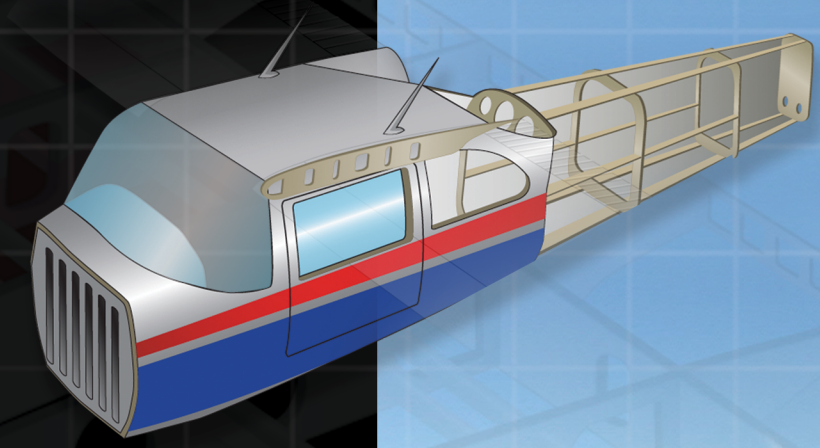
Chapter 3

Aircraft Construction



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 aircraft. Title 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 aircraft, balloon, glider, powered parachute, and gyroplane, have their own handbooks to include detailed information regarding aerodynamics and control.

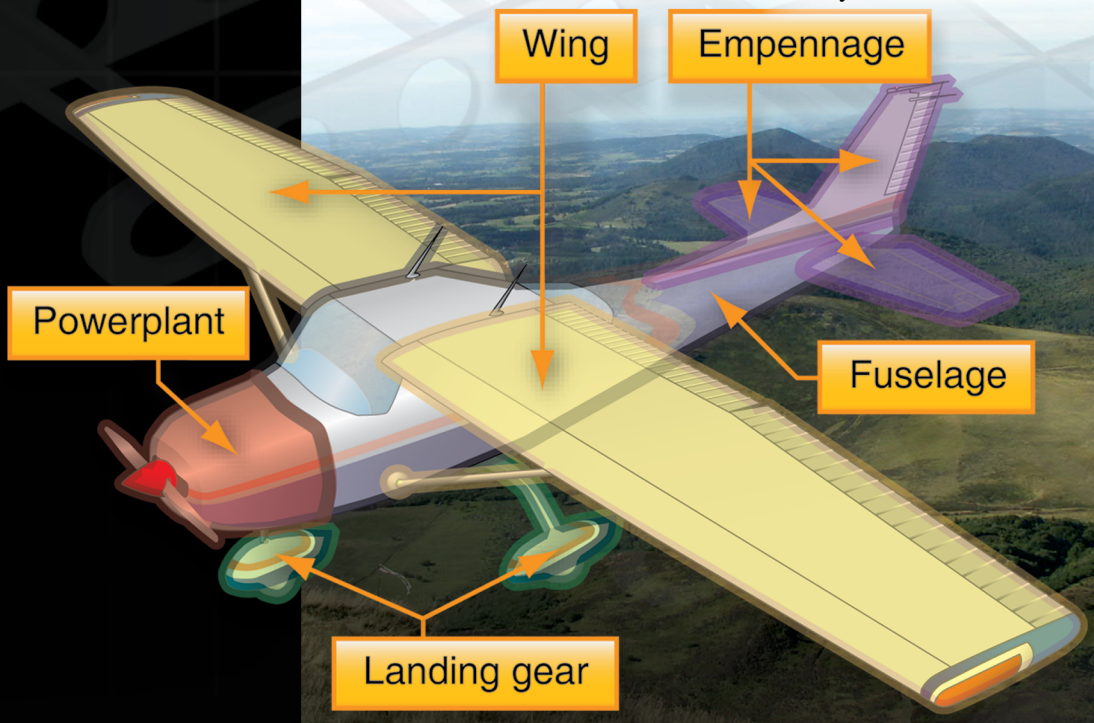


Figure 1-1. Airplane components

Aircraft Design, Certification, and Airworthiness

The FAA certifies three types of aviation products: aircraft, aircraft engines, and propellers. Each of these products has been designed to a set of airworthiness standards. These standards are parts of Title 14 of the Code of Federal Regulations (14 CFR), published by the FAA. The airworthiness standards were developed to help ensure that aviation products are designed with no unsafe features. Different airworthiness standards apply to the different categories of aviation products as follows:

- Normal, Utility, Acrobatic, and Commuter Category Airplanes- 14 CFR part 23
- Transport Category Airplanes—14 CFR part 25
- Normal Category—14 CFR part 27
- Transport Category Rotorcraft—14 CFR part 29
- Manned Free Balloons—14 CFR part 31
- Aircraft Engines—14 CFR part 33
- Propellers—14 CFR part 35

Some aircraft are considered "special classes" of aircraft and do not have their own airworthiness standards, such as gliders and powered lift. The airworthiness standards used for these aircraft are a combination of requirements in 14 CFR parts 23, 25, 27, and 29 that the FAA and the designer have agreed are appropriate for the proposed aircraft.

The FAA issues a Type Certificate (TC) for the product when they are satisfied it complies with the applicable airworthiness standards. When the TC is issued, a Type Certificate Data Sheet (TCDS) is generated that specifies the important design and operational characteristics of the aircraft, aircraft engine, or propeller. The TCDS defines the product and are available to the public from the FAA website at www.faa.gov.

A Note About Light Sport Aircraft

Light sport aircraft are not designed according to FAA airworthiness standards. Instead, they are designed to a consensus of standards agreed upon in the aviation industry. The FAA has agreed the consensus of standards is acceptable as the design criteria for these aircraft. Light sport aircraft do not necessarily have individually type certificated engines and propellers. Instead, a TC is issued to the aircraft as a whole. It includes the airframe, engine, and propeller.

Aircraft, aircraft engines, and propellers can be manufactured one at a time from the design drawings, or through an FAA approved manufacturing process, depending on the size and capabilities of the manufacturer. During the manufacturing process, each part is inspected to ensure that it has been built exactly according to the approved design. This inspection is called a conformity inspection.

When the aircraft is complete, with the airframe, engine, and propeller, it is inspected and the FAA issues an airworthiness certificate for the aircraft. Having an airworthiness certificate means the complete aircraft meets the design and manufacturing standards, and is in a condition for safe flight. This airworthiness certificate must be carried in the aircraft during all flight operations. The airworthiness certificate remains valid as long as the required maintenance and inspections are kept up to date for the aircraft.

