooling of the engine, an additional method of cooling is necessary for the engine's external surface. Most small aircraft are air cooled, although some are liquid cooled.

Air cooling is accomplished by air flowing into the engine compartment through openings in front of the engine cowling. Baffles route this air over fins attached to the engine cylinders, and other parts of the engine, where the air absorbs the engine heat. Expulsion of the hot air takes place through

one or more openings in the lower, aft portion of the engine cowling. [Figure 6-19]

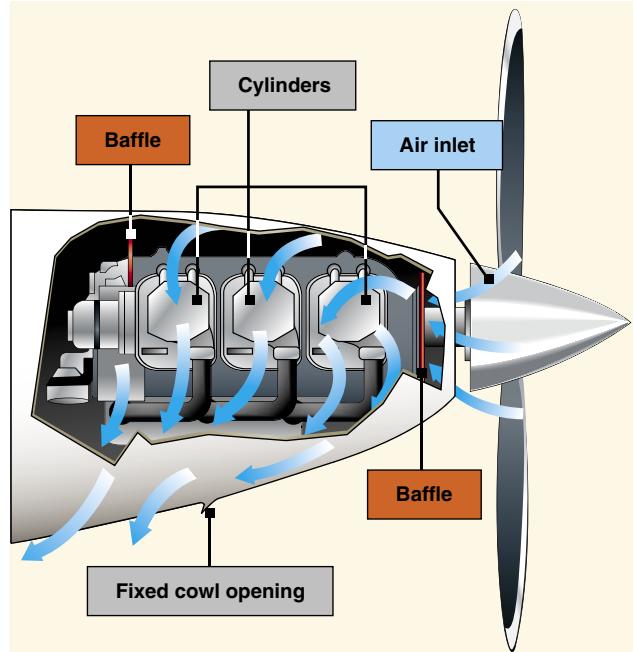


Figure 6-19. Outside air aids in cooling the engine.

The outside air enters the engine compartment through an inlet behind the propeller hub. Baffles direct it to the hottest parts of the engine, primarily the cylinders, which have fins that increase the area exposed to the airflow.

The air cooling system is less effective during ground operations, takeoffs, go-arounds, and other periods of high-power, low-airspeed operation. Conversely, high-speed descents provide excess air and can shock cool the engine, subjecting it to abrupt temperature fluctuations.

Operating the engine at higher than its designed temperature can cause loss of power, excessive oil consumption, and detonation. It will also lead to serious permanent damage, such as scoring the cylinder walls, damaging the pistons and rings, and burning and warping the valves. Monitoring the flight deck engine temperature instruments will aid in avoiding high operating temperature.

Under normal operating conditions in aircraft not equipped with cowl flaps, the engine temperature can be controlled by changing the airspeed or the power output of the engine. High engine temperatures can be decreased by increasing the airspeed and/or reducing the power.

The oil temperature gauge gives an indirect and delayed indication of rising engine temperature, but can be used for

determining engine temperature if this is the only means available.

Most aircraft are equipped with a cylinder-head temperature gauge which indicates a direct and immediate cylinder temperature change. This instrument is calibrated in degrees Celsius or Fahrenheit, and is usually color coded with a green arc to indicate the normal operating range. A red line on the instrument indicates maximum allowable cylinder head temperature.

To avoid excessive cylinder head temperatures, increase airspeed, enrich the mixture, and/or reduce power. Any of these procedures help to reduce the engine temperature. On aircraft equipped with cowl flaps, use the cowl flap positions to control the temperature. Cowl flaps are hinged covers that fit over the opening through which the hot air is expelled. If the engine temperature is low, the cowl flaps can be closed, thereby restricting the flow of expelled hot air and increasing engine temperature. If the engine temperature is high, the cowl flaps can be opened to permit a greater flow of air through the system, thereby decreasing the engine temperature.

Exhaust Systems

Engine exhaust systems vent the burned combustion gases overboard, provide heat for the cabin, and defrost the windscreen. An exhaust system has exhaust piping attached to the cylinders, as well as a muffler and a muffler shroud. The exhaust gases are pushed out of the cylinder through the exhaust valve and then through the exhaust pipe system to the atmosphere.

For cabin heat, outside air is drawn into the air inlet and is ducted through a shroud around the muffler. The muffler is heated by the exiting exhaust gases and, in turn, heats the air around the muffler. This heated air is then ducted to the cabin for heat and defrost applications. The heat and defrost are controlled in the flight deck, and can be adjusted to the desired level.

Exhaust gases contain large amounts of carbon monoxide, which is odorless and colorless. Carbon monoxide is deadly, and its presence is virtually impossible to detect. The exhaust system must be in good condition and free of cracks.

Some exhaust systems have an EGT probe. This probe transmits the EGT to an instrument in the flight deck. The EGT gauge measures the temperature of the gases at the exhaust manifold. This temperature varies with the ratio of fuel to air entering the cylinders and can be used as a

basis for regulating the fuel/air mixture. The EGT gauge is highly accurate in indicating the correct mixture setting. When using the EGT to aid in leaning the fuel/air mixture, fuel consumption can be reduced. For specific procedures, refer to the manufacturer's recommendations for leaning the mixture.

Starting System

Most small aircraft use a direct-cranking electric starter system. This system consists of a source of electricity, wiring, switches, and solenoids to operate the starter and a starter motor. Most aircraft have starters that automatically engage and disengage when operated, but some older aircraft have starters that are mechanically engaged by a lever actuated by the pilot. The starter engages the aircraft flywheel, rotating the engine at a speed that allows the engine to start and maintain operation.

Electrical power for starting is usually supplied by an onboard battery, but can also be supplied by external power through an external power receptacle. When the battery switch is turned on, electricity is supplied to the main power bus bar through the battery solenoid. Both the starter and the starter switch draw current from the main bus bar, but the starter will not operate until the starting solenoid is energized by the starter switch being turned to the "start" position. When the starter switch is released from the "start" position, the solenoid removes power from the starter motor. The starter motor is protected from being driven by the engine through a clutch in the starter drive that allows the engine to run faster than the starter motor. [Figure 6-20]

When starting an engine, the rules of safety and courtesy should be strictly observed. One of the most important is to make sure there is no one near the propeller. In addition, the wheels should be chocked and the brakes set, to avoid hazards caused by unintentional movement. To avoid damage to the propeller and property, the aircraft should be in an area where the propeller will not stir up gravel or dust.

Combustion

During normal combustion, the fuel/air mixture burns in a very controlled and predictable manner. In a spark ignition engine the process occurs in a fraction of a second. The mixture actually begins to burn at the point where it is ignited by the spark plugs, then burns away from the plugs until it is all consumed. This type of combustion causes a smooth build-up of temperature and pressure and ensures that the expanding gases deliver the maximum force to the piston at exactly the right time in the power stroke. [Figure 6-21]

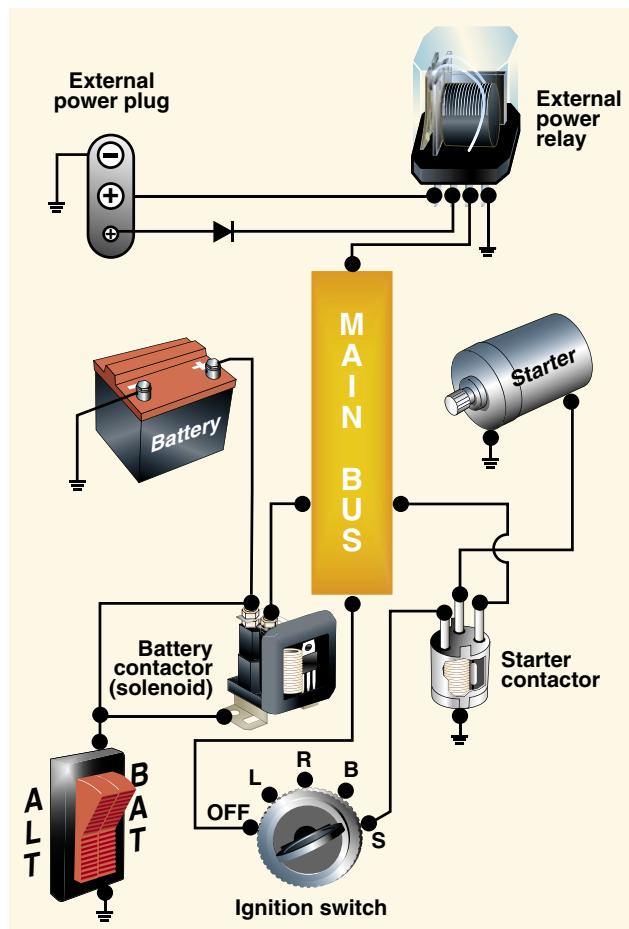


Figure 6-20. Typical starting circuit.

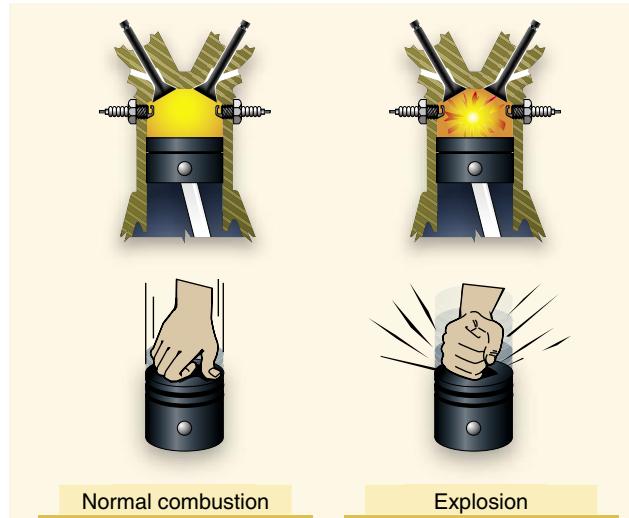


Figure 6-21. Normal combustion and explosive combustion.

Detonation is an uncontrolled, explosive ignition of the fuel/air mixture within the cylinder's combustion chamber. It causes excessive temperatures and pressures which, if not corrected, can quickly lead to failure of the piston, cylinder, or valves. In less severe cases, detonation causes engine overheating, roughness, or loss of power.

Detonation is characterized by high cylinder head temperatures and is most likely to occur when operating at high power settings. Common operational causes of detonation are:

- Use of a lower fuel grade than that specified by the aircraft manufacturer.
- Operation of the engine with extremely high manifold pressures in conjunction with low rpm.
- Operation of the engine at high power settings with an excessively lean mixture.
- Maintaining extended ground operations or steep climbs in which cylinder cooling is reduced.

Detonation may be avoided by following these basic guidelines during the various phases of ground and flight operations:

- Make sure the proper grade of fuel is used.
- Keep the cowl flaps (if available) in the full-open position while on the ground to provide the maximum airflow through the cowling.
- Use an enriched fuel mixture, as well as a shallower climb angle to increase cylinder cooling during takeoff and initial climb.
- Avoid extended, high power, steep climbs.
- Develop the habit of monitoring the engine instruments to verify proper operation according to procedures established by the manufacturer.

Preignition occurs when the fuel/air mixture ignites prior to the engine's normal ignition event. Premature burning is usually caused by a residual hot spot in the combustion chamber, often created by a small carbon deposit on a spark plug, a cracked spark plug insulator, or other damage in the cylinder that causes a part to heat sufficiently to ignite the fuel/air charge. Preignition causes the engine to lose power, and produces high operating temperature. As with detonation, preignition may also cause severe engine damage, because the expanding gases exert excessive pressure on the piston while still on its compression stroke.

Detonation and preignition often occur simultaneously and one may cause the other. Since either condition causes high engine temperature accompanied by a decrease in engine performance, it is often difficult to distinguish between the

two. Using the recommended grade of fuel and operating the engine within its proper temperature, pressure, and rpm ranges reduce the chance of detonation or preignition.

Full Authority Digital Engine Control (FADEC)

FADEC is a system consisting of a digital computer and ancillary components that control an aircraft's engine and propeller. First used in turbine-powered aircraft, and referred to as full authority digital electronic control, these sophisticated control systems are increasingly being used in piston powered aircraft.

In a spark ignition reciprocating engine the FADEC uses speed, temperature, and pressure sensors to monitor the status of each cylinder. A digital computer calculates the ideal pulse for each injector and adjusts ignition timing as necessary to achieve optimal performance. In a compression ignition engine the FADEC operates similarly and performs all of the same functions, excluding those specifically related to the spark ignition process.

FADEC systems eliminate the need for magnetos, carburetor heat, mixture controls, and engine priming. A single throttle lever is characteristic of an aircraft equipped with a FADEC system. The pilot simply positions the throttle lever to a desired detent such as start, idle, cruise power, or max power, and the FADEC system adjusts the engine and propeller automatically for the mode selected. There is no need for the pilot to monitor or control the air/fuel mixture.

During aircraft starting, the FADEC primes the cylinders, adjusts the mixture, and positions the throttle based on engine temperature and ambient pressure. During cruise flight, the FADEC constantly monitors the engine and adjusts fuel flow, and ignition timing individually in each cylinder. This precise control of the combustion process often results in decreased fuel consumption and increased horsepower.

FADEC systems are considered an essential part of the engine and propeller control, and may be powered by the aircraft's main electrical system. In many aircraft FADEC uses power from a separate generator connected to the engine. In either case, there must be a backup electrical source available because failure of a FADEC system could result in a complete loss of engine thrust. To prevent loss of thrust, two separate and identical digital channels are incorporated for redundancy, each channel capable of providing all engine and propeller functions without limitations.

Turbine Engines

An aircraft turbine engine consists of an air inlet, compressor, combustion chambers, a turbine section, and exhaust. Thrust is produced by increasing the velocity of the air flowing through the engine. Turbine engines are highly desirable aircraft powerplants. They are characterized by smooth operation and a high power-to-weight ratio, and they use readily available jet fuel. Prior to recent advances in material, engine design, and manufacturing processes, the use of turbine engines in small/light production aircraft was cost prohibitive. Today, several aviation manufacturers are producing or plan to produce small/light turbine-powered aircraft. These smaller turbine-powered aircraft typically seat between three and seven passengers and are referred to as very light jets (VLJs) or microjets. [Figure 6-22]



Figure 6-22. Eclipse 500 VLJ.

Types of Turbine Engines

Turbine engines are classified according to the type of compressors they use. There are three types of compressors—centrifugal flow, axial flow, and centrifugal-axial flow. Compression of inlet air is achieved in a centrifugal flow engine by accelerating air outward perpendicular to the longitudinal axis of the machine. The axial-flow engine compresses air by a series of rotating and stationary airfoils moving the air parallel to the longitudinal axis. The centrifugal-axial flow design uses both kinds of compressors to achieve the desired compression.

The path the air takes through the engine and how power is produced determines the type of engine. There are four types of aircraft turbine engines—turbojet, turboprop, turbofan, and turboshaft.

Turbojet

The turbojet engine consists of four sections: compressor, combustion chamber, turbine section, and exhaust. The compressor section passes inlet air at a high rate of speed to

the combustion chamber. The combustion chamber contains the fuel inlet and igniter for combustion. The expanding air drives a turbine, which is connected by a shaft to the compressor, sustaining engine operation. The accelerated exhaust gases from the engine provide thrust. This is a basic application of compressing air, igniting the fuel-air mixture, producing power to self-sustain the engine operation, and exhaust for propulsion. [Figure 6-23]

Turbojet engines are limited in range and endurance. They are also slow to respond to throttle applications at slow compressor speeds.

Turboprop

A turboprop engine is a turbine engine that drives a propeller through a reduction gear. The exhaust gases drive a power turbine connected by a shaft that drives the reduction gear assembly. Reduction gearing is necessary in turboprop engines because optimum propeller performance is achieved at much slower speeds than the engine's operating rpm. Turboprop engines are a compromise between turbojet engines and reciprocating powerplants. Turboprop engines are most efficient at speeds between 250 and 400 mph and altitudes between 18,000 and 30,000 feet. They also perform well at the slow airspeeds required for takeoff and landing, and are fuel efficient. The minimum specific fuel consumption of the turboprop engine is normally available in the altitude range of 25,000 feet to the tropopause. [Figure 6-24]

Turbofan

Turbofans were developed to combine some of the best features of the turbojet and the turboprop. Turbofan engines are designed to create additional thrust by diverting a secondary airflow around the combustion chamber. The turbofan bypass air generates increased thrust, cools the engine, and aids in exhaust noise suppression. This provides turbojet-type cruise speed and lower fuel consumption.

The inlet air that passes through a turbofan engine is usually divided into two separate streams of air. One stream passes through the engine core, while a second stream bypasses the engine core. It is this bypass stream of air that is responsible for the term "bypass engine." A turbofan's bypass ratio refers to the ratio of the mass airflow that passes through the fan divided by the mass airflow that passes through the engine core. [Figure 6-25]

Turboshaft

The fourth common type of jet engine is the turboshaft. [Figure 6-26] It delivers power to a shaft that drives something other than a propeller. The biggest difference between a turbojet and turboshaft engine is that on a

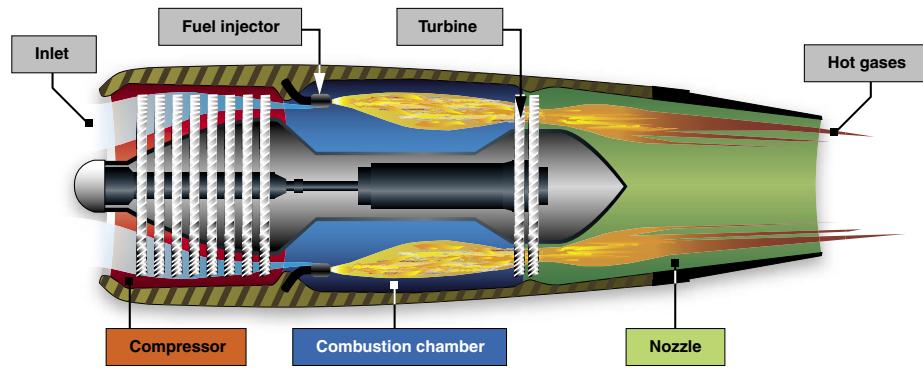


Figure 6-23. Turbojet engine.

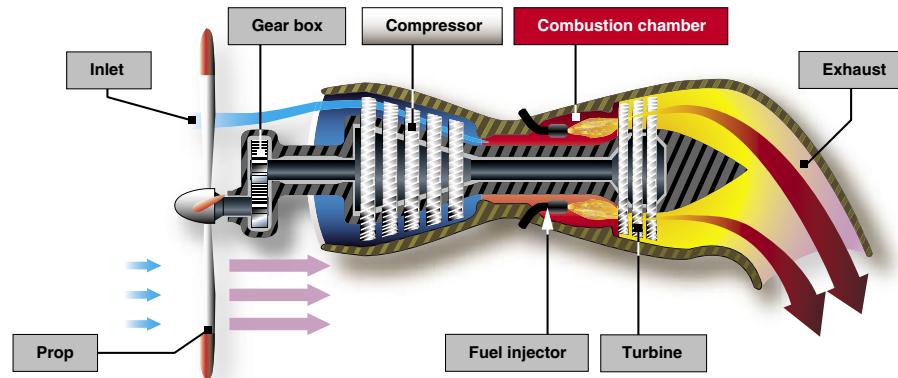


Figure 6-24. Turboprop engine.

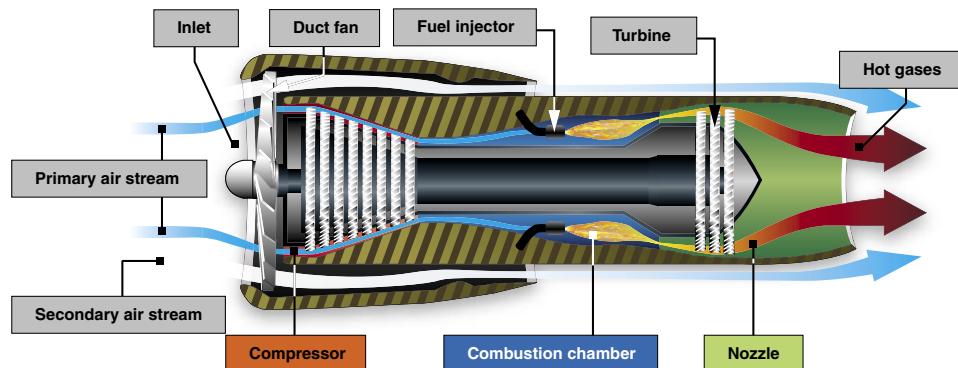


Figure 6-25. Turbofan engine.

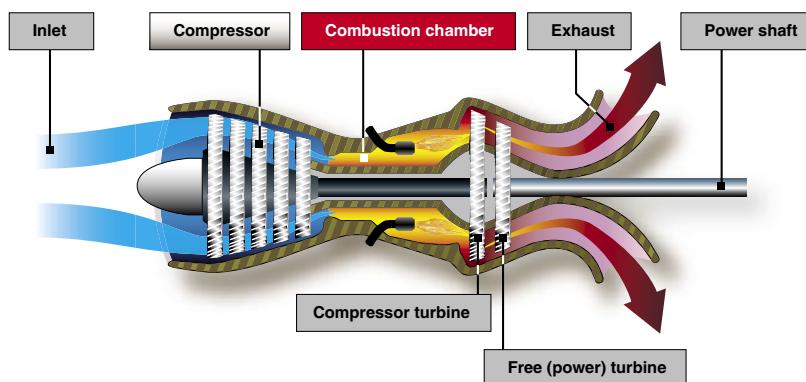


Figure 6-26. Turboshaft engine.

turboshaft engine, most of the energy produced by the expanding gases is used to drive a turbine rather than produce thrust. Many helicopters use a turboshaft gas turbine engine. In addition, turboshaft engines are widely used as auxiliary power units on large aircraft.

Turbine Engine Instruments

Engine instruments that indicate oil pressure, oil temperature, engine speed, exhaust gas temperature, and fuel flow are common to both turbine and reciprocating engines. However, there are some instruments that are unique to turbine engines. These instruments provide indications of engine pressure ratio, turbine discharge pressure, and torque. In addition, most gas turbine engines have multiple temperature-sensing instruments, called thermocouples, which provide pilots with temperature readings in and around the turbine section.

Engine Pressure Ratio (EPR)

An engine pressure ratio (EPR) gauge is used to indicate the power output of a turbojet/turbofan engine. EPR is the ratio of turbine discharge to compressor inlet pressure. Pressure measurements are recorded by probes installed in the engine inlet and at the exhaust. Once collected, the data is sent to a differential pressure transducer, which is indicated on a flight deck EPR gauge.

EPR system design automatically compensates for the effects of airspeed and altitude. Changes in ambient temperature require a correction be applied to EPR indications to provide accurate engine power settings.

Exhaust Gas Temperature (EGT)

A limiting factor in a gas turbine engine is the temperature of the turbine section. The temperature of a turbine section must be monitored closely to prevent overheating the turbine blades and other exhaust section components. One common way of monitoring the temperature of a turbine section is with an EGT gauge. EGT is an engine operating limit used to monitor overall engine operating conditions.

Variations of EGT systems bear different names based on the location of the temperature sensors. Common turbine temperature sensing gauges include the turbine inlet temperature (TIT) gauge, turbine outlet temperature (TOT) gauge, interstage turbine temperature (ITT) gauge, and turbine gas temperature (TGT) gauge.

Torquemeter

Turboprop/turboshaft engine power output is measured by the torquemeter. Torque is a twisting force applied to a shaft. The torquemeter measures power applied to the shaft. Turboprop and turboshaft engines are designed to produce torque for

driving a propeller. Torquemeters are calibrated in percentage units, foot-pounds, or psi.

N_1 Indicator

N_1 represents the rotational speed of the low pressure compressor and is presented on the indicator as a percentage of design rpm. After start the speed of the low pressure compressor is governed by the N_1 turbine wheel. The N_1 turbine wheel is connected to the low pressure compressor through a concentric shaft.

N_2 Indicator

N_2 represents the rotational speed of the high pressure compressor and is presented on the indicator as a percentage of design rpm. The high pressure compressor is governed by the N_2 turbine wheel. The N_2 turbine wheel is connected to the high pressure compressor through a concentric shaft. [Figure 6-27]

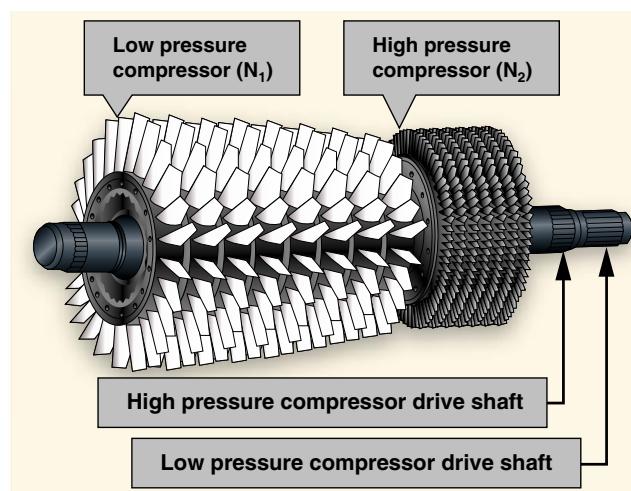


Figure 6-27. Dual-spool axial-flow compressor.

Turbine Engine Operational Considerations

The great variety of turbine engines makes it impractical to cover specific operational procedures, but there are certain operational considerations common to all turbine engines. They are engine temperature limits, foreign object damage, hot start, compressor stall, and flameout.

Engine Temperature Limitations

The highest temperature in any turbine engine occurs at the turbine inlet. Turbine inlet temperature is therefore usually the limiting factor in turbine engine operation.

