Chapter 5

Aircraft Systems

This chapter covers the main systems found on small airplanes. These include the engine, propeller, and induction systems, as well as the ignition, fuel, lubrication, cooling, electrical, landing gear, autopilot, and environmental control systems. A comprehensive introduction to gas turbine engines is included at the end of this chapter.

POWERPLANT

The airplane engine and propeller, often referred to as a **powerplant,** work in combination to produce thrust. The powerplant propels the airplane and drives the various systems that support the operation of an airplane.

RECIPROCATING ENGINES

Most small airplanes are designed with reciprocating engines. The name is derived from the back-and-forth, or reciprocating, movement of the pistons. It is this motion that produces the mechanical energy needed to accomplish work. Two common means of classifying reciprocating engines are:

1. by cylinder arrangement with respect to the crankshaft—radial, in-line, v-type or opposed, or

2. by the method of cooling—liquid or air-cooled.

Powerplant—A complete engine and propeller combination with accessories.

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

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

Opposed-type engines are the most popular reciprocating engines used on small airplanes. These engines always have an even number of cylinders, since a cylinder on one side of the crankcase "opposes" a cylinder on the other side. The majority of these engines are air cooled and usually are mounted in a horizontal position when installed on fixed-wing airplanes. Opposed-type engines have high power-to-weight ratios because they have a comparatively small, lightweight crankcase. In addition, the compact cylinder arrangement reduces the engine's frontal area and allows a streamlined installation that minimizes aerodynamic drag.

The main parts of a reciprocating engine include the cylinders, crankcase, and accessory housing. The intake/exhaust valves, spark plugs, and pistons are located in the cylinders. The crankshaft and connecting rods are located in the crankcase. [Figure 5-1] The magnetos are normally located on the engine accessory housing.

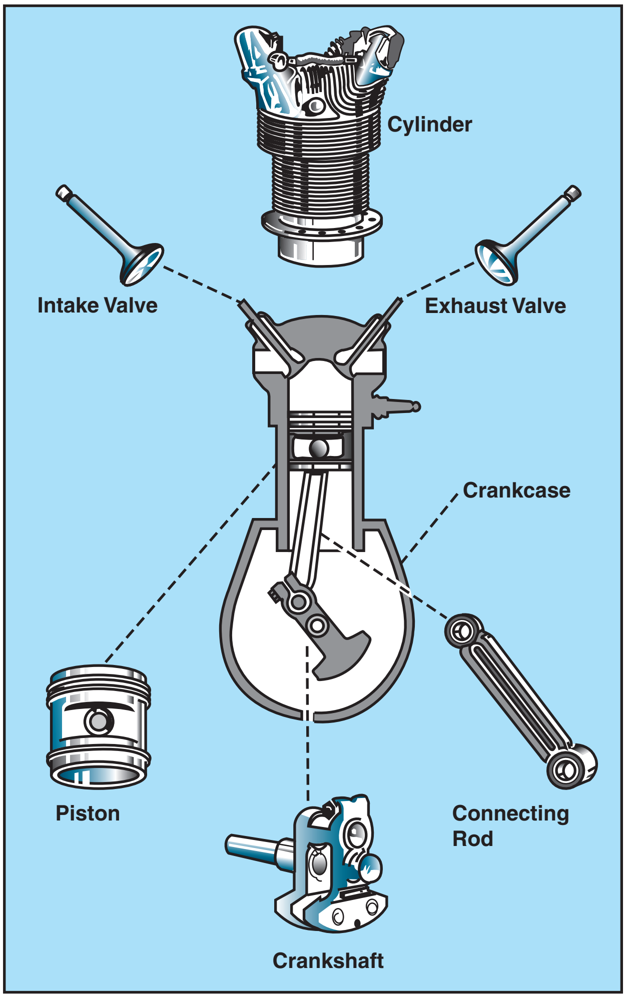


Figure 5-1. Main components of a reciprocating engine.

The basic principle for reciprocating engines involves the conversion of chemical energy, in the form of fuel, into mechanical energy. This occurs within the cylinders of the engine through a process known as the four-stroke operating cycle. These strokes are called intake, compression, power, and exhaust. [Figure 5-2]

1. The intake stroke begins as the piston starts its downward travel. When this happens, the intake valve opens and the fuel/air mixture is drawn into the cylinder.

2. The compression stroke begins when the intake valve closes and the piston starts moving back to the top of the cylinder. This phase of the cycle is used to obtain a much greater power output from the fuel/air mixture once it is ignited.