Airworthiness certificates are classified as either "Standard" or "Special." Standard airworthiness certificates are white, and are issued for normal, utility, acrobatic, commuter, or transport category aircraft. They are also issued for manned free balloons and aircraft designated as "Special Class."

Special airworthiness certificates are pink, and are issued for primary, restricted, and limited category aircraft, and light sport aircraft. They are also issued as provisional airworthiness certificates, special flight permits (ferry permits), and for experimental aircraft.

More information on airworthiness certificates can be found in Chapter 9, in 14 CFR parts 175-225, and also on the FAA website at www.faa.gov.

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 5, 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 3-1]*

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.

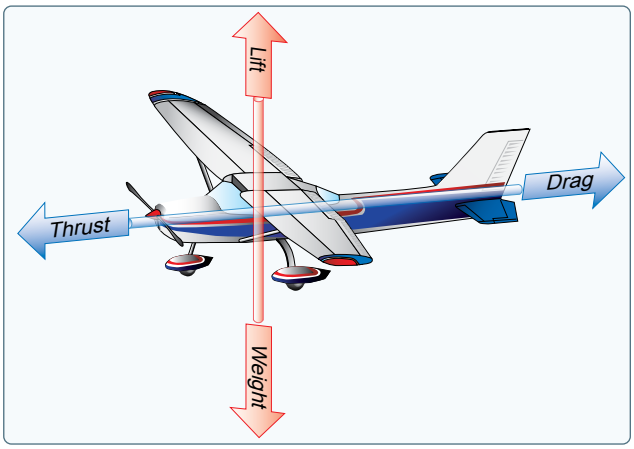


Figure 3-1. *The four forces.*

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

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 aircraft in flight. *[Figure 3-2]*

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 3-3]* The CG is computed during initial design and construction and is further affected by the installation of onboard equipment, aircraft loading, and other factors.

Major Components

Although airplanes are designed for a variety of purposes, most of them have the same major components. *[Figure 3-4]* 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 3-5]* The most popular types of fuselage structures used in today's aircraft are the monocoque (French for "single shell") and semimonocoque. These structure types 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

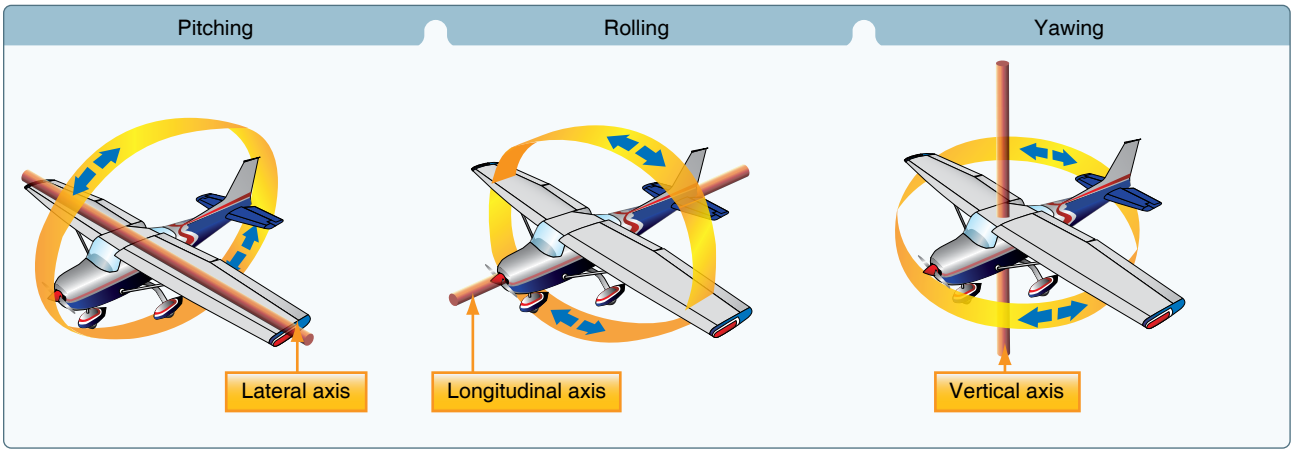


Figure 3-2. *Illustrates the pitch, roll, and yaw motion of the aircraft along the lateral, longitudinal, and vertical axes, respectively.*