Thrust Variations

Turbine engine thrust varies directly with air density. As air density decreases, so does thrust. Additionally, because air

density decreases with an increase in temperature, increased temperatures will also result in decreased thrust. While both turbine and reciprocating powered engines are affected to some degree by high relative humidity, turbine engines will experience a negligible loss of thrust, while reciprocating engines a significant loss of brake horsepower.

Foreign Object Damage (FOD)

Due to the design and function of a turbine engine's air inlet, the possibility of ingestion of debris always exists. This causes significant damage, particularly to the compressor and turbine sections. When ingestion of debris occurs, it is called foreign object damage (FOD). Typical FOD consists of small nicks and dents caused by ingestion of small objects from the ramp, taxiway, or runway, but FOD damage caused by bird strikes or ice ingestion also occur. Sometimes FOD results in total destruction of an engine.

Prevention of FOD is a high priority. Some engine inlets have a tendency to form a vortex between the ground and the inlet during ground operations. A vortex dissipater may be installed on these engines. Other devices, such as screens and/or deflectors, may also be utilized. Preflight procedures include a visual inspection for any sign of FOD.

Turbine Engine Hot/Hung Start

When the EGT exceeds the safe limit of an aircraft, it experiences a "hot start." It is caused by too much fuel entering the combustion chamber, or insufficient turbine rpm. Any time an engine has a hot start, refer to the AFM/POH or an appropriate maintenance manual for inspection requirements.

If the engine fails to accelerate to the proper speed after ignition or does not accelerate to idle rpm, a hung or false start has occurred. A hung start may be caused by an insufficient starting power source or fuel control malfunction.

Compressor Stalls

Compressor blades are small airfoils and are subject to the same aerodynamic principles that apply to any airfoil. A compressor blade has an angle of attack which is a result of inlet air velocity and the compressor's rotational velocity. These two forces combine to form a vector, which defines the airfoil's actual angle of attack to the approaching inlet air.

A compressor stall is an imbalance between the two vector quantities, inlet velocity and compressor rotational speed. Compressor stalls occur when the compressor blades' angle of attack exceeds the critical angle of attack. At this point, smooth airflow is interrupted and turbulence is created with pressure fluctuations. Compressor stalls cause air flowing

in the compressor to slow down and stagnate, sometimes reversing direction. [Figure 6-28]

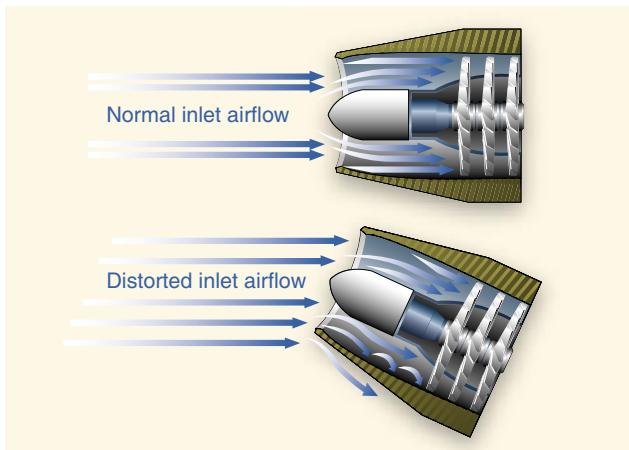


Figure 6-28. Comparison of normal and distorted airflow into the compressor section.

Compressor stalls can be transient and intermittent or steady and severe. Indications of a transient/interruption stall are usually an intermittent "bang" as backfire and flow reversal take place. If the stall develops and becomes steady, strong vibration and a loud roar may develop from the continuous flow reversal. Often, the flight deck gauges do not show a mild or transient stall, but they do indicate a developed stall. Typical instrument indications include fluctuations in rpm and an increase in exhaust gas temperature. Most transient stalls are not harmful to the engine and often correct themselves after one or two pulsations. The possibility of severe engine damage from a steady state stall is immediate. Recovery must be accomplished by quickly reducing power, decreasing the aircraft's angle of attack, and increasing airspeed.

Although all gas turbine engines are subject to compressor stalls, most models have systems that inhibit them. One system uses a variable inlet guide vane (VIGV) and variable stator vanes, which direct the incoming air into the rotor blades at an appropriate angle. To prevent air pressure stalls, operate the aircraft within the parameters established by the manufacturer. If a compressor stall does develop, follow the procedures recommended in the AFM/POH.

Flameout

A flameout occurs in the operation of a gas turbine engine in which the fire in the engine unintentionally goes out. If the rich limit of the fuel/air ratio is exceeded in the combustion chamber, the flame will blow out. This condition is often referred to as a rich flameout. It generally results from very fast engine acceleration, in which an overly rich mixture causes the fuel temperature to drop below the combustion

temperature. It may also be caused by insufficient airflow to support combustion.

A more common flameout occurrence is due to low fuel pressure and low engine speeds, which typically are associated with high-altitude flight. This situation may also occur with the engine throttled back during a descent, which can set up the lean-condition flameout. A weak mixture can easily cause the flame to die out, even with a normal airflow through the engine.

Any interruption of the fuel supply can result in a flameout. This may be due to prolonged unusual attitudes, a malfunctioning fuel control system, turbulence, icing or running out of fuel.

Symptoms of a flameout normally are the same as those following an engine failure. If the flameout is due to a transitory condition, such as an imbalance between fuel flow and engine speed, an astart may be attempted once the condition is corrected. In any case, pilots must follow the applicable emergency procedures outlined in the AFM/POH. Generally these procedures contain recommendations concerning altitude and airspeed where the astart is most likely to be successful.

Performance Comparison

It is possible to compare the performance of a reciprocating powerplant and different types of turbine engines. For the comparison to be accurate, thrust horsepower (usable horsepower) for the reciprocating powerplant must be used rather than brake horsepower, and net thrust must be used for the turbine-powered engines. In addition, aircraft design configuration and size must be approximately the same. When comparing performance, the following definitions are useful:

Brake horsepower (BHP)—the horsepower actually delivered to the output shaft. Brake horsepower is the actual usable horsepower.

Net thrust—the thrust produced by a turbojet or turbofan engine.

Thrust horsepower (THP)—the horsepower equivalent of the thrust produced by a turbojet or turbofan engine.

Equivalent shaft horsepower (ESHP)—with respect to turboprop engines, the sum of the shaft horsepower (SHP) delivered to the propeller and THP produced by the exhaust gases.

Figure 6-29 shows how four types of engines compare in net thrust as airspeed is increased. This figure is for explanatory purposes only and is not for specific models of engines. The following are the four types of engines:

- Reciprocating powerplant
- Turbine, propeller combination (turboprop)
- Turbine engine incorporating a fan (turbofan)
- Turbojet (pure jet)

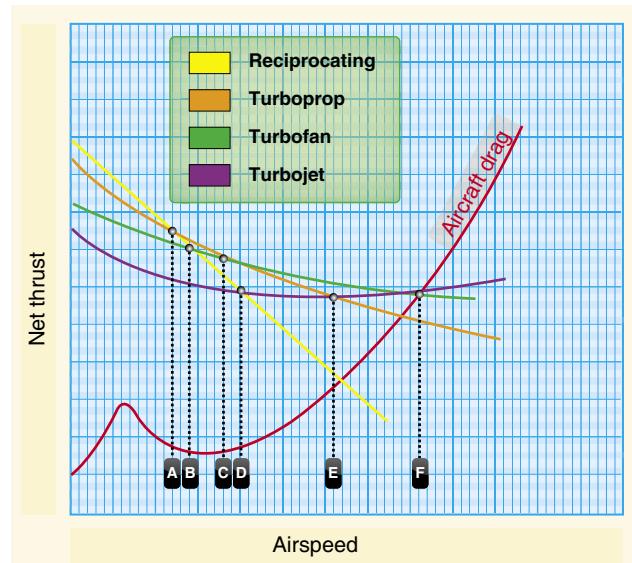


Figure 6-29. Engine net thrust versus aircraft speed and drag. Points A through F are explained in the text below.

By plotting the performance curve for each engine, a comparison can be made of maximum aircraft speed variation with the type of engine used. Since the graph is only a means of comparison, numerical values for net thrust, aircraft speed, and drag are not included.

Comparison of the four powerplants on the basis of net thrust makes certain performance capabilities evident. In the speed range shown to the left of line A, the reciprocating powerplant outperforms the other three types. The turboprop outperforms the turbofan in the range to the left of line C. The turbofan engine outperforms the turbojet in the range to the left of line F. The turbofan engine outperforms the reciprocating powerplant to the right of line B and the turboprop to the right of line C. The turbojet outperforms the reciprocating powerplant to the right of line D, the turboprop to the right of line E, and the turbofan to the right of line F.

The points where the aircraft drag curve intersects the net thrust curves are the maximum aircraft speeds. The vertical lines from each of the points to the baseline of the graph indicate that the turbojet aircraft can attain a higher maximum speed than aircraft equipped with the other types of engines. Aircraft equipped with the turbofan engine will attain a higher maximum speed than aircraft equipped with a turboprop or reciprocating powerplant.

Airframe Systems

Fuel, electrical, hydraulic, and oxygen systems make up the airframe systems.

Fuel Systems

The fuel system is designed to provide an uninterrupted flow of clean fuel from the fuel tanks to the engine. The fuel must be available to the engine under all conditions of engine power, altitude, attitude, and during all approved flight maneuvers. Two common classifications apply to fuel systems in small aircraft: gravity-feed and fuel-pump systems.

Gravity-Feed System

The gravity-feed system utilizes the force of gravity to transfer the fuel from the tanks to the engine. For example, on high-wing airplanes, the fuel tanks are installed in the wings. This places the fuel tanks above the carburetor, and the fuel is gravity fed through the system and into the carburetor. If the design of the aircraft is such that gravity cannot be used to transfer fuel, fuel pumps are installed. For example, on low-wing airplanes, the fuel tanks in the wings are located below the carburetor. [Figure 6-30]

Fuel-Pump System

Aircraft with fuel-pump systems have two fuel pumps. The main pump system is engine driven with an electrically driven auxiliary pump provided for use in engine starting and in the event the engine pump fails. The auxiliary pump, also known as a boost pump, provides added reliability to the fuel system. The electrically driven auxiliary pump is controlled by a switch in the flight deck.

Fuel Primer

Both gravity-feed and fuel-pump systems may incorporate a fuel primer into the system. The fuel primer is used to draw fuel from the tanks to vaporize fuel directly into the cylinders prior to starting the engine. During cold weather, when engines are difficult to start, the fuel primer helps because there is not enough heat available to vaporize the fuel in the carburetor. It is important to lock the primer in place when it is not in use. If the knob is free to move, it may vibrate out during flight and can cause an excessively rich mixture. To avoid overpriming, read the priming instructions for the aircraft.

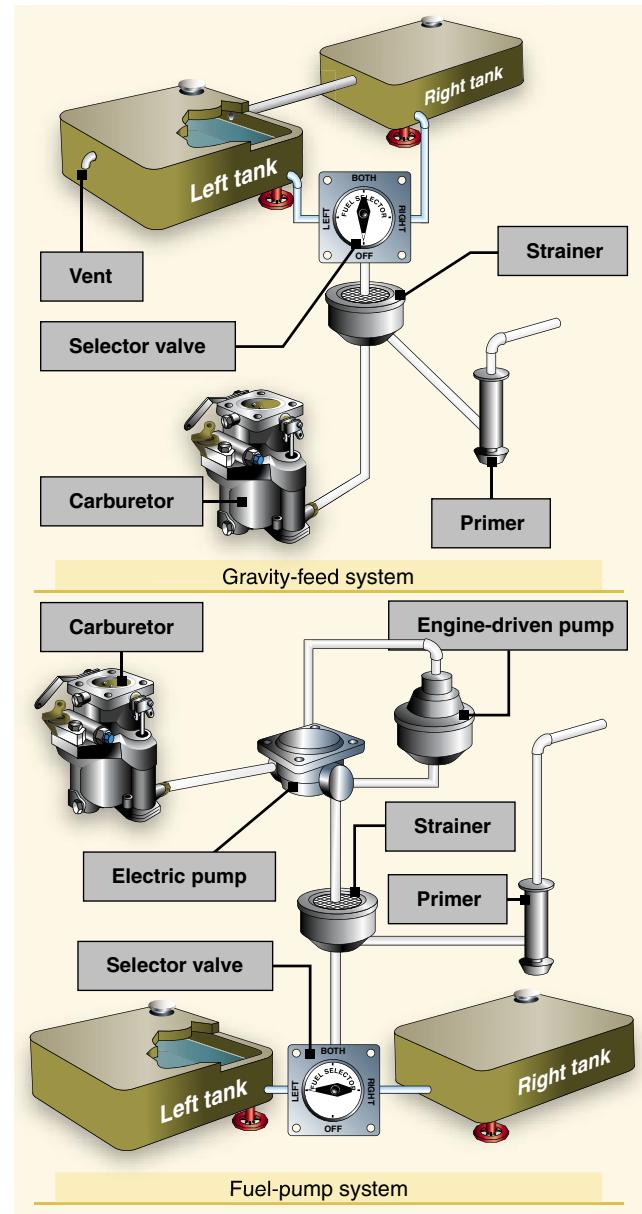


Figure 6-30. Gravity-feed and fuel-pump systems.

Fuel Tanks

The fuel tanks, normally located inside the wings of an airplane, have a filler opening on top of the wing through which they can be filled. A filler cap covers this opening. The tanks are vented to the outside to maintain atmospheric pressure inside the tank. They may be vented through the filler cap or through a tube extending through the surface of the wing. Fuel tanks also include an overflow drain that may stand alone or be collocated with the fuel tank vent. This allows fuel to expand with increases in temperature without damage to the tank itself. If the tanks have been filled on a hot day, it is not unusual to see fuel coming from the overflow drain.

Fuel Gauges

The fuel quantity gauges indicate the amount of fuel measured by a sensing unit in each fuel tank and is displayed in gallons or pounds. Aircraft certification rules require accuracy in fuel gauges only when they read “empty.” Any reading other than “empty” should be verified. Do not depend solely on the accuracy of the fuel quantity gauges. Always visually check the fuel level in each tank during the preflight inspection, and then compare it with the corresponding fuel quantity indication.

If a fuel pump is installed in the fuel system, a fuel pressure gauge is also included. This gauge indicates the pressure in the fuel lines. The normal operating pressure can be found in the AFM/POH or on the gauge by color coding.

Fuel Selectors

The fuel selector valve allows selection of fuel from various tanks. A common type of selector valve contains four positions: LEFT, RIGHT, BOTH, and OFF. Selecting the LEFT or RIGHT position allows fuel to feed only from that tank, while selecting the BOTH position feeds fuel from both tanks. The LEFT or RIGHT position may be used to balance the amount of fuel remaining in each wing tank. [Figure 6-31]

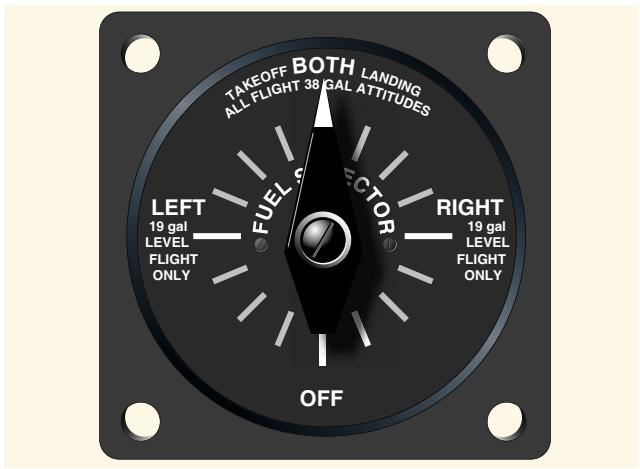


Figure 6-31. Fuel selector valve.

Fuel placards will show any limitations on fuel tank usage, such as “level flight only” and/or “both” for landings and takeoffs.

Regardless of the type of fuel selector in use, fuel consumption should be monitored closely to ensure that a tank does not run completely out of fuel. Running a fuel tank dry will not only cause the engine to stop, but running for prolonged periods on one tank causes an unbalanced fuel load between tanks. Running a tank completely dry may allow air to enter the fuel system and cause vapor lock, which makes it difficult to restart the engine. On fuel-injected engines, the fuel becomes

so hot it vaporizes in the fuel line, not allowing fuel to reach the cylinders.

Fuel Strainers, Sumps, and Drains

After leaving the fuel tank and before it enters the carburetor, the fuel passes through a strainer which removes any moisture and other sediments in the system. Since these contaminants are heavier than aviation fuel, they settle in a sump at the bottom of the strainer assembly. A sump is a low point in a fuel system and/or fuel tank. The fuel system may contain sump, fuel strainer, and fuel tank drains, which may be collocated.

The fuel strainer should be drained before each flight. Fuel samples should be drained and checked visually for water and contaminants.

Water in the sump is hazardous because in cold weather the water can freeze and block fuel lines. In warm weather, it can flow into the carburetor and stop the engine. If water is present in the sump, more water in the fuel tanks is probable and they should be drained until there is no evidence of water. Never take off until all water and contaminants have been removed from the engine fuel system.

Because of the variation in fuel systems, become thoroughly familiar with the systems that apply to the aircraft being flown. Consult the AFM/POH for specific operating procedures.

Fuel Grades

Aviation gasoline (AVGAS) is identified by an octane or performance number (grade), which designates the antiknock value or knock resistance of the fuel mixture in the engine cylinder. The higher the grade of gasoline, the more pressure the fuel can withstand without detonating. Lower grades of fuel are used in lower-compression engines because these fuels ignite at a lower temperature. Higher grades are used in higher-compression engines, because they ignite at higher temperatures, but not prematurely. If the proper grade of fuel is not available, use the next higher grade as a substitute. Never use a grade lower than recommended. This can cause the cylinder head temperature and engine oil temperature to exceed their normal operating ranges, which may result in detonation.

Several grades of AVGAS are available. Care must be exercised to ensure that the correct aviation grade is being used for the specific type of engine. The proper fuel grade is stated in the AFM/POH, on placards in the flight deck, and next to the filler caps. Auto gas should NEVER be used in aircraft engines unless the aircraft has been modified with a Supplemental Type Certificate (STC) issued by the Federal Aviation Administration (FAA).

The current method identifies AVGAS for aircraft with reciprocating engines by the octane and performance number, along with the abbreviation AVGAS. These aircraft use AVGAS 80, 100, and 100LL. Although AVGAS 100LL performs the same as grade 100, the “LL” indicates it has a low lead content. Fuel for aircraft with turbine engines is classified as JET A, JET A-1, and JET B. Jet fuel is basically kerosene and has a distinctive kerosene smell. Since use of the correct fuel is critical, dyes are added to help identify the type and grade of fuel. [Figure 6-32]

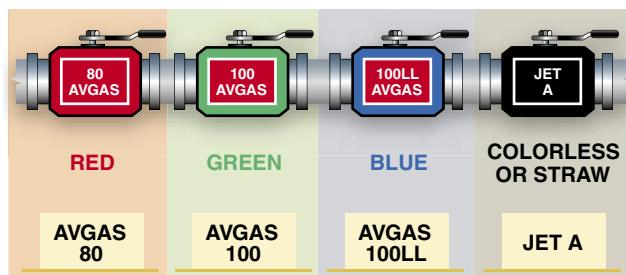


Figure 6-32. Aviation fuel color-coding system.

In addition to the color of the fuel itself, the color-coding system extends to decals and various airport fuel handling equipment. For example, all AVGAS is identified by name, using white letters on a red background. In contrast, turbine fuels are identified by white letters on a black background.

Fuel Contamination

Accidents attributed to powerplant failure from fuel contamination have often been traced to:

- Inadequate preflight inspection by the pilot.
- Servicing aircraft with improperly filtered fuel from small tanks or drums.
- Storing aircraft with partially filled fuel tanks.
- Lack of proper maintenance.

Fuel should be drained from the fuel strainer quick drain and from each fuel tank sump into a transparent container, and then checked for dirt and water. When the fuel strainer is being drained, water in the tank may not appear until all the fuel has been drained from the lines leading to the tank. This indicates that water remains in the tank, and is not forcing the fuel out of the fuel lines leading to the fuel strainer. Therefore, drain enough fuel from the fuel strainer to be certain that fuel is being drained from the tank. The amount will depend on the length of fuel line from the tank to the drain. If water or other contaminants are found in the first sample, drain further samples until no trace appears.

Water may also remain in the fuel tanks after the drainage from the fuel strainer has ceased to show any trace of water.

This residual water can be removed only by draining the fuel tank sump drains.

Water is the principal fuel contaminant. Suspended water droplets in the fuel can be identified by a cloudy appearance of the fuel, or by the clear separation of water from the colored fuel, which occurs after the water has settled to the bottom of the tank. As a safety measure, the fuel sumps should be drained before every flight during the preflight inspection.

Fuel tanks should be filled after each flight or after the last flight of the day to prevent moisture condensation within the tank. To prevent fuel contamination, avoid refueling from cans and drums.

In remote areas or in emergency situations, there may be no alternative to refueling from sources with inadequate anti-contamination systems. While a chamois skin and funnel may be the only possible means of filtering fuel, using them is hazardous. Remember, the use of a chamois will not always ensure decontaminated fuel. Worn-out chamois will not filter water; neither will a new, clean chamois that is already water-wet or damp. Most imitation chamois skins will not filter water.

Refueling Procedures

Static electricity is formed by the friction of air passing over the surfaces of an aircraft in flight and by the flow of fuel through the hose and nozzle during refueling. Nylon, Dacron, or wool clothing is especially prone to accumulate and discharge static electricity from the person to the funnel or nozzle. To guard against the possibility of static electricity igniting fuel fumes, a ground wire should be attached to the aircraft before the fuel cap is removed from the tank. Because both the aircraft and refueler have different static charges, bonding both components to each other is critical. By bonding both components to each other, the static differential charge is equalized. The refueling nozzle should be bonded to the aircraft before refueling begins and should remain bonded throughout the refueling process. When a fuel truck is used, it should be grounded prior to the fuel nozzle contacting the aircraft.

If fueling from drums or cans is necessary, proper bonding and grounding connections are important. Drums should be placed near grounding posts and the following sequence of connections observed:

1. Drum to ground
2. Ground to aircraft
3. Bond drum to aircraft or nozzle to aircraft before the fuel cap is removed

When disconnecting, reverse the order.

The passage of fuel through a chamois increases the charge of static electricity and the danger of sparks. The aircraft must be properly grounded and the nozzle, chamois filter, and funnel bonded to the aircraft. If a can is used, it should be connected to either the grounding post or the funnel. Under no circumstances should a plastic bucket or similar nonconductive container be used in this operation.

Electrical System

Most aircraft are equipped with either a 14- or a 28-volt direct current electrical system. A basic aircraft electrical system consists of the following components:

- Alternator/generator
- Battery
- Master/battery switch
- Alternator/generator switch
- Bus bar, fuses, and circuit breakers
- Voltage regulator
- Ammeter/loadmeter
- Associated electrical wiring

Engine-driven alternators or generators supply electric current to the electrical system. They also maintain a sufficient electrical charge in the battery. Electrical energy stored in a battery provides a source of electrical power for starting the engine and a limited supply of electrical power for use in the event the alternator or generator fails.

Most direct-current generators will not produce a sufficient amount of electrical current at low engine rpm to operate the entire electrical system. During operations at low engine rpm, the electrical needs must be drawn from the battery, which can quickly be depleted.

Alternators have several advantages over generators. Alternators produce sufficient current to operate the entire electrical system, even at slower engine speeds, by producing alternating current, which is converted to direct current. The electrical output of an alternator is more constant throughout a wide range of engine speeds.

Some aircraft have receptacles to which an external ground power unit (GPU) may be connected to provide electrical energy for starting. These are very useful, especially during cold weather starting. Follow the manufacturer's recommendations for engine starting using a GPU.

The electrical system is turned on or off with a master switch. Turning the master switch to the ON position provides electrical energy to all the electrical equipment circuits

except the ignition system. Equipment that commonly uses the electrical system for its source of energy includes:

- Position lights
- Anticollision lights
- Landing lights
- Taxi lights
- Interior cabin lights
- Instrument lights
- Radio equipment
- Turn indicator
- Fuel gauges
- Electric fuel pump
- Stall warning system
- Pitot heat
- Starting motor

Many aircraft are equipped with a battery switch that controls the electrical power to the aircraft in a manner similar to the master switch. In addition, an alternator switch is installed which permits the pilot to exclude the alternator from the electrical system in the event of alternator failure. [Figure 6-33]

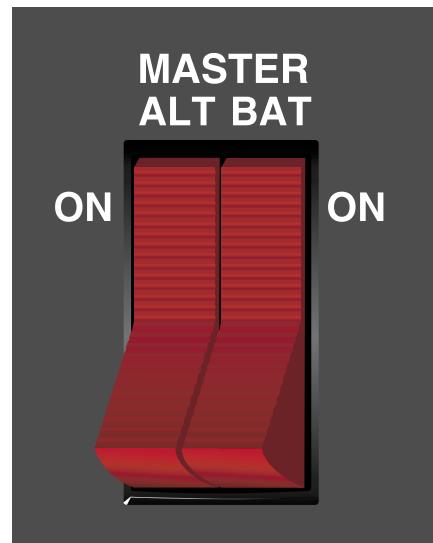


Figure 6-33. On this master switch, the left half is for the alternator and the right half is for the battery.

With the alternator half of the switch in the OFF position, the entire electrical load is placed on the battery. All nonessential electrical equipment should be turned off to conserve battery power.