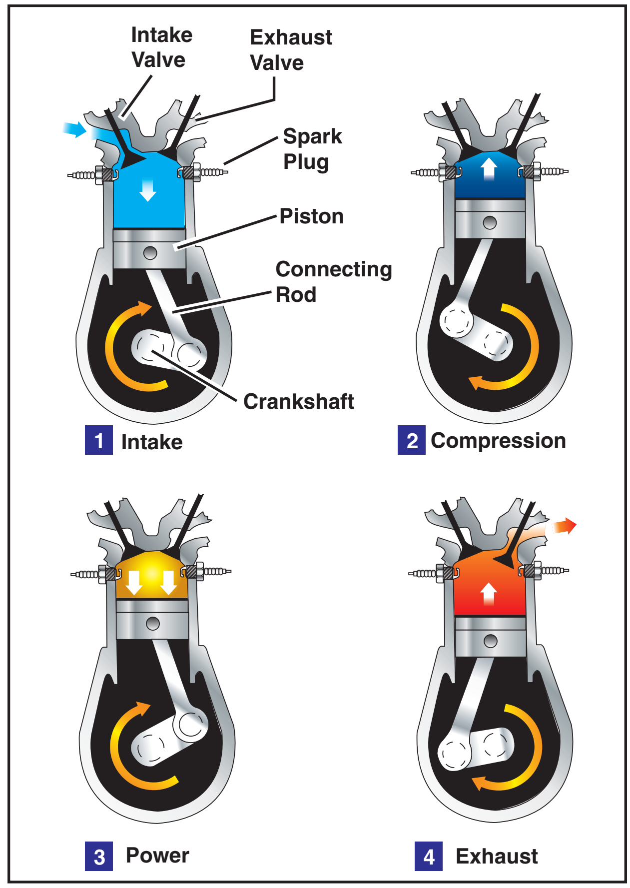


Figure 5-2. The arrows in this illustration indicate the direction of motion of the crankshaft and piston during the four-stroke cycle.

3. The power stroke begins when the fuel/air mixture is ignited. This causes a tremendous pressure increase in the cylinder, and forces the piston downward away from the cylinder head, creating the power that turns the crankshaft.

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

Even when the engine is operated at a fairly low speed, the four-stroke cycle takes place several hundred times each minute. In a four-cylinder engine, each cylinder operates on a different stroke. Continuous rotation of a crankshaft is maintained by the precise timing of the power strokes in each cylinder. Continuous operation of the engine depends on the simultaneous function of auxiliary systems, including the induction, ignition, fuel, oil, cooling, and exhaust systems.

PROPELLER

The propeller is a rotating airfoil, subject to induced drag, stalls, and other aerodynamic principles that apply to any airfoil. It provides the necessary thrust to pull, or in some cases push, the airplane through the air. The engine power is used to rotate the propeller, which in turn generates thrust very similar to the manner in which a wing produces lift. The amount of thrust produced depends on the shape of the airfoil, the angle of attack of the propeller blade, and the r.p.m. of the engine. The propeller itself is twisted so the blade angle changes from hub to tip. The greatest angle of incidence, or the highest pitch, is at the hub while the smallest pitch is at the tip. [Figure 5-3]

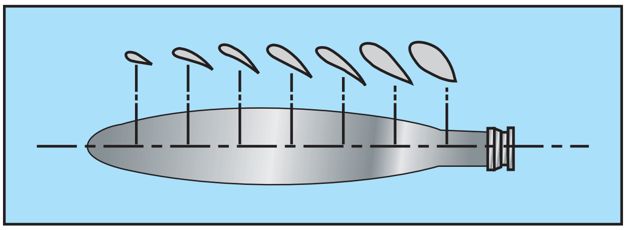


Figure 5-3. Changes in propeller blade angle from hub to tip.

The reason for the twist is to produce uniform lift from the hub to the tip. As the blade rotates, there is a difference in the actual speed of the various portions of the blade. The tip of the blade travels faster than that part near the hub, because the tip travels a greater distance than the hub in the same length of time. Changing the angle of incidence (pitch) from the hub to the tip to correspond with the speed produces uniform lift throughout the length of the blade. If the propeller blade was designed with the same angle of incidence throughout its entire length, it would be inefficient, because as airspeed increases in flight, the portion near the hub would have a negative angle of attack while the blade tip would be stalled. [Figure 5-4]

