Chapter 8 AIRCRAFT IN MOTION

Aircraft, spacecraft and even submarines (in a limited way) are capable of moving in all possible directions. That is, if one considers such craft to be suspended at the center of an imaginary sphere, the vehicles can move in any direction away from the center of the sphere, and aircraft and spacecraft can roll and spin toward any of the possible directions. This movement or motion is in three dimensions. Automobiles, trains and surface ships are restricted to two-dimensional movement because they move over the earth's surface only.

No matter how you paint it, it's still going to roll, pitch and yaw. *(EAA)*

Everyone is familiar with control over the motion of an automobile. The driver can speed it up, slow it down or stop it. A car's direction of movement can be controlled by changing the direction toward which its wheels point, but it cannot go above or below the road. A train's movement is restricted by the rails over which it must travel, so its range of motion is either forward or backward. The airplane and the spacecraft are the only true three-dimensional machines because of their complete freedom of motion. They can move in any of three axes.

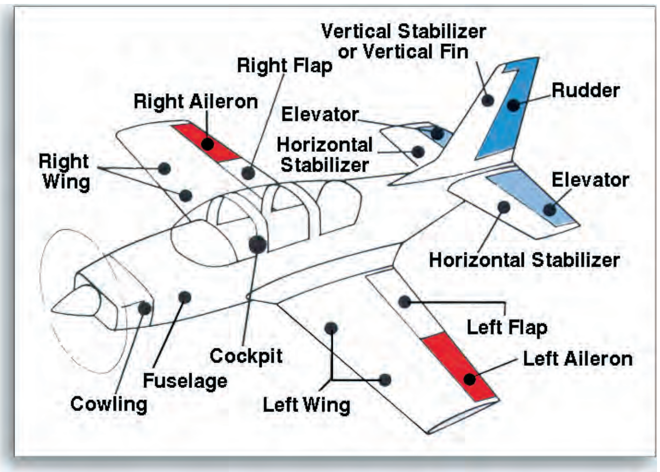
Objectives

Identify the basic parts of a conventional airplane.
Name the three axes of rotation.
Describe the locations of the three axes of rotation with regard to a conventional airplane.
Identify the three different types of fuselage classification.
Explain why box construction is better than wire support.
Describe how the use of aluminum and composites in aircraft construction improve each force of flight.
Identify the purpose of landing gear.
Describe the three types of landing gear arrangements.
Describe the typical functions of aircraft fuel systems.
Describe the typical functions of aircraft hydraulic systems.
Describe the typical functions of aircraft electrical systems.
Describe the earliest aircraft instruments.
Classify the three major groups of aircraft instruments by their uses.
Classify the three major groups of aircraft instruments by their principles of operation.
Describe any one new concept in aviation.

The Axes of an Aircraft

The airplane shown in the picture to the right demonstrates the typical parts of a fixed wing aircraft. There are many variations to the parts shown, and rotary wing aircraft have a design quite different from fixed wing aircraft.

The fuselage of the conventional airplane is the basic structure to which all the other parts are attached. Even the engine is attached to the fuselage, and this is true for most single-engine aircraft. The primary source of lift is the wing, and attached to the wing are its ailerons. The tail, or empennage, consists of the horizontal stabilizer with its attached elevators and the vertical stabilizer with its attached rudder. Often, the vertical stabilizer is referred to as the vertical fin.



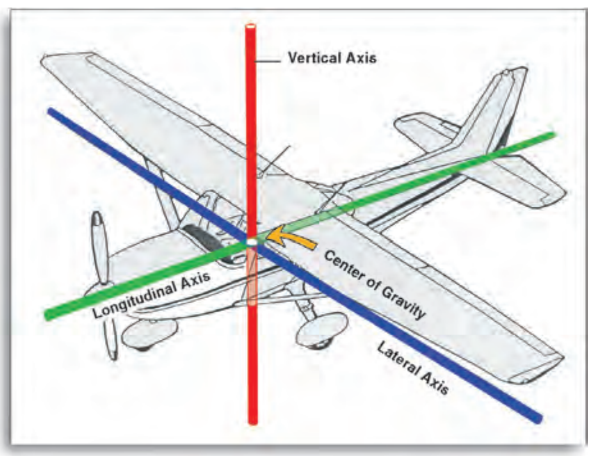
The Basic Airplane and Its Parts

The Longitudinal (Roll) Axis

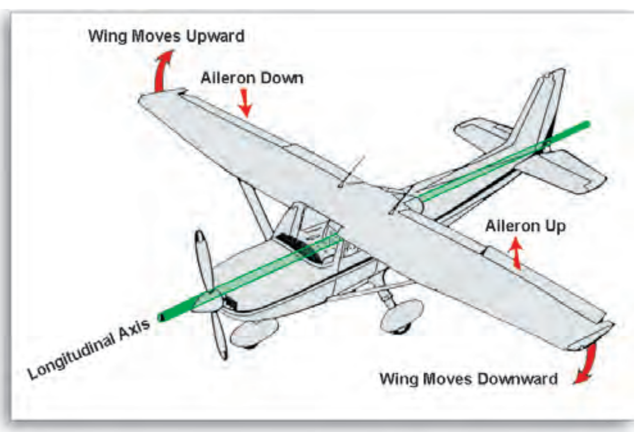
Running from the tip of the nose to the tip of the tail is the longitudinal axis of a single-engine airplane. This axis can be thought of as a line running from the tail to the nose of the aircraft.

Aircraft roll is a motion about the longitudinal axis and is a result of aileron movement. The ailerons are attached to the wing and to the control column in a manner that ensures one aileron will deflect downward when the other is deflected upward.

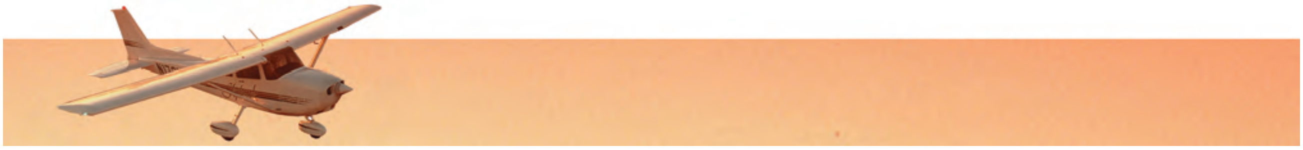
When an aileron is not in perfect alignment with the total wing, it changes the wing's lift characteristics. This change in lift is due to a change in the wing camber. In the picture below, notice that the left wing aileron is deflected upward and the right downward. The lift on the right is increased



Three Axes of an Airplane

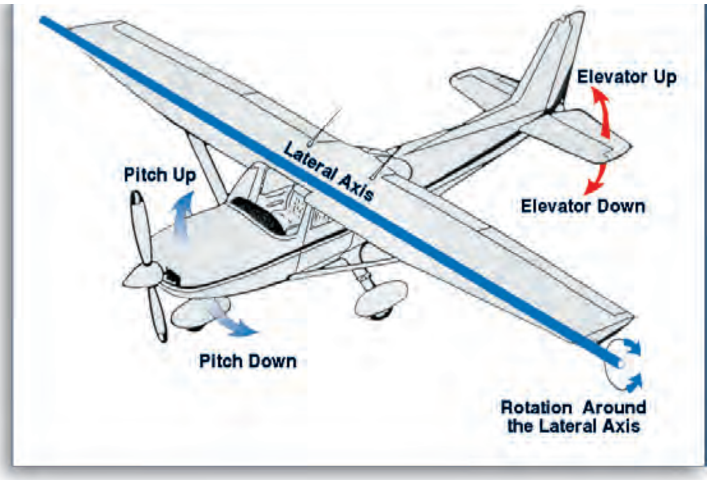


The Longitudinal Axis



because the camber is increased. More lift on the right and less on the left result in a rolling motion to the left around the longitudinal axis.

The Lateral (Pitch) Axis



The Lateral Axis

Another imaginary line, running from one wingtip through the fuselage and exiting the other wingtip, forms an airplane's lateral axis. Another name for the lateral axis is the pitch axis. This name makes sense because the airplane is actually caused to pitch its nose upward or downward, and such movement is made about the lateral axis. This pitching movement is caused by the elevator, which is attached to the horizontal stabilizer. The elevator can be deflected up or down as the pilot moves the control column backward or forward.

Movement backward on the control column (or stick) moves the elevator upward. This changes the shape of the stabilizer airfoil so that the direction of lift on this particular tail surface is down. Thus, it pulls everything aft of the airplane's lateral axis down with it and causes everything forward of the lateral axis to pitch upward. This movement increases the wings' angle of attack creating more lift and causing the airplane to climb.

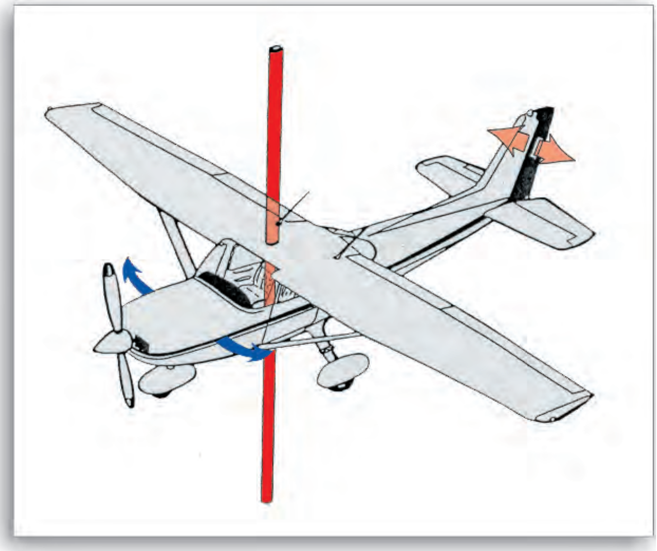
Deflection of the elevator downward increases the camber of the tail and increases lift at the tail. Before leaving the horizontal stabilizer, the term *stabilator* should be clarified. Some aircraft are no longer designed to use a stabilizer with an elevator arrangement. Instead, the entire horizontal tail surface is hinged so that the surface's angle of attack is changed as the pilot pulls or pushes on the control column. This type of design is doing the job of both a stabilizer and elevator so it is called a stabilator.

The stabilator design originated during the first supersonic flight testing of the Bell X-1 at Edwards Air Force Base in California. As the test aircraft approached supersonic speeds, the elevator became ineffective. The stabilator was found to be more effective as the shock waves passed over the aircraft.

The Vertical (Yaw) Axis

Another imaginary rod or axis, which passes vertically through the meeting point of the longitudinal and lateral axes, is called the vertical or yaw axis. Aircraft yaw is a motion of the longitudinal axis, either left or right, around the vertical axis. It would be like turning the nose left without banking the wings. The nose goes left, the tail goes right. This would be called a left yaw.

When the pilot moves the airplane's rudder, the aircraft yaws about this axis. When the pilot presses on the cockpit-located rudder pedals, the rudder is deflected from its neutral, or streamlined, position

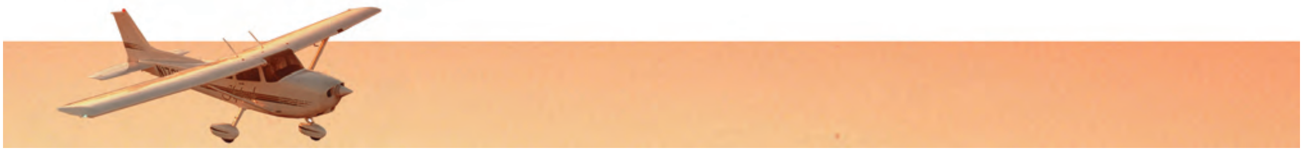


The Vertical Axis

with the vertical stabilizer. Like the elevator and stabilizer, the deflected rudder forms a curved or cambered airfoil surface, which on one side generates induced lift while on the other side dynamic lift results.

The rudder controls are rigged so that the rudder moves toward the direction of the rudder pedal that is pressed. This causes the airplane's nose to point toward the direction (left or right) of the rudder pedal being pressed.