A bus bar is used as a terminal in the aircraft electrical system to connect the main electrical system to the equipment using electricity as a source of power. This simplifies the wiring system and provides a common point from which voltage can be distributed throughout the system. [Figure 6-34]

Fuses or circuit breakers are used in the electrical system to protect the circuits and equipment from electrical overload.

Spare fuses of the proper amperage limit should be carried in the aircraft to replace defective or blown fuses. Circuit breakers have the same function as a fuse but can be manually reset, rather than replaced, if an overload condition occurs in the electrical system. Placards at the fuse or circuit breaker panel identify the circuit by name and show the amperage limit.

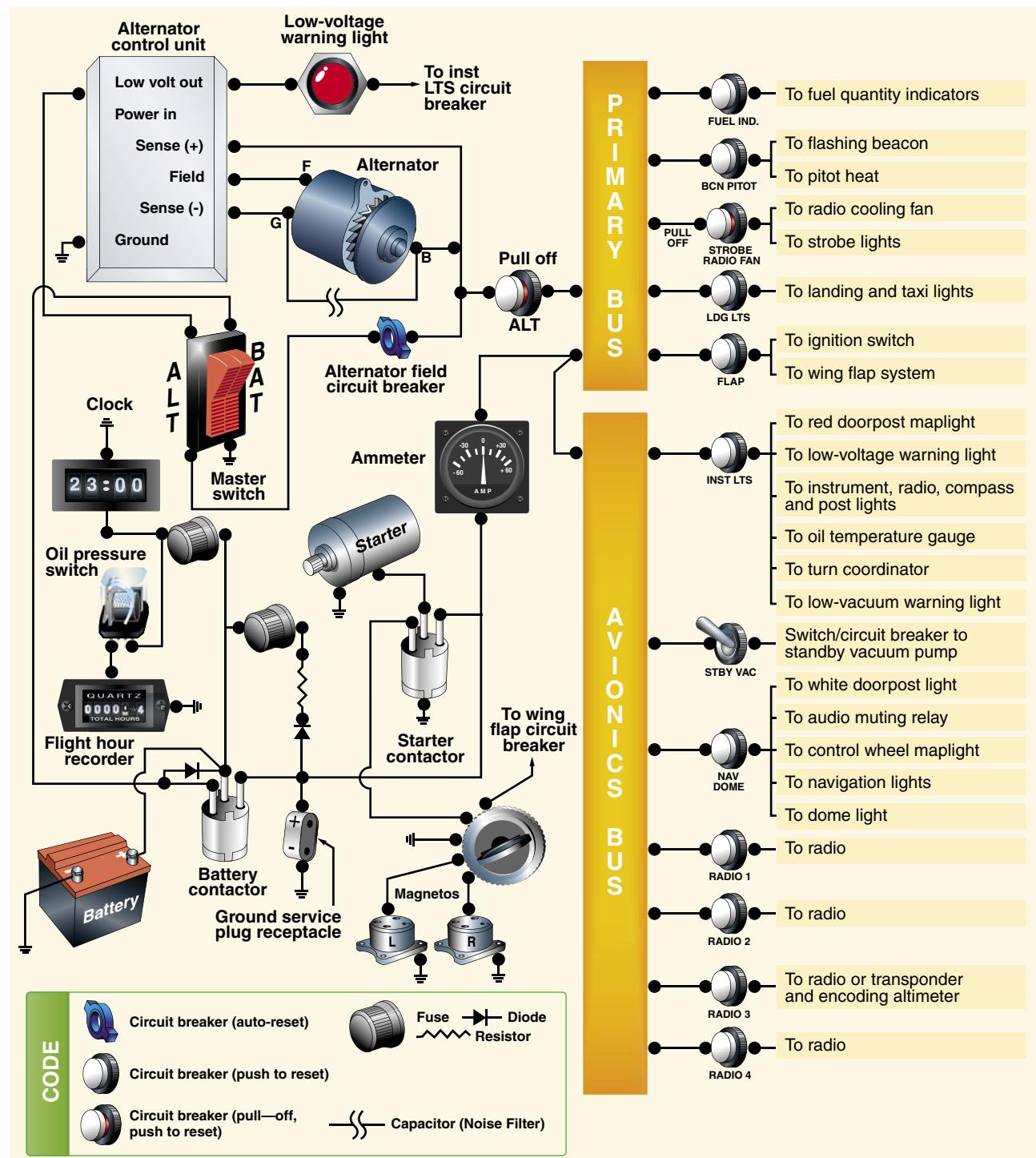


Figure 6-34. Electrical system schematic.

An ammeter is used to monitor the performance of the aircraft electrical system. The ammeter shows if the alternator/generator is producing an adequate supply of electrical power. It also indicates whether or not the battery is receiving an electrical charge.

Ammeters are designed with the zero point in the center of the face and a negative or positive indication on either side. [Figure 6-35] When the pointer of the ammeter is on the plus side, it shows the charging rate of the battery. A minus indication means more current is being drawn from the battery than is being replaced. A full-scale minus deflection indicates a malfunction of the alternator/generator. A full-scale positive deflection indicates a malfunction of the regulator. In either case, consult the AFM or POH for appropriate action to be taken.

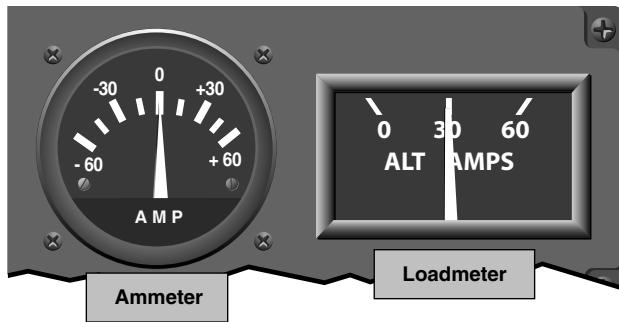


Figure 6-35. Ammeter and loadmeter.

Not all aircraft are equipped with an ammeter. Some have a warning light that, when lighted, indicates a discharge in the system as a generator/alternator malfunction. Refer to the AFM or POH for appropriate action to be taken.

Another electrical monitoring indicator is a loadmeter. This type of gauge has a scale beginning with zero and shows the load being placed on the alternator/generator. [Figure 6-35] The loadmeter reflects the total percentage of the load placed on the generating capacity of the electrical system by the electrical accessories and battery. When all electrical components are turned off, it reflects only the amount of charging current demanded by the battery.

A voltage regulator controls the rate of charge to the battery by stabilizing the generator or alternator electrical output. The generator/alternator voltage output should be higher than the battery voltage. For example, a 12-volt battery would be fed by a generator/alternator system of approximately 14 volts. The difference in voltage keeps the battery charged.

Hydraulic Systems

There are multiple applications for hydraulic use in aircraft, depending on the complexity of the aircraft. For example,

hydraulics is often used on small airplanes to operate wheel brakes, retractable landing gear, and some constant-speed propellers. On large airplanes, hydraulics is used for flight control surfaces, wing flaps, spoilers, and other systems.

A basic hydraulic system consists of a reservoir, pump (either hand, electric, or engine driven), a filter to keep the fluid clean, selector valve to control the direction of flow, relief valve to relieve excess pressure, and an actuator. [Figure 6-36]

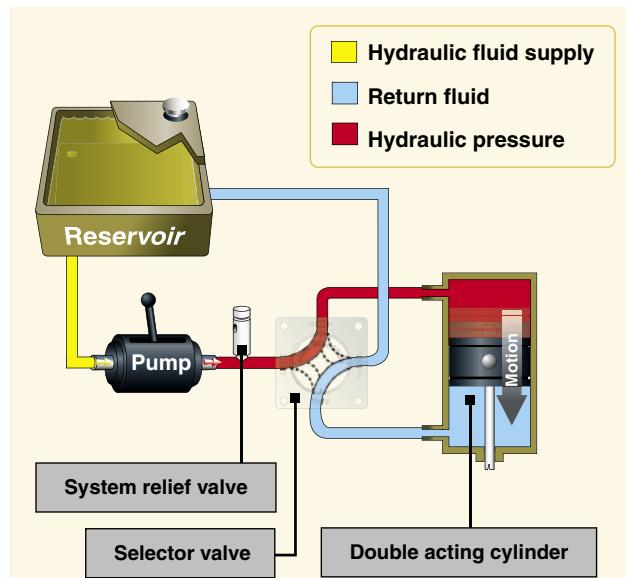


Figure 6-36. Basic hydraulic system.

The hydraulic fluid is pumped through the system to an actuator or servo. A servo is a cylinder with a piston inside that turns fluid power into work and creates the power needed to move an aircraft system or flight control. Servos can be either single-acting or double-acting, based on the needs of the system. This means that the fluid can be applied to one or both sides of the servo, depending on the servo type. A single-acting servo provides power in one direction. The selector valve allows the fluid direction to be controlled. This is necessary for operations such as the extension and retraction of landing gear during which the fluid must work in two different directions. The relief valve provides an outlet for the system in the event of excessive fluid pressure in the system. Each system incorporates different components to meet the individual needs of different aircraft.

A mineral-based hydraulic fluid is the most widely used type for small aircraft. This type of hydraulic fluid, a kerosene-like petroleum product, has good lubricating properties, as well as additives to inhibit foaming and prevent the formation of corrosion. It is chemically stable, has very little viscosity change with temperature, and is dyed for identification. Since several types of hydraulic fluids are commonly used,

an aircraft must be serviced with the type specified by the manufacturer. Refer to the AFM/POH or the Maintenance Manual.

Landing Gear

The landing gear forms the principal support of an aircraft on the surface. The most common type of landing gear consists of wheels, but aircraft can also be equipped with floats for water operations or skis for landing on snow. [Figure 6-37]



Figure 6-37. The landing gear supports the airplane during the takeoff run, landing, taxiing, and when parked.

The landing gear on small aircraft consists of three wheels: two main wheels (one located on each side of the fuselage) and a third wheel positioned either at the front or rear of the airplane. Landing gear employing a rear-mounted wheel is called conventional landing gear. Airplanes with conventional landing gear are often referred to as tailwheel airplanes. When the third wheel is located on the nose, it is called a nosewheel, and the design is referred to as a tricycle gear. A steerable nosewheel or tailwheel permits the airplane to be controlled throughout all operations while on the ground.

Tricycle Landing Gear Airplanes

A tricycle gear airplane has three advantages:

1. It allows more forceful application of the brakes during landings at high speeds without causing the aircraft to nose over.
2. It permits better forward visibility for the pilot during takeoff, landing, and taxiing.
3. It tends to prevent ground looping (swerving) by providing more directional stability during ground operation since the aircraft's center of gravity (CG) is forward of the main wheels. The forward CG keeps the airplane moving forward in a straight line rather than ground looping.

Nosewheels are either steerable or castering. Steerable nosewheels are linked to the rudders by cables or rods, while castering nosewheels are free to swivel. In both cases, the aircraft is steered using the rudder pedals. Aircraft with a castering nosewheel may require the pilot to combine the use of the rudder pedals with independent use of the brakes.

Tailwheel Landing Gear Airplanes

Tailwheel landing gear aircraft have two main wheels attached to the airframe ahead of its CG that support most of the weight of the structure. A tailwheel at the very back of the fuselage provides a third point of support. This arrangement allows adequate ground clearance for a larger propeller and is more desirable for operations on unimproved fields. [Figure 6-38]



Figure 6-38. Tailwheel landing gear.

With the CG located behind the main gear, directional control of this type aircraft becomes more difficult while on the ground. This is the main disadvantage of the tailwheel landing gear. For example, if the pilot allows the aircraft to swerve while rolling on the ground at a low speed, he or she may not have sufficient rudder control and the CG will attempt to get ahead of the main gear which may cause the airplane to ground loop.

Lack of good forward visibility when the tailwheel is on or near the ground is a second disadvantage of tailwheel landing gear aircraft. These inherent problems mean specific training is required in tailwheel aircraft.

Fixed and Retractable Landing Gear

Landing gear can also be classified as either fixed or retractable. A fixed gear always remains extended and has the advantage of simplicity combined with low maintenance. A retractable gear is designed to streamline the airplane by allowing the landing gear to be stowed inside the structure during cruising flight. [Figure 6-39]



Figure 6-39. Fixed (left) and retractable (right) gear airplanes.

Brakes

Airplane brakes are located on the main wheels and are applied by either a hand control or by foot pedals (toe or heel). Foot pedals operate independently and allow for differential braking. During ground operations, differential braking can supplement nosewheel/tailwheel steering.

Pressurized Aircraft

Aircraft are flown at high altitudes for two reasons. First, an aircraft flown at high altitude consumes less fuel for a given airspeed than it does for the same speed at a lower altitude because the aircraft is more efficient at a high altitude. Second, bad weather and turbulence may be avoided by flying in relatively smooth air above the storms. Many modern aircraft are being designed to operate at high altitudes, taking advantage of that environment. In order to fly at higher altitudes, the aircraft must be pressurized. It is important for pilots who fly these aircraft to be familiar with the basic operating principles.

In a typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit capable of containing air under a pressure higher than outside atmospheric pressure. On aircraft powered by turbine engines, bleed air from the engine compressor section is used to pressurize the cabin. Superchargers may be used on older model turbine-powered aircraft to pump air into the sealed fuselage. Piston-powered aircraft may use air supplied from each engine turbocharger through a sonic venturi (flow limiter). Air is released from the fuselage by a device called an outflow valve. By regulating the air exit, the outflow valve allows for a constant inflow of air to the pressurized area. [Figure 6-40]

A cabin pressurization system typically maintains a cabin pressure altitude of approximately 8,000 feet at the maximum designed cruising altitude of an aircraft. This prevents rapid changes of cabin altitude that may be uncomfortable or cause

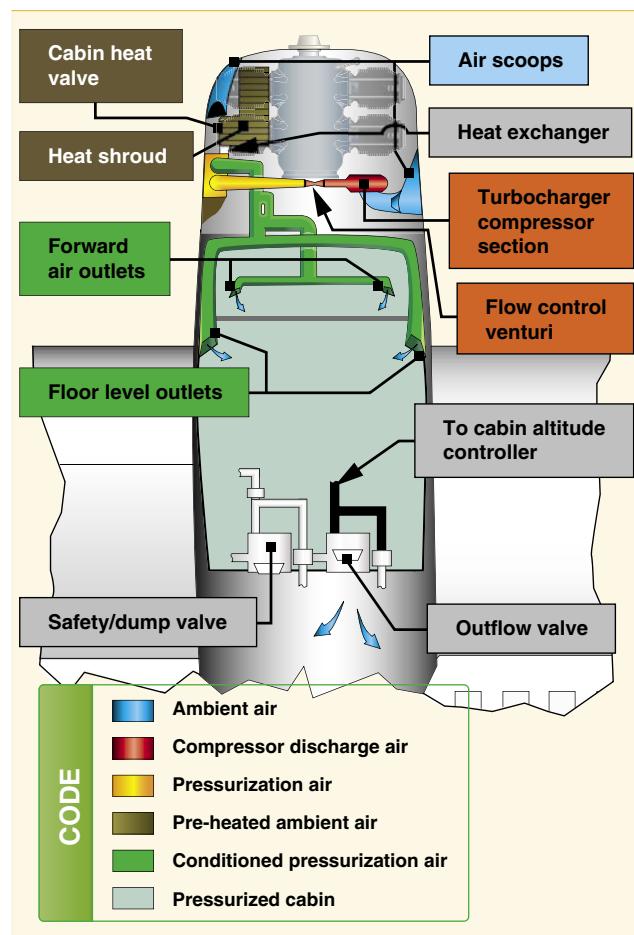


Figure 6-40. High performance airplane pressurization system.

injury to passengers and crew. In addition, the pressurization system permits a reasonably fast exchange of air from the inside to the outside of the cabin. This is necessary to eliminate odors and to remove stale air. [Figure 6-41]

Pressurization of the aircraft cabin is an accepted method of protecting occupants against the effects of hypoxia. Within a pressurized cabin, occupants can be transported comfortably

Atmosphere pressure	
Altitude (ft)	Pressure (psi)
Sea level	14.7
2,000	13.7
4,000	12.7
6,000	11.8
8,000	10.9
10,000	10.1
12,000	9.4
14,000	8.6
16,000	8.0
18,000	7.3
20,000	6.8
22,000	6.2
24,000	5.7
26,000	5.2
28,000	4.8
30,000	4.4

The altitude at which the standard air pressure is equal to 10.9 psi can be found at 8,000 feet.

At an altitude of 28,000 feet, standard atmospheric pressure is 4.8 psi. By adding this pressure to the cabin pressure differential of 6.1 psi difference (psid), a total air pressure of 10.9 psi is obtained.

Figure 6-41. Standard atmospheric pressure chart.

and safely for long periods of time, particularly if the cabin altitude is maintained at 8,000 feet or below, where the use of oxygen equipment is not required. The flight crew in this type of aircraft must be aware of the danger of accidental loss of cabin pressure and be prepared to deal with such an emergency whenever it occurs.

The following terms will aid in understanding the operating principles of pressurization and air conditioning systems:

- Aircraft altitude—the actual height above sea level at which the aircraft is flying
- Ambient temperature—the temperature in the area immediately surrounding the aircraft
- Ambient pressure—the pressure in the area immediately surrounding the aircraft
- Cabin altitude—cabin pressure in terms of equivalent altitude above sea level
- Differential pressure—the difference in pressure between the pressure acting on one side of a wall and the pressure acting on the other side of the wall. In aircraft air-conditioning and pressurizing systems, it is the difference between cabin pressure and atmospheric pressure.

The cabin pressure control system provides cabin pressure regulation, pressure relief, vacuum relief, and the means for selecting the desired cabin altitude in the isobaric and differential range. In addition, dumping of the cabin pressure is a function of the pressure control system. A cabin pressure regulator, an outflow valve, and a safety valve are used to accomplish these functions.

The cabin pressure regulator controls cabin pressure to a selected value in the isobaric range and limits cabin pressure to a preset differential value in the differential range. When an aircraft reaches the altitude at which the difference between the pressure inside and outside the cabin is equal to the highest differential pressure for which the fuselage structure is designed, a further increase in aircraft altitude will result in a corresponding increase in cabin altitude. Differential control is used to prevent the maximum differential pressure, for which the fuselage was designed, from being exceeded. This differential pressure is determined by the structural strength of the cabin and often by the relationship of the cabin size to the probable areas of rupture, such as window areas and doors.

The cabin air pressure safety valve is a combination pressure relief, vacuum relief, and dump valve. The pressure relief valve prevents cabin pressure from exceeding a predetermined differential pressure above ambient pressure. The vacuum relief prevents ambient pressure from exceeding cabin pressure by allowing external air to enter the cabin when ambient pressure exceeds cabin pressure. The flight deck control switch actuates the dump valve. When this switch is positioned to ram, a solenoid valve opens, causing the valve to dump cabin air to atmosphere.

The degree of pressurization and the operating altitude of the aircraft are limited by several critical design factors. Primarily, the fuselage is designed to withstand a particular maximum cabin differential pressure.

Several instruments are used in conjunction with the pressurization controller. The cabin differential pressure gauge indicates the difference between inside and outside pressure. This gauge should be monitored to assure that the cabin does not exceed the maximum allowable differential pressure. A cabin altimeter is also provided as a check on the performance of the system. In some cases, these two instruments are combined into one. A third instrument indicates the cabin rate of climb or descent. A cabin rate-of-climb instrument and a cabin altimeter are illustrated in *Figure 6-42*.

Decompression is defined as the inability of the aircraft's pressurization system to maintain its designed pressure differential. This can be caused by a malfunction in the pressurization system or structural damage to the aircraft.

Physiologically, decompressions fall into two categories:

- Explosive decompression—a change in cabin pressure faster than the lungs can decompress, possibly causing lung damage. Normally, the time required to release air from the lungs without restrictions, such as masks, is 0.2 seconds. Most authorities consider any



Figure 6-42. Cabin pressurization instruments.

decompression that occurs in less than 0.5 seconds to be explosive and potentially dangerous.

- Rapid decompression—a change in cabin pressure in which the lungs decompress faster than the cabin, resulting in no likelihood of lung damage.

During an explosive decompression, there may be noise, and one may feel dazed for a moment. The cabin air fills with fog, dust, or flying debris. Fog occurs due to the rapid drop in temperature and the change of relative humidity. Normally, the ears clear automatically. Air rushes from the mouth and nose due to the escape of air from the lungs, and may be noticed by some individuals.

Rapid decompression decreases the period of useful consciousness because oxygen in the lungs is exhaled rapidly, reducing pressure on the body. This decreases the partial pressure of oxygen in the blood and reduces the pilot's effective performance time by one-third to one-fourth its normal time. For this reason, an oxygen mask should be worn when flying at very high altitudes (35,000 feet or higher). It is recommended that the crewmembers select the 100 percent oxygen setting on the oxygen regulator at high altitude if the aircraft is equipped with a demand or pressure demand oxygen system.

The primary danger of decompression is hypoxia. Quick, proper utilization of oxygen equipment is necessary to avoid unconsciousness. Another potential danger that pilots, crew, and passengers face during high altitude decompressions is evolved gas decompression sickness. This occurs when the pressure on the body drops sufficiently, nitrogen comes out of solution, and forms bubbles that can have adverse effects on some body tissues.

Decompression caused by structural damage to the aircraft presents another type of danger to pilots, crew, and passengers—being tossed or blown out of the aircraft if they are located near openings. Individuals near openings should wear safety harnesses or seatbelts at all times when the aircraft is pressurized and they are seated. Structural damage also has the potential to expose them to wind blasts and extremely cold temperatures.

Rapid descent from altitude is necessary if these problems are to be minimized. Automatic visual and aural warning systems are included in the equipment of all pressurized aircraft.

Oxygen Systems

Most high altitude aircraft come equipped with some type of fixed oxygen installation. If the aircraft does not have a fixed installation, portable oxygen equipment must be readily accessible during flight. The portable equipment usually consists of a container, regulator, mask outlet, and pressure gauge. Aircraft oxygen is usually stored in high pressure system containers of 1,800–2,200 psi. When the ambient temperature surrounding an oxygen cylinder decreases, pressure within that cylinder decreases because pressure varies directly with temperature if the volume of a gas remains constant. If a drop in indicated pressure on a supplemental oxygen cylinder is noted, there is no reason to suspect depletion of the oxygen supply, which has simply been compacted due to storage of the containers in an unheated area of the aircraft. High pressure oxygen containers should be marked with the psi tolerance (i.e., 1,800 psi) before filling the container to that pressure. The containers should be supplied with aviation oxygen only, which is 100 percent pure oxygen. Industrial oxygen is not intended for breathing.

and may contain impurities, and medical oxygen contains water vapor that can freeze in the regulator when exposed to cold temperatures. To assure safety, periodic inspection and servicing of the oxygen system should be done.

An oxygen system consists of a mask or cannula and a regulator that supplies a flow of oxygen dependent upon cabin altitude. Cannulas are not approved for flights above 18,000 feet. Regulators approved for use up to 40,000 feet are designed to provide zero percent cylinder oxygen and 100 percent cabin air at cabin altitudes of 8,000 feet or less, with the ratio changing to 100 percent oxygen and zero percent cabin air at approximately 34,000 feet cabin altitude. [Figure 6-43] Regulators approved up to 45,000 feet are designed to provide 40 percent cylinder oxygen and 60 percent cabin air at lower altitudes, with the ratio changing to 100 percent at the higher altitude. Pilots should avoid flying above 10,000 feet without oxygen during the day and above 8,000 feet at night.



Figure 6-43. Oxygen system regulator.

Pilots should be aware of the danger of fire when using oxygen. Materials that are nearly fireproof in ordinary air may be susceptible to combustion in oxygen. Oils and greases may ignite if exposed to oxygen, and cannot be used for sealing the valves and fittings of oxygen equipment. Smoking during any kind of oxygen equipment use is prohibited. Before each flight, the pilot should thoroughly inspect and test all oxygen equipment. The inspection should include a thorough examination of the aircraft oxygen equipment, including available supply, an operational check of the system, and assurance that the supplemental oxygen is readily accessible. The inspection should be accomplished with clean hands and should include a visual inspection of the mask and tubing for tears, cracks, or deterioration; the regulator for valve and lever condition and positions; oxygen quantity; and the location and functioning of oxygen pressure gauges, flow indicators and connections. The mask should be donned and the system should be tested. After any oxygen use, verify that all components and valves are shut off.

Oxygen Masks

There are numerous types and designs of oxygen masks in use. The most important factor in oxygen mask use is to insure the masks and oxygen system are compatible. Crew masks are fitted to the user's face with a minimum of leakage and usually contain a microphone. Most masks are the oronasal type, which covers only the mouth and nose.

A passenger mask may be a simple, cup-shaped rubber molding sufficiently flexible to obviate individual fitting. It may have a simple elastic head strap or the passenger may hold it to his or her face.

All oxygen masks should be kept clean to reduce the danger of infection and prolong the life of the mask. To clean the mask, wash it with a mild soap and water solution and rinse it with clear water. If a microphone is installed, use a clean swab, instead of running water, to wipe off the soapy solution. The mask should also be disinfected. A gauze pad that has been soaked in a water solution of Merthiolate can be used to swab out the mask. This solution used should contain one-fifth teaspoon of Merthiolate per quart of water. Wipe the mask with a clean cloth and air dry.

Cannula

A cannula is an ergonomic piece of plastic tubing which runs under the nose and is often used to administer oxygen in non-pressurized aircraft. [Figure 6-44] Cannulas are typically more comfortable than masks and can be used up to 18,000 feet. Altitudes greater than 18,000 feet require the



Figure 6-44. Cannula with green flow detector.

use of an oxygen mask. Many cannulas have a flow meter in the line. If equipped, a periodic check of the green flow detector should be part of a pilot's regular scan.