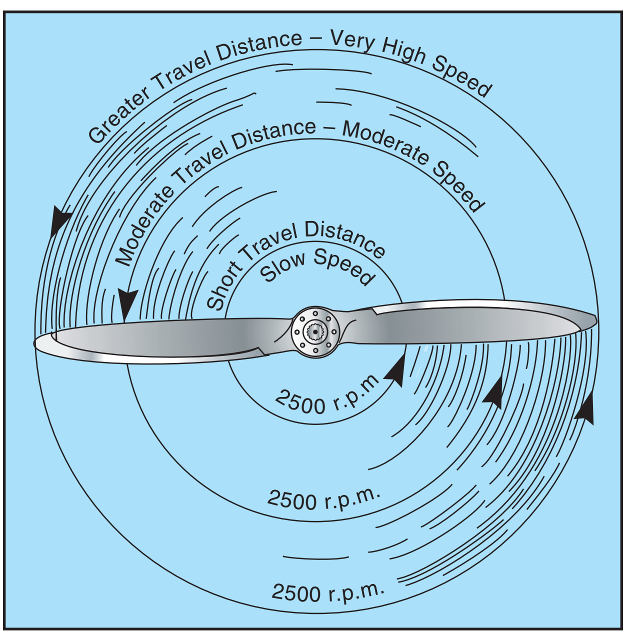


Figure 5-4. Relationship of travel distance and speed of various portions of propeller blade.

Angle of Incidence—For a propeller, it is the angle formed by the chord line and the reference plane containing the propeller hub. For a wing, it is the angle formed by the chord line of the wing and the longitudinal axis of the airplane.

Small airplanes are equipped with either one of two types of propellers. One is the fixed-pitch, and the other is the controllable-pitch.

FIXED-PITCH PROPELLER

The pitch of this propeller is set by the manufacturer, and cannot be changed. With this type of propeller, the best efficiency is achieved only at a given combination of airspeed and r.p.m.

There are two types of fixed-pitch propellers—the climb propeller and the cruise propeller. Whether the airplane has a climb or cruise propeller installed depends upon its intended use:

- The climb propeller has a lower pitch, therefore less drag. Less drag results in higher r.p.m. and more horsepower capability, which increases performance during takeoffs and climbs, but decreases performance during cruising flight.

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

The propeller is usually mounted on a shaft, which may be an extension of the engine crankshaft. In this case, the r.p.m. of the propeller would be the same as the crankshaft r.p.m. On some engines, the propeller is mounted on a shaft geared to the engine crankshaft. In this type, the r.p.m. of the propeller is different than that of the engine. In a fixed-pitch propeller, the tachometer is the indicator of engine power. [Figure 5-5]

Figure 5-5. Engine r.p.m. is indicated on the tachometer.

A tachometer is calibrated in hundreds of r.p.m., and gives a direct indication of the engine and propeller r.p.m. The instrument is color-coded, with a green arc denoting the maximum continuous operating r.p.m. Some tachometers have additional markings to reflect engine and/or propeller limitations. Therefore, the manufacturer's recommendations should be used as a reference to clarify any misunderstanding of tachometer markings.

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

When operating altitude increases, the tachometer may not show correct power output of the engine. For example, 2,300 r.p.m. at 5,000 feet produce less horsepower than 2,300 r.p.m. at sea level. The reason for this is that power output depends on air density. Air density decreases as altitude increases. Therefore, a decrease in air density (higher density altitude) decreases the power output of the engine. As altitude changes, the position of the throttle must be changed to maintain the same r.p.m. As altitude is increased, the throttle must be opened further to indicate the same r.p.m. as at a lower altitude.

ADJUSTABLE-PITCH PROPELLER

Although some older adjustable-pitch propellers could only be adjusted on the ground, most modern adjustable-pitch propellers are designed so that you can change the propeller pitch in flight. The first adjustable-pitch propeller systems provided only two pitch settings—a low-pitch setting and a high-pitch setting. Today, however, nearly all adjustable-pitch propeller systems are capable of a range of pitch settings.

A constant-speed propeller is the most common type of adjustable-pitch propeller. The main advantage of a constant-speed propeller is that it converts a high percentage of brake horsepower (BHP) into thrust horsepower (THP) over a wide range of r.p.m. and airspeed combinations. A constant-speed propeller is more efficient than other propellers because it allows selection of the most efficient engine r.p.m. for the given conditions.

An airplane with a constant-speed propeller has two controls—the throttle and the propeller control. The throttle controls power output, and the propeller control regulates engine r.p.m. and, in turn, propeller r.p.m., which is registered on the tachometer.

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

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

On airplanes that are equipped with a constant-speed propeller, power output is controlled by the throttle and indicated by a manifold pressure gauge. The gauge measures the absolute pressure of the fuel/air mixture inside the intake manifold and is more correctly a measure of **manifold absolute pressure (MAP)**. At a constant r.p.m. and altitude, the amount of power produced is directly related to the fuel/air flow being delivered to the combustion chamber. As you increase the throttle setting, more fuel and air is flowing to the engine; therefore, MAP increases. When the engine is not running, the manifold pressure gauge indicates ambient air pressure (i.e., 29.92 in. Hg). When the engine is started, the manifold pressure indication will decrease to a value less than ambient pressure (i.e., idle at 12 in. Hg). Correspondingly, engine failure or power loss is indicated on the manifold gauge as an increase in manifold pressure to a value corresponding to the ambient air pressure at the altitude where the failure occurred. [Figure 5-6]

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

For any given r.p.m., there is a manifold pressure that should not be exceeded. If manifold pressure is excessive for a given r.p.m., the pressure within the cylinders could be exceeded, thus placing undue stress on the cylinders. If repeated too frequently, this stress could weaken the cylinder components, and eventually cause engine failure.