The *Proteus*, designed by Burt Rutan, has a front-mounted airfoil called a "canard." It provides lift and pitch control. *(EAA)*

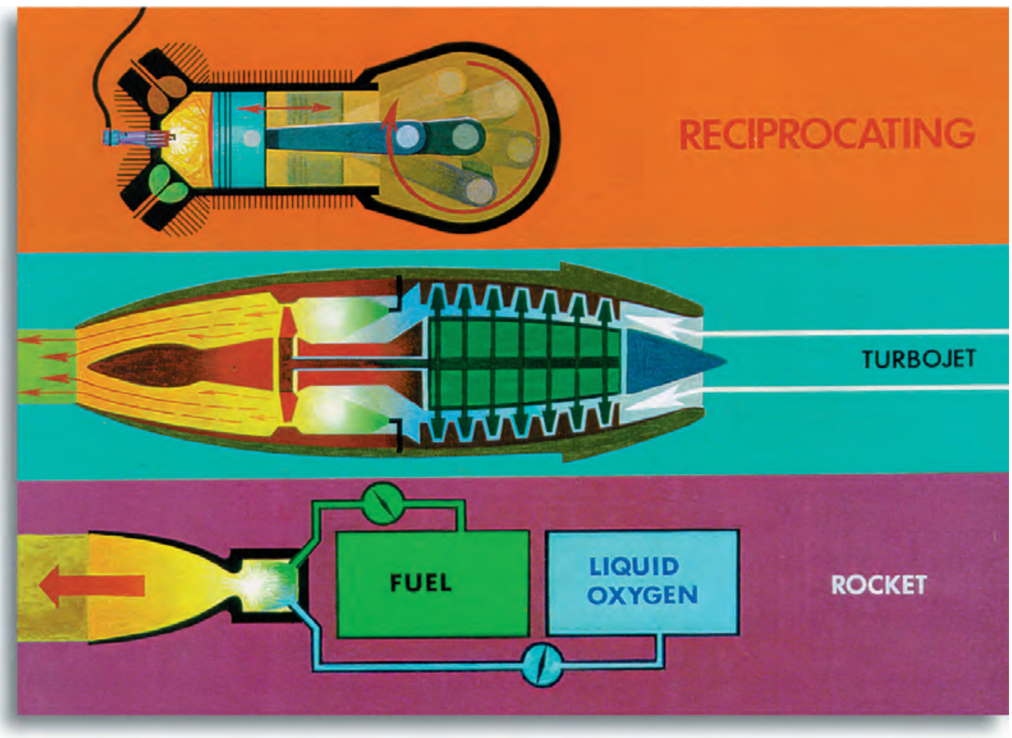


Aircraft Structures and Components

Engines

With the exception of an occasional feat like the human-powered airplane, all aircraft that can climb are propelled by some type of engine. The two types of common engines are the reciprocating engine and the turbine engine. Other types of engines include ramjets, scramjets and rockets.

Previous discussions about aeronautics, aerodynamics and aircraft control have considered only the effects of the aircraft's propulsion system. It is now time to discuss the types and general operating principles of various aircraft propulsion systems.

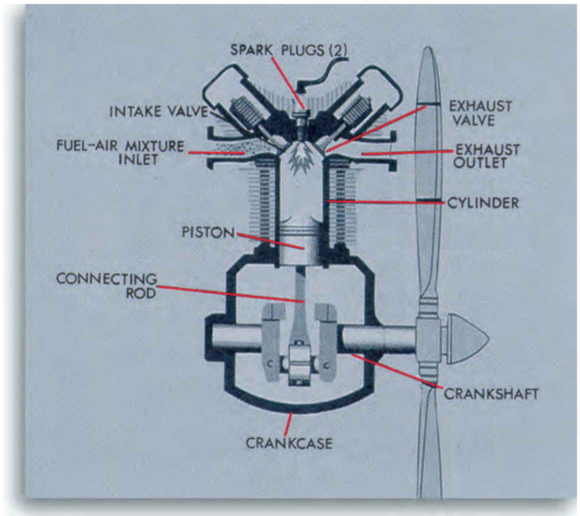


Aircraft Reciprocating Engines

Reciprocating engines power the conventional vehicles used for transportation, work and pleasure. Reciprocating engines provide power for automobiles, lawn mowers, tractors, motorcycles, boats, airplanes and many other devices used today.

All reciprocating engines are basically the same. The term reciprocating is the common factor, and it means that certain parts move back and forth in straight-line motion. This straight-line motion has to be changed to rotary motion in order to turn the wheels of automobiles and trains, and the propellers of boats and airplanes.

The reciprocating engine is also known as an internal-combustion engine. This name is used because a fuel-air mixture is burned within the engine. To understand how a reciprocating engine operates, a familiarity with its parts is essential. The most vital parts are (1) the cylinders, (2) the pistons, (3) the connecting rods, (4) the crankshaft, (5) the valves, (6) the spark plugs and (7) a valve-operating mechanism (cam).



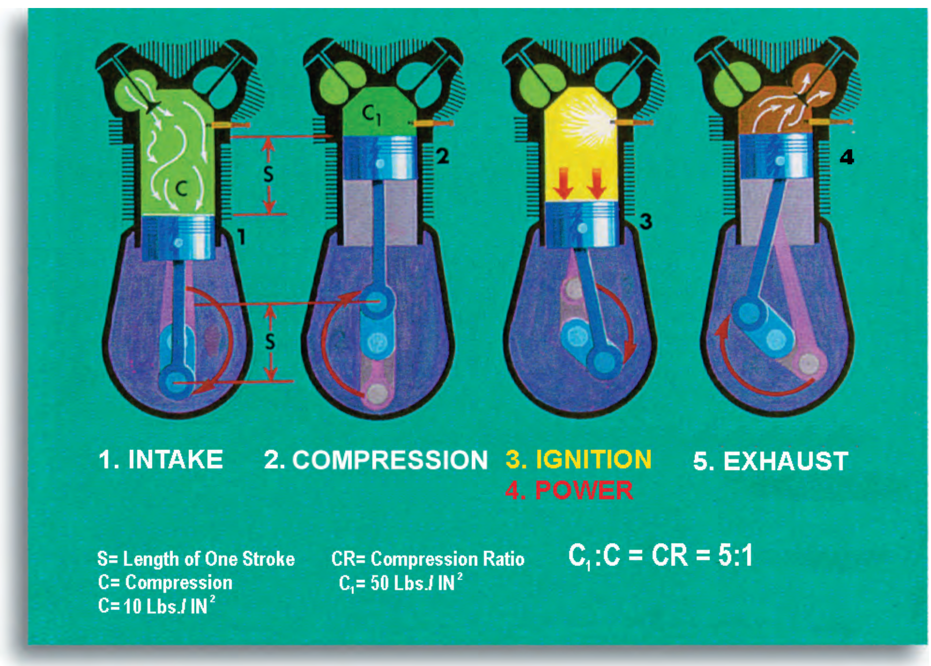
Parts of a Reciprocating Engine

Principle of Operation. The cylinder is the central area where fuel is converted into energy. It is closed on one end (the cylinder head), and the piston fits snugly in the cylinder.

As the engine runs, the cam also controls the opening and closing of the intake and exhaust valves. All of this motion happens in a regular cycle called the Otto Cycle for gas engines, after Nicholas A. Otto, who built the first successful engine in 1876.

Consider the movements of the piston (four strokes) and the five events of the Otto Cycle depicted in the picture below.

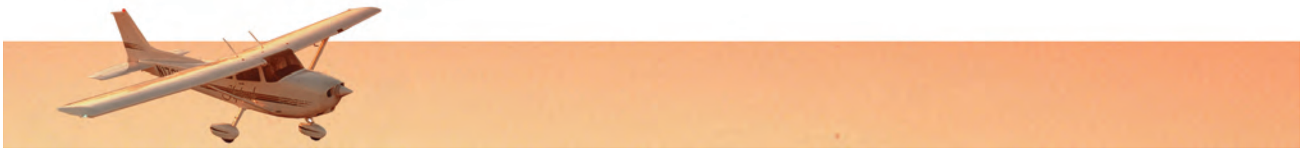
The Intake Stroke (1). The cycle begins with the piston at top center of the cylinder. As the crankshaft pulls the piston downward, a partial vacuum is created in the cylinder chamber. The cam arrangement has opened the intake valve and the vacuum causes a mixture of fuel and air to be drawn into the cylinder.



The 4 Stroke, 5 Event Cycle

Compression Stroke (2). As the crankshaft drives the piston upward in the cylinder, the fuel and air mixture is compressed. The intake closes as this upward stroke begins.

Ignition and Power Stroke (3 & 4). As the compression stroke is completed and just before the piston reaches its top position, the compressed mixture is ignited by the spark plug.



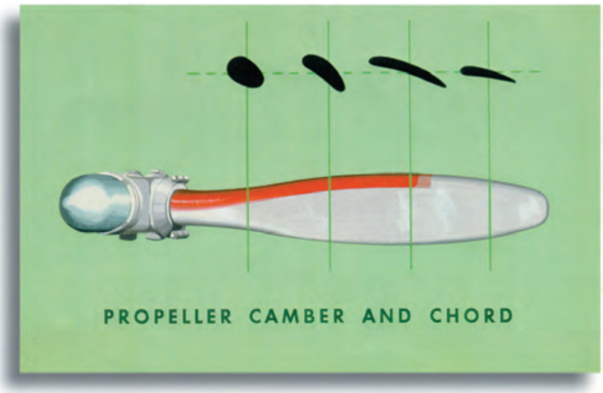
The very hot gases expand with tremendous force, driving the piston down and turning the crankshaft. The valves are closed during this stroke also.

Exhaust Stroke (5). On the second upward stroke, the exhaust valve is opened and the piston forces the burned gases out.

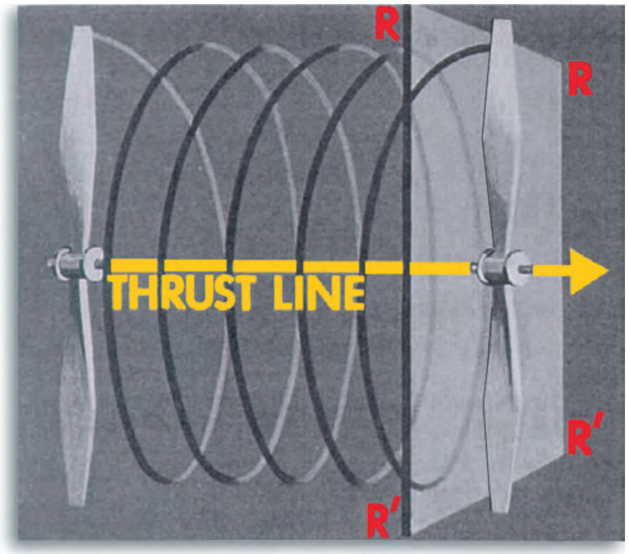
At the moment the piston completes the exhaust stroke, the cycle is started again by the intake stroke. Each piston within the engine must make four strokes to complete one cycle, and this complete cycle occurs hundreds of times per minute as the engine runs.

The up-and-down movement of the piston is converted to rotary motion. This turns the propeller. It is in this way that the power provided by the engine is turned into a thrust force.

Propeller. The propeller is the action end of an aircraft's reciprocating engine because it converts the useful energy of the engine into thrust as it spins around and around. The propeller has the general shape of a wing, but the camber and chord (curvature and cross-sectional length) of each section of the propeller are different. The wing has only one motion, which is forward, while the propeller has both forward and rotary motion. The path of these two motions is like a corkscrew as the propeller goes through the air.



The Cross-section of a Propeller



The Motion of a Propeller Through the Air

As the propeller turns, it generates "forward lift" in the direction of the nose of the aircraft. This force pulls the airplane forward through the air resulting in the corkscrew motion shown above. The pulling force of the propeller is the thrust force generated by this type of engine.

Aircraft Turbine Engines

Most powered airplanes that do not use reciprocating engines as their source of thrust use some type of turbine engine. The word turbine means "whirl" and refers to any type of wheel device that has vanes attached to it in a manner that will cause the wheel to turn as the vanes are struck by the force of a moving fluid. Remember that air is a fluid.

Turbine engines found in aircraft use the force of hot flowing gases striking a turbine. Some of these engines are geared to propellers, which are similar to the types of propellers used with reciprocating engines. The turbine engine has also found widespread use as the source of power for military and civilian helicopters. In helicopters, the turbine is linked by gears to the helicopter's rotor in a manner that can be compared to the turbine-driven propellers for airplanes.

Turbines are of four basic types. They may be classified as turbojet, turbofan, turboprop, and propfan. Improvements in each type help make them more efficient and capable of flying higher and faster.