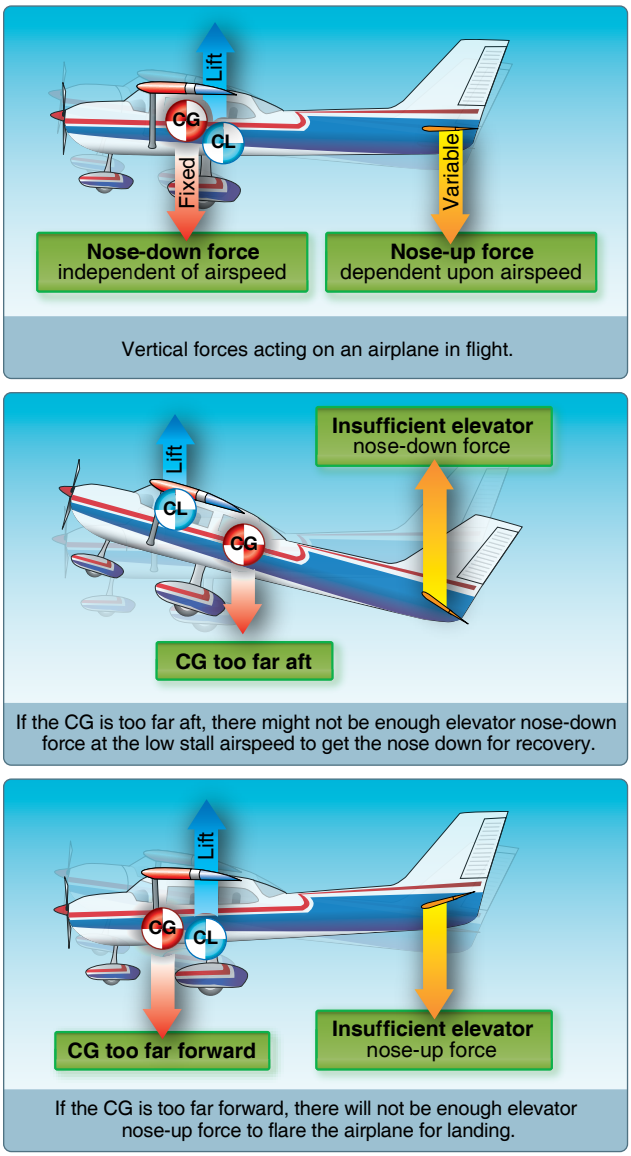


Figure 3-3. *Center of gravity (CG).*

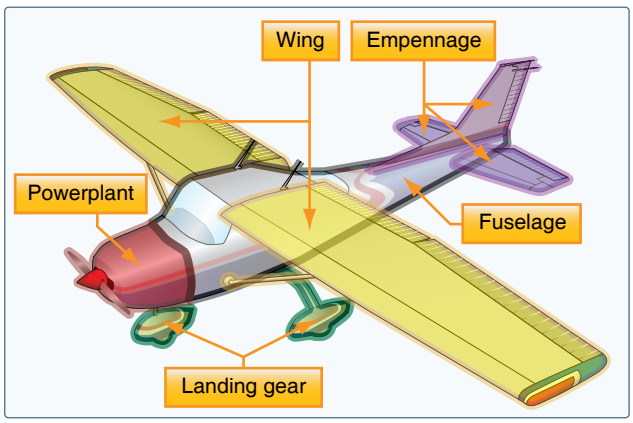


Figure 3-4. *Airplane components.*

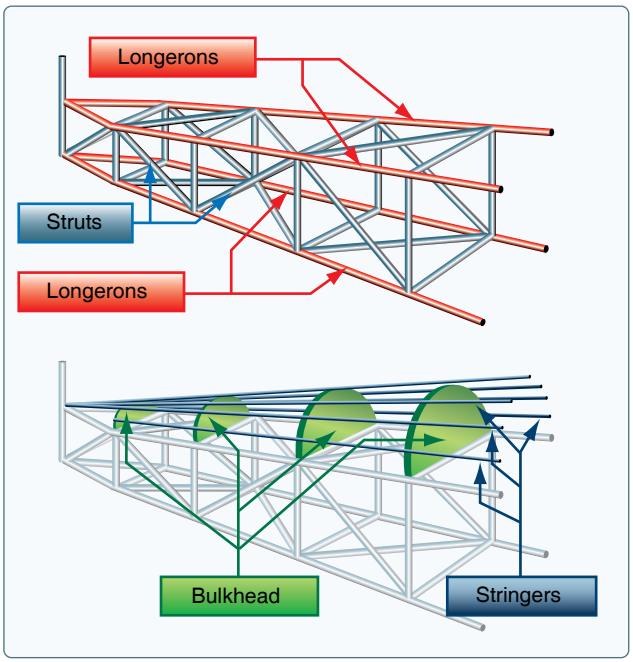


Figure 3-5. *Truss-type fuselage structure.*

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 5, 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 monoplanes, while those with two sets are called biplanes. *[Figure 3-6]*

Many high-wing airplanes have external braces, or wing struts that 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 3-7]* 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 are either an integral part of the wing's structure or consist of flexible containers mounted inside of the wing.

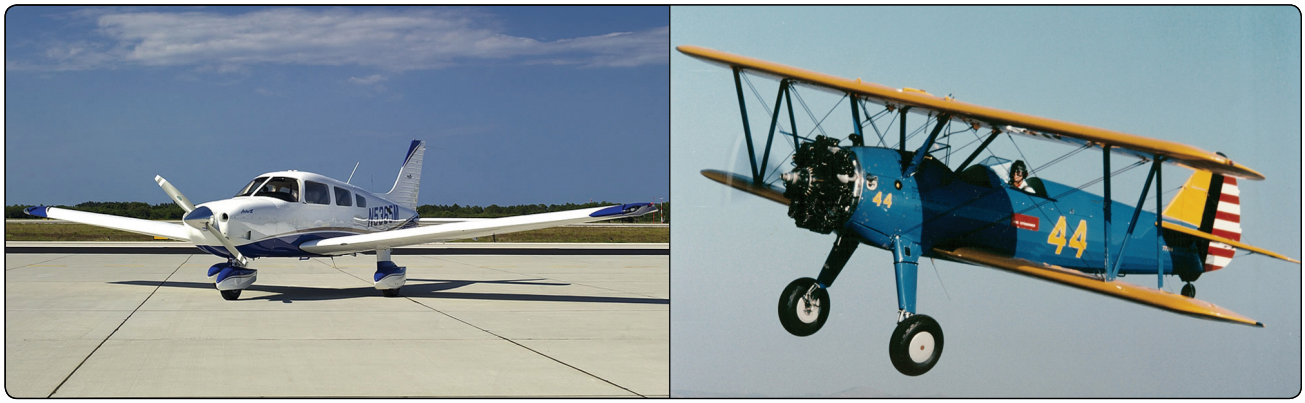


Figure 3-6. *Monoplane (left) and biplane (right).*

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 3-8]*

Alternate Types of Wings

Alternate types of wings are often found on aircraft. The shape and design of a wing is dependent upon the type of operation for which an aircraft is intended and is tailored to specific types of flying. These design variations are discussed in Chapter 5, 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). For example, the wing of the weight-shift control aircraft is highly swept in an effort to reduce drag and allow for the shifting of weight to provide controlled flight. *[Figure 3-9]* Handbooks specific to most categories of aircraft are available for the interested pilot and can be found on the Federal Aviation Administration (FAA) website at www.faa.gov.