Manifold Absolute Pressure (MAP)—The absolute pressure of the fuel/air mixture within the intake manifold, usually indicated in inches of mercury.

Figure 5-6. Engine power output is indicated on the manifold pressure gauge.

You can avoid conditions that could overstress the cylinders by being constantly aware of the r.p.m., especially when increasing the manifold pressure. Conform to the manufacturer's recommendations for power settings of a particular engine so as to maintain the proper relationship between manifold pressure and r.p.m.

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

- When power settings are being decreased, reduce manifold pressure before reducing r.p.m. If r.p.m. is reduced before manifold pressure, manifold pressure will automatically increase and possibly exceed the manufacturer's tolerances.
- When power settings are being increased, reverse the order—increase r.p.m. first, then manifold pressure.
- To prevent damage to radial engines, operating time at maximum r.p.m. and manifold pressure must be held to a minimum, and operation at maximum r.p.m. and low manifold pressure must be avoided.

Under normal operating conditions, the most severe wear, fatigue, and damage to high performance reciprocating engines occurs at high r.p.m. and low manifold pressure.

INDUCTION SYSTEMS

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

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

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

CARBURETOR SYSTEMS

Carburetors are classified as either float-type or pressure-type. Pressure carburetors are usually not found on small airplanes. The basic difference between a pressure carburetor and a float-type is the pressure carburetor delivers fuel under pressure by a fuel pump.

In the operation of the float-type carburetor system, the outside air first flows through an air filter, usually located at an air intake in the front part of the engine cowling. This filtered air flows into the carburetor and through a venturi, a narrow throat in the carburetor. When the air flows through the venturi, a low-pressure area is created, which forces the fuel to flow through a main fuel jet located at the throat. The fuel then flows into the airstream, where it is mixed with the flowing air. See figure 5-7 on page 5-6.

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

MIXTURE CONTROL

Carburetors are normally calibrated at sea-level pressure, where the correct fuel-to-air mixture ratio is established with the mixture control set in the FULL RICH position. However, as altitude increases, the density of air entering the carburetor decreases, while the density of the fuel remains the same. This creates a