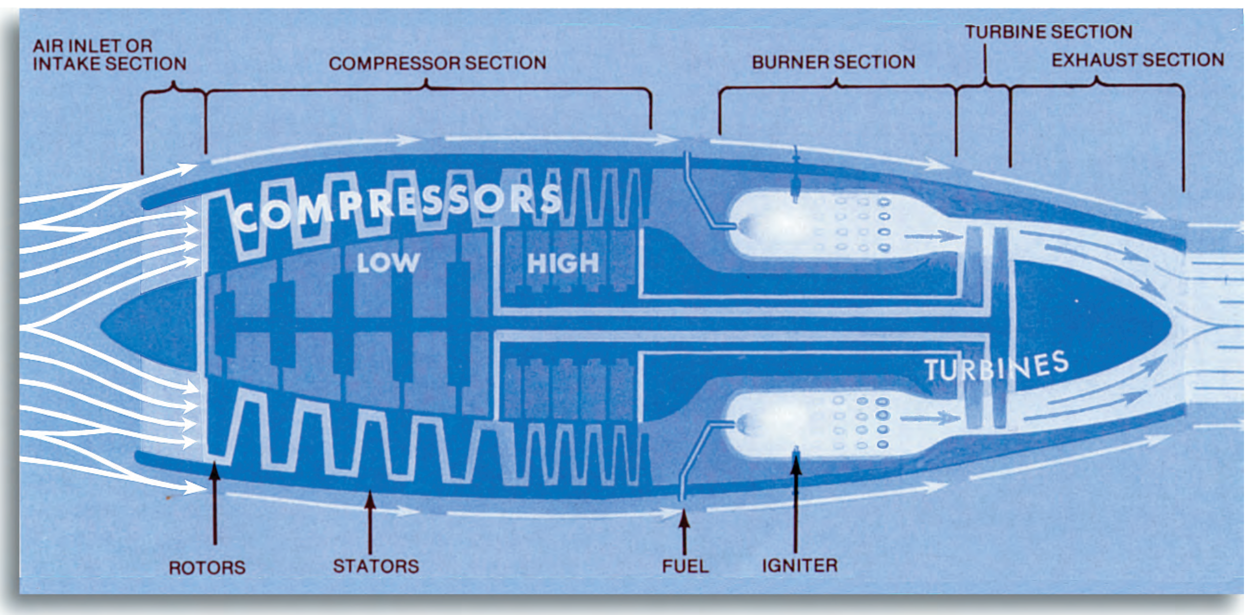
As a group, the turbine engines have many advantages over reciprocating engines. They are capable of flying at higher altitudes and higher speeds. Engine vibration is less as a result of rotating parts rather than reciprocating parts. Cooling is less complicated because the engine "processes" a large amount of air. The most important advantage is the simplest to understand; they make more thrust per pound of engine weight...always back to the four forces of flight!

Some disadvantages are high fuel consumption and poor performance at low power settings, low speeds and low altitudes. However, engineers are continuing to find ways to reduce these disadvantages and make turbines more useful throughout a very large flight envelope.

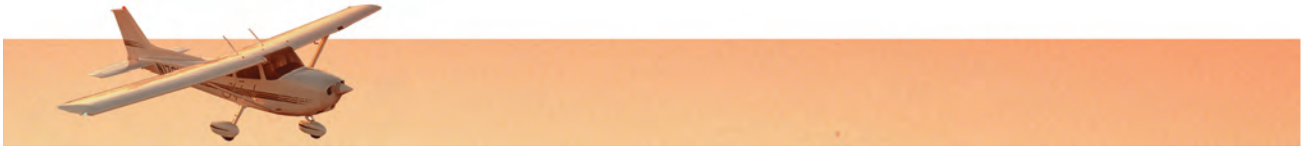
Principle of Operation. Turbine engine operation is very simple. They take in a small amount of air at the intake and accelerate it to extremely high velocities through the exhaust nozzle. The high velocity air pushes the aircraft forward and is the thrust force generated by the engine.

Turbine engineering and materials are very complex. The rotating parts of a turbine spin at rates in the tens of thousands of revolutions per minute. The air temperatures inside the engine can be several thousand degrees Fahrenheit. As engineers become more inventive and tougher, and lighter materials are developed, the turbines will spin faster and get hotter.

There are five basic sections to a turbine engine (depicted below). These are the inlet, compressor, burner (combustor), turbine and exhaust (nozzle). As the different types of engines are presented, remember that all turbine engines operate according to the same principles.



Sections and Parts of a Turbojet Engine Simplified



Turbojet Engines

The turbojet uses a series of fan-like compressor blades to bring air into the engine and compress it with a series of rotor and stator blades. Rotor blades perform somewhat like propellers in that they gather and push air backward into the engine. The stator blades serve to straighten the flow of this air as it passes from one set of rotor blades to the next.

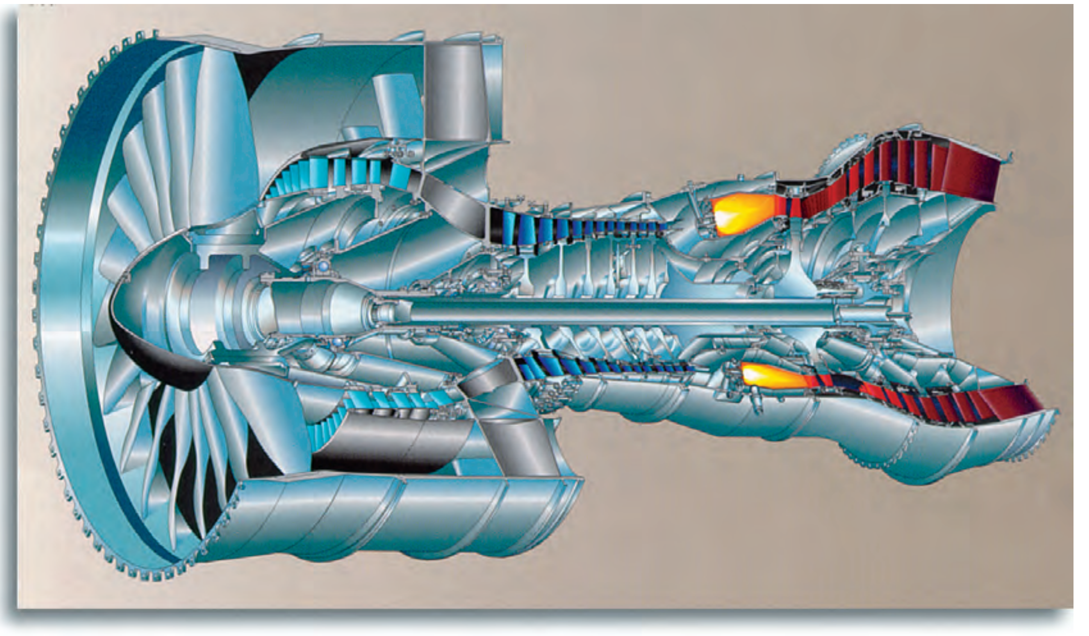
As the air continues to be forced further into the engine, it travels from the low-compression set of rotors and stators to the high-compression set. This last set puts a final squeeze on the air.

The combustion chamber receives the high-pressure air, mixes fuel with it and burns the mixture. The hot, very high-velocity gases produced strike the blades of the turbine and cause it to spin rapidly. The turbine is mounted on a shaft connected to the compressor. Thus, the spinning turbine is what causes the compressor sections to turn. After passing the turbine blades, the hot, highly accelerated gases go into the engine's exhaust section.

The exhaust section of the jet engine is designed to give additional acceleration to the gases and increase thrust. The exhaust section also serves to straighten the flow of the gases as they come from the turbine.

With all the heat produced in the turbojet engine, how is it kept from overheating? Like most reciprocating aircraft engines, the jet is also air-cooled. Of all the air entering into the compressor section, about 75 percent passes around the combustion chamber and turbine area to serve as a coolant.

Turbojet engines used in certain military aircraft will have an afterburner attached to the exhaust section. The afterburner is used for short-term bursts of additional thrust, such as required in some takeoffs and in combat situations. Afterburners are an additional length of the engine's exhaust section. When needed, fuel is sprayed directly into the afterburner and ignited. This is really nothing more than a controlled explosion that accelerates the exhaust to higher velocities and adds thrust.



See if you can name the components of this Pratt and Whitney PW6000 turbofan engine.

Turbofan Engines

The turbofan engine has gained popularity for a variety of reasons. One or more rows of compressor blades extend beyond the normal compressor blades. The result is that much more air is pulled into the turbofan engine than is pulled into the simple turbojet.

Most of this excess air is ducted through bypasses around the power section and out the rear of the engine with the exhaust gases. This sounds like it is wasted airflow, but it is not. There are two ways to get high thrust. You can either take a small amount of air and accelerate it to very high speeds, or you can take a large amount of air and accelerate it a little. Turbofans use a turbine engine to help get a large amount of air moving faster, creating very high thrust.

Turbofans are much quieter than turbojets, which makes them more acceptable to people who live near airports. The turbofan engine is also more fuel-efficient than the turbojet. Using the same amount of fuel, a turbofan produces greater thrust for taking off, for climbing and for cruising flight. However, turbofans have speed limitations and poor low-altitude performance, which make them undesirable for some aircraft.

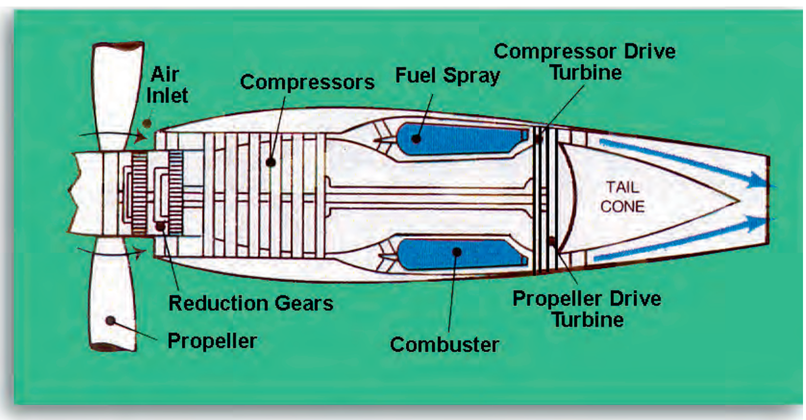
Turboprop Engines

The turboprop engine is the result of an effort to combine the best features of turbojet and propeller aircraft. The first is to be more efficient at high speeds and high altitudes; the latter are to be more efficient at speeds under 400 mph and below 30,000 feet.

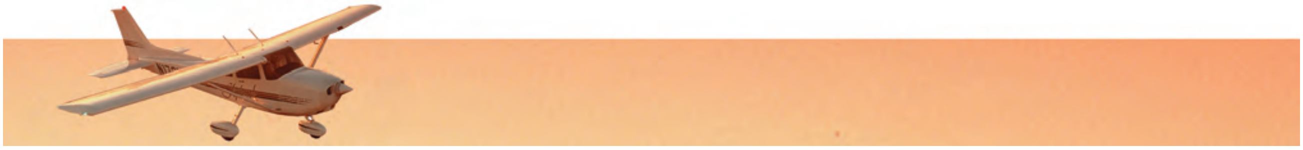
The turboprop uses a gas turbine to turn a propeller. Its turbine uses almost all the engine's power to turn its compressor and propeller. It depends on the propeller for thrust rather than on the high-velocity gases going out of the exhaust. Study the figure below and particularly note how the turbine turns the compressors and the propeller.

The gas turbine can turn a propeller with twice the power of a reciprocating engine and is lighter in weight. Reduction gears slow the propeller below the turbine's high speed. This must be done because propellers do not operate efficiently as their tips approach supersonic speeds.

Just to prove that engineers dislike limits, newer prop designs have been developed that reduce this limitation and increase the flight envelope for prop aircraft. So, the turboprop engine receives fairly extensive use in military and civilian aviation circles.



An Axial-flow Turboprop Engine



Propfan Systems

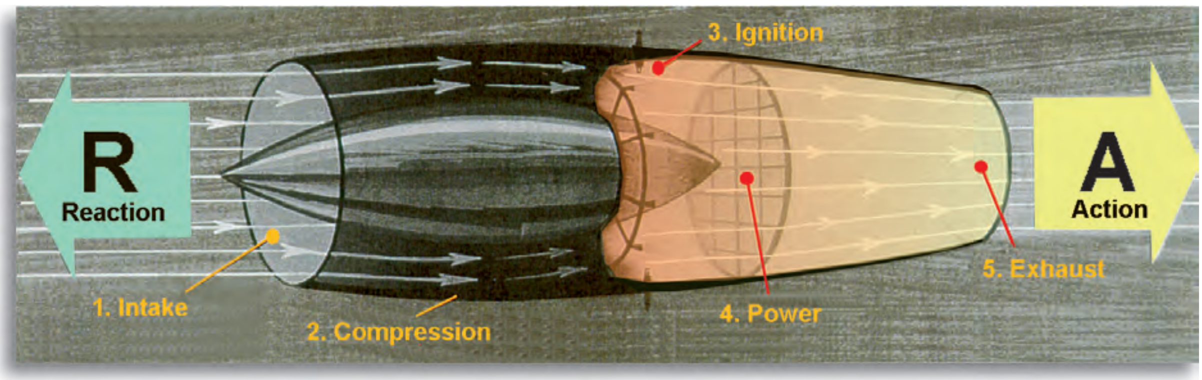
August 20, 1986, marked the first flight of an advanced-technology propfan engine. It replaced the regular turbofan of a Boeing 727-100. The thruster resembles a ship's screw more than it does an airplane propeller. The propfan system combines the air-moving efficiency of the turbofan engine with the thrusting efficiency of the propeller. What is achieved is a dramatic reduction (up to 30 percent) in fuel consumption while retaining the turbofan's high power and the speed it makes possible.