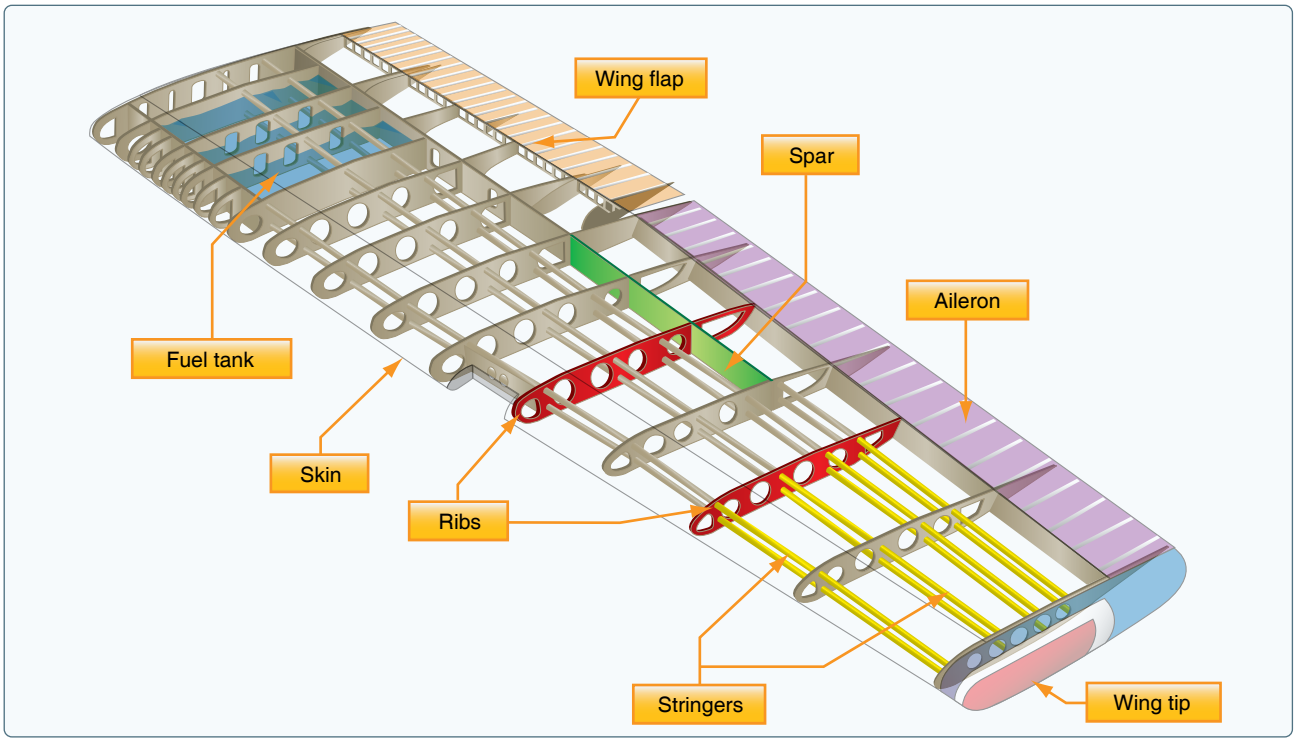


Figure 3-7. *Wing components.*

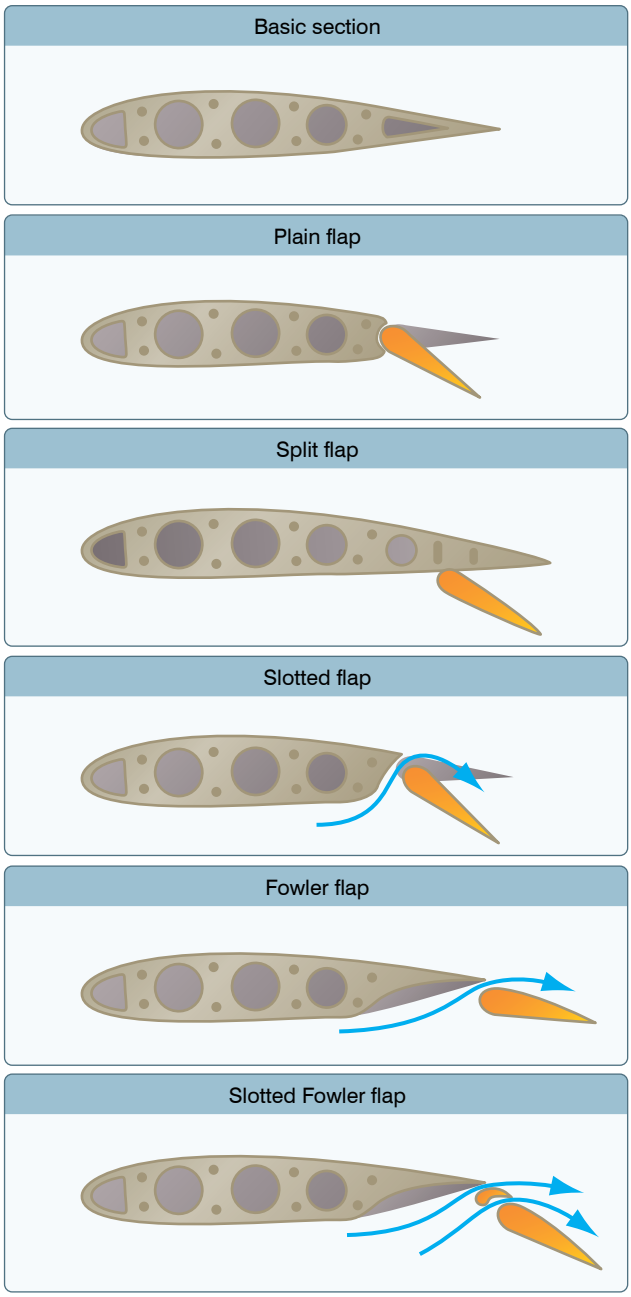


Figure 3-8. *Types of flaps.*

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 3-10]*

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

Figure 3-9. *Weight-shift control aircraft use the shifting of weight for control.*

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 3-11]*

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.

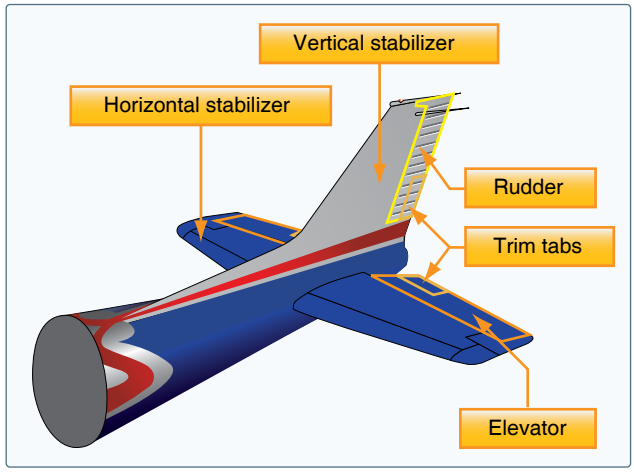


Figure 3-10. *Empennage components.*

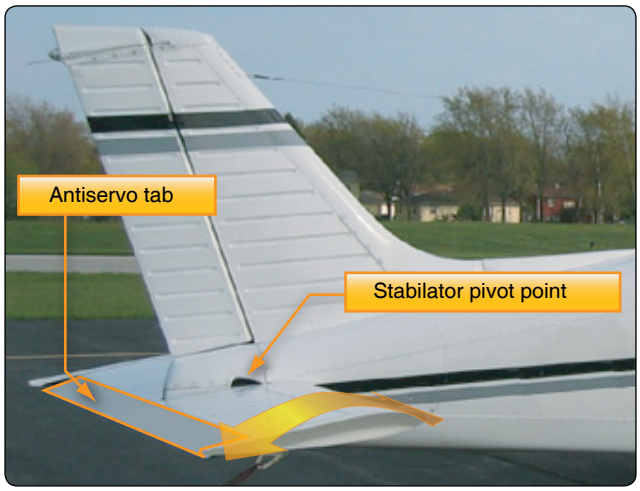


Figure 3-11. *Stabilator components.*

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 3-12]*

Wheeled 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.