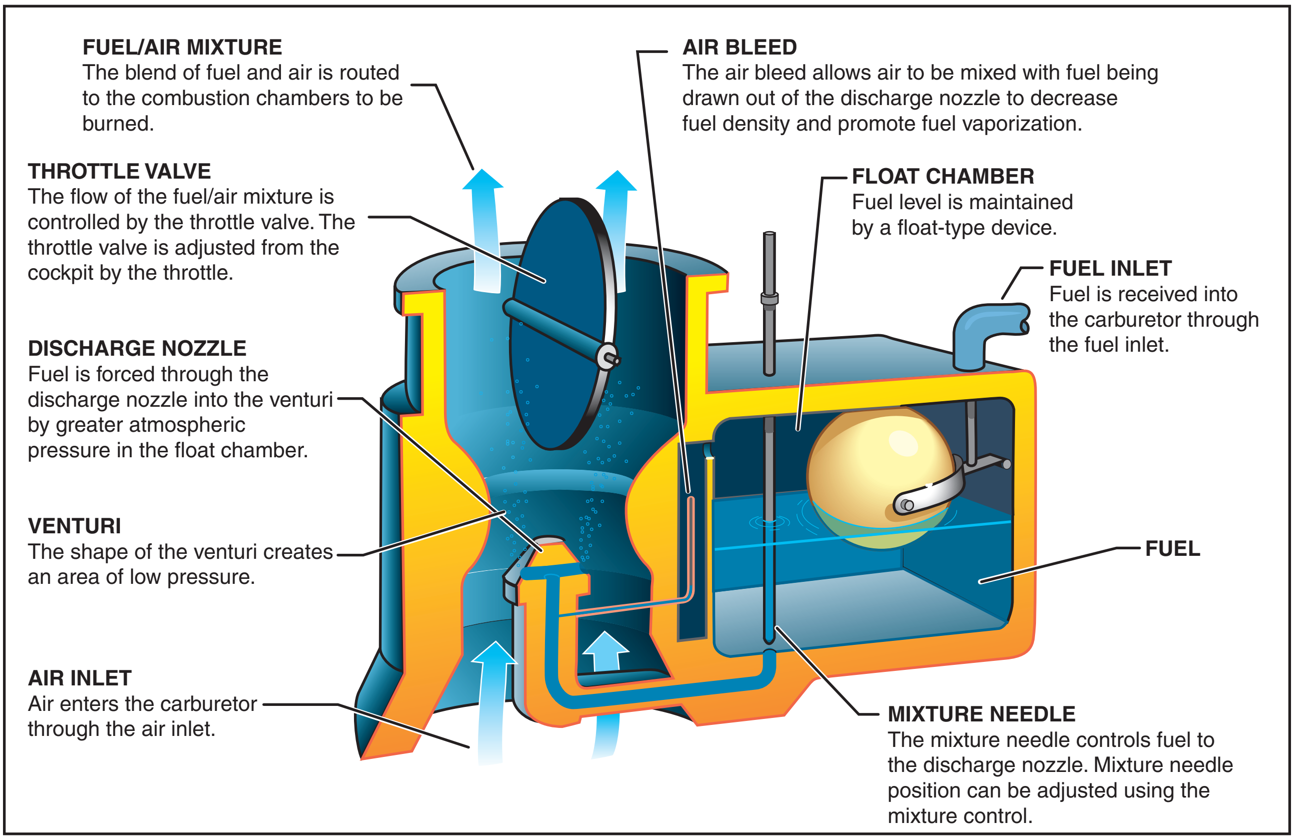


Figure 5-7. Float-type carburetor.

progressively richer mixture, which can result in engine roughness and an appreciable loss of power. The roughness normally is due to spark plug fouling from excessive carbon buildup on the plugs. Carbon buildup occurs because the excessively rich mixture lowers the temperature inside the cylinder, inhibiting complete combustion of the fuel. This condition may occur during the pretakeoff runup at high-elevation airports and during climbs or cruise flight at high altitudes. To maintain the correct fuel/air mixture, you must lean the mixture using the mixture control. Leaning the mixture decreases fuel flow, which compensates for the decreased air density at high altitude.

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

CARBURETOR ICING

One disadvantage of the float-type carburetor is its icing tendency. Carburetor ice occurs due to the effect of fuel vaporization and the decrease in air pressure in the venturi, which causes a sharp temperature drop in the carburetor. If water vapor in the air condenses when the carburetor temperature is at or below freezing, ice may form on internal surfaces of the carburetor, including the throttle valve. [Figure 5-8]

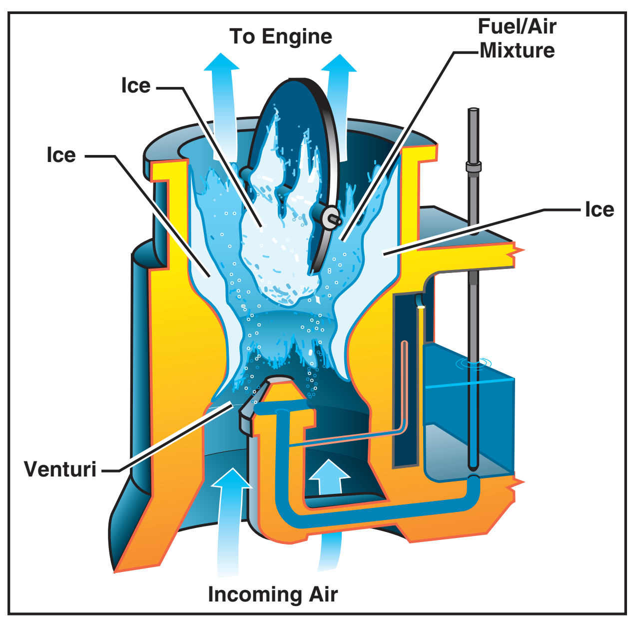


Figure 5-8. The formation of carburetor ice may reduce or block fuel/air flow to the engine.

The reduced air pressure, as well as the vaporization of fuel, contributes to the temperature decrease in the carburetor. Ice generally forms in the vicinity of the throttle valve and in the venturi throat. This restricts the flow of the fuel/air mixture and reduces power. If enough ice builds up, the engine may cease to operate.