More specifically, the propfan system combines elements of the other three turbine systems. In this system, a turbojet serves as the gas generator to drive a large external fan, or propulsor. Sometimes the prop consists of two propulsors rotating in opposite directions.

The multi-bladed propulsors move large amounts of air at a relatively slow speed while a much smaller amount is burned and accelerated through the core of the engine at a higher velocity. Propulsion systems of this type have bypass ratios of 60 to 1 or greater. This means 60 times as much air flows around the turbine core as passes through it. High bypass engines are very efficient at subsonic speeds. For airliners, this is about Mach 0.8 or 525 mph.

Ramjet and Scramjet Engines

Frenchman Rene Lorin invented the ramjet in 1913. It is the simplest type of all-jet engines because it has no moving parts. The picture below shows a typical arrangement of the parts of a ramjet engine. The force of inertia "rams" air into a streamlined chamber of a fast-flying ramjet. Air flowing through the chamber is compressed, slowed down to subsonic speed, mixed with fuel, ignited, and released. The airflow will extinguish the flame, unless flame holders or slowly burning grain (a mixture of fuel, binder, and a small amount of oxidizer) is used. Scramjets work the same way, only the air is not slowed to subsonic speeds within the engine.



Functions of a ram jet engine compared to five-event cycle of a reciprocating engine.

A ramjet/scramjet whose intake does not change shape provides thrust within a narrow range of velocities, typically 1-2 km/s. A variable geometry ramjet provides thrust over a wider range of velocities, but is much heavier.

Ramjets and scramjets will not make thrust until enough air is coming through the intake to create a high-pressure flow. Otherwise, the expanding gases of the burning fuel-air mixture would be expelled from both ends of the engine.

The ramjet/scramjet has to be traveling through the air very fast before it is started. This means that it has to be boosted to the proper speed by some other type of engine or rocket propellant. Using two engines on a single-air vehicle may not always be practical, but may have some specific applications as the flight envelope is expanded for commercial and military aviation.

In theory, these engines have no maximum speed; they can keep accelerating indefinitely as long as it stays within the atmosphere. In practice, the engine is limited to low-hypersonic speeds (five times the speed of sound) because atmospheric friction will melt the materials used in its production. They also suffer from a high rate of fuel consumption.

In the early 1950s, a ramjet (on the blade tips) was used to power an experimental helicopter known as the *Hiller Hornet*. *(EAA)*

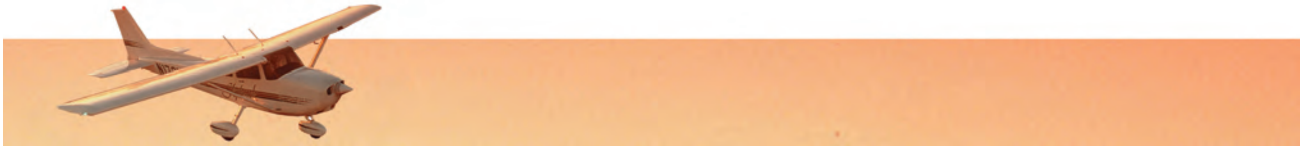
Flight Controls

Wilbur and Orville Wright were not the first people to fly. There were many inventors and aviation enthusiasts who developed gliders or built balloons long before their historic flight at Kitty Hawk. What they did contribute to the aviation field was the first sustained, controlled, powered flight of a heavier-than-air vehicle. The key word for this section is controlled, because flying at the whim of the air currents lends little to the practical use of flight.

Control of the aircraft is accomplished through the control surfaces. These include the ailerons for roll, elevators for pitch and rudder for yaw control. Combined use of these devices allows for pilot control of all motions through all three axes.

There are a wider variety of control surfaces developed every day. Wilbur and Orville used a technique called “wing warping” to reshape the wings of their aircraft and provide steerage. Eventually, separate surfaces were invented that were hinged to the wing and tail, and could be bent into the free flowing air to control the aircraft. Later, in the 20th century, NASA developed reactive wings that could reshape themselves to optimize the flow of air over the airfoil as the situation required.

The use of computer flight control systems have given engineers the opportunity to control aircraft in ways we could never have imagined only a few years ago. Aircraft can be built that defy every aeronautical engineering principle of controlled flight. They are controlled using programmed, high-speed computers that correct the flight path far faster than their human pilots could do by hand. For instance, the B-2 has no vertical fin or rudder for yaw control. It uses aileron-like control surfaces that are moved at different amounts on the left and right side of the airplane to control yaw.



By adding various structures to an airplane's airfoils, its aerodynamics can be changed significantly. Perhaps you have been aboard an airliner when the pilot prepares for landing. All kinds of devices start moving from the leading and trailing edge of the wing.

These devices are thrust into the airstream to increase the lift efficiency of the wing at low airspeeds. Other approaches for increasing lift are being developed and used every day.

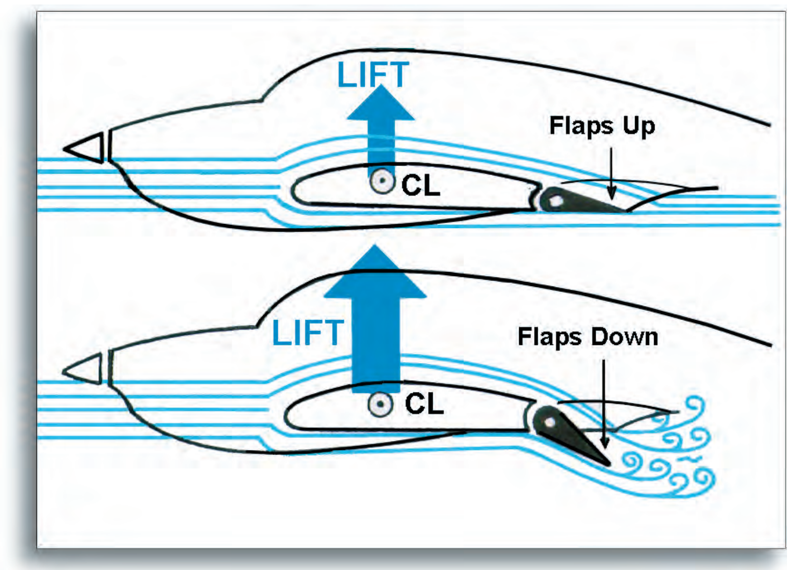
Flaps

The flaps of an airplane are attached to the trailing edge of the wing. In cruising flight, the flaps simply continue the streamlined shape of the wing's airfoil.

When flaps are lowered either partially or fully, two things happen: lift is increased and so is drag. This is why pilots use flaps only during certain takeoff conditions and during most landing conditions.

The flap increases the camber of the wing airfoil for that portion of the wing to which it is attached. It does not affect the remainder of the wing. Looking at a wing cross-section with flaps lowered, air flowing over the top of the wing now has farther to travel. This causes the air to speed up, particularly over the wing section where the most lift is created. On the underside of the wing, dynamic lift is increased because there is now more surface area exposed to the impact of the relative wind.

On the negative side of this situation is the drag produced by the flap. Anything that obstructs the airflow increases drag. So what is the total effect of this increased-lift/increased-drag situation when flaps are lowered? Without an increase in power to compensate for the additional drag, the airplane will descend much more steeply than possible without flaps and the increased lift will allow slower flight because the stall speed is decreased. The pilot can land more steeply and avoid the trees at the end of the runway. He can also stop on a shorter runway because he is going slower when he lands.



The Effects of Flaps on Lift

Using flaps when taking off helps the airplane get off the ground in a short distance. This might be desired when the runway is short and a short-distance takeoff is necessary. Using flaps when taking off from a soft or muddy field helps too by keeping weight off the wheels.

There are many different types of flaps. Some hinge, some slide, some open with slots and some help the flow of air over the wing remain smoother even though high angles of attack are flown during landing. Each has been given a unique name based upon its look or its inventor. Some are simple and some are mechanical miracles…but they all help do the same thing.

Slats

Slats are protrusions from the leading edge of a wing. They also add to the induced lift of a wing and can be found on the more sophisticated flap systems. The secret of the slat is the slot it produces. Particularly at a high angle of attack, the relative wind passing through the slot is speeded up, and this additional velocity helps keep the airflow smooth. This is how slats and flaps work together to maintain laminar flow over the top of the wing. The slat causes energy to be added at the front, while the flap causes energy to be added at the back. The combined actions of these devices result in a significant increase in lift.

Spoilers

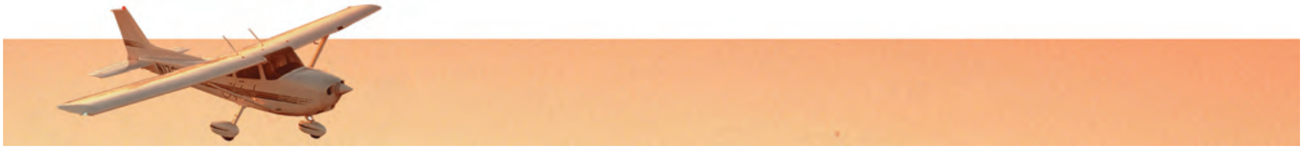
Where flaps and slats work to increase lift and where ailerons, elevators and rudders work to change the direction of lift, spoilers work to destroy lift. This is the origin of the name spoiler—it spoils lift.

Spoilers are found on various aircraft from the jet airliner to the sailplane. The spoiler will be found somewhere along the top of the wing and it will be located along a line on the airfoil where its deployment will be the most effective. The term *deployment* is used because spoilers fit into or flush with the surface of the airfoil. The size of the spoiler will vary according to how much lift is to be "spoiled."

On faster aircraft, spoilers are hinged so that their aft portion is tilted upward into the laminar airflow. Many of the sailplane types are designed to thrust straight up from the wing's surface. Both arrangements of spoilers do the same thing. They destroy the laminar flow of air for a portion of the wing, thereby reducing a certain amount of induced lift. Their design is different because faster airspeeds tend to damage spoilers that stick out straight into the airflow.

This Air Force Academy TG-7A has spoilers above and below the wing. They are located just inboard of the USAF insignia.

An airplane, such as an airliner, can fly at a safe airspeed while reducing some of the induced lift using a spoiler. The result is a steep descent for landing or quick change of altitude in a short distance. A most favorable feature about spoilers is that they can be deployed or retracted quickly. If, for instance, an airplane has them deployed and is descending toward the runway but suddenly has to "go around," the spoilers can be retracted and lift is restored.



The use of flaps lowers the stall speed so an airplane may fly again, if it bounces upon landing. When the airplane is equipped with spoilers, the pilot can keep this from happening. The next time you are on a jet airliner watch how the spoilers pop up when the craft lands. Quick spoiling of the lift prevents the airliner from flying back up into the air, even for a poor landing, but not the worst of poor landings.

Spoilers serve a similar purpose for sailplanes. The sailplane's wing is an especially high-lift device. If it were not for the effect of spoilers, it would be very difficult to get some models of sailplanes to land within the confines of the airport.

Spoilers can also be used like ailerons to roll the air vehicle. If the pilot moves the control wheel to the right, the right wing spoiler pops up and the right wing loses lift. The aircraft responds with a turn to the right. The General Dynamics F-111 used spoilers and differential stabilators to turn. It did not have ailerons because its wing was designed to sweep back for high-speed flight. Ailerons would have been ineffective for rolling the aircraft when the wings were swept back. Can you reason why this would be so?

An inventer by the name of Molt Taylor created a very successful car that flew!
(EAA)

Drag Devices

Some airplanes are equipped with special devices that produce drag only. These devices may be located at the trailing edges of the wings or they may protrude from the craft's fuselage upon activation by the pilot.

Ultralights are fun to fly even if they don't have much of a fuselage. *(EAA)*

These devices may be called speed brakes, air brakes, dive flaps or drag parachutes. Their purpose is to produce a significant amount of drag without affecting the airfoil's lift. Why would such devices be needed? Because they allow very steep descents and rapid changes in airspeed which can be stopped almost instantaneously by retracting the devices.

The devices discussed in this section are not all of the flight control surfaces that exist. We already mentioned that vectored thrust could allow for very slow flight and rapid changes to aircraft attitude. In a sense, vectored thrust acts like another flight control. When its use is programmed into a computer to respond to control stick and throttle positions, it is acting directly as a control surface. Engineers can be very inventive, and will continue to make new control surfaces and devices.