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 3-13]* The engine is covered by a cowling, or a nacelle, which are both types of covered housing. The purpose of the cowling or nacelle 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. A propeller

Figure 3-12. *Types of landing gear: floats (top), skis (middle), and wheels (bottom).*

is a rotating airfoil that produces thrust through aerodynamic action. A high-pressure area is formed at the back of the propeller's airfoil, and low 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 develops thrust from the propeller, which in turn pulls the airplane forward. Engines may be turned around to be pushers with the propeller at the rear.

There are two significant factors involved in the design of a propeller that impact its effectiveness. The angle of a

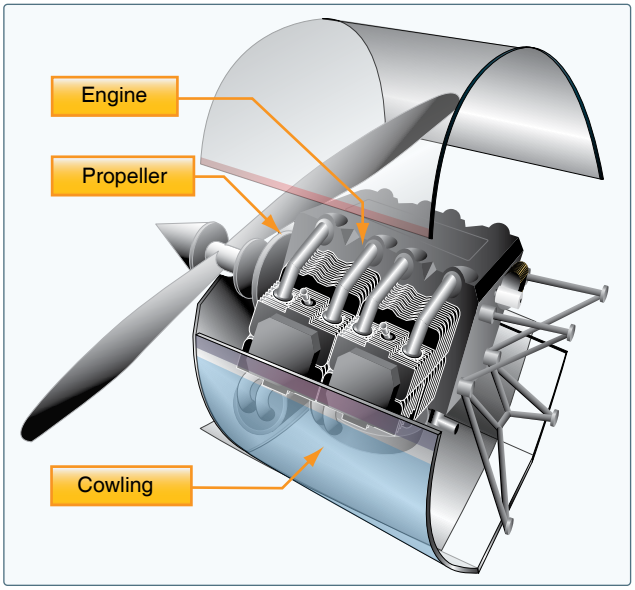


Figure 3-13. *Engine compartment.*

propeller blade, as measured against the hub of the propeller, keeps the angle of attack (AOA) (See definition in Glossary) relatively constant along the span of the propeller blade, reducing or eliminating the possibility of a stall. The amount of lift being produced by the propeller is directly related to the AOA, which is the angle at which the relative wind meets the blade. The AOA continuously changes during the flight depending upon the direction of the aircraft.

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, and passenger services, such as cabin lighting.

The flight controls are the devices and systems that govern the attitude of an aircraft and, as a result, the flight path 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.

In the case of most modern airplanes, 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 3-14]*

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

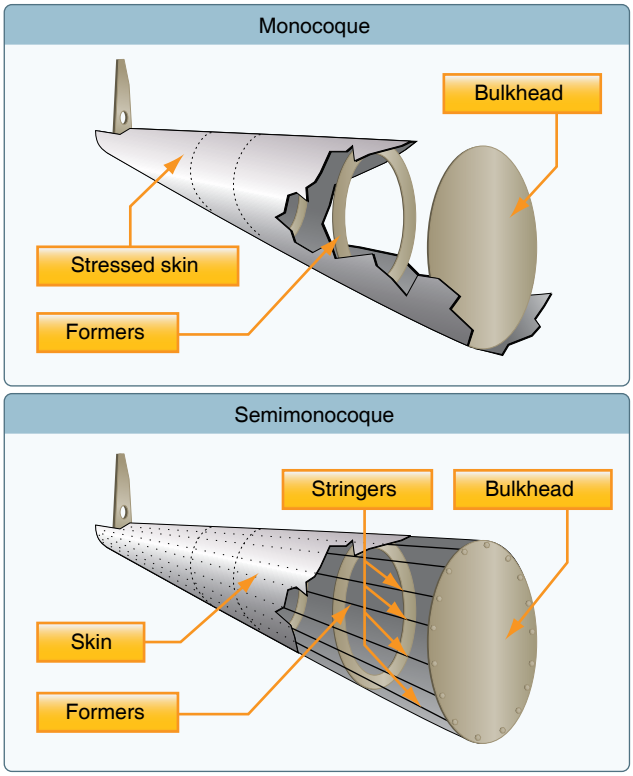


Figure 3-14. *Semimonocoque and monocoque fuselage design.*

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 3-15]*

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.

Figure 3-15. *Composite aircraft.*

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 somewhat 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 of 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 3-16]*

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 it 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.