Diluter-Demand Oxygen Systems

Diluter-demand oxygen systems supply oxygen only when the user inhales through the mask. An automix lever allows the regulators to automatically mix cabin air and oxygen or supply 100 percent oxygen, depending on the altitude. The demand mask provides a tight seal over the face to prevent dilution with outside air and can be used safely up to 40,000 feet. A pilot who has a beard or mustache should be sure it is trimmed in a manner that will not interfere with the sealing of the oxygen mask. The fit of the mask around the beard or mustache should be checked on the ground for proper sealing.

Pressure-Demand Oxygen Systems

Pressure-demand oxygen systems are similar to diluter demand oxygen equipment, except that oxygen is supplied to the mask under pressure at cabin altitudes above 34,000 feet. Pressure-demand regulators create airtight and oxygen-tight seals, but they also provide a positive pressure application of oxygen to the mask face piece that allows the user's lungs to be pressurized with oxygen. This feature makes pressure demand regulators safe at altitudes above 40,000 feet. Some systems may have a pressure demand mask with the regulator attached directly to the mask, rather than mounted on the instrument panel or other area within the flight deck. The mask-mounted regulator eliminates the problem of a long hose that must be purged of air before 100 percent oxygen begins flowing into the mask.

Continuous-Flow Oxygen System

Continuous-flow oxygen systems are usually provided for passengers. The passenger mask typically has a reservoir bag, which collects oxygen from the continuous-flow oxygen system during the time when the mask user is exhaling. The oxygen collected in the reservoir bag allows a higher respiratory flow rate during the inhalation cycle, which reduces the amount of air dilution. Ambient air is added to the supplied oxygen during inhalation after the reservoir bag oxygen supply is depleted. The exhaled air is released to the cabin. [Figure 6-45]

Electrical Pulse-Demand Oxygen System

Portable electrical pulse-demand oxygen systems deliver oxygen by detecting an individual's inhalation effort and provide oxygen flow during the initial portion of inhalation. Pulse demand systems do not waste oxygen during the breathing cycle because oxygen is only delivered during inhalation. Compared to continuous-flow systems, the pulse-demand method of oxygen delivery can reduce the amount



Figure 6-45. Continuous flow mask and rebreather bag.

of oxygen needed by 50–85 percent. Most pulse-demand oxygen systems also incorporate an internal barometer that automatically compensates for changes in altitude by increasing the amount of oxygen delivered for each pulse as altitude is increased. [Figure 6-46]



Figure 6-46. EDS-011 portable pulse-demand oxygen system.

Pulse Oximeters

A pulse oximeter is a device that measures the amount of oxygen in an individual's blood, in addition to heart rate. This non-invasive device measures the color changes that red blood cells undergo when they become saturated with oxygen. By transmitting a special light beam through a fingertip to evaluate the color of the red cells, a pulse oximeter can calculate the degree of oxygen saturation within one percent of directly measured blood oxygen. Because of their portability and speed, pulse oximeters are very useful for pilots operating in nonpressurized aircraft above 12,500 feet where supplemental oxygen is required. A pulse oximeter permits crewmembers and passengers of an aircraft to evaluate their actual need for supplemental oxygen. [Figure 6-47]



Figure 6-47. Onyx pulse oximeter.

Servicing of Oxygen Systems

Before servicing any aircraft with oxygen, consult the specific aircraft service manual to determine the type of equipment required and procedures to be used. Certain precautions should be observed whenever aircraft oxygen systems are to be serviced. Oxygen system servicing should be accomplished only when the aircraft is located outside of the hangars. Personal cleanliness and good housekeeping are imperative when working with oxygen. Oxygen under pressure and petroleum products create spontaneous results when they are brought in contact with each other. Service people should be certain to wash dirt, oil, and grease (including lip salves and hair oil) from their hands before working around oxygen equipment. It is also essential that clothing and tools are free of oil, grease, and dirt. Aircraft with permanently installed oxygen tanks usually require two persons to accomplish servicing of the system. One should be stationed at the service equipment control valves, and the other stationed where he or she can observe the aircraft system pressure gauges. Oxygen system servicing is not recommended during aircraft fueling operations or while other work is performed that could provide a source of ignition. Oxygen system servicing while passengers are on board the aircraft is not recommended.

Anti-Ice and Deice Systems

Anti-icing equipment is designed to prevent the formation of ice, while deicing equipment is designed to remove ice once it has formed. These systems protect the leading edge of wing and tail surfaces, pitot and static port openings, fuel tank vents, stall warning devices, windshields, and propeller blades. Ice detection lighting may also be installed on some aircraft to determine the extent of structural icing during night flights.

Most light aircraft have only a heated pitot tube and are not certified for flight in icing. These light aircraft have limited cross-country capability in the cooler climates during late fall, winter, and early spring. Noncertified aircraft must exit icing conditions immediately. Refer to the AFM/POH for details.

Airfoil Anti-Ice and Deice

Inflatable deicing boots consist of a rubber sheet bonded to the leading edge of the airfoil. When ice builds up on the leading edge, an engine-driven pneumatic pump inflates the rubber boots. Many turboprop aircraft divert engine bleed air to the wing to inflate the rubber boots. Upon inflation, the ice is cracked and should fall off the leading edge of the wing. Deicing boots are controlled from the flight deck by a switch and can be operated in a single cycle or allowed to cycle at automatic, timed intervals. [Figure 6-48]

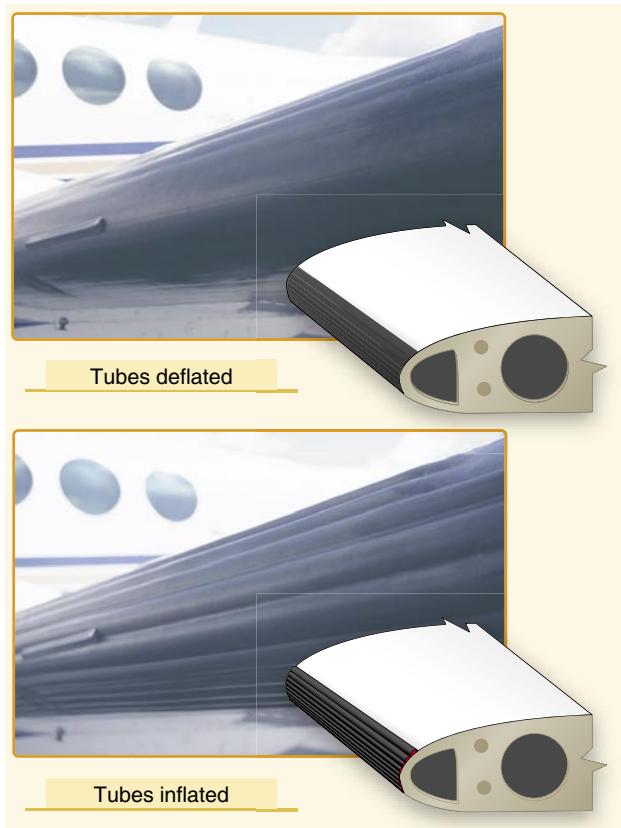


Figure 6-48. Deicing boots on the leading edge of the wing.

In the past it was believed that if the boots were cycled too soon after encountering ice, the ice layer would expand instead of breaking off, resulting in a condition referred to as ice “bridging.” Consequently, subsequent deice boot cycles would be ineffective at removing the ice buildup. Although some residual ice may remain after a boot cycle, “bridging” does not occur with any modern boots. Pilots can cycle the boots as soon as an ice accumulation is observed. Consult the AFM/POH for information on the operation of deice boots on an aircraft.

Many deicing boot systems use the instrument system suction gauge and a pneumatic pressure gauge to indicate proper boot operation. These gauges have range markings that indicate the operating limits for boot operation. Some systems may also incorporate an annunciator light to indicate proper boot operation.

Proper maintenance and care of deicing boots are important for continued operation of this system. They need to be carefully inspected during preflight.

Another type of leading edge protection is the thermal anti-ice system. Heat provides one of the most effective methods for preventing ice accumulation on an airfoil. High performance turbine aircraft often direct hot air from the compressor section of the engine to the leading edge surfaces. The hot air heats the leading edge surfaces sufficiently to prevent the formation of ice. A newer type of thermal anti-ice system referred to as thermawing uses electrically heated graphite foil laminate applied to the leading edge of the wing and horizontal stabilizer. Thermawing systems typically have two zones of heat application. One zone on the leading edge receives continuous heat; the second zone further aft receives heat in cycles to dislodge the ice allowing aerodynamic forces to remove it. Thermal anti-ice systems should be activated prior to entering icing conditions.

An alternate type of leading edge protection that is not as common as thermal anti-ice and deicing boots is known as a weeping wing. The weeping-wing design uses small holes located in the leading edge of the wing to prevent the formation and build-up of ice. An antifreeze solution is pumped to the leading edge and weeps out through the holes. Additionally, the weeping wing is capable of deicing an aircraft. When ice has accumulated on the leading edges, application of the antifreeze solution chemically breaks down the bond between the ice and airframe, allowing aerodynamic forces to remove the ice. [Figure 6-48]

Windscreen Anti-Ice

There are two main types of windscreen anti-ice systems. The first system directs a flow of alcohol to the windscreens.

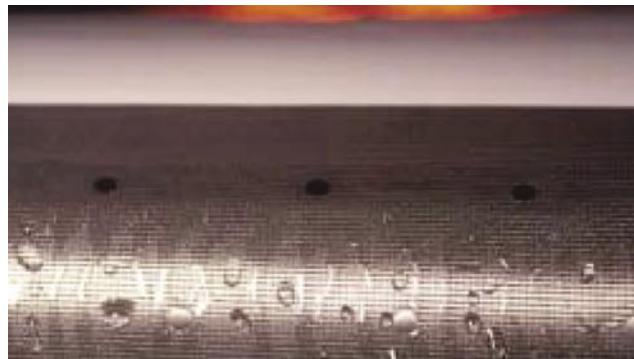


Figure 6-48. TKS weeping wing anti-ice/deicing system.

If used early enough, the alcohol will prevent ice from building up on the windscreens. The rate of alcohol flow can be controlled by a dial in the flight deck according to procedures recommended by the aircraft manufacturer.

Another effective method of anti-icing equipment is the electric heating method. Small wires or other conductive material is imbedded in the windscreens. The heater can be turned on by a switch in the flight deck, causing an electrical current to be passed across the shield through the wires to provide sufficient heat to prevent the formation of ice on the windscreens. The heated windscreens should only be used during flight. Do not leave it on during ground operations, as it can overheat and cause damage to the windscreens. Warning: the electrical current can cause compass deviation errors by as much as 40°.

Propeller Anti-Ice

Propellers are protected from icing by the use of alcohol or electrically heated elements. Some propellers are equipped with a discharge nozzle that is pointed toward the root of the blade. Alcohol is discharged from the nozzles, and centrifugal force drives the alcohol down the leading edge of the blade. The boots are also grooved to help direct the flow of alcohol. This prevents ice from forming on the leading edge of the propeller. Propellers can also be fitted with propeller anti-ice boots. The propeller boot is divided into two sections—the inboard and the outboard sections. The boots are imbedded with electrical wires that carry current for heating the propeller. The prop anti-ice system can be monitored for proper operation by monitoring the prop anti-ice ammeter. During the preflight inspection, check the propeller boots for proper operation. If a boot fails to heat one blade, an unequal blade loading can result, and may cause severe propeller vibration. [Figure 6-49]

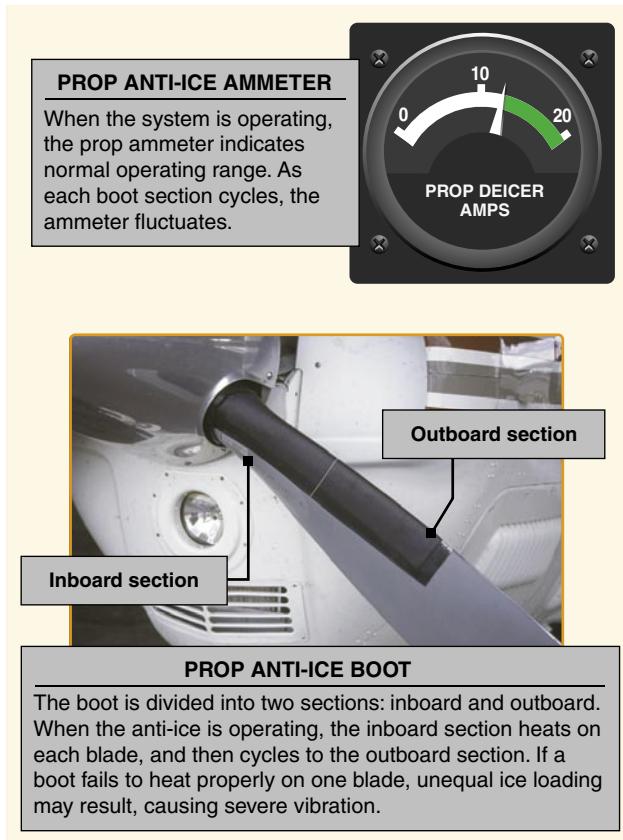


Figure 6-49. Prop ammeter and anti-ice boots.

Other Anti-Ice and Deice Systems

Pitot and static ports, fuel vents, stall-warning sensors, and other optional equipment may be heated by electrical elements. Operational checks of the electrically heated systems are to be checked in accordance with the AFM /POH.

Operation of aircraft anti-icing and deicing systems should be checked prior to encountering icing conditions. Encounters with structural ice require immediate action. Anti-icing and deicing equipment are not intended to sustain long-term flight in icing conditions.

Chapter Summary

All aircraft have a requirement for essential systems such as the engine, propeller, induction, ignition systems as well as the fuel, lubrication, cooling, electrical, landing gear, and environmental control systems to support flight. Understanding the aircraft systems of the aircraft being flown is critical to its safe operation and proper maintenance. Consult the AFM/POH for specific information pertaining to the aircraft being flown. Various manufacturer and owners group websites can also be a valuable source of additional information.

Chapter 7

Flight Instruments

Introduction

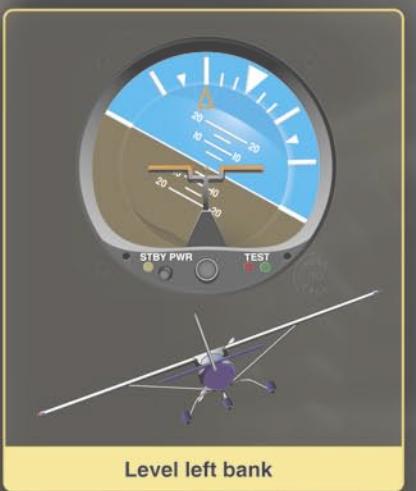
In order to safely fly any aircraft, a pilot must understand how to interpret and operate the flight instruments. The pilot also needs to be able to recognize associated errors and malfunctions of these instruments. This chapter addresses the pitot-static system and associated instruments, the vacuum system and related instruments, gyroscopic instruments, and the magnetic compass. When a pilot understands how each instrument works and recognizes when an instrument is malfunctioning, he or she can safely utilize the instruments to their fullest potential.

Pitot-Static Flight Instruments

The pitot-static system is a combined system that utilizes the static air pressure, and the dynamic pressure due to the motion of the aircraft through the air. These combined pressures are utilized for the operation of the airspeed indicator (ASI), altimeter, and vertical speed indicator (VSI). [Figure 7-1]



Climbing left bank



Level left bank



Descending left bank



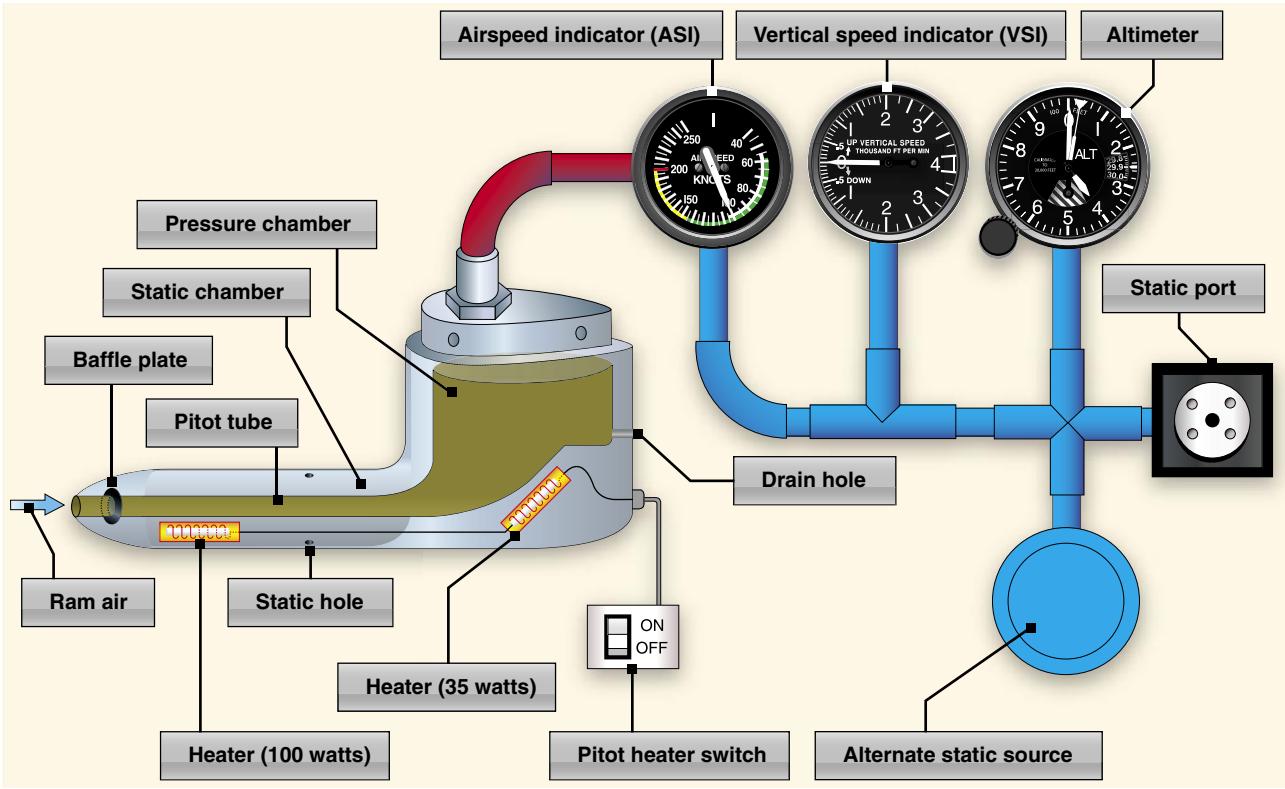


Figure 7-1. Pitot-static system and instruments.

Impact Pressure Chamber and Lines

The pitot tube is utilized to measure the total combined pressures that are present when an aircraft moves through the air. Static pressure, also known as ambient pressure, is always present whether an aircraft is moving or at rest. It is simply the barometric pressure in the local area. Dynamic pressure is present only when an aircraft is in motion; therefore, it can be thought of as a pressure due to motion. Wind also generates dynamic pressure. It does not matter if the aircraft is moving through still air at 70 knots or if the aircraft is facing a wind with a speed of 70 knots, the same dynamic pressure is generated.

When the wind blows from an angle less than 90° off the nose of the aircraft, dynamic pressure can be depicted on the ASI. The wind moving across the airfoil at 20 knots is the same as the aircraft moving through calm air at 20 knots. The pitot tube captures the dynamic pressure, as well as the static pressure that is always present.

The pitot tube has a small opening at the front which allows the total pressure to enter the pressure chamber. The total pressure is made up of dynamic pressure plus static pressure. In addition to the larger hole in the front of the pitot tube, there is a small hole in the back of the chamber which allows moisture to drain from the system should the aircraft enter precipitation. Both openings in the pitot tube need to

be checked prior to flight to insure that neither is blocked. Many aircraft have pitot tube covers installed when they sit for extended periods of time. This helps to keep bugs and other objects from becoming lodged in the opening of the pitot tube.

The one instrument that utilizes the pitot tube is the ASI. The total pressure is transmitted to the ASI from the pitot tube's pressure chamber via a small tube. The static pressure is also delivered to the opposite side of the ASI which serves to cancel out the two static pressures, thereby leaving the dynamic pressure to be indicated on the instrument. When the dynamic pressure changes, the ASI shows either increase or decrease, corresponding to the direction of change. The two remaining instruments (altimeter and VSI) utilize only the static pressure which is derived from the static port.

Static Pressure Chamber and Lines

The static chamber is vented through small holes to the free undisturbed air on the side(s) of the aircraft. As the atmospheric pressure changes, the pressure is able to move freely in and out of the instruments through the small lines which connect the instruments into the static system. An alternate static source is provided in some aircraft to provide static pressure should the primary static source become blocked. The alternate static source is normally found inside of the flight deck. Due to the venturi effect of the air flowing

around the fuselage, the air pressure inside the flight deck is lower than the exterior pressure.

When the alternate static source pressure is used, the following instrument indications are observed:

1. The altimeter indicates a slightly higher altitude than actual.
2. The ASI indicates an airspeed greater than the actual airspeed.
3. The VSI shows a momentary climb and then stabilizes if the altitude is held constant.

Each pilot is responsible for consulting the Aircraft Flight Manual (AFM) or the Pilot's Operating Handbook (POH) to determine the amount of error that is introduced into the system when utilizing the alternate static source. In an aircraft not equipped with an alternate static source, an alternate method of introducing static pressure into the system should a blockage occur is to break the glass face of the VSI. This most likely renders the VSI inoperative. The reason for choosing the VSI as the instrument to break is that it is the least important static source instrument for flight.

Altimeter

The altimeter is an instrument that measures the height of an aircraft above a given pressure level. Pressure levels are discussed later in detail. Since the altimeter is the only instrument that is capable of indicating altitude, this is one of the most vital instruments installed in the aircraft. To use the altimeter effectively, the pilot must understand the operation of the instrument, as well as the errors associated with the altimeter and how each effect the indication.

A stack of sealed aneroid wafers comprise the main component of the altimeter. An aneroid wafer is a sealed wafer that is evacuated to an internal pressure of 29.92 inches of mercury (29.92 "Hg). These wafers are free to expand and contract with changes to the static pressure. A higher static pressure presses down on the wafers and causes them to collapse. A lower static pressure (less than 29.92 "Hg) allows the wafers to expand. A mechanical linkage connects the wafer movement to the needles on the indicator face, which translates compression of the wafers into a decrease in altitude and translates an expansion of the wafers into an increase in altitude. [Figure 7-2]

Notice how the static pressure is introduced into the rear of the sealed altimeter case. The altimeter's outer chamber is sealed, which allows the static pressure to surround the aneroid wafers. If the static pressure is higher than the pressure in the aneroid wafers (29.92 "Hg), then the wafers are compressed until the pressure inside the wafers is equal to the surrounding

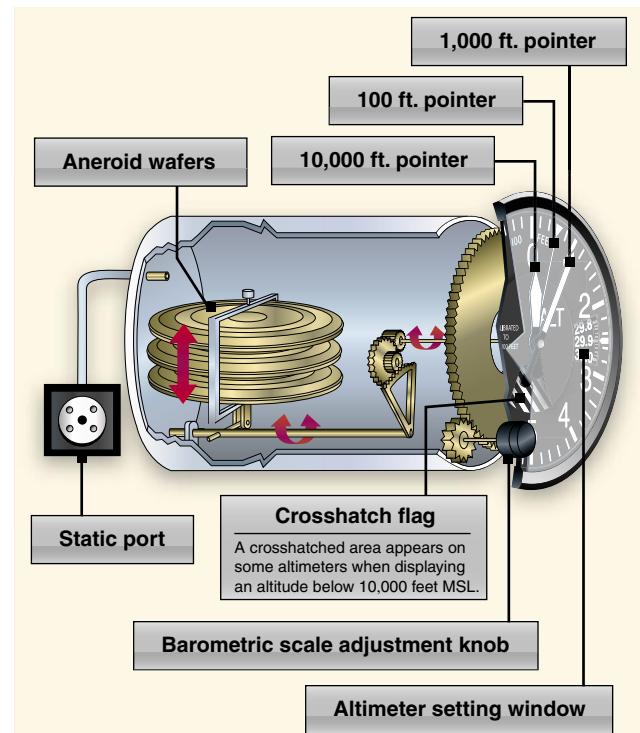


Figure 7-2. Altimeter.

static pressure. Conversely, if the static pressure is less than the pressure inside of the wafers, the wafers are able to expand which increases the volume. The expansion and contraction of the wafers moves the mechanical linkage, which drives the needles on the face of the ASI.

Principle of Operation

The pressure altimeter is an aneroid barometer that measures the pressure of the atmosphere at the level where the altimeter is located, and presents an altitude indication in feet. The altimeter uses static pressure as its source of operation. Air is denser at sea level than aloft—as altitude increases, atmospheric pressure decreases. This difference in pressure at various levels causes the altimeter to indicate changes in altitude.

The presentation of altitude varies considerably between different types of altimeters. Some have one pointer while others have two or more. Only the multipointer type is discussed in this handbook. The dial of a typical altimeter is graduated with numerals arranged clockwise from zero to nine. Movement of the aneroid element is transmitted through gears to the three hands that indicate altitude. The shortest hand indicates altitude in tens of thousands of feet, the intermediate hand in thousands of feet, and the longest hand in hundreds of feet.