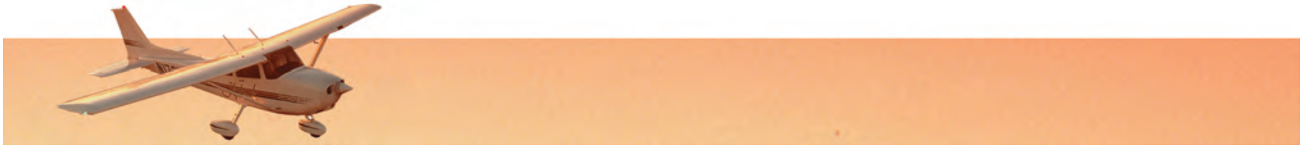
The Fuselage Structure

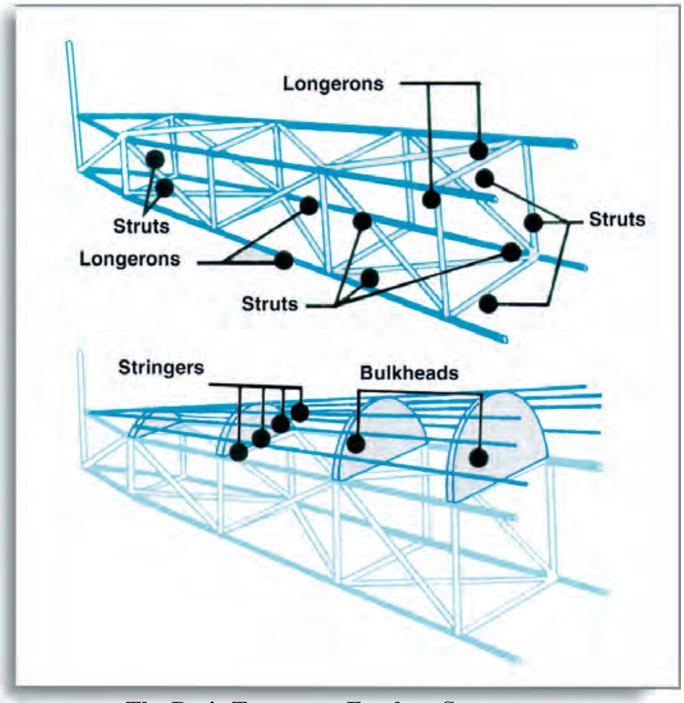
The word fuselage is based on the French word *fuseler*, which means "to shape like a spindle; to streamline." Since the normal fuselage contains the flight crew, passengers, and other cargo and must also withstand many of the forces created by the airfoils and landing gear, it must be strong in addition to being streamlined.

Fuselage Assembly at Boeing *(Boeing photo)*

Fuselages are usually classified according to the design of their force-resisting structure. These classifications are known as the truss, the semimonocoque and the monocoque.

The truss-type structure for fuselages is made of





The Basic Truss-type Fuselage Structure

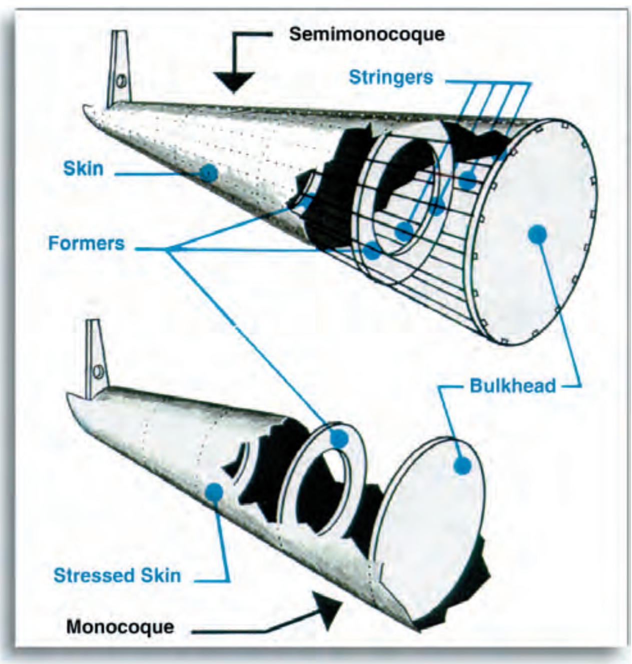
tubing welded in place to form a well-braced framework as shown. Long lengths of tubing called longerons characterize the basic form. Welded to these longerons are vertical and horizontal struts which give the structure a square or rectangular shape as viewed from one end; however, this isn't enough bracing. Other struts must be placed so that stresses coming from all directions are resisted. Thus, struts at various angles to the longerons and horizontal/vertical struts are necessary. Imagine how the truss structure could be twisted, bent, stretched, sheared and compressed. This is how the total structure performs its job.

The truss structure is not a streamlined shape. Before the skin is added, something must be done to make the structure a streamlined one or the aircraft will have a form drag problem. Additions to the basic truss structure can be added. The label "bulkhead" may also be known as a "former," but in either case, if the addition is to give shape to the fuselage, it will have stringers attached. The purpose of these stringers is to support the covering that will go over the fuselage.

Monocoque is a French word which means single shell. The true monocoque construction depends on the covering or skin to provide the required strength to resist the stresses of flight. True monocoque construction like that illustrated in the picture to the right is not common. The semimonocoque is the most often used approach for high-performance aircraft.

The semimonocoque construction uses internal braces to help the skin carry the forces generated. Semimonocoque literally means half a single shell. The internal braces include longitudinal stringers and vertical bulkheads or formers.

The semimonocoque structure is easier to streamline than the truss structure. Since the skin of the semimonocoque structure must carry much of the fuselage's strength, it will be thicker at those points where the stresses on it will be the greatest.



Semimonocoque and Monocoque Fuselage Structures

Why cover the fuselage anyway? It's not the airfoil, so should the engineer be concerned with airflow over the fuselage? Certainly, because everything in the flow of air affects the forces of flight.

An 1/8-inch strut or supporting wire, like those used on old biplanes to brace the wings, creates as much drag as a conventional cambered airfoil. If the fuselage remained open, the drag created from each strut would soon overcome the engine's ability to thrust the vehicle forward enough to generate more lift than weight. This would require either a more powerful engine or less weight. Aerodynamics always returns to the four forces of flight.

If we now understand that a covering for the fuselage is required, with what should it be covered? Something strong would make the vehicle more durable and capable of more dynamic maneuvers. But strength usually means more weight, and you know where that leads you. So the best choice is the strongest, lightest material that can be manufactured and fitted to the fuselage.

Aluminum sheeting is generally the cheapest and most effective choice for covering. Engineers hate doing anything the usual way, so they have continued to develop new materials that are stronger, lighter and more easily molded to a fuselage shape. Composite materials are one such invention.

Composites are many materials layered together in a strength-producing pattern, similar to a radial tire or woven fabric. Because many materials are used, designers can add materials that give the aircraft structure special characteristics – like radar stealth. The materials are very flexible when first constructed, much like fiberglass. They can be molded to almost any shape and allow for extremely useful designs that could not be cheaply constructed using aluminum and pop-rivets.

Landing Gear

The *Wright Flyer* used skids as its landing gear at first, but the inventors soon attached wheels to the skids. Since that time, various arrangements have been used for wheels and structures to connect the wheels to the airplane's fuselage and/or wings. Today, there are three types of landing gear arrangements in common use: the conventional, the tricycle and the tandem.

Conventional

The conventional landing gear consists of two wheels forward of the aircraft's center of gravity and a third, small wheel at the tail. All landing gear must be strong to withstand the extra load of the

The conventional landing gear is nicknamed "taildragger".

aircraft's weight plus the downward force of landing. To help absorb this additional force, some type of arrangement must be made to cushion or absorb some of the additional stresses encountered. The earlier conventional gear aircraft used a flexible material for the landing-gear struts (the part between the airframe and the wheels). This allowed the landing-gear assembly to flex outward upon landing.

The tailwheel, which evolved from the plain tailskid of the past, is castered - free to turn in any direction. How does a pilot maintain control while taxiing with the conventional landing gear system if the front wheels are not steerable? It is done with a combination of rudder movement and the careful application of brakes.

At taxi speed, the prop-wash from the propeller and relative wind striking the tail, coupled with the freewheeling tail wheel make rudder control possible. The rudder is deflected into the prop-wash and turns the tail of the aircraft just like it would in the air. The use of brakes is necessary only at a very low taxi speed when the rudder is ineffective.

Landing an airplane that has conventional gear is more difficult than the other types. At least, this is the claim made by pilots who are qualified to fly them. The claim seems reasonable in that the main landing gear provides a fulcrum about which the airplane can be pitched fairly easy. The application of brakes too soon and/or too much just after touchdown could cause this pitching action to take place, and the result could be a complete nose-over. Another possible cause of nose-over could be the tailwheel striking the ground first If this happens with enough force, the main landing wheels are slammed onto the surface and the entire airplane pitches over.

The tendency for conventional-gear airplanes to pivot about the vertical axis can be another problem during windy landing conditions. The main landing gear provides a pivot point about which the usually large rudder moves the airplane very easily and quickly when strong wind hits the rudder.

Tricycle

Tricycle landing gear make an airplane very easy to control on the ground. This is particularly true of the newer models because the nose gear is linked to the rudder pedals and is steerable.

This is an example of tricycle landing gear. *(EAA)*

Landing forces are absorbed through the use of a shock absorbing system called the oleo strut. The shock-absorbing strut cushions the landing and helps keep your dining tray in the up and stowed position.

Like the conventional gear, the main landing gear on the tricycle types are fitted with brakes. These brakes also operate independently of each other so they can be used in steering the airplane if necessary.

Tandem

Tandem landing gear is an arrangement where the main gear consists of two sets of wheels which are located one behind the other on the fuselage (tandem may also be called bicycle). The B-52 bomber, AV-8 Harrier close air support aircraft and the U-2 reconnaissance/research aircraft have this type of landing gear. The tandem landing gear requires the use of outrigger wheels mounted on a highly flexible wing for lateral support.

The AV-8 Harrier has a tandem landing gear. *(EAA)*

Brakes

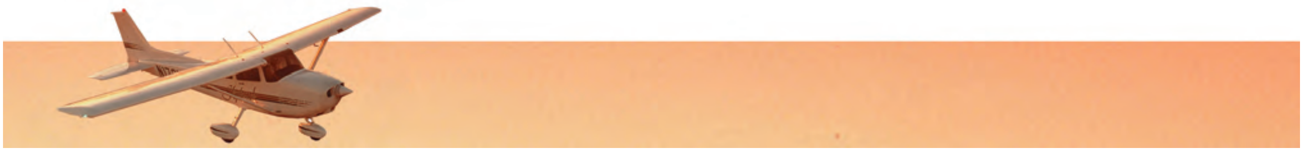
Although all aircraft landing gear are fitted with brakes, they must be used with caution. An airplane moves much faster than a car, so there is a great deal more stopping force required of the airplane's brakes. Too much sustained brake pressure upon landing can cause overheating, warping or even complete brake failure. Should a brake lock upon landing, the tire will wear through and fail rather quickly and this could cause an accident.

To prevent or help prevent this from happening, aircraft use what is called an antiskid system. This system actually keeps the brakes or wheels from locking by automatically releasing the brakes upon the first indication that the wheel isn't turning. This means that it also works if the wheels start sliding on a slippery surface, such as ice. If the pilot has applied brakes to slow the airplane and just one of the wheels hits a patch of ice, the brakes on that wheel will be released as soon as the wheel stops turning and starts skidding.

Fixed vs. Retractable

In addition to the arrangement of the landing gear—conventional, tricycle, or tandem—the gear can be either fixed or retractable. Generally speaking, the less expensive, smaller airplanes have fixed gears because it is much less costly to build and to maintain. The basic reason for making landing gear retractable is to get them out of the airstream and thereby reduce drag, which allows the airplane to fly faster. The reason why most small aircraft do not have retractable gear is that the additional expense and weight of a more complex system added to a slow moving aircraft is not justified.

The Aerosport II has fixed landing gear. *(EAA)*



An example of retractable landing gear.

Systems

Every aircraft is made up of many parts. Some parts are structures, like the previous sections have detailed. Other parts are needed to manage the flow of fluids, control engine parameters, receive radio signals, and release weapons or cargo. These parts are called the aircraft's systems.

Each aircraft has a different set of systems that help it get the task of flying done correctly. The major systems of most aircraft include a method to handle fuel, hydraulics, and electrical power.

Fuel

Fuel Systems. The fuel system for an aircraft engine includes everything that involves delivery of fuel to the engine. The beginning of this delivery system is the fuel tanks, the middle is the fuel lines and the end is the engine's combustion chamber.