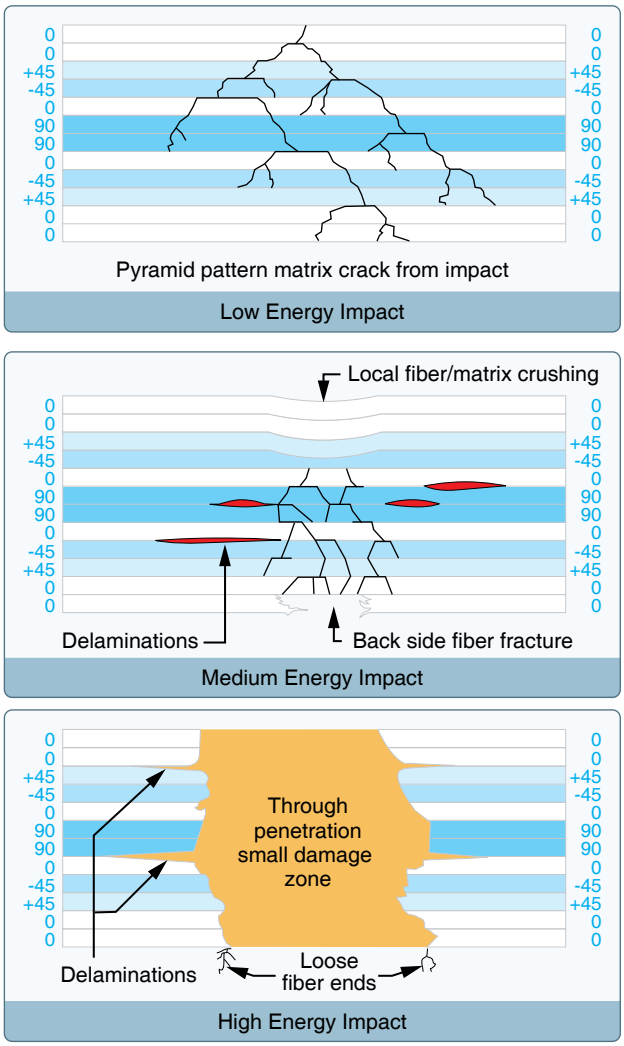


Figure 3-16. *Impact energy affects the visibility, as well as the severity, of damage in composite structures. High and medium energy impacts, while severe, are easy to detect. Low energy impacts can easily cause hidden damage.*

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 aircraft often have specific recommendations on allowable paint colors. If the aircraft 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.

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 does not attack the paint, it will not 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) aircraft 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, where 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 3-17]*

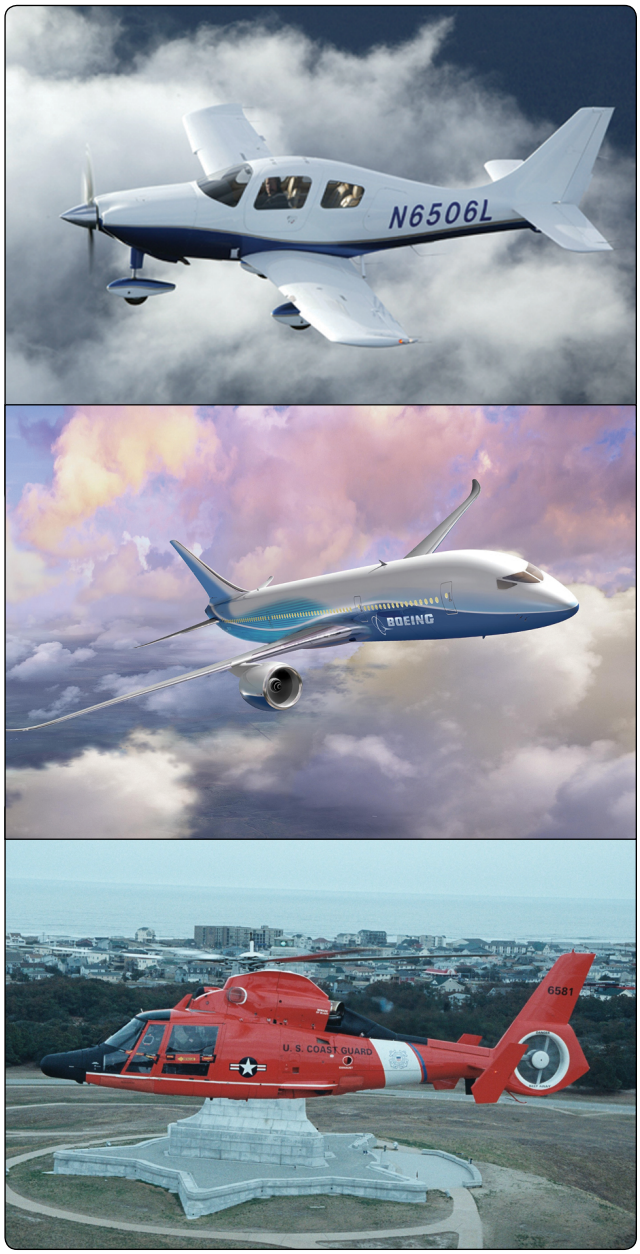


Figure 3-17. *Composite materials in aircraft, such as Columbia 350 (top), Boeing 787 (middle), and a Coast Guard HH-65 (bottom).*

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 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 instruments that have a failure rate far less than those of conventional analog instrumentation. *[Figure 3-18]*

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 2, Aeronautical Decision-Making.

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 3-19]*

Figure 3-18. *Analog display (top) and digital display (bottom) from a Cessna 172.*

Control Instruments

The control instruments display immediate attitude and power changes and are calibrated to permit adjustments in precise increments. *[Figure 3-20]* The instrument for attitude display is the attitude indicator. The control instruments do not indicate aircraft speed or altitude. In order to determine these variables 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 3-21* and *3-22]*

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 17, 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 that contain valuable flying information. As discussed in Chapter 1, the National Aeronautics and Space Administration (NASA) and the FAA also offer free information for pilots.