This indicated altitude is correct, however, only when the sea level barometric pressure is standard (29.92 "Hg), the sea level free air temperature is standard (+15 degrees Celsius ($^{\circ}\text{C}$) or 59 degrees Fahrenheit ($^{\circ}\text{F}$)), and the pressure and temperature decrease at a standard rate with an increase in altitude. Adjustments for nonstandard pressures are accomplished by setting the corrected pressure into a barometric scale located on the face of the altimeter. The barometric pressure window is sometimes referred to as the Kollsman window; only after the altimeter is set does it indicate the correct altitude. The word “correct” will need to be better explained when referring to types of altitudes, but is commonly used in this case to denote the approximate altitude above sea level. In other words, the indicated altitude refers to the altitude read off of the altitude which is uncorrected, after the barometric pressure setting is dialed into the Kollsman window. The additional types of altitudes are further explained later.

Effect of Nonstandard Pressure and Temperature

It is easy to maintain a consistent height above ground if the barometric pressure and temperature remain constant, but this is rarely the case. The pressure temperature can change between takeoff and landing even on a local flight. If these changes are not taken into consideration, flight becomes dangerous.

If altimeters could not be adjusted for nonstandard pressure, a hazardous situation could occur. For example, if an aircraft is flown from a high pressure area to a low pressure area without adjusting the altimeter, a constant altitude will be displayed, but the actual height of the aircraft above the ground would be lower than the indicated altitude. There is an old aviation axiom: “GOING FROM A HIGH TO A LOW, LOOK OUT

BELOW.” Conversely, if an aircraft is flown from a low pressure area to a high pressure area without an adjustment of the altimeter, the actual altitude of the aircraft is higher than the indicated altitude. Once in flight, it is important to frequently obtain current altimeter settings en route to ensure terrain and obstruction clearance.

Many altimeters do not have an accurate means of being adjusted for barometric pressures in excess of 31.00 inches of mercury ("Hg). When the altimeter cannot be set to the higher pressure setting, the aircraft actual altitude will be higher than the altimeter indicates. When low barometric pressure conditions occur (below 28.00), flight operations by aircraft unable to set the actual altimeter setting are not recommended.

Adjustments to compensate for nonstandard pressure do not compensate for nonstandard temperature. Since cold air is denser than warm air, when operating in temperatures that are colder than standard, the altitude is lower than the altimeter indication. [Figure 7-3] It is the magnitude of this “difference” that determines the magnitude of the error. It is the difference due to colder temperatures that concerns the pilot. When flying into a cooler air mass while maintaining a constant indicated altitude, true altitude is lower. If terrain or obstacle clearance is a factor in selecting a cruising altitude, particularly in mountainous terrain, remember to anticipate that a colder-than-standard temperature places the aircraft lower than the altimeter indicates. Therefore, a higher indicated altitude may be required to provide adequate terrain clearance. A variation of the memory aid used for pressure can be employed: “FROM HOT TO COLD, LOOK OUT BELOW.” When the air is warmer than standard, the aircraft is higher than the

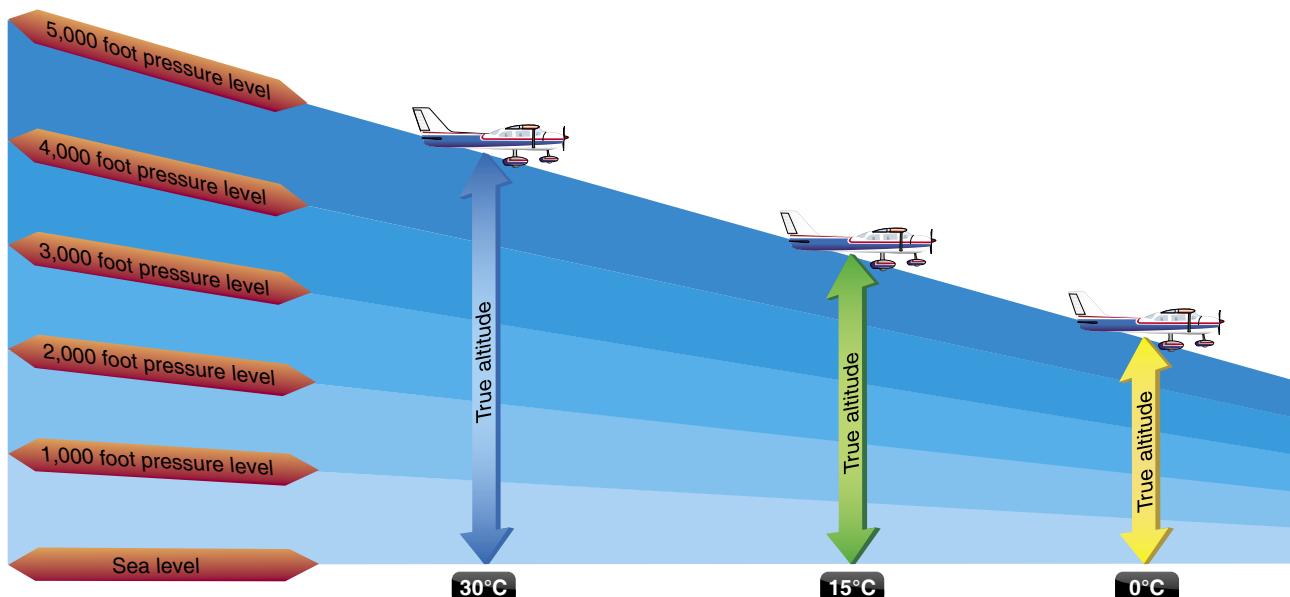


Figure 7-3. Effects of nonstandard temperature on an altimeter.

altimeter indicates. Altitude corrections for temperature can be computed on the navigation computer.

Extremely cold temperatures will also affect altimeter indications. *Figure 7-4*, which was derived from ICAO formulas, indicates how much error can exist when the temperature is extremely cold.

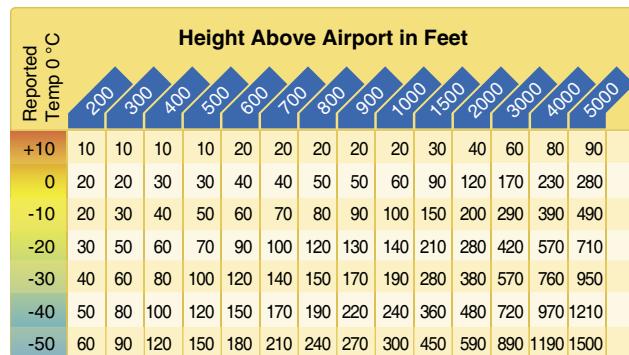


Figure 7-4. Look at the chart using a temperature of -10°C and the aircraft altitude is 1,000 feet above the airport elevation. The chart shows that the reported current altimeter setting may place the aircraft as much as 100 feet below the altitude indicated by the altimeter.

Setting the Altimeter

Most altimeters are equipped with a barometric pressure setting window (or Kollsman window) providing a means to adjust the altimeter. A knob is located at the bottom of the instrument for this adjustment.

To adjust the altimeter for variation in atmospheric pressure, the pressure scale in the altimeter setting window, calibrated in inches of mercury ("Hg) and/or millibars (mb), is adjusted to match the given altimeter setting. Altimeter setting is defined as station pressure reduced to sea level, but, an altimeter setting is accurate only in the vicinity of the reporting station. Therefore, the altimeter must be adjusted as the flight progresses from one station to the next. Air traffic control (ATC) will advise when updated altimeter settings are available. If a pilot is not utilizing ATC assistance, local altimeter settings can be obtained by monitoring local automated weather observing system/automated surface observation system (AWOS/ASOS) or automatic terminal information service (ATIS) broadcasts.

Many pilots confidently expect the current altimeter setting will compensate for irregularities in atmospheric pressure at all altitudes, but this is not always true. The altimeter setting broadcast by ground stations is the station pressure corrected to mean sea level. It does not account for the irregularities at higher levels, particularly the effect of nonstandard temperature.

If each pilot in a given area is using the same altimeter setting, each altimeter should be equally affected by temperature and pressure variation errors, making it possible to maintain the desired vertical separation between aircraft. This does not guarantee vertical separation though. It is still imperative to maintain a regimented visual scan for intruding air traffic.

When flying over high, mountainous terrain, certain atmospheric conditions cause the altimeter to indicate an altitude of 1,000 feet or more higher than the actual altitude. For this reason, a generous margin of altitude should be allowed—not only for possible altimeter error, but also for possible downdrafts that might be associated with high winds.

To illustrate the use of the altimeter setting system, follow a flight from Dallas Love Field, Texas, to Abilene Municipal Airport, Texas, via Mineral Wells. Before taking off from Love Field, the pilot receives a current altimeter setting of 29.85 "Hg from the control tower or ATIS, and sets this value in the altimeter setting window. The altimeter indication should then be compared with the known airport elevation of 487 feet. Since most altimeters are not perfectly calibrated, an error may exist.

When over Mineral Wells, assume the pilot receives a current altimeter setting of 29.94 "Hg and sets this in the altimeter window. Before entering the traffic pattern at Abilene Municipal Airport, a new altimeter setting of 29.69 "Hg is received from the Abilene Control Tower, and set in the altimeter setting window. If the pilot desires to fly the traffic pattern at approximately 800 feet above the terrain, and the field elevation of Abilene is 1,791 feet, an indicated altitude of 2,600 feet should be maintained ($1,791 \text{ feet} + 800 \text{ feet} = 2,591 \text{ feet}$, rounded to 2,600 feet).

The importance of properly setting the altimeter cannot be overemphasized. Assume the pilot did not adjust the altimeter at Abilene to the current setting and continued using the Mineral Wells setting of 29.94 "Hg. When entering the Abilene traffic pattern at an indicated altitude of 2,600 feet, the aircraft would be approximately 250 feet below the proper traffic pattern altitude. Upon landing, the altimeter would indicate approximately 250 feet higher than the field elevation.

Mineral Wells altimeter setting	29.94
Abilene altimeter setting	29.69
Difference	0.25

(Since 1 inch of pressure is equal to approximately 1,000 feet of altitude, $0.25 \times 1,000 \text{ feet} = 250 \text{ feet}$.)

When determining whether to add or subtract the amount of altimeter error, remember that, when the actual pressure is lower than what is set in the altimeter window, the actual altitude of the aircraft is lower than what is indicated on the altimeter.

The following is another method of computing the altitude deviation. Start by subtracting the current altimeter setting from 29.94 "Hg. Always remember to place the original setting as the top number. Then subtract the current altimeter setting.

Mineral Wells altimeter setting	29.94
Abilene altimeter setting	29.69
29.94 – 29.69 = Difference	0.25

(Since 1 inch of pressure is equal to approximately 1,000 feet of altitude, $0.25 \times 1,000$ feet = 250 feet.) Always subtract the number from the indicated altitude.

$$2,600 - 250 = 2,350$$

Now, try a lower pressure setting. Adjust from altimeter setting 29.94 to 30.56 "Hg.

Mineral Wells altimeter setting	29.94
Altimeter setting	30.56
29.94 – 30.56 = Difference	-0.62

(Since 1 inch of pressure is equal to approximately 1,000 feet of altitude, $0.62 \times 1,000$ feet = 620 feet.) Always subtract the number from the indicated altitude.

$$2,600 - (-620) = 3,220$$

The pilot will be 620 feet high.

Notice the difference is a negative number. Starting with the current indicated altitude of 2,600 feet, subtracting a negative number is the same as adding the two numbers. By utilizing this method, a pilot should be able to better understand what is happening with the aircraft's altitude. This method always yields the correct result and tells a pilot what the altitude is and the direction. (The implications of not understanding where the errors lie and in what direction are important to a safe flight.) If the altitude was lower than actually indicated, an aircraft could be in danger of colliding with an obstacle.

Altimeter Operation

There are two means by which the altimeter pointers can be moved. The first is a change in air pressure, while the other is an adjustment to the barometric scale. When the aircraft climbs or descends, changing pressure within the altimeter case expands or contracts the aneroid barometer.

This movement is transmitted through mechanical linkage to rotate the pointers.

A decrease in pressure causes the altimeter to indicate an increase in altitude, and an increase in pressure causes the altimeter to indicate a decrease in altitude. Accordingly, if the aircraft is sitting on the ground with a pressure level of 29.98 "Hg and the pressure level changes to 29.68 "Hg, the altimeter would show an increase of approximately 300 feet in altitude. This pressure change is most noticeable when the aircraft is left parked over night. As the pressure falls, the altimeter interprets this as a climb. The altimeter indicates an altitude above the actual field elevation. If the barometric pressure setting is reset to the current altimeter setting of 29.68 "Hg, then the field elevation is again indicated on the altimeter.

This pressure change is not as easily noticed in flight since aircraft fly specific altitudes. The aircraft steadily decreases true altitude while the altimeter is held constant through pilot action as discussed in the previous section.

Knowing the aircraft's altitude is vitally important to a pilot. The pilot must be sure that the aircraft is flying high enough to clear the highest terrain or obstruction along the intended route. It is especially important to have accurate altitude information when visibility is restricted. To clear obstructions, the pilot must constantly be aware of the altitude of the aircraft and the elevation of the surrounding terrain. To reduce the possibility of a midair collision, it is essential to maintain altitude in accordance with air traffic rules.

Types of Altitude

Altitude in itself is a relevant term only when it is specifically stated to which type of altitude a pilot is referring to. Normally when the term altitude is used, it is referring to altitude above sea level since this is the altitude which is used to depict obstacles and airspace, as well as to separate air traffic.

Altitude is vertical distance above some point or level used as a reference. There are as many kinds of altitude as there are reference levels from which altitude is measured, and each may be used for specific reasons. Pilots are mainly concerned with five types of altitudes:

1. Indicated altitude—read directly from the altimeter (uncorrected) when it is set to the current altimeter setting.
2. True altitude—the vertical distance of the aircraft above sea level—the actual altitude. It is often expressed as feet above mean sea level (MSL). Airport, terrain,

and obstacle elevations on aeronautical charts are true altitudes.

3. Absolute altitude—the vertical distance of an aircraft above the terrain, or above ground level (AGL).
4. Pressure altitude—the altitude indicated when the altimeter setting window (barometric scale) is adjusted to 29.92 "Hg. This is the altitude above the standard datum plane, which is a theoretical plane where air pressure (corrected to 15 °C) equals 29.92" Hg. Pressure altitude is used to compute density altitude, true altitude, true airspeed (TAS), and other performance data.
5. Density altitude—pressure altitude corrected for variations from standard temperature. When conditions are standard, pressure altitude and density altitude are the same. If the temperature is above standard, the density altitude is higher than pressure altitude. If the temperature is below standard, the density altitude is lower than pressure altitude. This is an important altitude because it is directly related to the aircraft's performance.

A pilot must understand how the performance of the aircraft is directly related to the density of the air. The density of the air affects how much power a naturally aspirated engine produces, as well as how efficient the airfoils are. If there are fewer air molecules (lower pressure) to accelerate through the propeller, the acceleration to rotation speed is longer and thus produces a longer takeoff roll, which translates to a decrease in performance.

As an example, consider an airport with a field elevation of 5,048 feet MSL where the standard temperature is 5 °C. Under these conditions, pressure altitude and density altitude are the same—5,048 feet. If the temperature changes to 30 °C, the density altitude increases to 7,855 feet. This means an aircraft would perform on takeoff as though the field elevation were 7,855 feet at standard temperature. Conversely, a temperature of -25 °C would result in a density altitude of 1,232 feet. An aircraft would perform much better under these conditions.

Instrument Check

Prior to each flight, a pilot should examine the altimeter for proper indications in order to verify its validity. To determine the condition of an altimeter, set the barometric scale to the current reported altimeter setting transmitted by the local automated flight service station (AFSS) or any other reliable source, such as ATIS, AWOS, or ASOS. The altimeter pointers should indicate the surveyed field elevation of the airport. If the indication is off more than 75 feet from the

surveyed field elevation, the instrument should be referred to a certificated instrument repair station for recalibration.

Vertical Speed Indicator (VSI)

The VSI, which is sometimes called a vertical velocity indicator (VVI), indicates whether the aircraft is climbing, descending, or in level flight. The rate of climb or descent is indicated in feet per minute (fpm). If properly calibrated, the VSI indicates zero in level flight. [Figure 7-5]

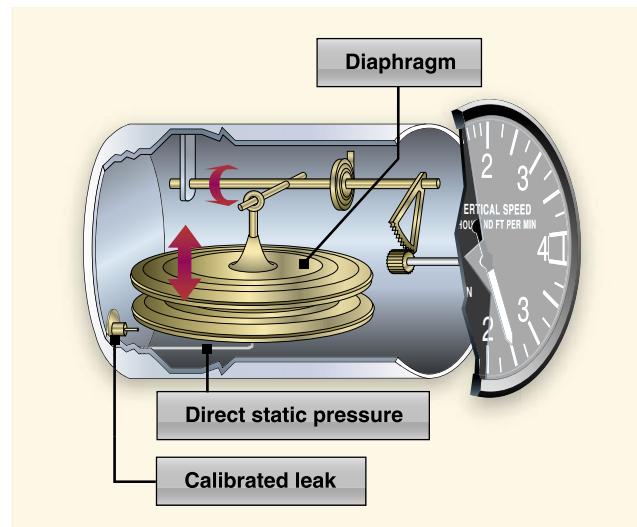


Figure 7-5. Vertical speed indicator (VSI).

Principle of Operation

Although the VSI operates solely from static pressure, it is a differential pressure instrument. It contains a diaphragm with connecting linkage and gearing to the indicator pointer inside an airtight case. The inside of the diaphragm is connected directly to the static line of the pitot-static system. The area outside the diaphragm, which is inside the instrument case, is also connected to the static line, but through a restricted orifice (calibrated leak).

Both the diaphragm and the case receive air from the static line at existing atmospheric pressure. The diaphragm receives unrestricted air while the case receives the static pressure via the metered leak. When the aircraft is on the ground or in level flight, the pressures inside the diaphragm and the instrument case are equal and the pointer is at the zero indication. When the aircraft climbs or descends, the pressure inside the diaphragm changes immediately, but due to the metering action of the restricted passage, the case pressure remains higher or lower for a short time, causing the diaphragm to contract or expand. This causes a pressure differential that is indicated on the instrument needle as a climb or descent.

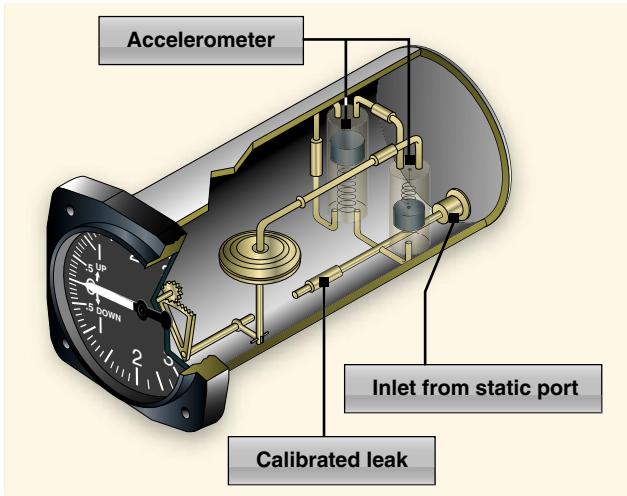


Figure 7-6. An IVSI incorporates accelerometers to help the instrument immediately indicate changes in vertical speed.

When the pressure differential stabilizes at a definite ratio, the needle indicates the rate of altitude change.

The VSI displays two different types of information:

- Trend information shows an immediate indication of an increase or decrease in the aircraft's rate of climb or descent.
- Rate information shows a stabilized rate of change in altitude.

The trend information is the direction of movement of the VSI needle. For example, if an aircraft is maintaining level flight and the pilot pulls back on the control yoke causing the nose of the aircraft to pitch up, the VSI needle moves upward to indicate a climb. If the pitch attitude is held constant, the needle stabilizes after a short period (6–9 seconds) and indicates the rate of climb in hundreds of fpm. The time period from the initial change in the rate of climb, until the VSI displays an accurate indication of the new rate, is called the lag. Rough control technique and turbulence can extend the lag period and cause erratic and unstable rate indications. Some aircraft are equipped with an instantaneous vertical speed indicator (IVSI), which incorporates accelerometers to compensate for the lag in the typical VSI. [Figure 7-6]

Instrument Check

As part of a preflight check, proper operation of the VSI must be established. Make sure the VSI indicates near zero prior to leaving the ramp area and again just before takeoff. If the VSI indicates anything other than zero, that indication can be referenced as the zero mark. Normally, if the needle is not exactly zero, it is only slightly above or below the zero line. After takeoff, the VSI should trend upward to indicate

a positive rate of climb and then, once a stabilized climb is established, a rate of climb can be referenced.

Airspeed Indicator (ASI)

The ASI is a sensitive, differential pressure gauge which measures and promptly indicates the difference between pitot (impact/dynamic pressure) and static pressure. These two pressures are equal when the aircraft is parked on the ground in calm air. When the aircraft moves through the air, the pressure on the pitot line becomes greater than the pressure in the static lines. This difference in pressure is registered by the airspeed pointer on the face of the instrument, which is calibrated in miles per hour, knots (nautical miles per hour), or both. [Figure 7-7]

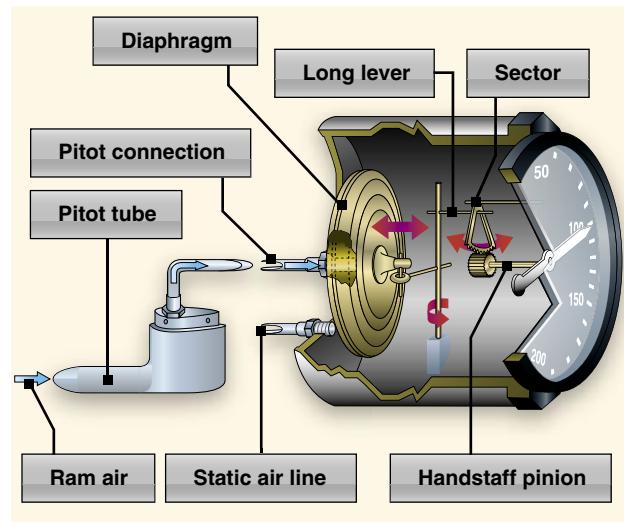


Figure 7-7. Airspeed indicator (ASI).

The ASI is the one instrument that utilizes both the pitot, as well as the static system. The ASI introduces the static pressure into the airspeed case while the pitot pressure (dynamic) is introduced into the diaphragm. The dynamic pressure expands or contracts one side of the diaphragm, which is attached to an indicating system. The system drives the mechanical linkage and the airspeed needle.

Just as in altitudes, there are multiple types of airspeeds. Pilots need to be very familiar with each type.

- Indicated airspeed (IAS)—the direct instrument reading obtained from the ASI, uncorrected for variations in atmospheric density, installation error, or instrument error. Manufacturers use this airspeed as the basis for determining aircraft performance. Takeoff, landing, and stall speeds listed in the AFM/POH are IAS and do not normally vary with altitude or temperature.

- Calibrated airspeed (CAS)—IAS corrected for installation error and instrument error. Although manufacturers attempt to keep airspeed errors to a minimum, it is not possible to eliminate all errors throughout the airspeed operating range. At certain airspeeds and with certain flap settings, the installation and instrument errors may total several knots. This error is generally greatest at low airspeeds. In the cruising and higher airspeed ranges, IAS and CAS are approximately the same. Refer to the airspeed calibration chart to correct for possible airspeed errors.
- True airspeed (TAS)—CAS corrected for altitude and nonstandard temperature. Because air density decreases with an increase in altitude, an aircraft has to be flown faster at higher altitudes to cause the same pressure difference between pitot impact pressure and static pressure. Therefore, for a given CAS, TAS increases as altitude increases; or for a given TAS, CAS decreases as altitude increases. A pilot can find TAS by two methods. The most accurate method is to use a flight computer. With this method, the CAS is corrected for temperature and pressure variation by using the airspeed correction scale on the computer. Extremely accurate electronic flight computers are also available. Just enter the CAS, pressure altitude, and temperature, and the computer calculates the TAS. A second method, which is a rule of thumb, provides the approximate TAS. Simply add 2 percent to the CAS for each 1,000 feet of altitude. The TAS is the speed which is used for flight planning and is used when filing a flight plan.
- Groundspeed (GS)—the actual speed of the airplane over the ground. It is TAS adjusted for wind. GS decreases with a headwind, and increases with a tailwind.

Airspeed Indicator Markings

Aircraft weighing 12,500 pounds or less, manufactured after 1945, and certificated by the FAA, are required to have ASIs marked in accordance with a standard color-coded marking system. This system of color-coded markings enables a pilot to determine at a glance certain airspeed limitations that are important to the safe operation of the aircraft. For example, if during the execution of a maneuver, it is noted that the airspeed needle is in the yellow arc and rapidly approaching the red line, the immediate reaction should be to reduce airspeed.

As shown in *Figure 7-8*, ASIs on single-engine small aircraft include the following standard color-coded markings:

- White arc—commonly referred to as the flap operating range since its lower limit represents the full flap stall speed and its upper limit provides the maximum flap speed. Approaches and landings are usually flown at speeds within the white arc.
- Lower limit of white arc (V_{S0})—the stalling speed or the minimum steady flight speed in the landing configuration. In small aircraft, this is the power-off stall speed at the maximum landing weight in the landing configuration (gear and flaps down).
- Upper limit of the white arc (V_{FE})—the maximum speed with the flaps extended.
- Green arc—the normal operating range of the aircraft. Most flying occurs within this range.
- Lower limit of green arc (V_{S1})—the stalling speed or the minimum steady flight speed obtained in a specified configuration. For most aircraft, this is the power-off stall speed at the maximum takeoff weight in the clean configuration (gear up, if retractable, and flaps up).
- Upper limit of green arc (V_{NO})—the maximum structural cruising speed. Do not exceed this speed except in smooth air.
- Yellow arc—caution range. Fly within this range only in smooth air, and then, only with caution.