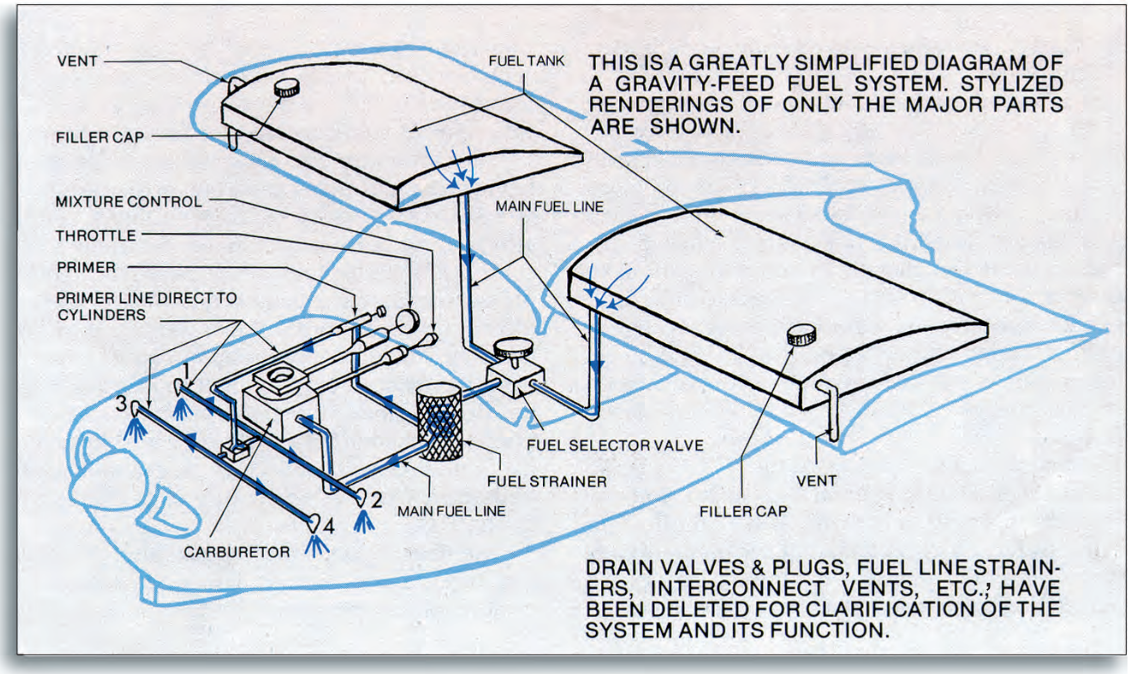
Fuel Tanks. Fuel tanks can be located anywhere in the aircraft. Some aircraft have fuel stored in tanks inside the wings, some in the fuselage and others in any place the fuel will fit. The need for fuel and the rate at which it is burned helps the aircraft designer decide how much fuel is to be available.

Fuel is forced from the tanks into the engine where it is mixed with air and drawn into the combustion chamber. To get the fuel from the tanks to the engine requires force. This force may be provided by one of two possible fuel-feed systems.

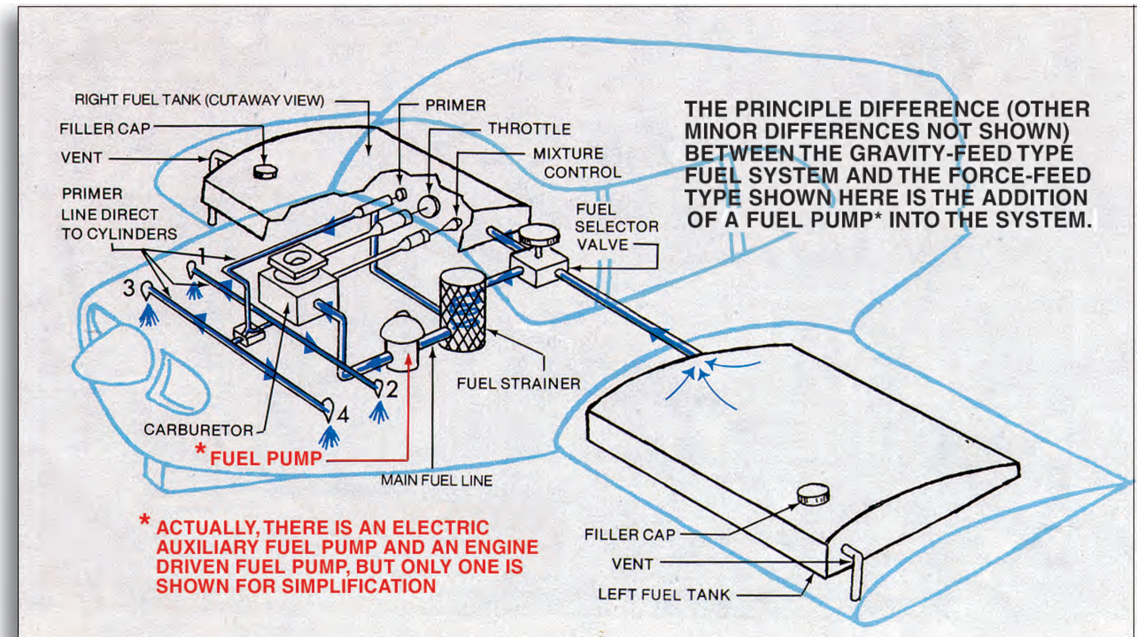
The simplest is known as gravity feed, and as the name implies, uses gravity to cause the fuel to flow from the tanks downward to the engine. The gravity-feed system will most likely be found in a high-wing airplane or as a backup to the next type of feed system.

Most airplanes use a pump to drive fuel from the tanks to the engine. The fuel pump usually is run from the electrical power system of the aircraft. It is a small motor that helps to keep a positive flow of fuel from the tanks to the engine so that it does not stall. In some high performance aircraft this is a difficult task. The F-15 Eagle in full afterburner consumes over 80,000 pounds of fuel per hour at sea level. That's over 200 gallons per minute!

All fuel tanks must have a place where fuel can enter for the filling process; this is known as the filler cap. In addition to this filler cap, all such tanks must have a vent pipe to the outside. The vent allows expansion of the fuel when it is heated by the sun and protects the tank from being broken open by the pressure of expanding fuel vapors. On a very hot day at an airport, you might see liquid fuel



Gravity-feed Fuel System

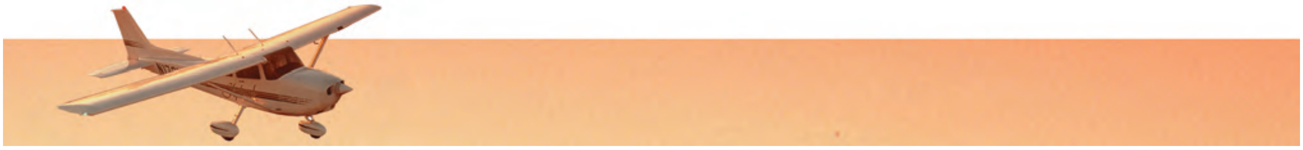


Force-feed Fuel System

coming out of these vents on some airplanes.

Within the fuel tanks are some mechanisms that measure how much fuel there is in the tanks. These mechanisms might be simple floats or complicated rods that measure fuel electrical capacitance.

At the lowest point in each tank is a fuel-tank drain. These drains are designed to remove any water



that may have condensed from the air within the unfilled portion of the tank. If there is any water in the fuel and the fuel is drained into a container, the water can be seen because it is heavier than the fuel. The water will appear on the bottom of the container as a water "bubble." This draining and checking process can continue until all water is removed.

One other element within the tank is a fuel strainer. This strainer keeps any sediment from entering the fuel line that leads from the tank.

Fuel Lines. Fuel lines lead from each fuel tank to distribute the fuel throughout the aircraft. In some light civil aircraft, these fuel lines merge somewhere in the cockpit and are joined by a fuel selector. Fuel selectors allow pilots to manage their fuel supply by taking fuel from the tank of their choice. Some airplanes also have a "both" selection that permits fuel to flow from the left and right tanks at the same time. Larger aircraft have automated fuel control systems that are electrically controlled. This is often necessary when fuel management would be complex, time consuming or dangerous to do manually. If the fuel storage was miscalculated, the aircraft might exceed weight distribution limits and depart controlled flight.

Hydraulic and Electrical Systems

Hydraulic Systems

The word hydraulic comes from Greek words meaning "water tube." An aircraft's hydraulic system may operate the brakes, lower the landing gear, move the flight controls, and extend and lower the flaps. The mechanism that controls the pitch of the propeller may be hydraulically operated. In fact, any mechanism that can use a pressurized fluid to make parts move as the pilot desires can be hydraulically run.

More than three centuries ago, French mathematician and philosopher Blaise Pascal stated what we know today as **Pascal's law:**

> Pressure exerted anywhere on a liquid in a closed container is transmitted undiminished to all parts of the wall of the vessel containing the liquid. The pressure acts at right angles to all surfaces with an equal force on equal areas.

What does this mean? It means that when a fluid such as oil is confined in a container, the fluid can be made to transfer the pressure put on it to something else. It can also be made to multiply the original pressure.

In using a lever to pry up a rock, one can exert more force than if he or she tried to lift the rock directly. This is called mechanical advantage, which is the same principle used in hydraulics.

By using the mechanical advantage gained in the hydraulic system, the pilot can exert great pressure on the aircraft control systems or structures within his human strength limits. Aircraft have hydraulic pumps to generate the hydraulic pressure necessary to operate the various components of the aircraft. These pumps pressurize the system and allow the pilot to stop thousands of pounds of aircraft with the flex of his ankles on the brake pedals.

Hydraulic systems look a great deal like fuel systems. The fluid is stored in tanks called reservoirs. It is pressurized, strained and then distributed through hydraulic lines to the parts of the plane that need it. Once it has done its work, it is returned to the reservoir for later use.

Electrical Systems

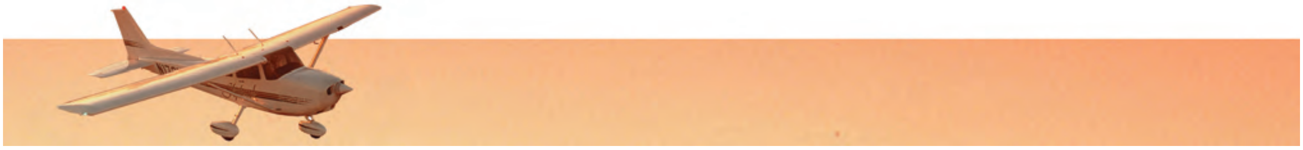
The electrical system, like the hydraulic system, is important in operating an aircraft. A generator mechanically attached to an aircraft's engine provides the electricity required to charge the battery, start the engine, operate the radios, and operate navigation and landing lights. Any electrical device can be run from this system if the designer plans for the proper voltage and current.

On some aircraft, electricity may be used through electric motors to change the pitch of propellers, lower and raise flaps, and actuate portions of the hydraulic system. More modern aircraft are usually dependent on the electrical system to power critical parts of the vehicle. These parts might be as basic as the Liquid Crystal Displays (LCDs) used to fly in the weather or as complex as the digital flight control system used to point the aircraft where you would like it to go.

Without the assistance of hydraulic systems and electrical systems, pilots could not fly the larger, more sophisticated aircraft. Even the smallest aircraft powered by an engine must have an electrical system at least for ignition. Most require power to control and display the many aircraft instruments that help the pilot fly and navigate.

Aircraft Instruments

Instrument Panel of a Cessna 182



The size of an airplane and its tasks determine how many instruments there will be in the cockpit. The purpose of the instruments is to convey to the pilot some information. This might be attitude information, such as which way is up. It might be position information, such as miles from the airport. It might even be weapon information, such as lethal shot distances.

It is not absolutely necessary to have any instruments for the pilot to monitor. An airplane can be flown without instruments. Crop dusters and ultralights rely on the pilot's eyes and ears to provide enough environmental clues to remain aloft. However, as the mission becomes more complex, it is often necessary to give the pilot more than his eyes and ears can provide.

Early Aircraft Instruments

The first aviators had to rely on their senses, as there were no flight instruments. Instruments were then invented to help the pilot. Although they were very primitive by today's standards, many early instruments proved to be adequate for "low and slow" aircraft.

Airspeed was first judged by the force of the wind on the pilot's face and the whine of wind through the rigging. If the pitch of the wind whistling through the wires was "right," the airspeed was correct. Early airspeed indicators were merely wind gauges.

When pilots could see farther than they intended to fly, heading indicators and navigational instruments were unnecessary luxuries. Similarly, altimeters were not of much value when the aircraft could get only a few hundred feet off the ground. When they could climb higher, perhaps above an altitude where the air was thin enough to cause the pilot to pass out, altimeters became a safety necessity.

Cockpit and instrument panel of the immortal P-51 Mustang. *(EAA)*

In the early days, it was possible to estimate how long the fuel would last, but it was also easy for pilots to forget to check takeoff time and then to have to guess when the fuel would run out. The problem was solved by putting a stick with a cork on it in the fuel tank. By tying a piece of colored string near the top of the stick, another safety feature was added. When the string disappeared, it was time to land.

The attitude of the aircraft was extremely critical in the early days. Pilots solved this problem by tying a piece of heavy string to the aircraft. If the string was flying straight back, the pilot was doing fine. However, if the free end of the string was off to one side, the airplane was not flying directly into the wind. It was trying to fly sideways and this increased the aircraft drag. What type of drag would this be?