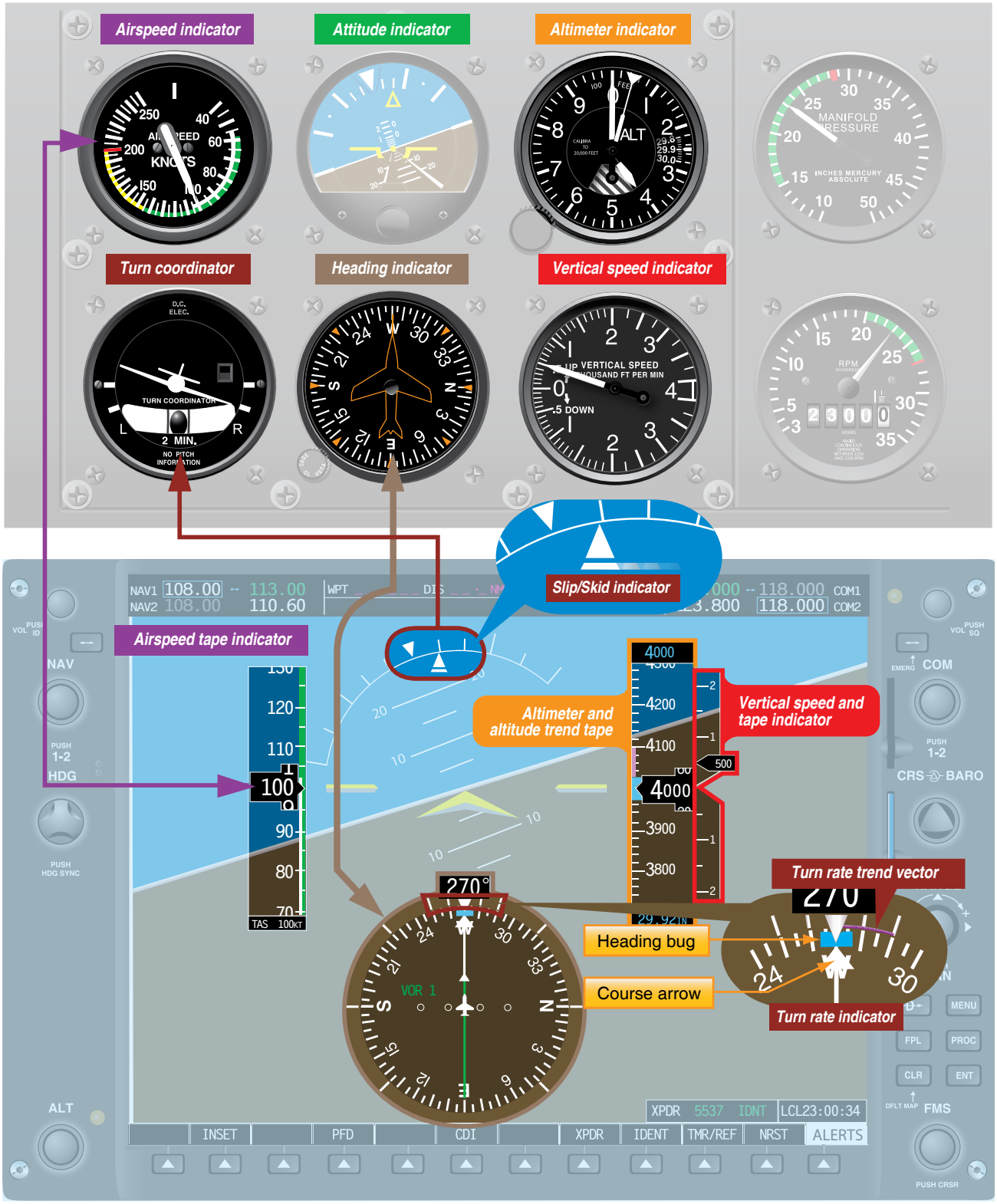


Figure 3-19. *Performance instruments.*

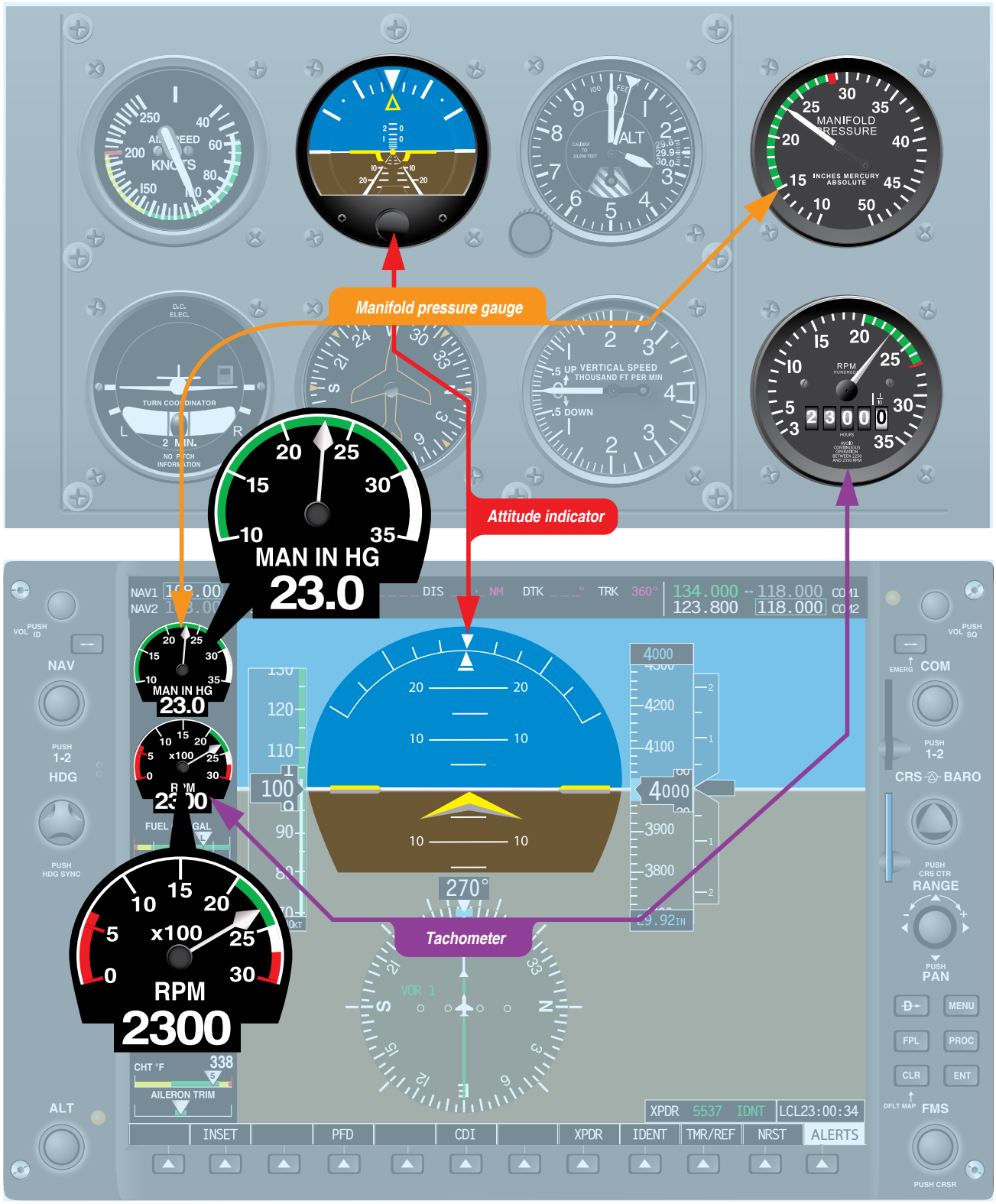


Figure 3-20. *Control instruments.*

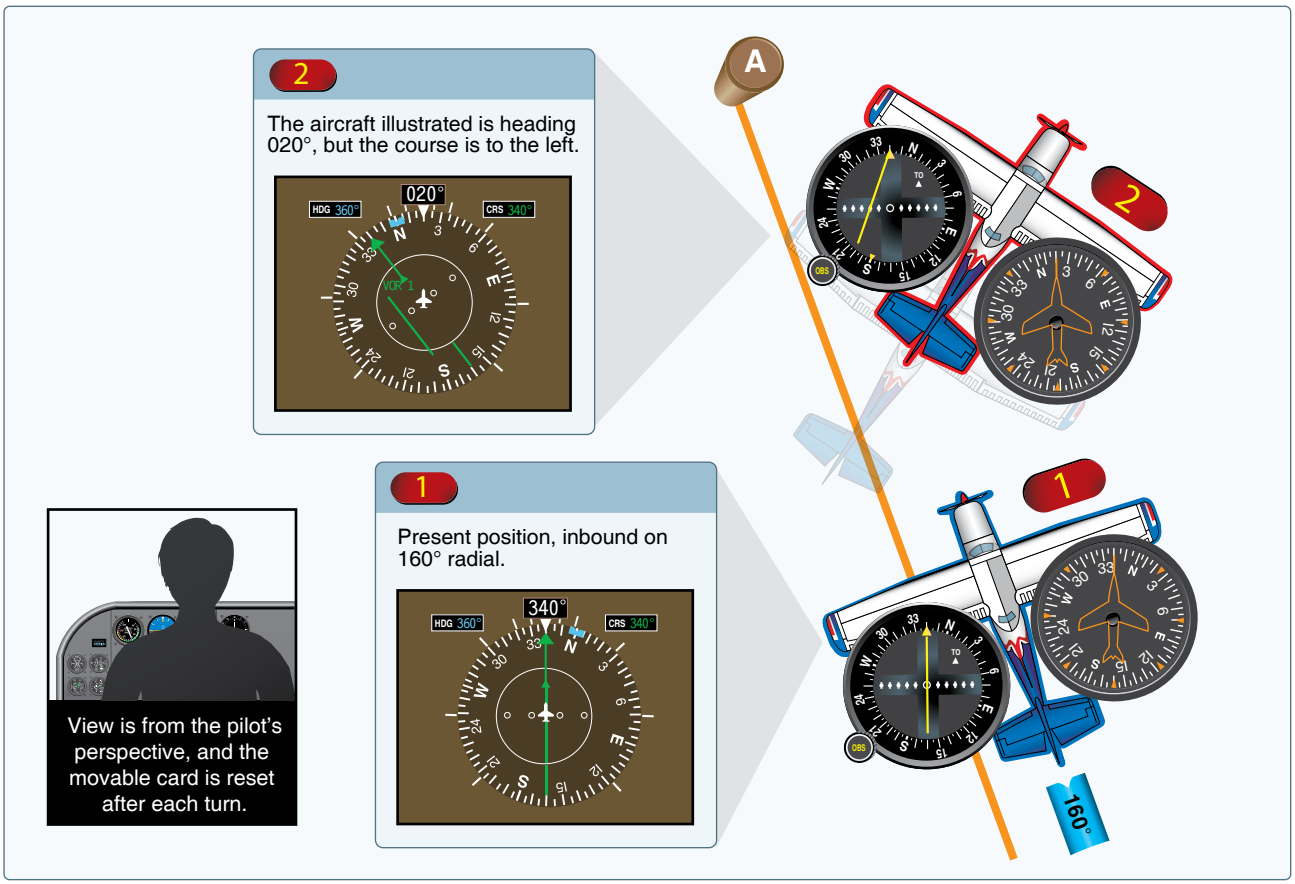