Carburetor ice is most likely to occur when temperatures are below 70°F (21°C) and the relative humidity is above 80 percent. However, due to the sudden cooling that takes place in the carburetor, icing can occur even with temperatures as high as 100°F (38°C) and humidity as low as 50 percent. This temperature drop can be as much as 60 to 70°F. Therefore, at an outside air temperature of 100°F, a temperature drop of 70°F results in an air temperature in the carburetor of 30°F. [Figure 5-9]

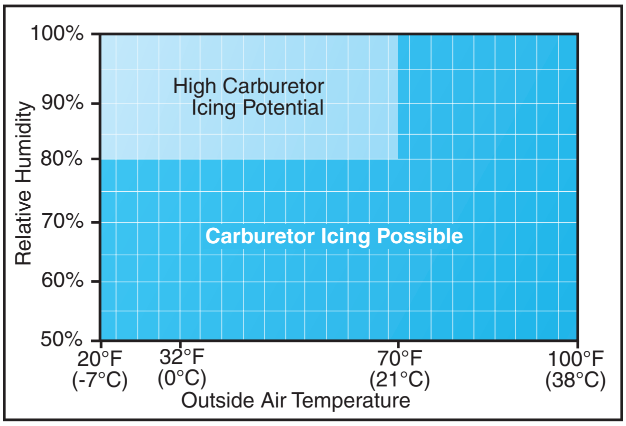


Figure 5-9. Although carburetor ice is most likely to form when the temperature and humidity are in ranges indicated by this chart, carburetor ice is possible under conditions not depicted.

The first indication of carburetor icing in an airplane with a fixed-pitch propeller is a decrease in engine r.p.m., which may be followed by engine roughness. In an airplane with a constant-speed propeller, carburetor icing usually is indicated by a decrease in manifold pressure, but no reduction in r.p.m. Propeller pitch is automatically adjusted to compensate for loss of power. Thus, a constant r.p.m. is maintained. Although carburetor ice can occur during any phase of flight, it is particularly dangerous when using reduced power during a descent. Under certain conditions, carburetor ice could build unnoticed until you try to add power. To combat the effects of carburetor ice, engines with float-type carburetors employ a carburetor heat system.

CARBURETOR HEAT

Carburetor heat is an anti-icing system that preheats the air before it reaches the carburetor. Carburetor heat is intended to keep the fuel/air mixture above the freezing temperature to prevent the formation of carburetor ice. Carburetor heat can be used to melt ice that has already formed in the carburetor provided that the accumulation is not too great. The emphasis, however, is on using carburetor heat as a preventative measure.

The carburetor heat should be checked during the engine runup. When using carburetor heat, follow the manufacturer's recommendations.

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

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

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

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

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

CARBURETOR AIR TEMPERATURE GAUGE

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

Certain carburetor air temperature gauges have a red radial, which indicates the maximum permissible carburetor inlet air temperature recommended by the engine manufacturer; also, a green arc may be included to indicate the normal operating range.

OUTSIDE AIR TEMPERATURE GAUGE

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

FUEL INJECTION SYSTEMS

In a fuel injection system, the fuel is injected either directly into the cylinders, or just ahead of the intake valve. A fuel injection system is considered to be less susceptible to icing than the carburetor system. Impact icing on the air intake, however, is a possibility in either system. Impact icing occurs when ice forms on the exterior of the airplane, and blocks openings such as the air intake for the injection system.

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

A fuel injection system usually incorporates these basic components—an engine-driven fuel pump, a fuel/air control unit, fuel manifold (fuel distributor), discharge nozzles, an auxiliary fuel pump, and fuel pressure/flow indicators. [Figure 5-10]

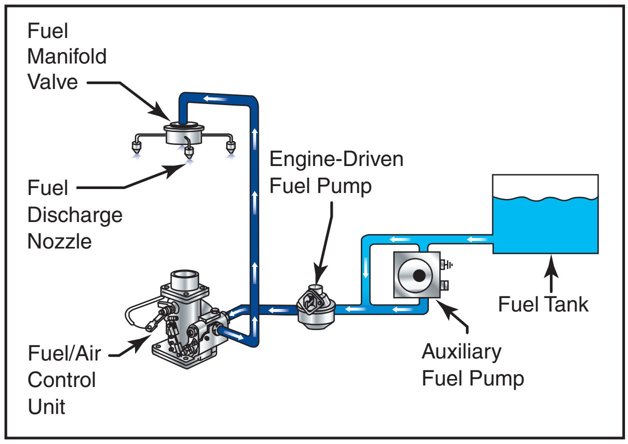


Figure 5-10. Fuel injection system.

The auxiliary fuel pump provides fuel under pressure to the fuel/air control unit for engine starting and/or emergency use. After starting, the engine-driven fuel pump provides fuel under pressure from the fuel tank to the fuel/air control unit. This control unit, which essentially replaces the carburetor, meters fuel based on the mixture control setting, and sends it to the fuel manifold valve at a rate controlled by the throttle. After reaching the fuel manifold valve, the fuel is distributed to the individual fuel discharge nozzles. The discharge nozzles, which are located in each cylinder head, inject the fuel/air mixture directly into each cylinder intake port.