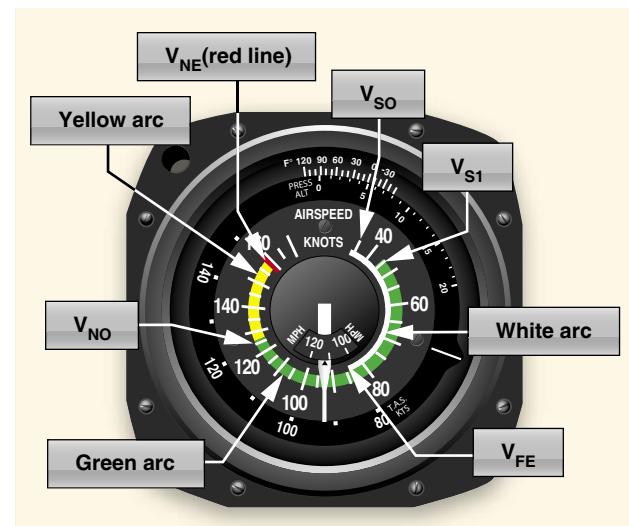


Figure 7-8. Airspeed indicator (ASI).

- Red line (V_{NE})—never exceed speed. Operating above this speed is prohibited since it may result in damage or structural failure.

Other Airspeed Limitations

Some important airspeed limitations are not marked on the face of the ASI, but are found on placards and in the AFM/POH. These airspeeds include:

- Design maneuvering speed (V_A)—the maximum speed at which the structural design's limit load can be imposed (either by gusts or full deflection of the control surfaces) without causing structural damage. It is important to consider weight when referencing this speed. For example, V_A may be 100 knots when an airplane is heavily loaded, but only 90 knots when the load is light.
- Landing gear operating speed (V_{LO})—the maximum speed for extending or retracting the landing gear if flying an aircraft with retractable landing gear.
- Landing gear extended speed (V_{LE})—the maximum speed at which an aircraft can be safely flown with the landing gear extended.
- Best angle-of-climb speed (V_X)—the airspeed at which an aircraft gains the greatest amount of altitude in a given distance. It is used during a short-field takeoff to clear an obstacle.
- Best rate-of-climb speed (V_Y)—the airspeed that provides the most altitude gain in a given period of time.
- Single-engine best rate-of-climb (V_{YSE})—the best rate-of-climb or minimum rate-of-sink in a light twin-engine aircraft with one engine inoperative. It is marked on the ASI with a blue line. V_{YSE} is commonly referred to as “Blue Line.”
- Minimum control speed (V_{MC})—the minimum flight speed at which a light, twin-engine aircraft can be satisfactorily controlled when an engine suddenly becomes inoperative and the remaining engine is at takeoff power.

Instrument Check

Prior to takeoff, the ASI should read zero. However, if there is a strong wind blowing directly into the pitot tube, the ASI may read higher than zero. When beginning the takeoff, make sure the airspeed is increasing at an appropriate rate.

Blockage of the Pitot-Static System

Errors almost always indicate blockage of the pitot tube, the static port(s), or both. Blockage may be caused by moisture (including ice), dirt, or even insects. During preflight, make

sure the pitot tube cover is removed. Then, check the pitot and static port openings. A blocked pitot tube affects the accuracy of the ASI, but, a blockage of the static port not only affects the ASI, but also causes errors in the altimeter and VSI.

Blocked Pitot System

The pitot system can become blocked completely or only partially if the pitot tube drain hole remains open. If the pitot tube becomes blocked and its associated drain hole remains clear, ram air no longer is able to enter the pitot system. Air already in the system vents through the drain hole, and the remaining pressure drops to ambient (outside) air pressure. Under these circumstances, the ASI reading decreases to zero, because the ASI senses no difference between ram and static air pressure. The ASI no longer operates since dynamic pressure can not enter the pitot tube opening. Static pressure is able to equalize on both sides since the pitot drain hole is still open. The apparent loss of airspeed is not usually instantaneous but happens very quickly. [Figure 7-9]

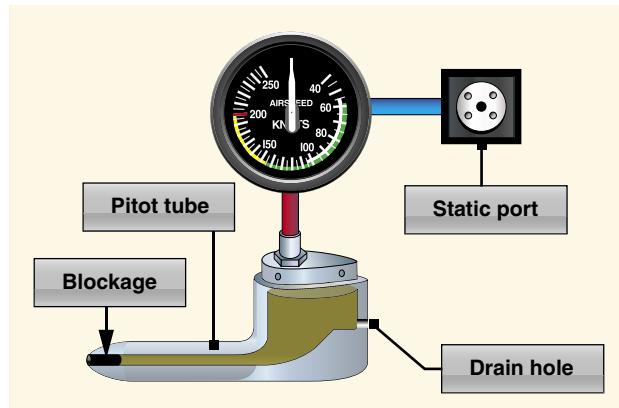


Figure 7-9. A blocked pitot tube, but clear drain hole.

If both the pitot tube opening and the drain hole should become clogged simultaneously, then the pressure in the pitot tube is trapped. No change is noted on the airspeed indication should the airspeed increase or decrease. If the static port is unblocked and the aircraft should change altitude, then a change is noted on the ASI. The change is not related to a change in airspeed but a change in static pressure. The total pressure in the pitot tube does not change due to the blockage; however, the static pressure will change.

Because airspeed indications rely upon both static and dynamic pressure together, the blockage of either of these systems affects the ASI reading. Remember that the ASI has a diaphragm in which dynamic air pressure is entered. Behind this diaphragm is a reference pressure called static pressure that comes from the static ports. The diaphragm pressurizes against this static pressure and as a result changes the airspeed indication via levers and indicators. [Figure 7-10]

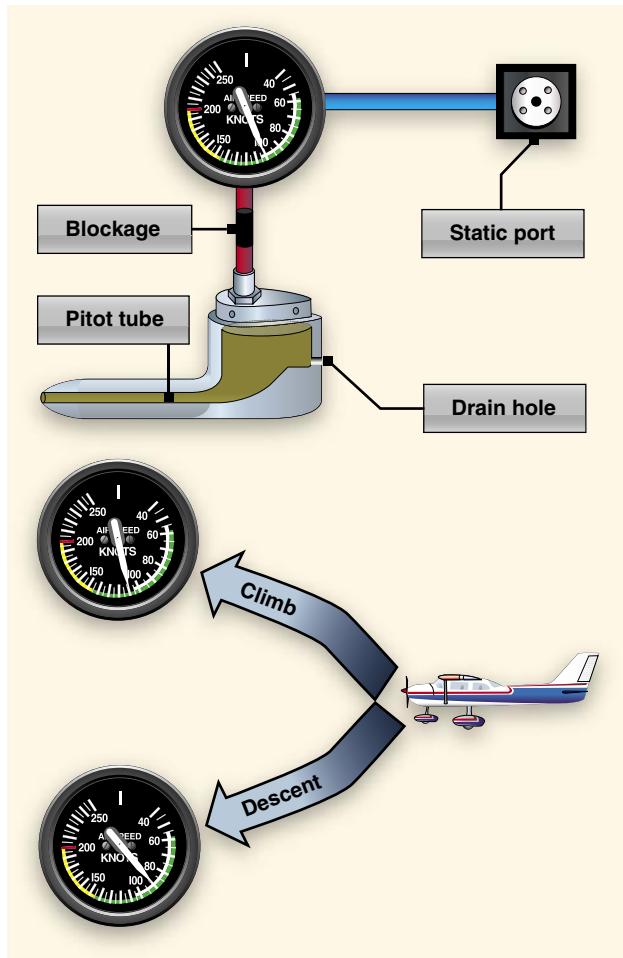


Figure 7-10. Blocked pitot system with clear static system.

For example, take an aircraft and slow it down to zero knots at given altitude. If the static port (providing static pressure) and the pitot tube (providing dynamic pressure) are both unobstructed, the following claims can be made:

1. The ASI would be zero.
2. There must be a relationship between both dynamic and static pressure. At zero speed, dynamic pressure and static pressure are the same: static air pressure.
3. Because both dynamic and static air pressure are equal at zero speed with increased speed, dynamic pressure must include two components: static pressure and dynamic pressure.

It can be inferred that airspeed indication must be based upon a relationship between these two pressures, and indeed it is. An ASI uses the static pressure as a reference pressure and as a result, the ASI's case is kept at this pressure behind the diaphragm. On the other hand, the dynamic pressure through the pitot tube is connected to a highly sensitive diaphragm within the ASI case. Because an aircraft in zero motion (regardless of altitude) results in a zero airspeed, the pitot

tube always provides static pressure in addition to dynamic pressure.

Therefore, the airspeed indication is the result of two pressures: the pitot tube static and dynamic pressure within the diaphragm as measured against the static pressure in case. What does this mean if the pitot tube is obstructed?

If the aircraft were to descend, the pressure in the pitot system including the diaphragm would remain constant. It is clogged and the diaphragm is at a single pressure. But as the descent is made, the static pressure would increase against the diaphragm causing it to compress thereby resulting in an indication of decreased airspeed. Conversely, if the aircraft were to climb, the static pressure would decrease allowing the diaphragm to expand, thereby showing an indication of greater airspeed. [Figure 7-10]

The pitot tube may become blocked during flight due to visible moisture. Some aircraft may be equipped with pitot heat for flight in visible moisture. Consult the AFM/POH for specific procedures regarding the use of pitot heat.

Blocked Static System

If the static system becomes blocked but the pitot tube remains clear, the ASI continues to operate; however, it is inaccurate. The airspeed indicates lower than the actual airspeed when the aircraft is operated above the altitude where the static ports became blocked, because the trapped static pressure is higher than normal for that altitude. When operating at a lower altitude, a faster than actual airspeed is displayed due to the relatively low static pressure trapped in the system.

Revisiting the ratios that were used to explain a blocked pitot tube, the same principle applies for a blocked static port. If the aircraft descends, the static pressure increases on the pitot side showing an increase on the ASI. This assumes that the aircraft does not actually increase its speed. The increase in static pressure on the pitot side is equivalent to an increase in dynamic pressure since the pressure can not change on the static side.

If an aircraft begins to climb after a static port becomes blocked, the airspeed begins to show a decrease as the aircraft continues to climb. This is due to the decrease in static pressure on the pitot side, while the pressure on the static side is held constant.

A blockage of the static system also affects the altimeter and VSI. Trapped static pressure causes the altimeter to freeze at the altitude where the blockage occurred. In the case of the VSI, a blocked static system produces a continuous zero indication. [Figure 7-11]

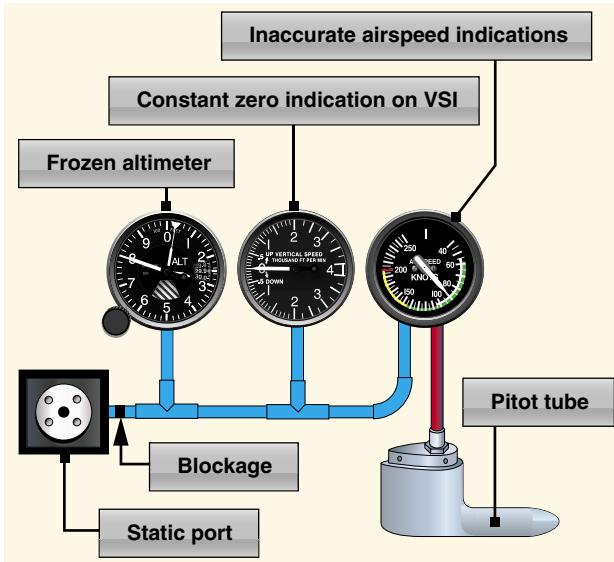


Figure 7-11. Blocked static system.

Some aircraft are equipped with an alternate static source in the flight deck. In the case of a blocked static source, opening the alternate static source introduces static pressure from the flight deck back into the system. Flight deck static pressure is lower than outside static pressure. Check the aircraft AOM/POH for airspeed corrections when utilizing alternate static pressure.

Electronic Flight Display (EFD)

Advances in digital displays and solid state electronic components have been introduced into the flight decks of general aviation (GA) aircraft. In addition to the improvement in system reliability, which increases overall safety, electronic flight displays (EFD) have decreased the overall cost of equipping aircraft with state-of-the-art instrumentation. Primary electronic instrumentation packages are less prone to failure than their analogue counterparts. No longer is it necessary for aircraft designers to create cluttered panel layouts in order to accommodate all necessary flight instruments. Instead, multi-panel digital flight displays combine all flight instruments onto a single screen which is called a primary flight display (PFD). The traditional “six pack” of instruments is now displayed on one liquid crystal display (LCD) screen.

Airspeed Tape

Configured similarly to traditional panel layouts, the ASI is located on the left side of the screen and is displayed as a vertical speed tape. As the aircraft increases in speed, the larger numbers descend from the top of the tape. The TAS is displayed at the bottom of the tape through the input to the air data computer (ADC) from the outside air temperature probe. Airspeed markings for V_x , V_y , and rotation speed (V_R) are

displayed for pilot reference. An additional pilot-controlled airspeed bug is available to set at any desired reference speed. As on traditional analogue ASIs, the electronic airspeed tape displays the color-coded ranges for the flap operating range, normal range, and caution range. [Figure 7-12] The number value changes color to red when the airspeed exceeds V_{NE} to warn the pilot of exceeding the maximum speed limitation.

Attitude Indicator

One improvement over analogue instrumentation is the larger attitude indicator on EFD. The artificial horizon spans the entire width of the PFD. [Figure 7-12] This expanded instrumentation offers better reference through all phases of flight and all flight maneuvers. The attitude indicator receives its information from the Attitude Heading and Reference System (AHRS).

Altimeter

The altimeter is located on the right side of the PFD. [Figure 7-12] As the altitude increases, the larger numbers descend from the top of the display tape, with the current altitude being displayed in the black box in the center of the display tape. The altitude is displayed in increments of 20 feet.

Vertical Speed Indicator (VSI)

The VSI is displayed to the right of the altimeter tape and can take the form of an arced indicator or a vertical speed tape. [Figure 7-12] Both are equipped with a vertical speed bug.

Heading Indicator

The heading indicator is located below the artificial horizon and is normally modeled after a Horizontal Situation Indicator (HSI). [Figure 7-12] As in the case of the attitude indicator, the heading indicator receives its information from the magnetometer which feeds information to the AHRS unit and then out to the PFD.

Turn Indicator

The turn indicator takes a slightly different form than the traditional instrumentation. A sliding bar moves left and right below the triangle to indicate deflection from coordinated flight. [Figure 7-12] Reference for coordinated flight comes from accelerometers contained in the AHRS unit.

Tachometer

The sixth instrument normally associated with the “six pack” package is the tachometer. This is the only instrument that is not located on the PFD. The tachometer is normally located on the multi-function display (MFD). In the event of a display screen failure, it is displayed on the remaining screen with the PFD flight instrumentation. [Figure 7-13]

Slip/Skid Indicator

The slip/skid indicator [Figure 7-12] is the horizontal line below the roll pointer. Like a ball in a turn-and-slip indicator, a bar width off center is equal to one ball width displacement.

Turn Rate Indicator

The turn rate indicator, illustrated in Figure 7-12, is typically found directly above the rotating compass card. Tick marks to the left and right of the center line denote the turn (standard-rate versus half standard-rate). Typically denoted by a trend line, if the trend vector is extended to the second tick mark the aircraft is in a standard-rate turn.

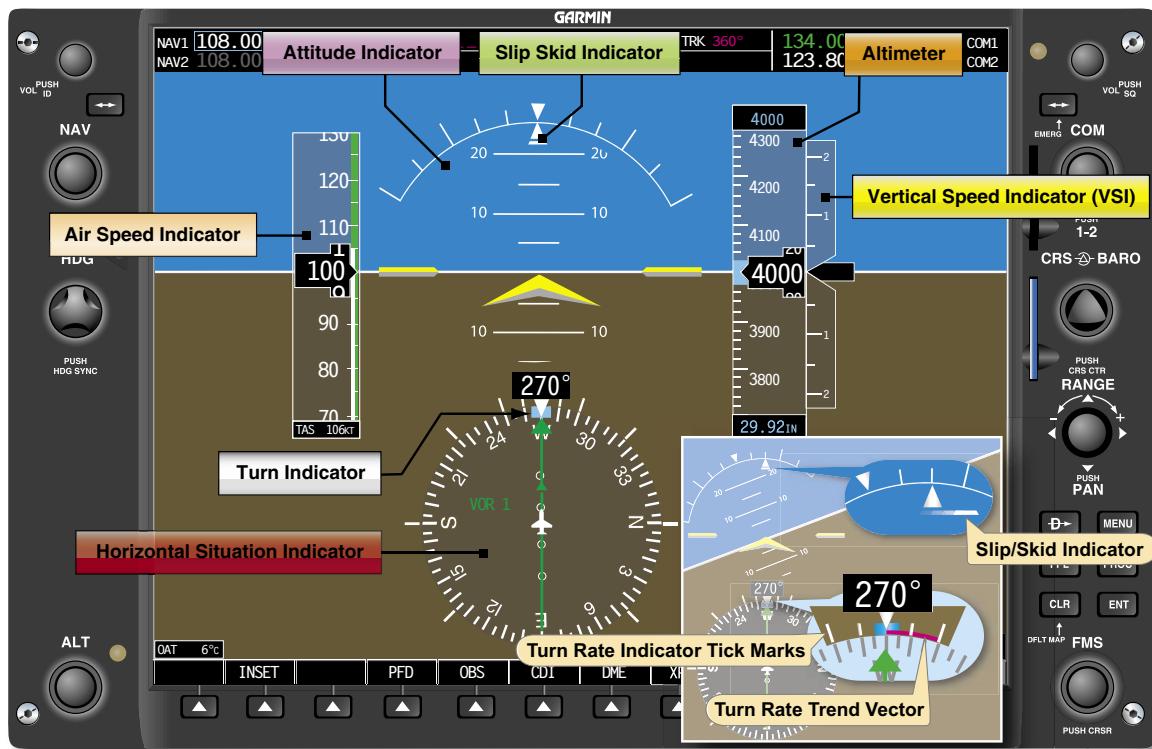


Figure 7-12. Primary flight display. Note that the actual location of indications vary depending on manufacturers.



Figure 7-13. Multi-function display.

Individual panel displays are able to be configured for a variety of aircraft simply by installing different software packages. [Figure 7-14] Manufacturers are also able to upgrade existing instrument displays in a similar manner, eliminating the need to replace individual gauges in order to upgrade.

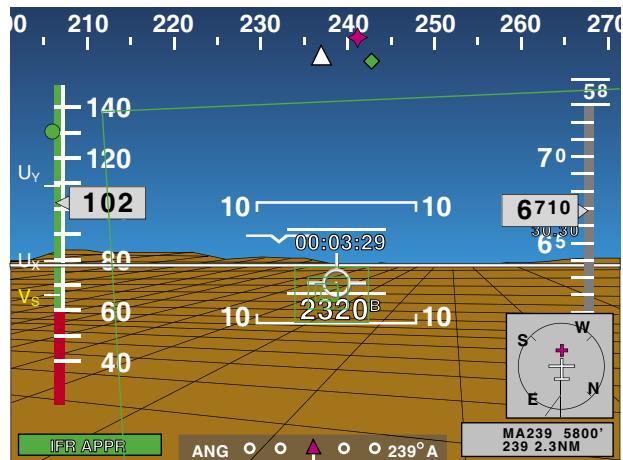


Figure 7-14. Chelton's FlightLogic (top) and Avidyne's Entegra (bottom) are examples of panel displays that are configurable.

Air Data Computer (ADC)

Electronic flight displays utilize the same type of instrument inputs as traditional analogue gauges; however, the processing system is different. The pitot static inputs are received by an ADC. The ADC computes the difference between the total pressure and the static pressure, and generates the information necessary to display the airspeed on the PFD. Outside air temperatures are also monitored and introduced into various components within the system, as well as being displayed on the PFD screen. [Figure 7-15]

The ADC is a separate solid state device which, in addition to providing data to the PFD, is capable of providing data to the

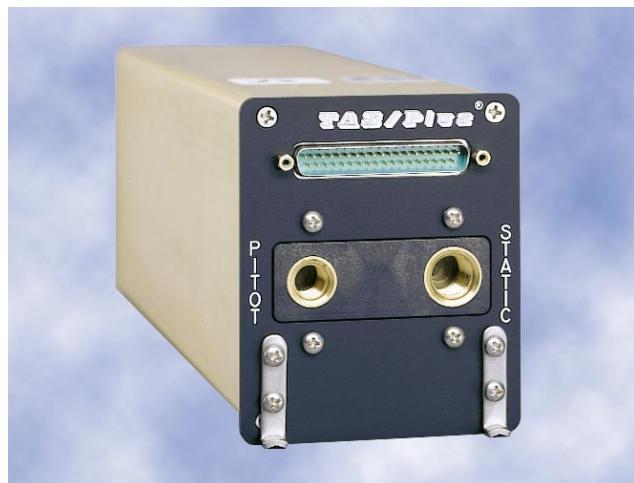


Figure 7-15. Teledyne's 90004 TAS/Plus Air Data Computer (ADC) computes air data information from the pitot-static pneumatic system, aircraft temperature probe, and barometric correction device to help create a clear picture of flight characteristics.

autopilot control system. In the event of system malfunction, the ADC can quickly be removed and replaced in order to decrease down time and maintenance turn-around times.

Altitude information is derived from the static pressure port just as an analogue system does; however, the static pressure does not enter a diaphragm. The ADC computes the received barometric pressure and sends a digital signal to the PFD to display the proper altitude readout. Electronic flight displays also show trend vectors which show the pilot how the altitude and airspeed are progressing.

Trend Vectors

Trend vectors are magenta lines which move up and down both the ASI and the altimeter. [Figures 7-16 and 7-17] The

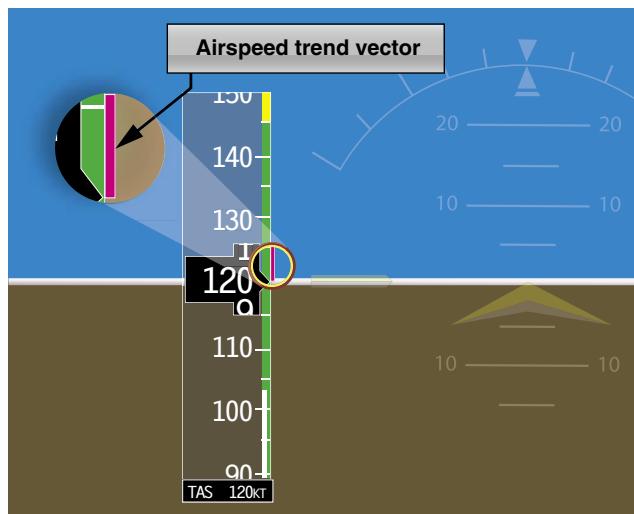


Figure 7-16. Airspeed trend vector.

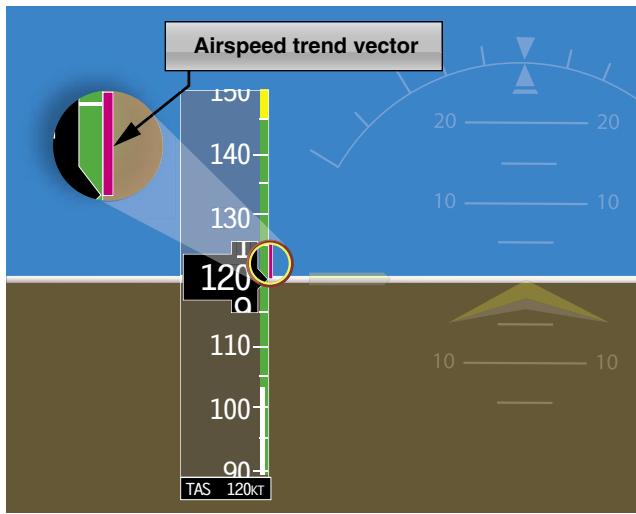


Figure 7-17. Altimeter trend vector.

ADC computes the rate of change and displays the 6-second projection of where the aircraft will be. Pilots can utilize the trend vectors to better control the aircraft's attitude. By including the trend vectors in the instrument scan, pilots are able to precisely control airspeed and altitude. Additional information can be obtained by referencing the Instrument Flying Handbook or specific avionics manufacturer's training material.

Gyroscopic Flight Instruments

Several flight instruments utilize the properties of a gyroscope for their operation. The most common instruments containing gyroscopes are the turn coordinator, heading indicator, and the attitude indicator. To understand how these instruments operate requires knowledge of the instrument power systems, gyroscopic principles, and the operating principles of each instrument.

Gyroscopic Principles

Any spinning object exhibits gyroscopic properties. A wheel or rotor designed and mounted to utilize these properties is called a gyroscope. Two important design characteristics of an instrument gyro are great weight for its size, or high density, and rotation at high speed with low friction bearings.

There are two general types of mountings; the type used depends upon which property of the gyro is utilized. A freely or universally mounted gyroscope is free to rotate in any direction about its center of gravity. Such a wheel is said to have three planes of freedom. The wheel or rotor is free to rotate in any plane in relation to the base and is balanced so that, with the gyro wheel at rest, it remains in the position in which it is placed. Restricted or semi-rigidly mounted gyroscopes are those mounted so that one of the planes of freedom is held fixed in relation to the base.

There are two fundamental properties of gyroscopic action: rigidity in space and precession.

Rigidity in Space

Rigidity in space refers to the principle that a gyroscope remains in a fixed position in the plane in which it is spinning. An example of rigidity in space is that of a bicycle wheel. As the bicycle wheels increase speed, they become more and more stable in their plane of rotation. This is why a bicycle is very unstable and very maneuverable at low speeds and very stable and less maneuverable at higher speeds.