Figure 3-21. *A comparison of navigation information as depicted on both analog and digital displays.*

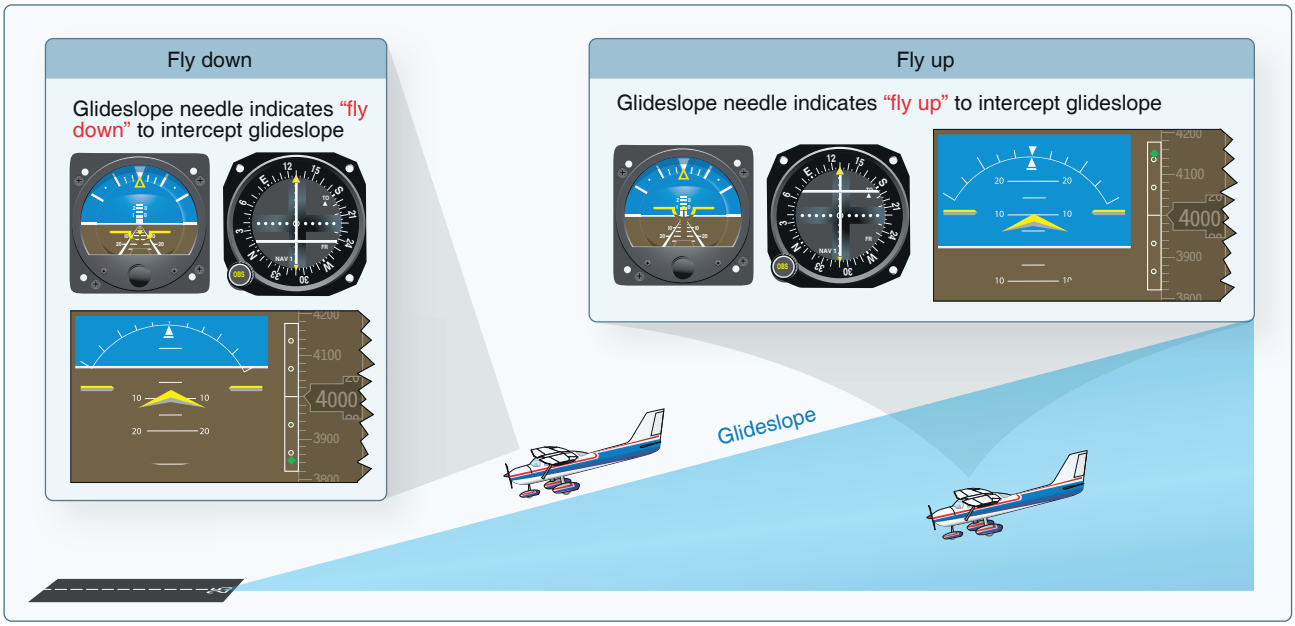


Figure 3-22. *Analog and digital indications for glideslope interception.*