Some of the advantages of fuel injection are:

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

Disadvantages usually include:

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

SUPERCHARGERS AND TURBOSUPERCHARGERS

To increase an engine's horsepower, manufacturers have developed supercharger and turbosupercharger systems that compress the intake air to increase its density. Airplanes with these systems have a manifold pressure gauge, which displays manifold absolute pressure (MAP) within the engine's intake manifold.

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

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

SUPERCHARGERS

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

Service Ceiling—The maximum density altitude where the best rate-of-climb airspeed will produce a 100 feet-per-minute climb at maximum weight while in a clean configuration with maximum continuous power.

Supercharger—An engine-driven air compressor used to provide additional pressure to the induction air so the engine can produce additional power.

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

An early version of a single-stage, single-speed supercharger may be referred to as a sea-level supercharger. An engine equipped with this type of supercharger is called a **sea-level engine**. With this type of supercharger, a single gear-driven impeller is used to increase the power produced by an engine at all altitudes. The drawback, however, is that with this type of supercharger, engine power output still decreases with an increase in altitude, in the same way that it does with a normally aspirated engine.

Single-stage, single-speed superchargers are found on many high-powered radial engines, and use an air intake that faces forward so the induction system can take full advantage of the ram air. Intake air passes through ducts to a carburetor, where fuel is metered in proportion to the airflow. The fuel/air charge is then ducted to the supercharger, or blower impeller, which accelerates the fuel/air mixture outward. Once accelerated, the fuel/air mixture passes through a diffuser, where air velocity is traded for pressure energy. After compression, the resulting high pressure fuel/air mixture is directed to the cylinders.

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

Under normal operations, takeoff is made with the supercharger in the low blower position. In this mode, the engine performs as a ground-boosted engine, and the power output decreases as the aircraft gains altitude. However, once the aircraft reaches a specified altitude, a power reduction is made, and the supercharger control is switched to the high blower position. The throttle is then reset to the desired

Sea-Level Engine—A reciprocating aircraft engine having a rated takeoff power that is producible only at sea level.

manifold pressure. An engine equipped with this type of supercharger is called an **altitude engine**. [Figure 5-11]

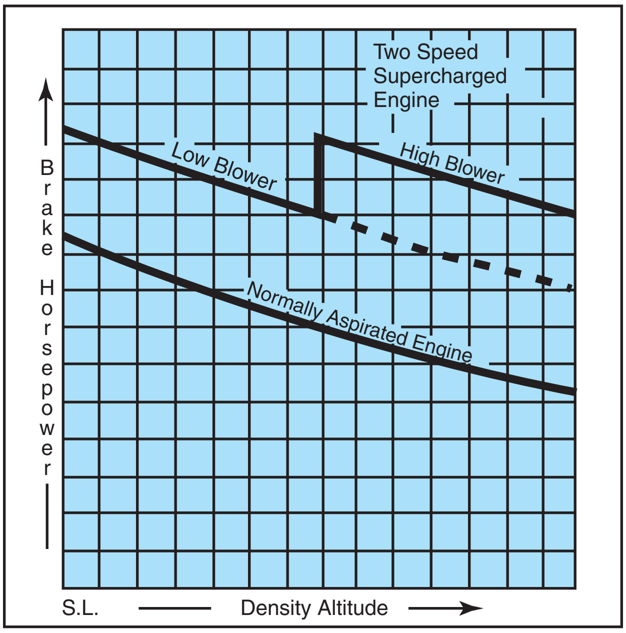


Figure 5-11. Power output of normally aspirated engine compared to a single-stage, two-speed supercharged engine.

TURBOSUPERCHARGERS

The most efficient method of increasing horsepower in a reciprocating engine is by use of a turbosupercharger, or **turbocharger**, as it is usually called. A drawback of gear-driven superchargers is that they use a large amount of the engine's power output for the amount of power increase they produce. This problem is avoided with a turbocharger, because turbochargers are powered by an engine's exhaust gases. This means a turbocharger recovers energy from hot exhaust gases that would otherwise be lost.

Another advantage of turbochargers is that they can be controlled to maintain an engine's rated sea-level horsepower from sea level up to the engine's critical altitude. Critical altitude is the maximum altitude at which a turbocharged engine can produce its rated horsepower. Above the critical altitude, power output begins to decrease like it does for a normally aspirated engine.