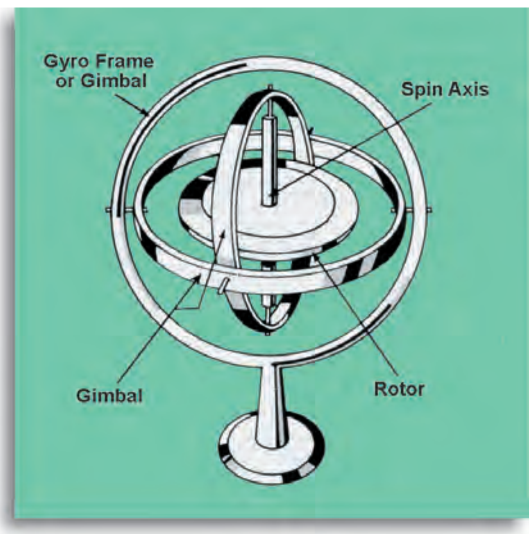
These early instruments were designed to give pilots specific information about the engine or the attitude of the aircraft. Even today, all aircraft instruments can be classified according to how they assist the pilot.

Instrument Classification

Aircraft instruments are classified either in terms of their use or in terms of the principle underlying their operation or construction.What the instruments tell the pilot is usually of more use to the aviator than how the instruments work, so we'll concentrate on that.

Classification by Principle of Operation. Instruments can be classified by their principle of operation. The three major groups are: mechanical (including gyroscopic) instruments, pressure instruments, and electrical instruments. A brief description of these operational groupings is useful because it helps to understand how an instrument works as well as what it tells the pilot.

Mechanical Instruments. Some mechanical instruments work by means of direct mechanical linkage. For example, a gear may be attached directly to the engine of an aircraft in order to give a reading on a gauge of how fast the engine is operating. A float might rise and fall in a fuel cell and be linked to the fuel gauge by a cable.



Parts of a Gyroscope

Some mechanical instruments work on the principle of the gyroscope. Because the gyroscope is used so extensively in flight instruments, here is a brief review of its operation. A gyroscope consists of a heavy rotor wheel mounted so that it is free to rotate on its axis within a frame. This frame is designed so that the rotor can move any direction—pitch, roll, or yaw.

The principle that you should know about the operation of the gyroscope is gyroscopic stability. Gyroscopic stability means that a spinning flat weight tends to line up on one of its axis. That axis is the one perpendicular to the face of the weight. Once the weight is aligned on the axis, it will remain there, just like a top does.

For example, if you held the gyroscope by the base, you could move the base to any position but the rotor (spinning weight) and spin axis would still point in the original direction. Gyroscopic stability helps you ride a bicycle. As the wheels turn (spinning weight) they become stable around the axle's axis. It is then harder to lean left or right, or fall down, because the wheels stabilize the bike.

If a flying airplane can move around any of its three axes, then it might be useful to have something on board that does not move with the aircraft. Why, you might ask? Because at some point after we have pitched the airplane up, rolled it left and kicked the rudder to yaw, the pilot will want to know how to get back to straight and level flight. If, while on the level ground before takeoff, he aligned a

Instrument Panel of the *B-25 Mitchell* Bomber *(EAA)*

gyroscope with the ground he would always know up from down. The gyroscope would stay level while he moved the aircraft around it.

Pressure Instruments. Pressure instruments work on the idea that a fluid, such as air, exerts pressure. Pressure decreases with height, and pressure instruments use this principle to tell the pilot about the performance of the aircraft. How could pressure changes tell the pilot how high he is flying?

Electrical Instruments. Electrical instruments operate on the principles of electricity, including magnetism. Electrical instruments often take the place of mechanical and pressure instruments, and are being used more and more in modern aircraft. They are usually more accurate and give the aviator a way to precisely control his aircraft.

By viewing the instruments in these ways, one can see that each has a separate functional purpose and means of operation. Even though the instrument panel of today's aircraft looks complicated and confusing, pilots need to know all of the information the instruments provide. If you had to know what every gauge or dial read at every moment, you would be overwhelmed. Engineers design warning systems that monitor critical instrument readings and alert the aviator of problems. This allows the pilot to focus on flying, monitor other indications and focus on problems when they happen.

Classification by Use. Instruments classified by their use fall into two major groups: performance and control instruments. Performance instruments tell us how the aircraft has responded to our commands. Control instruments tell us the current state of some aircraft devices, so that we are aware of its condition.

It is a little easier, however, to discuss instruments as they are actually used. With that in mind, we'll look at instruments in three categories: engine, flight and navigation.

Engine instruments keep the pilot aware of how his thrust-producing device is operating. These instruments might tell him engine speed (rpm), oil temperature, oil pressure, fuel flow, etc. Flight instruments inform the pilot of the altitude, the airspeed, and the attitude of the aircraft. Navigation instruments help the pilot find the way from the point of departure to the destination. Such instruments include the clock, the compass, the directional gyro, the radio, radar, GPS, and radio direction finder.

Typical Instruments

Engine Instruments. One of the most important of the four basic engine instruments is called the tachometer. This instrument derives its name from the Greek word tachos, meaning speed, and the word meter, which means measure. Thus, tachometer means speed measure and that's what it shows—how fast the engine's crankshaft is turning.

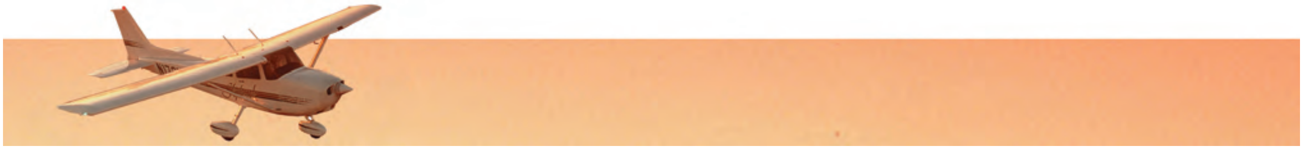
Tachometer

This measure is expressed in revolutions per minute (rpm). On the smaller aircraft engines, these revolutions per minute are conveyed from the crankshaft to the cockpit tachometer by a flexible shaft, making it a mechanical instrument. If the engine placement or complexity makes this difficult to design, the flexible shaft linkage is replaced with electrical tachometers. The electrical tachometer uses an electric generator that is geared to the engine's crankshaft. As the crankshaft turns, the generator makes electricity. The faster the crankshaft turns, the more electricity generated. The varying amount of generated electricity produces a varying RPM reading on the tachometer.

Whether the tachometer is mechanical or electrical, it will have a colored arc printed on the scale to show the normal operating range (green) and a red line for maximum allowable revolutions per minute. For safety and long engine life, engine operation should be kept within the green arc. The red line is definitely a danger point where the engine could fail, especially if the engine is run at that speed for more than a few seconds.

Another metering operation shown by the tachometer is time on the engine. This part of the tachometer records the total number of hours and tenths of hours that the engine has run since it was installed. The purpose of this information is to keep engine maintenance up to date.

Oil pressure and temperature gauges provide constant readings on the pressure and temperature of oil while the engine is operating. Both gauges have the standardized green markings for safe operating ranges and the red markings for maximums. If these gauges indicate anything but the green operating range, pilots know that they must take corrective action. This may be as simple as reducing engine speed or as drastic as preparing for an emergency landing.



Oil Temperature and Pressure Gauge in a Cessna 182

Aircraft engines have other gauges that are either necessary or helpful to the pilot. Depending on design these are mechanical, pressure, or electrical instruments. One safe bet is that every engine instrument is worth monitoring. Most pilots and passengers dislike the sudden silence that accompanies engine failure.

Flight Instruments. Flight instruments have two purposes. The first and most important purpose is that they allow for safe flight through clouds and at night. The second purpose is that the instruments show the pilot how well the airplane is being controlled.

Flight instruments are not absolutely necessary. After all, airplanes were flown before flight instruments were invented. Many pilots fly by "the seat of their pants." They reference outside-the-cockpit visual clues plus the sound of the engine, the feel of control pressure, and the feel of flight forces acting upon their bodies.

Seat-of-the-pants flying is not as effective when the earth's horizon and surface cannot be seen. Under these conditions, the pilot must rely on the airspeed indicator, the altimeter, the turn-and-slip indicator, the vertical speed indicator, and the attitude indicator. Human senses were not developed in the air, so they are unreliable if you take away the horizon, light and the solid feel of the ground under your feet.

The airspeed indicator informs the pilot of the speed through the air in terms of miles per hour and/or knots. It measures pressure of air rammed into a pitot tube at the front of the aircraft and translates it into aircraft speed.

Airspeed Indicator

Airspeed indicators are marked with colored areas to show maximum allowable speeds, normal speeds and approved flap-operating speeds. The range from stalling speed through normal operating speeds may be shown by a green arc; a yellow arc may show the speed from the maximum normal operating to the never exceed speed; and, a white arc may indicate flap operating speeds. These markings help keep the pilot from structurally damaging his aircraft from the dynamic pressure of the relative wind.

Aircraft altimeters are aneroid barometers that read in feet of altitude and are calibrated to atmospheric pressure in inches of mercury. Recall that pressure decreases with altitude, and the pressure change is shown on the altimeter reading. Even if the airplane is on the ground, a change in local air pressure will cause the altimeter to show an altitude change. Therefore, to get an accurate measurement, the pilot has to adjust the altimeter to show the atmospheric pressure for the flying area.

If the pilot sets the altimeter to zero while on the ground, it will then show actual height above the ground as he flies in the local area. This is only true if all of the ground in the area is the same height from

Altimeter

the center of the earth and the local pressure does not change. For most flying, height above sea level is more useful because the height of the ground changes as you fly over it. Local atmospheric pressure is updated as the pilot travels, but usually does not change very rapidly.

Pictured here is a typical altimeter, although the appearance may differ according to manufacturer. The long pointer shows changes of altitude in units of 20 and 100 feet. It can be read in units of 10 feet when the pointer is between two 20-foot units. The short pointer shows units of 200 and 1,000 feet.

This altimeter is of a dial-type style. Other styles exist which make quick recognition of altitude a little easier on the aviator. These styles include vertical tapes that go up as the aircraft altitude gets higher and those with digital readouts. Whatever style is employed, on any indicator, the goal should always be to let the pilot understand the reading as quickly as possible. It may be the difference between a nice landing and explaining why your Cessna is parked in someone's living room.

The turn-and-slip indicator is actually two instruments in one. The turn indicator, which is the needle, indicates the direction and rate of the turn. The ball in the glass tube, called the inclinometer, indicates the quality of the turn.

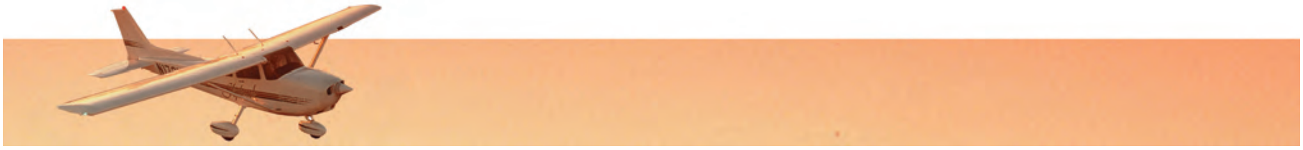
If the airplane is slipping toward the inside of the turn, the ball will be displaced in that direction or to the low side. That would mean that your tail is slipping down to the inside of the turn. This would create added drag and is referred to as *uncoordinated* flight. Can you reason why there would be more drag in a slip than coordinated flight?

If the airplane is skidding, displacement will be in the other direction. Skidding happens when the tail is being thrown toward the outside of the turn. This is also a type of uncoordinated flight.

The ball will stay in the middle if the turn is properly coordinated. The turn indicator is calibrated to show when the airplane is turning at the rate of 3° per second, or a full circle in 2 minutes. To fly wings-level in a constant direction, the pilot would keep the indicator centered.

Some aircraft are equipped with what is called a turn coordinator. The **turn coordinator** does the same things as the turn-and-slip indicator. However, a small aircraft silhouette (aft view) replaces the turn indicator or needle. As the aircraft banks, the silhouette banks. This view is easier for the pilot to visualize, so he gets an understanding of the instrument quicker.

The vertical velocity indicator (VVI) tells the pilot at what rate (in feet per minute) the airplane is climbing or descending. It is a pressure instrument much like the altimeter in that the reading is a reflection of atmospheric pressure changes. The more rapid the pressure change, the greater the rate of climb or descent. The needle rotates clockwise to indicate climb and counterclockwise to indicate descent. The vertical speed indicator may also be known as the **rate-of-climb indicator.**



Turn Coordinator

Vertical Velocity Indicator (VVI)

Attitude Indicator or Artificial Horizon

The attitude indicator is a gyroscopic instrument that provides an artificial horizon to the pilot. If the aircraft goes into the clouds and the pilot cannot see the real horizon, he can look at the attitude indicator and still fly level.