By mounting this wheel, or gyroscope, on a set of gimbal rings, the gyro is able to rotate freely in any direction. Thus, if the gimbal rings are tilted, twisted, or otherwise moved, the gyro remains in the plane in which it was originally spinning. [Figure 7-18]

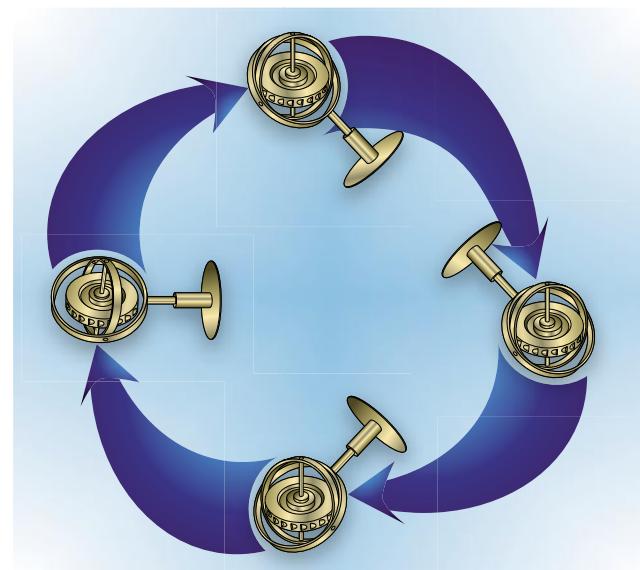


Figure 7-18. Regardless of the position of its base, a gyro tends to remain rigid in space, with its axis of rotation pointed in a constant direction.

Precession

Precession is the tilting or turning of a gyro in response to a deflective force. The reaction to this force does not occur at the point at which it was applied; rather, it occurs at a point that is 90° later in the direction of rotation. This principle allows the gyro to determine a rate of turn by sensing the amount of pressure created by a change in direction. The rate at which the gyro precesses is inversely proportional to the speed of the rotor and proportional to the deflective force.

Using the example of the bicycle, precession acts on the wheels in order to allow the bicycle to turn. While riding at normal speed, it is not necessary to turn the handle bars in the direction of the desired turn. A rider simply leans in the direction that he or she wishes to go. Since the wheels are rotating in a clockwise direction when viewed from the right side of the bicycle, if a rider leans to the left, a force is applied to the top of the wheel to the left. The force actually acts 90° in the direction of rotation, which has the effect of applying a force to the front of the tire, causing the bicycle to move to the left. There is a need to turn the handlebars at low speeds because of the instability of the slowly turning gyros, and also to increase the rate of turn.

Precession can also create some minor errors in some instruments. [Figure 7-19] Precession can cause a freely spinning gyro to become displaced from its intended plane of rotation through bearing friction, etc. Certain instruments may require corrective realignment during flight, such as the heading indicator.

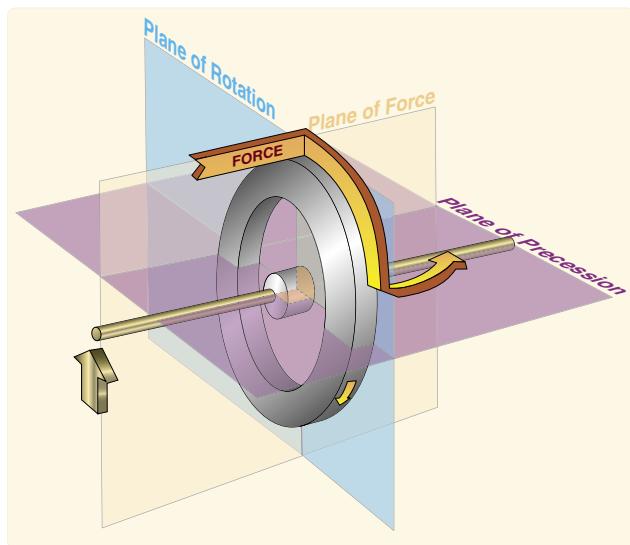


Figure 7-19. Precession of a gyroscope resulting from an applied deflective force.

Sources of Power

In some aircraft, all the gyros are vacuum, pressure, or electrically operated. In other aircraft, vacuum or pressure systems provide the power for the heading and attitude indicators, while the electrical system provides the power for the turn coordinator. Most aircraft have at least two sources of power to ensure at least one source of bank information is available if one power source fails. The vacuum or pressure system spins the gyro by drawing a stream of air against the rotor vanes to spin the rotor at high speed, much like the operation of a waterwheel or turbine. The amount of vacuum

or pressure required for instrument operation varies, but is usually between 4.5 "Hg and 5.5 "Hg.

One source of vacuum for the gyros is a vane-type engine-driven pump that is mounted on the accessory case of the engine. Pump capacity varies in different airplanes, depending on the number of gyros.

A typical vacuum system consists of an engine-driven vacuum pump, relief valve, air filter, gauge, and tubing necessary to complete the connections. The gauge is mounted in the aircraft's instrument panel and indicates the amount of pressure in the system (vacuum is measured in inches of mercury less than ambient pressure).

As shown in Figure 7-20, air is drawn into the vacuum system by the engine-driven vacuum pump. It first goes through a filter, which prevents foreign matter from entering the vacuum or pressure system. The air then moves through the attitude and heading indicators, where it causes the gyros to spin. A relief valve prevents the vacuum pressure, or suction, from exceeding prescribed limits. After that, the air is expelled overboard or used in other systems, such as for inflating pneumatic deicing boots.

It is important to monitor vacuum pressure during flight, because the attitude and heading indicators may not provide reliable information when suction pressure is low. The vacuum, or suction, gauge is generally marked to indicate the normal range. Some aircraft are equipped with a warning light that illuminates when the vacuum pressure drops below the acceptable level.

When the vacuum pressure drops below the normal operating range, the gyroscopic instruments may become unstable and inaccurate. Cross checking the instruments routinely is a good habit to develop.

Turn Indicators

Aircraft use two types of turn indicators: turn-and-slip indicator and turn coordinator. Because of the way the gyro is mounted, the turn-and-slip indicator shows only the rate of turn in degrees per second. The turn coordinator is mounted at an angle, or canted, so it can initially show roll rate. When the roll stabilizes, it indicates rate of turn. Both instruments indicate turn direction and quality (coordination), and also serve as a backup source of bank information in the event an attitude indicator fails. Coordination is achieved by referring to the inclinometer, which consists of a liquid-filled curved tube with a ball inside. [Figure 7-21]

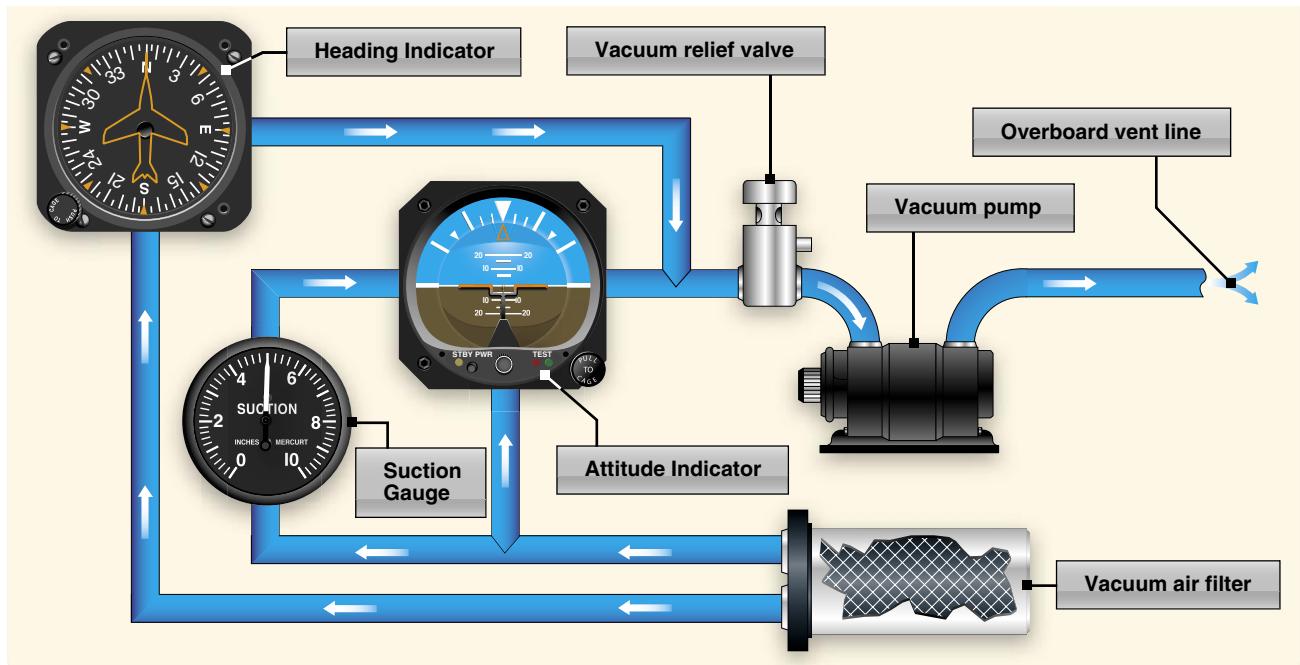


Figure 7-20. Typical vacuum system.

Turn-and-Slip Indicator

The gyro in the turn-and-slip indicator rotates in the vertical plane, corresponding to the aircraft's longitudinal axis. A single gimbal limits the planes in which the gyro can tilt, and a spring tries to return it to center. Because of precession, a yawing force causes the gyro to tilt left or right, as viewed from the pilot seat. The turn-and-slip indicator uses a pointer, called the turn needle, to show the direction and rate of turn. The turn-and-slip indicator is incapable of "tumbling" off its rotational axis because of the restraining springs. When extreme forces are applied to a gyro, the gyro is displaced from its normal plane of rotation, rendering its indications

invalid. Certain instruments have specific pitch and bank limits that induce a tumble of the gyro.

Turn Coordinator

The gimbal in the turn coordinator is canted; therefore, its gyro can sense both rate of roll and rate of turn. Since turn coordinators are more prevalent in training aircraft, this discussion concentrates on that instrument. When rolling into or out of a turn, the miniature aircraft banks in the direction the aircraft is rolled. A rapid roll rate causes the miniature aircraft to bank more steeply than a slow roll rate.

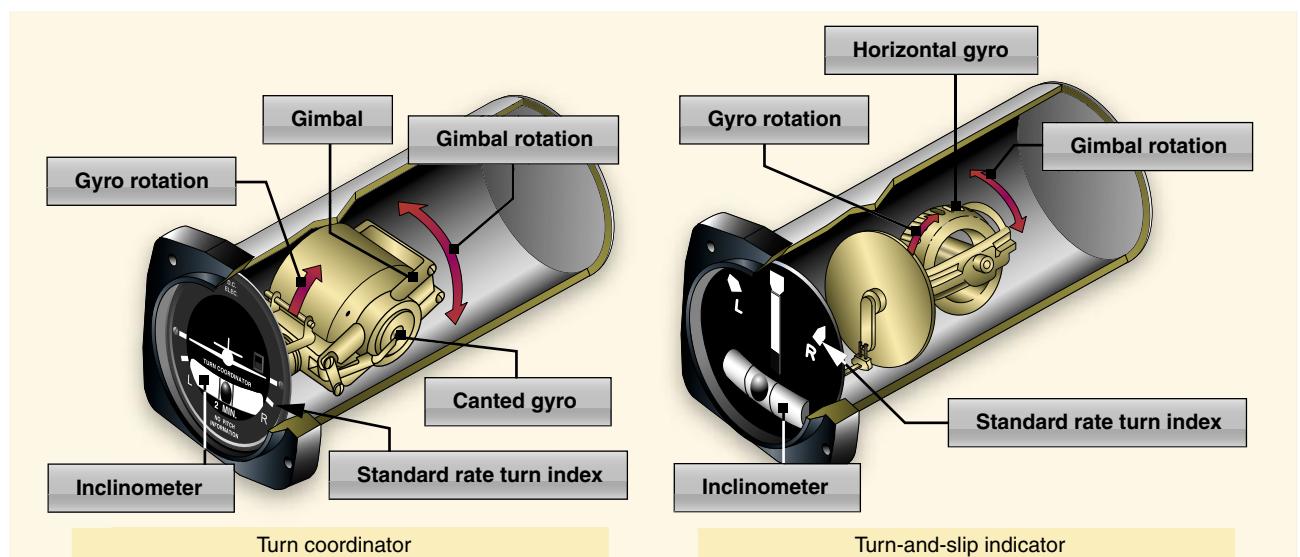


Figure 7-21. Turn indicators rely on controlled precession for their operation.

The turn coordinator can be used to establish and maintain a standard-rate turn by aligning the wing of the miniature aircraft with the turn index. *Figure 7-22* shows a picture of a turn coordinator. There are two marks on each side (left and right) of the face of the instrument. The first mark is used to reference a wings level zero rate of turn. The second mark on the left and right side of the instrument serve to indicate a standard rate of turn. A standard-rate turn is defined as a turn rate of 3° per second. The turn coordinator indicates only the rate and direction of turn; it does not display a specific angle of bank.

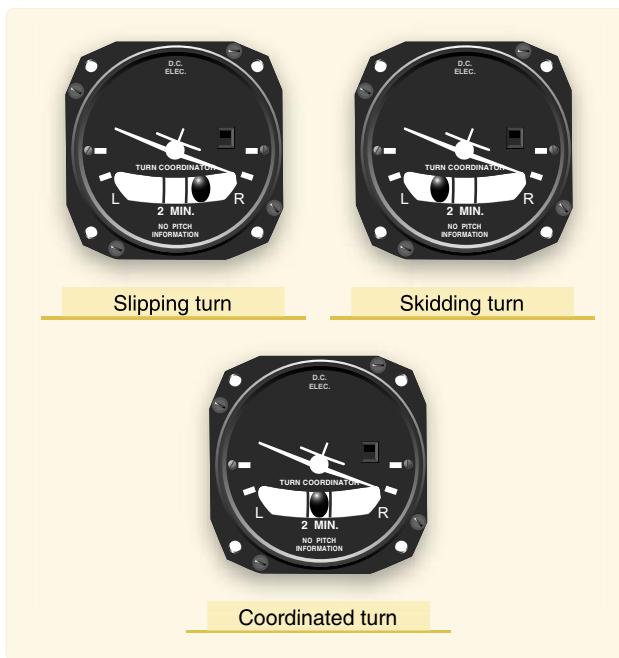


Figure 7-22. If inadequate right rudder is applied in a right turn, a slip results. Too much right rudder causes the aircraft to skid through the turn. Centering the ball results in a coordinated turn.

Inclinometer

The inclinometer is used to depict aircraft yaw, which is the side-to-side movement of the aircraft's nose. During coordinated, straight-and-level flight, the force of gravity causes the ball to rest in the lowest part of the tube, centered between the reference lines. Coordinated flight is maintained by keeping the ball centered. If the ball is not centered, it can be centered by using the rudder.

To center the ball, apply rudder pressure on the side to which the ball is deflected. Use the simple rule, "step on the ball," to remember which rudder pedal to press. If aileron and rudder are coordinated during a turn, the ball remains centered in the tube. If aerodynamic forces are unbalanced, the ball moves away from the center of the tube. As shown in *Figure 7-22*, in a slip, the rate of turn is too slow for the angle of bank, and the ball moves to the inside of the turn. In a skid, the rate of

turn is too great for the angle of bank, and the ball moves to the outside of the turn. To correct for these conditions, and improve the quality of the turn, remember to "step on the ball." Varying the angle of bank can also help restore coordinated flight from a slip or skid. To correct for a slip, decrease bank and/or increase the rate of turn. To correct for a skid, increase the bank and/or decrease the rate of turn.

Yaw String

One additional tool which can be added to the aircraft is a yaw string. A yaw string is simply a string or piece of yarn attached to the center of the wind screen. When in coordinated flight, the string trails straight back over the top of the wind screen. When the aircraft is either slipping or skidding, the yaw string moves to the right or left depending on the direction of slip or skid.

Instrument Check

During the preflight, check to see that the inclinometer is full of fluid and has no air bubbles. The ball should also be resting at its lowest point. When taxiing, the turn coordinator should indicate a turn in the correct direction while the ball moves opposite the direction of the turn.

Attitude Indicator

The attitude indicator, with its miniature aircraft and horizon bar, displays a picture of the attitude of the aircraft. The relationship of the miniature aircraft to the horizon bar is the same as the relationship of the real aircraft to the actual horizon. The instrument gives an instantaneous indication of even the smallest changes in attitude.

The gyro in the attitude indicator is mounted in a horizontal plane and depends upon rigidity in space for its operation. The horizon bar represents the true horizon. This bar is fixed to the gyro and remains in a horizontal plane as the aircraft is pitched or banked about its lateral or longitudinal axis, indicating the attitude of the aircraft relative to the true horizon. [*Figure 7-23*]

The gyro spins in the horizontal plane and resists deflection of the rotational path. Since the gyro relies on rigidity in space, the aircraft actually rotates around the spinning gyro.

An adjustment knob is provided with which the pilot may move the miniature aircraft up or down to align the miniature aircraft with the horizon bar to suit the pilot's line of vision. Normally, the miniature aircraft is adjusted so that the wings overlap the horizon bar when the aircraft is in straight-and-level cruising flight.

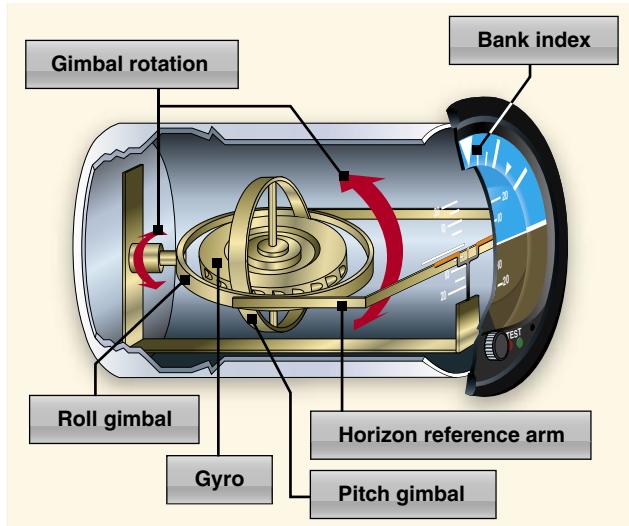


Figure 7-23. Attitude indicator.

The pitch and bank limits depend upon the make and model of the instrument. Limits in the banking plane are usually from 100° to 110°, and the pitch limits are usually from 60° to 70°. If either limit is exceeded, the instrument will tumble or spill and will give incorrect indications until realigned. A number of modern attitude indicators do not tumble.

Every pilot should be able to interpret the banking scale illustrated in *Figure 7-24*. Most banking scale indicators on the top of the instrument move in the same direction from that in which the aircraft is actually banked. Some other models move in the opposite direction from that in which the aircraft is actually banked. This may confuse the pilot if the indicator is used to determine the direction of bank. This scale should be used only to control the degree of desired bank. The relationship of the miniature aircraft to the horizon bar should be used for an indication of the direction of bank.

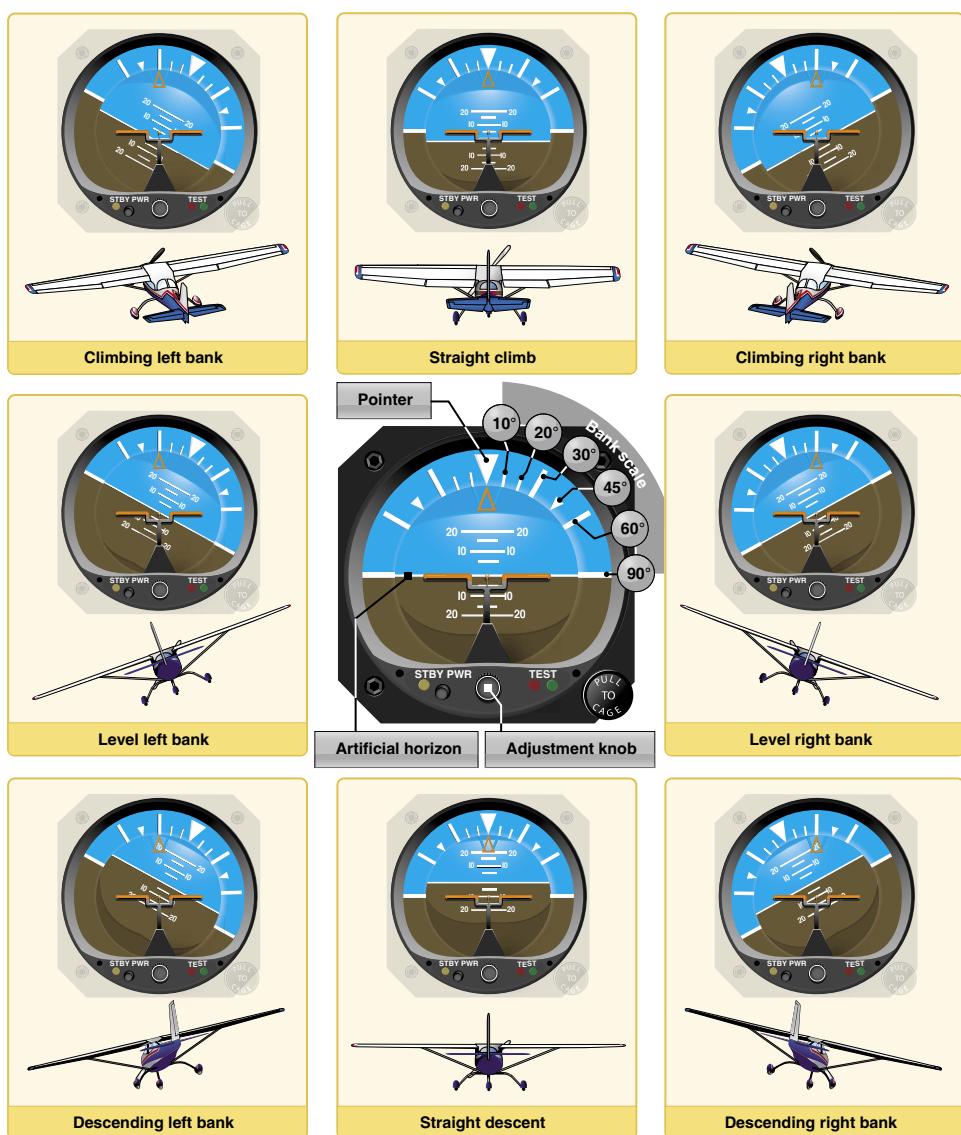


Figure 7-24. Attitude representation by the attitude indicator corresponds to the relation of the aircraft to the real horizon.

The attitude indicator is reliable and the most realistic flight instrument on the instrument panel. Its indications are very close approximations of the actual attitude of the aircraft.

Heading Indicator

The heading indicator is fundamentally a mechanical instrument designed to facilitate the use of the magnetic compass. Errors in the magnetic compass are numerous, making straight flight and precision turns to headings difficult to accomplish, particularly in turbulent air. A heading indicator, however, is not affected by the forces that make the magnetic compass difficult to interpret. [Figure 7-25]

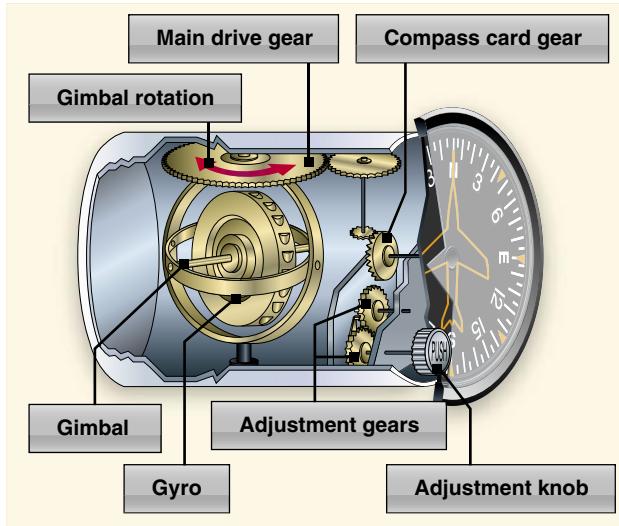


Figure 7-25. A heading indicator displays headings based on a 360° azimuth, with the final zero omitted. For example, “6” represents 060°, while “21” indicates 210°. The adjustment knob is used to align the heading indicator with the magnetic compass.

The operation of the heading indicator depends upon the principle of rigidity in space. The rotor turns in a vertical plane and fixed to the rotor is a compass card. Since the rotor remains rigid in space, the points on the card hold the same position in space relative to the vertical plane of the gyro. The aircraft actually rotates around the rotating gyro, not the other way around. As the instrument case and the aircraft revolve around the vertical axis of the gyro, the card provides clear and accurate heading information.

Because of precession caused by friction, the heading indicator creeps or drifts from a heading to which it is set. Among other factors, the amount of drift depends largely upon the condition of the instrument. If the bearings are worn, dirty, or improperly lubricated, the drift may be excessive. Another error in the heading indicator is caused by the fact that the gyro is oriented in space, and the Earth rotates in space at a rate of 15° in 1 hour. Thus, discounting precession

caused by friction, the heading indicator may indicate as much as 15° error per every hour of operation.

Some heading indicators referred to as horizontal situation indicators (HSI) receive a magnetic north reference from a magnetic slaving transmitter, and generally need no adjustment. The magnetic slaving transmitter is called a magnetometer.

Attitude and Heading Reference System (AHRS)

Electronic flight displays have replaced free-spinning gyros with solid-state laser systems that are capable of flight at any attitude without tumbling. This capability is the result of the development of the Attitude and Heading Reference System (AHRS).