Usually, one will find that a small stationary aircraft symbol on the instrument case is the point of reference to the horizon. If you imagine that the symbol is the rear of your airplane and that you are looking from the tail to nose of your aircraft, you'll see that the attitude indicator is just a picture of how you are flying. If the little symbol is above the horizon, you are climbing. If the symbol is below, you are diving. Right turns look like a right bank as seen from the rear of the airplane. Get it?

Navigation Instruments are those that help the pilot find the way to the destination. One might reason that several of the flight instruments help toward accomplishing this goal. As a matter of fact, the airspeed indicator can be considered a navigation instrument. If the pilot did not know what the airspeed was, it would be difficult to determine how fast he was flying toward the destination.

In addition to the airspeed indicator, a clock is a very important navigation instrument. The airplane will have a built-in clock on its instrument panel, but the pilot will have a backup clock, usually in the form of a wristwatch.

The most basic and most important navigation instrument is the magnetic compass. Every airplane has a magnetic compass because it is a very reliable direction-sensing device in the airplane. It is usually the best backup means of telling what your heading is in the event of a primary system failure.

Most airplanes have what is known as a **heading indicator** for a primary heading instrument. This is a type of compass, and it looks like one. The heading indicator has all the directions printed on its compass card which the pilot sees, but behind this compass card is a gyroscopic device. When the aircraft is started, the gyroscope spins up and is stabilized. The pilot either sets his known heading on the compass card or it is set by some other computerized system like an inertial

Heading Indicator

navigation system (INS) or GPS. From then on, the compass card continues to tell the pilot which way he is flying. What Wrong-Way Corrigan wouldn't have given for one of these!

Aircraft designers have come up with some very useful heading indicators that give the aviator a lot of information quickly. A horizontal situation indicator (HSI) gives the pilot one instrument that tells him heading and navigation information quickly. A moving map display is a *God's-eye* view from above the aircraft and tells the pilot his position relative to ground references, like highways.

New Concepts


Cockpit of the Russian MiG-15 *(EAA)*

If you were an engineer or pilot, and maybe you are, what would you change to make air vehicles better? What is better? Is it cheaper? Greater cargo capacity? Faster? Each and every answer here is "yes." You, the aviation interested individual, will decide the course of aviation development. Just like

DaVinci envisioned a human-powered air vehicle, you might envision a hypersonic transport that can fly half way around the world and still not have to serve a single meal.

During the time this text was written, civil aviation was concerned with speeding up the overall aviation system. That is, how to make aircraft that help get the passenger and cargo to their destination the quickest and cheapest way.

One popular concept was the V/STOL aircraft. V/STOL stands for vertical/short takeoff and landing. The V/STOL aircraft could get into and out of small airports that were located close to the customer's destination. This concept would help reduce congestion at larger airports by getting people directly to their final destination. It also would reduce the size of airports and help lessen environmental impacts like noise.

Below is one of the popular designs based on a tilt-rotor concept. These aircraft turn their rotors up to takeoff and land like helicopters, and down to fly like fixed-wing vehicles.

The Bell/Augusta 609 is a commercial tiltrotor aircraft. *(Bell Helicopter Textron Photo)*

Hypersonic transports are those designed to travel at Mach 5 and greater. These vehicles would allow extremely fast trips over large distances. A corporate executive could fly from New York to Hong Kong, negotiate new contracts, fly back to New York, and still have time for dinner with a friend.

Such convenience comes with some very heavy design costs. These vehicles will require special construction materials to help keep the fuselage from melting, reduce wasted material weight and adjust to the changing environment from low to hypersonic speeds.

For Mach 4-7 flights, the waverider concept is a candidate for transportation. A waverider is a hypersonic or supersonic vehicle that has an attached shock wave along its leading fuselage edge. The vehicle appears to be riding its own shock wave – hence the name waverider. This type of vehicle has been considered as an option for interplanetary transportation as well.

Military emphasis at the time this text was written was on cost-savings and multi-role uses. If there is not a great deal of money to spend on defense, then what is spent needs to meet more needs.

One concept was the modular air vehicle. The idea is to build air vehicles from different sections that allow the airplane to do different missions. The designer just mixes and matches sections to meet the needs of country defense.

The Joint Strike Fighter was one such aircraft. Modules were put together to make the aircraft capable of vertical takeoffs for the Army so that it could support battles close to the war front. The Air Force version was put together with modules that made it better for deep strikes behind enemy lines.

***LOFLYTE* (Low-observable Flight Test Experiment) is used to explore new flight control techniques involving neutral networks, which allow the aircraft control system to learn by mimicking the pilot.**

Boeing X-32A Joint Strike Fighter

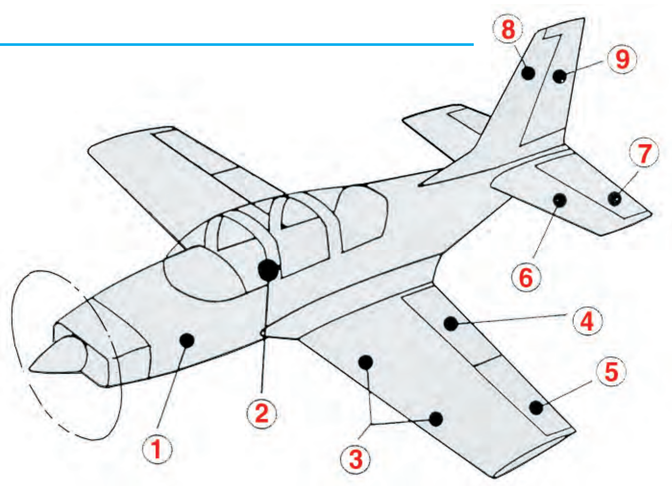
The flight deck of the Boeing 767 shows state-of-the-art instrumentation. (Boeing Photo)

Key Terms and Concepts

- aircraft parts: fuselage, wing, tail or empennage, horizontal and vertical stabilizer
- major flight control surfaces: ailerons, elevator, rudder
- aircraft control axes: longitudinal (roll), lateral (pitch), vertical (yaw)
- typical engine types: reciprocating, turbine, turbojet, turbofan, turboprop
- propfan system
- ramjet and scramjet engines
- other flight control surfaces: flaps, slats, spoilers and drag devices
- fuselage structures: truss, semimonocoque, monocoque
- landing gear types: conventional, tricycle, tandem
- fixed landing gear vs. retractable gear
- major aircraft systems: fuel, hydraulic, electrical
- performance vs. control instruments
- mechanical vs. pressure vs. electrical instruments
- flight instruments, engine instruments, navigation instruments
- gyroscopic stability
- V/STOL, waverider, modular air vehicle

? Test Your Knowledge ?

PICTURE TEST



1. 3 = ______________________________
2. 4 = ______________________________
3. 8 = ______________________________
4. 5 = ______________________________
5. 2 = ______________________________
6. 1 = ______________________________
7. 7 = ______________________________
8. 9 = ______________________________
9. 6 = ______________________________

FILL IN THE BLANKS

10. The __________ axis of rotation runs from one wingtip, through the fuselage and to the other wingtip and is controlled by the __________.

11. The __________ axis of rotation runs from the tip of the airplane nose to the tip of the tail and is controlled by the __________.

12. The __________ axis of rotation runs from the bottom of the fuselage through the top of the fuselage and is controlled by the __________.

13. The flap ______________ the camber of the wing airfoil for that portion of the wing to which it is attached.

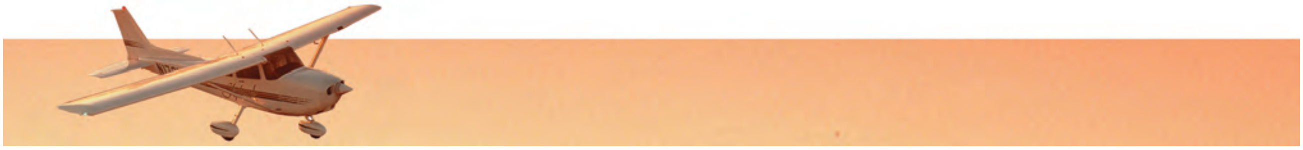
14. Flaps are often used for both __________ and __________.

15. The slat is a __________ from the __________ edge of a wing that produces a __________.

16. The slat adds to the __________ lift of a wing.

17. Spoilers destroy the __________ flow and simultaneously reduce a certain amount of __________ lift.

18. Drag devices produce drag without affecting the __________.



MATCHING

19. Air is accelerated and compressed by stator and rotor blades, then mixed with fuel and ignited in the combustion section, resulting in high-velocity gas or thrust.
20. Aircraft propellers turned by a turbine.
21. Crankshaft and pistons working together to convert straight-line motion to rotary motion in order to turn an aircraft propeller.
22. Have to be traveling through the air very fast in order to work.
23. Takes in air, accelerates it, pushes it out the exhaust nozzle to produce thrust that pushes the aircraft forward.
24. Combines the air-moving efficiency of the turbofan engine with the thrusting efficiency of a propeller.
25. Produce greater thrust and are more fuel efficient than standard turbojet engines.

a. reciprocating engine
b. turbine engine
c. turbojet engine
d. turbofan engine
e. turboprop engine
f. propfan system
g. ramjet/scramjet engine

MATCHING

26. Uses internal braces to help the skin carry the stresses generated in flight.
27. Utilizes longerons and struts welded together at various angles to form its basic shape.
28. Its covering provides the required strength to resist the stresses of flight.

a. truss
b. monocoque
c. semimonocoque

SHORT ANSWER

29. What name is given to the landing-gear arrangement that has two main front wheels and a small tailwheel?
30. If a plane has a nosewheel and two main wheels, what kind of landing gear does it have?
31. What type of landing gear has two sets of main wheels, one behind the other, located in tandem along the fuselage?
32. What is the purpose of anti-skid brakes?
33. Why do most small aircraft not have retractable landing gear?
34. What are the functions of these fuel system components: fuel pump, vent pipe, fuel tank drain, fuel strainer and cockpit fuel selector?

TRUE OR FALSE

35. *An hydraulic system is based on Pascal's law of pressure applied to a liquid in a closed container.*
36. *The hydraulic system of an aircraft may operate the brakes and control the flaps and propeller pitch, but is not used in lowering the landing gear.*
37. *A pilot can exert great pressure on control systems or structures by using the mechanical advantage gained in the hydraulic system.*
38. *A generator is a small electrical device used only to ignite the fuel-air mixture in the engine's cylinders.*
39. *Most electrical devices and controls on an aircraft receive their energy from the generator and battery system.*

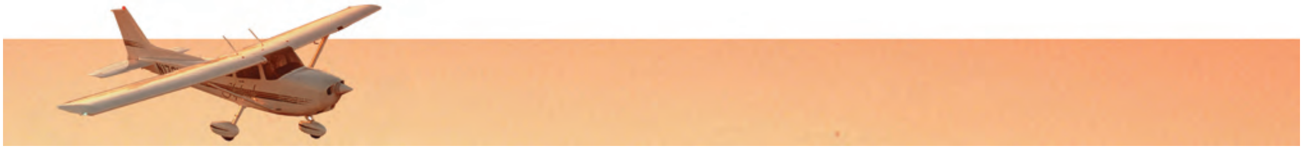
FILL IN THE BLANKS

40. *One of aviation's first fuel gauges involved string, a stick and a* __________.
41. *Early* __________ *indicators were merely wind gauges.*
42. *String was also used on the first aircraft by helping the pilot determine* __________.
43. *Instruments classified by their use are in the major categories of* __________, __________ *and* __________ *instruments.*
44. *Instruments classified by their principles of operation include* ________, ________ *and* ______ *instruments.*

MATCHING

45. *Measures altitude and most often is an aneroid barometer.*
46. *Heavy roto wheel mounted so it is free to rotate.*
47. *A type of compass which makes use of a gyroscopic device and is affected by very little turbulence.*
48. *The most basic and important navigational instrument.*
49. *Measures how fast the engine's crankshaft is turning.*
50. *Measures the passage of time.*
51. *A gyroscope instrument which provides a horizon to show relationship to pitch and bank.*
52. *Measures rate of climb or decent.*
53. *A two-in-one instrument revealing direction, rate and quality of turn.*
54. *Informs the pilot of his or her speed through the air by use of a pitot tube.*

a. gyroscope
b. tachometer
c. airspeed indicator
d. altimeter
e. turn-and-slip indicator
f. vertical velocity indicator
g. attitude indicator
h. clock
i. magnetic compass
j. heading indicator



TRUE OR FALSE

55. *The Wright brothers were the first to fly a sustained, controlled, powered flight of a heavier than air vehicle.*
56. *The Wright brothers used a technique called wing warping to reshape the wings of their aircraft.*
57. *The classifications of fuselages are slats, spoilers and truss.*
58. *The conventional landing gear has one wheel forward and two wheels in the back.*
59. *The fuel system for an aircraft engine includes everything that involves delivery of fuel to the engine.*