The AHRS sends attitude information to the PFD in order to generate the pitch and bank information of the attitude indicator. The heading information is derived from a magnetometer which senses the earth's lines of magnetic flux. This information is then processed and sent out to the PFD to generate the heading display. [Figure 7-26]



Figure 7-26. Attitude and heading reference system (AHRS).

The Flux Gate Compass System

As mentioned earlier, the lines of flux in the Earth's magnetic field have two basic characteristics: a magnet aligns with them, and an electrical current is induced, or generated, in any wire crossed by them.

The flux gate compass that drives slaved gyros uses the characteristic of current induction. The flux valve is a small, segmented ring, like the one in Figure 7-27, made of soft iron that readily accepts lines of magnetic flux. An electrical coil is wound around each of the three legs to accept the current

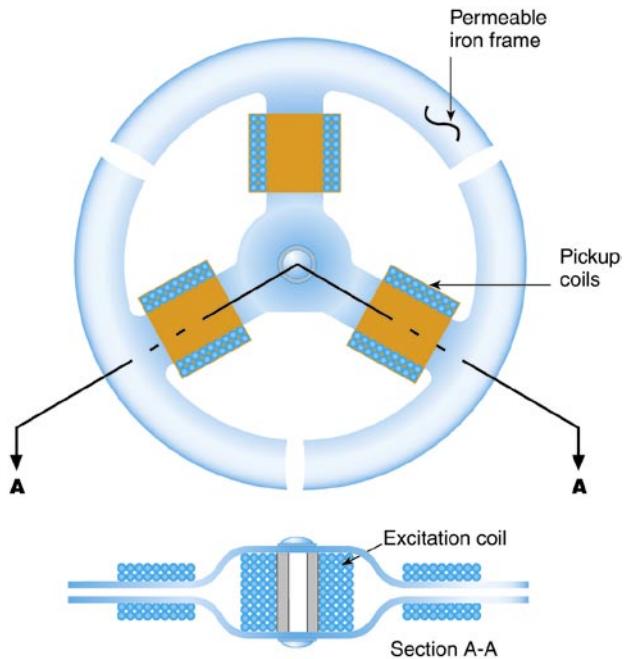


Figure 7-27. The soft iron frame of the flux valve accepts the flux from the Earth's magnetic field each time the current in the center coil reverses. This flux causes current to flow in the three pickup coils.

induced in this ring by the Earth's magnetic field. A coil wound around the iron spacer in the center of the frame has 400 Hz alternating current (AC) flowing through it. During the times when this current reaches its peak, twice during each cycle, there is so much magnetism produced by this coil that the frame cannot accept the lines of flux from the Earth's field.

As the current reverses between the peaks, it demagnetizes the frame so it can accept the flux from the Earth's field. As this flux cuts across the windings in the three coils, it causes current to flow in them. These three coils are connected in such a way that the current flowing in them changes as the heading of the aircraft changes. [Figure 7-28]

The three coils are connected to three similar but smaller coils in a synchro inside the instrument case. The synchro rotates the dial of a radio magnetic indicator (RMI) or a HSI.

Remote Indicating Compass

Remote indicating compasses were developed to compensate for the errors and limitations of the older type of heading indicators. The two panel-mounted components of a typical system are the pictorial navigation indicator and the slaving control and compensator unit. [Figure 7-29] The pictorial navigation indicator is commonly referred to as an HSI.

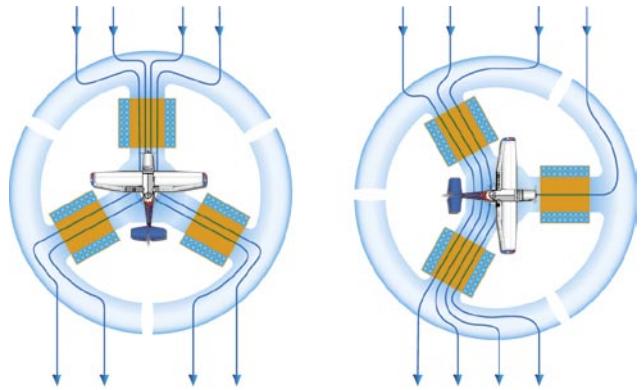


Figure 7-28. The current in each of the three pickup coils changes with the heading of the aircraft..

The slaving control and compensator unit has a push button that provides a means of selecting either the "slaved gyro" or "free gyro" mode. This unit also has a slaving meter and two manual heading-drive buttons. The slaving meter indicates the difference between the displayed heading and the magnetic heading. A right deflection indicates a clockwise error of the compass card; a left deflection indicates a counterclockwise error. Whenever the aircraft is in a turn and the card rotates, the slaving meter shows a full deflection to one side or the other. When the system is in "free gyro" mode, the compass card may be adjusted by depressing the appropriate heading-drive button.

A separate unit, the magnetic slaving transmitter is mounted remotely, usually in a wingtip to eliminate the possibility of



Figure 7-29. Pictorial navigation indicator (HSI, top), slaving meter (lower right), and slaving control compensator unit (lower left).

magnetic interference. It contains the flux valve, which is the direction-sensing device of the system. A concentration of lines of magnetic force, after being amplified, becomes a signal relayed to the heading indicator unit, which is also remotely mounted. This signal operates a torque motor in the heading indicator unit that processes the gyro unit until it is aligned with the transmitter signal. The magnetic slaving transmitter is connected electrically to the HSI.

There are a number of designs of the remote indicating compass; therefore, only the basic features of the system are covered here. Instrument pilots must become familiar with the characteristics of the equipment in their aircraft.

As instrument panels become more crowded and the pilot's available scan time is reduced by a heavier flight deck workload, instrument manufacturers have worked toward combining instruments. One good example of this is the RMI in *Figure 7-30*. The compass card is driven by signals from the flux valve, and the two pointers are driven by an automatic direction finder (ADF) and a very high frequency (VHF) omni-directional radio range (VOR).



Figure 7-30. Driven by signals from a flux valve, the compass card in this RMI indicates the heading of the aircraft opposite the upper center index mark. The green pointer is driven by the ADF.

Heading indicators that do not have this automatic northseeking capability are called "free" gyros, and require periodic adjustment. It is important to check the indications frequently (approximately every 15 minutes) and reset the heading indicator to align it with the magnetic compass when required. Adjust the heading indicator to the magnetic compass heading when the aircraft is straight and level at a constant speed to avoid compass errors.

The bank and pitch limits of the heading indicator vary with the particular design and make of instrument. On some heading indicators found in light aircraft, the limits are approximately 55° of pitch and 55° of bank. When either of these attitude limits is exceeded, the instrument "tumbles" or "spills" and no longer gives the correct indication until reset. After spilling, it may be reset with the caging knob. Many of the modern instruments used are designed in such a manner that they do not tumble.

An additional precession error may occur due to a gyro not spinning fast enough to maintain its alignment. When the vacuum system stops producing adequate suction to maintain the gyro speed, the heading indicator and the attitude indicator gyros begin to slow down. As they slow, they become more susceptible to deflection from the plane of rotation. Some aircraft have warning lights to indicate that a low vacuum situation has occurred. Other aircraft may have only a vacuum gauge that indicates the suction.

Instrument Check

As the gyro spools up, make sure there are no abnormal sounds. While taxiing, the instrument should indicate turns in the correct direction, and precession should not be abnormal. At idle power settings, the gyroscopic instruments using the vacuum system might not be up to operating speeds and precession might occur more rapidly than during flight.

Compass Systems

The Earth is a huge magnet, spinning in space, surrounded by a magnetic field made up of invisible lines of flux. These lines leave the surface at the magnetic north pole and reenter at the magnetic South Pole.

Lines of magnetic flux have two important characteristics: any magnet that is free to rotate will align with them, and an electrical current is induced into any conductor that cuts across them. Most direction indicators installed in aircraft make use of one of these two characteristics.

Magnetic Compass

One of the oldest and simplest instruments for indicating direction is the magnetic compass. It is also one of the basic instruments required by Title 14 of the Code of Federal Regulations (14 CFR) part 91 for both VFR and IFR flight.

A magnet is a piece of material, usually a metal containing iron, which attracts and holds lines of magnetic flux. Regardless of size, every magnet has two poles: north and south. When one magnet is placed in the field of another, the unlike poles attract each other, and like poles repel.

An aircraft magnetic compass, such as the one in *Figure 7-30*, has two small magnets attached to a metal float sealed inside a bowl of clear compass fluid similar to kerosene. A graduated scale, called a card, is wrapped around the float and viewed through a glass window with a lubber line across it. The card is marked with letters representing the cardinal directions, north, east, south, and west, and a number for each 30° between these letters. The final “0” is omitted from these directions. For example, 3 = 30° , 6 = 60° , and 33 = 330° . There are long and short graduation marks between the letters and numbers, each long mark representing 10° and each short mark representing 5° .



Figure 7-31. A magnetic compass. The vertical line is called the lubber line.

The float and card assembly has a hardened steel pivot in its center that rides inside a special, spring-loaded, hard glass jewel cup. The buoyancy of the float takes most of the weight off the pivot, and the fluid damps the oscillation of the float and card. This jewel-and-pivot type mounting allows the float freedom to rotate and tilt up to approximately 18° angle of bank. At steeper bank angles, the compass indications are erratic and unpredictable.

The compass housing is entirely full of compass fluid. To prevent damage or leakage when the fluid expands and contracts with temperature changes, the rear of the compass case is sealed with a flexible diaphragm, or with a metal bellows in some compasses.

The magnets align with the Earth’s magnetic field and the pilot reads the direction on the scale opposite the lubber line. Note that in *Figure 7-31*, the pilot sees the compass card from its backside. When the pilot is flying north as the compass shows, east is to the pilot’s right. On the card, “33”, which represents 330° (west of north), is to the right of north. The reason for this apparent backward graduation is that the card remains stationary, and the compass housing and the pilot turn around it, always viewing the card from its backside.

A compensator assembly mounted on the top or bottom of the compass allows an aviation maintenance technician (AMT) to create a magnetic field inside the compass housing that cancels the influence of local outside magnetic fields. This is done to correct for deviation error. The compensator assembly has two shafts whose ends have screwdriver slots accessible from the front of the compass. Each shaft rotates one or two small compensating magnets. The end of one shaft is marked E-W, and its magnets affect the compass when the aircraft is pointed east or west. The other shaft is marked N-S and its magnets affect the compass when the aircraft is pointed north or south.

Magnetic Compass Induced Errors

The magnetic compass is the simplest instrument in the panel, but it is subject to a number of errors that must be considered.

Variation

The Earth rotates about its geographic axis; maps and charts are drawn using meridians of longitude that pass through the geographic poles. Directions measured from the geographic poles are called true directions. The magnetic North Pole to which the magnetic compass points is not collocated with the geographic North Pole, but is some 1,300 miles away; directions measured from the magnetic poles are called magnetic directions. In aerial navigation, the difference between true and magnetic directions is called variation. This same angular difference in surveying and land navigation is called declination.

Figure 7-32 shows the isogonic lines that identify the number of degrees of variation in their area. The line that passes near Chicago is called the agonic line. Anywhere along this line the two poles are aligned, and there is no variation. East of this line, the magnetic North Pole is to the west of the geographic North Pole and a correction must be applied to a compass indication to get a true direction.

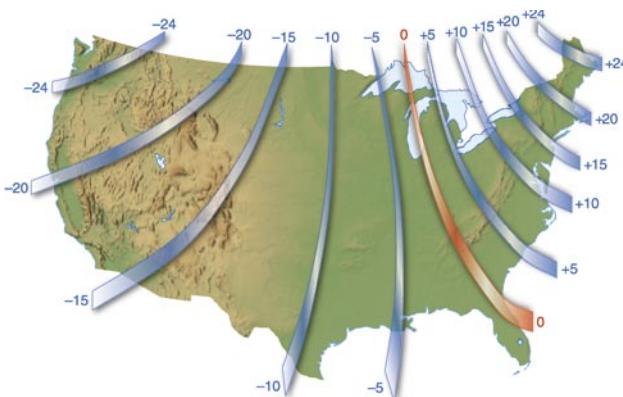


Figure 7-32. Isogonic lines are lines of equal variation.

Flying in the Washington, D.C., area, for example, the variation is 10° west. If a pilot wants to fly a true course of south (180°), the variation must be added to this, resulting in a magnetic course of 190° to fly. Flying in the Los Angeles, California, area, the variation is 14° east. To fly a true course of 180° there, the pilot would have to subtract the variation and fly a magnetic course of 166° . The variation error does not change with the heading of the aircraft; it is the same anywhere along the isogonic line.

Deviation

The magnets in a compass align with any magnetic field. Local magnetic fields in an aircraft caused by electrical current flowing in the structure, in nearby wiring or any magnetized part of the structure, conflict with the Earth's magnetic field and cause a compass error called deviation.

Deviation, unlike variation, is different on each heading, but it is not affected by the geographic location. Variation error cannot be reduced or changed, but deviation error can be minimized when an AMT performs the maintenance task known as "swinging the compass."

Most airports have a compass rose, which is a series of lines marked out on a ramp or maintenance runup area where there is no magnetic interference. Lines, oriented to magnetic north, are painted every 30° , as shown in *Figure 7-33*.

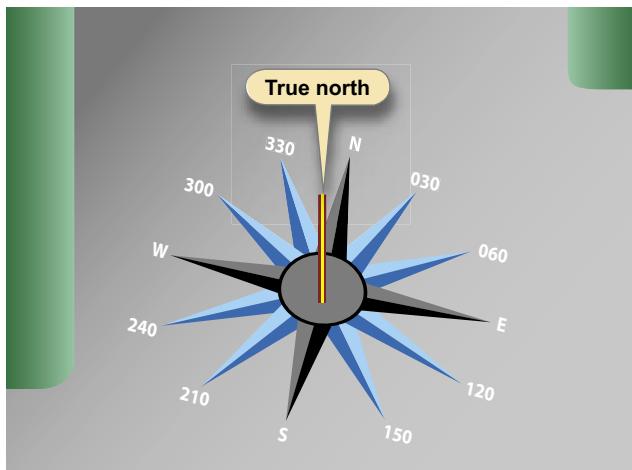


Figure 7-33. Utilization of a compass rose aids compensation for deviation errors.

The AMT aligns the aircraft on each magnetic heading and adjusts the compensating magnets to minimize the difference between the compass indication and the actual magnetic heading of the aircraft. Any error that cannot be removed is recorded on a compass correction card, like the one in *Figure 7-34*, and placed in a cardholder near the compass. The pilot can taxi the aircraft to the compass rose and maneuver the aircraft to the headings prescribed by the AMT, and if authorized to do so, the AMT can also taxi and maneuver the aircraft; however, only the AMT can adjust the compass or

FOR	000	030	060	090	120	150
STEER						
RDO. ON	001	032	062	095	123	155

FOR	180	210	240	270	300	330
STEER						
RDO. ON	176	210	243	271	296	325

Figure 7-34. A compass correction card shows the deviation correction for any heading.

complete the compass coreection card. If the pilot wants to fly a magnetic heading of 120° and the aircraft is operating with the radios on, the pilot should fly a compass heading of 123° .

The corrections for variation and deviation must be applied in the correct sequence and is shown below, starting from the true course desired.

Step 1: Determine the Magnetic Course

$$\text{True Course } (180^{\circ}) \pm \text{Variation } (+10^{\circ}) = \text{Magnetic Course } (190^{\circ})$$

The magnetic course (190°) is steered if there is no deviation error to be applied. The compass card must now be considered for the compass course of 190° .

Step 2: Determine the Compass Course

$$\text{Magnetic Course } (190^{\circ}, \text{from step 1}) \pm \text{Deviation } (-2^{\circ}, \text{from correction card}) = \text{Compass Course } (188^{\circ})$$

NOTE: Intermediate magnetic courses between those listed on the compass card need to be interpreted. Therefore, to steer a true course of 180° , the pilot would follow a compass course of 188° .

To find the true course that is being flown when the compass course is known:

$$\text{Compass Course} \pm \text{Deviation} = \text{Magnetic Course} \pm \text{Variation} = \text{True Course}$$

Dip Errors

The lines of magnetic flux are considered to leave the Earth at the magnetic North Pole and enter at the magnetic South Pole. At both locations the lines are perpendicular to the Earth's surface. At the magnetic equator, which is halfway between the poles, the lines are parallel with the surface. The magnets in a compass align with this field, and near the poles they dip, or tilt, the float and card. The float is balanced with a small dip-compensating weight, to dampen the effects of dip when operating in the middle latitudes of the northern hemisphere. This dip (and weight) causes two very noticeable errors: northerly turning error and acceleration error.

The pull of the vertical component of the Earth's magnetic field causes northerly turning error, which is apparent on a heading of north or south. When an aircraft flying on a heading of north makes a turn toward east, the aircraft banks to the right, and the compass card tilts to the right. The vertical component of the Earth's magnetic field pulls the northseeking end of the magnet to the right, and the float rotates, causing the card to rotate toward west, the direction opposite the direction the turn is being made. [Figure 7-35]

If the turn is made from north to west, the aircraft banks to the left and the compass card tilts down on the left side. The magnetic field pulls on the end of the magnet that causes the card to rotate toward east. This indication is again opposite to the direction the turn is being made. The rule for this error is: when starting a turn from a northerly heading, the compass indication lags behind the turn.

When an aircraft is flying on a heading of south and begins a turn toward east, the Earth's magnetic field pulls on the end of the magnet that rotates the card toward east, the same direction the turn is being made. If the turn is made from south toward west, the magnetic pull starts the card rotating toward west—again, in the same direction the turn is being made. The rule for this error is: when starting a turn from a southerly heading, the compass indication leads the turn.

In acceleration error, the dip-correction weight causes the end of the float and card marked N (the south-seeking end) to be heavier than the opposite end. When the aircraft is flying at a constant speed on a heading of east or west, the float and card is level. The effects of magnetic dip and the weight are approximately equal. If the aircraft accelerates on a heading of east [Figure 7-36], the inertia of the weight holds its end of the float back and the card rotates toward north. As soon as the

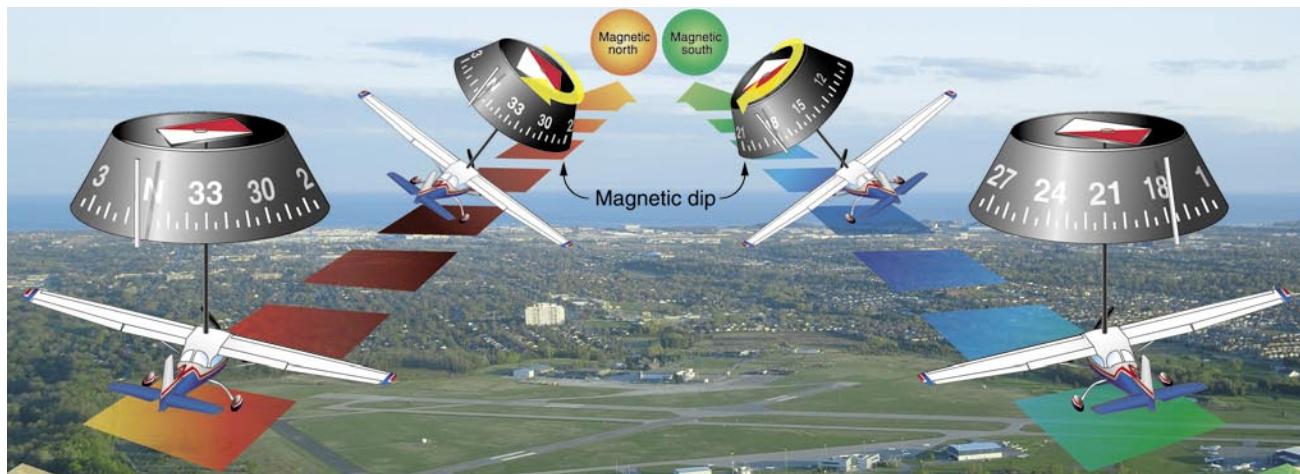


Figure 7-35. Northerly turning error.

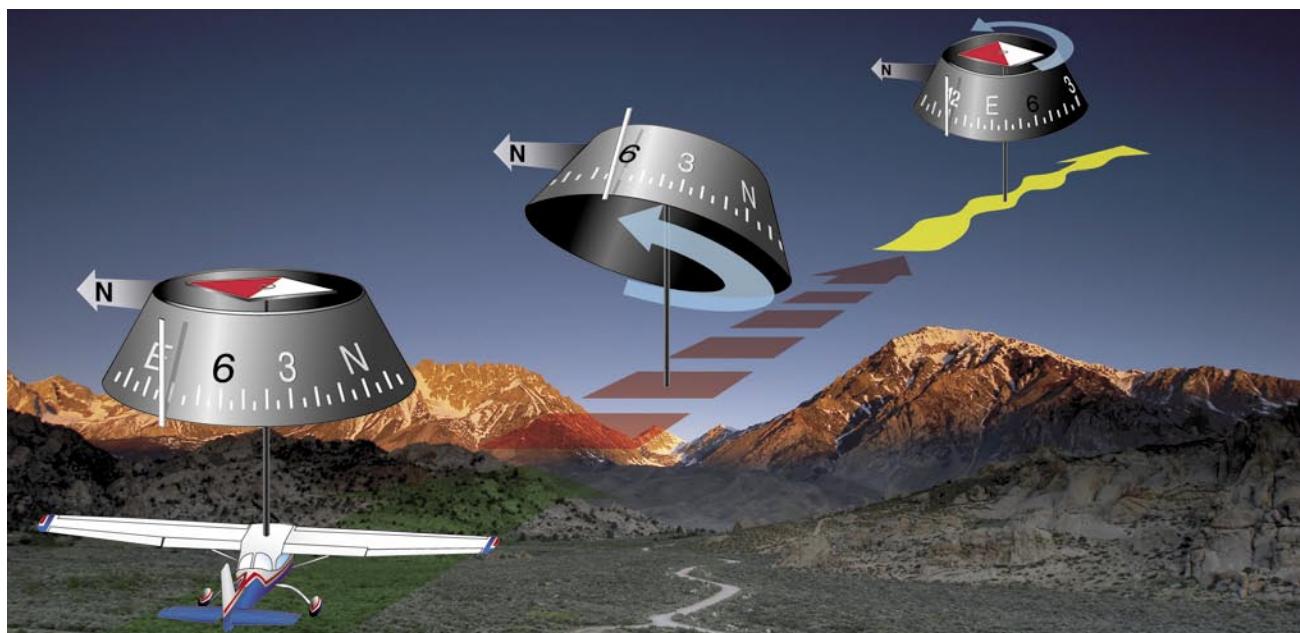


Figure 7-36. Effects of acceleration error.

speed of the aircraft stabilizes, the card swings back to its east indication. If, while flying on this easterly heading, the aircraft decelerates, the inertia causes the weight to move ahead and the card rotates toward south until the speed again stabilizes.

When flying on a heading of west, the same things happen. Inertia from acceleration causes the weight to lag, and the card rotates toward north. When the aircraft decelerates on a heading of west, inertia causes the weight to move ahead and the card rotates toward south.

A mnemonic, or memory jogger, for the effect of acceleration error is the word “ANDS” (acceleration—north, deceleration—south). Acceleration causes an indication toward north; deceleration causes an indication toward south.

Oscillation Error

Oscillation is a combination of all of the other errors, and it results in the compass card swinging back and forth around the heading being flown. When setting the gyroscopic heading indicator to agree with the magnetic compass, use the average indication between the swings.

The Vertical Card Magnetic Compass

The floating magnet type of compass not only has all the errors just described, but also lends itself to confused reading. It is easy to begin a turn in the wrong direction because its card appears backward. East is on what the pilot would expect to be the west side. The vertical card magnetic compass eliminates some of the errors and confusion. The dial of this compass is graduated with letters representing the cardinal directions, numbers every 30° , and tick marks every 5° . The dial is rotated by a set of gears from the shaft-mounted magnet, and the nose of the symbolic aircraft on the instrument glass represents the lubber line for reading the heading of the aircraft from the dial. Eddy currents induced into an aluminum-damping cup damp, or decrease, oscillation of the magnet. [Figure 7-37]



Figure 7-37. Vertical card compass.

Lags or Leads

When starting a turn from a northerly heading, the compass lags behind the turn. When starting a turn from a southerly heading, the compass leads the turn.

Eddy Current Damping

The decreased amplitude of oscillations by the interaction of magnetic fields. In the case of a vertical card magnetic compass, flux from the oscillating permanent magnet produces eddy currents in a damping disk or cup. The magnetic flux produced by the eddy currents opposes the flux from the permanent magnet and decreases the oscillations.

Outside Air Temperature (OAT) Gauge

The outside air temperature (OAT) gauge is a simple and effective device mounted so that the sensing element is exposed to the outside air. The sensing element consists of a bimetallic-type thermometer in which two dissimilar materials are welded together in a single strip and twisted into a helix. One end is anchored into protective tube and the other end is affixed to the pointer, which reads against the calibration on a circular face. OAT gauges are calibrated in degrees $^{\circ}\text{C}$, $^{\circ}\text{F}$, or both. An accurate air temperature provides the pilot with useful information about temperature lapse rate with altitude change. [Figure 7-38]



Figure 7-38. Outside air temperature (OAT) gauge.

Chapter Summary

Flight instruments enable an aircraft to be operated with maximum performance and enhanced safety, especially when flying long distances. Manufacturers provide the necessary flight instruments, but to use them effectively, pilots need to understand how they operate. As a pilot, it is important to become very familiar with the operational aspects of the pitot-static system and associated instruments, the vacuum system and associated instruments, the gyroscopic instruments, and the magnetic compass.