Turbochargers increase the pressure of the engine's induction air, which allows the engine to develop sea level or greater horsepower at higher altitudes. A turbocharger is comprised of two main elements—a turbine and a compressor. The compressor section houses an impeller that turns at a high rate of speed. As induction air is drawn across the impeller blades, the impeller accelerates the air, allowing a large volume of air to be drawn into the compressor housing. The impeller's action subsequently produces high-pressure, high-density air, which is delivered to the engine. To turn the impeller, the engine's exhaust gases are used to drive a turbine wheel that is mounted on the opposite end of the impeller's drive shaft. By directing different amounts of exhaust gases to flow over the turbine, more energy can be extracted, causing the impeller to deliver more compressed air to the engine. The **waste gate** is used to vary the mass of exhaust gas flowing into the turbine. A waste gate is essentially an adjustable butterfly valve that is installed in the exhaust system. When closed, most of the exhaust gases from the engine are forced to flow through the turbine. When open, the exhaust gases are allowed to bypass the turbine by flowing directly out through the engine's exhaust pipe. [Figure 5-12]

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

SYSTEM OPERATION

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

Other turbocharging system designs use a separate manual control to position the waste gate. With manual control, you must closely monitor the manifold pressure gauge to determine when the desired MAP has been achieved. Manual systems are often found on aircraft that have been modified with aftermarket turbocharging systems. These systems require special operating considerations. For example, if the waste gate is left closed after descending from a high altitude, it is possible to produce a manifold pressure that exceeds the engine's limitations. This condition is

Altitude Engine—A reciprocating aircraft engine having a rated takeoff power that is producible from sea level to an established higher altitude.

Turbocharger—An air compressor driven by exhaust gases, which increases the pressure of the air going into the engine through the carburetor or fuel injection system.

Waste Gate—A controllable valve in the exhaust system of a reciprocating engine equipped with a turbocharger. The valve is controlled to vary the amount of exhaust gases forced through the turbocharger turbine.

Intercooler—A device used to remove heat from air or liquid.

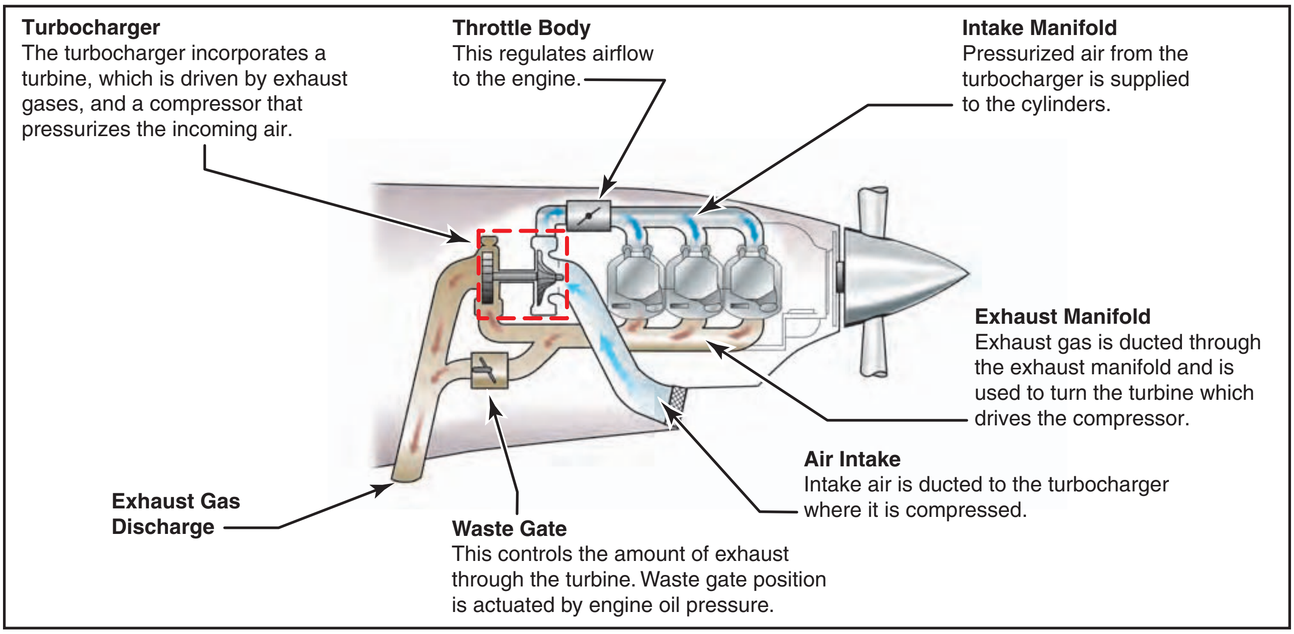


Figure 5-12. Turbocharger components.

referred to as an **overboost**, and it may produce severe detonation because of the leaning effect resulting from increased air density during descent.

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

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

Overboost—A condition in which a reciprocating engine has exceeded the maximum manifold pressure allowed by the manufacturer.

HIGH ALTITUDE PERFORMANCE

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

IGNITION SYSTEM

The ignition system provides the spark that ignites the fuel/air mixture in the cylinders and is made up of magnetos, spark plugs, high-tension leads, and the ignition switch. [Figure 5-13]

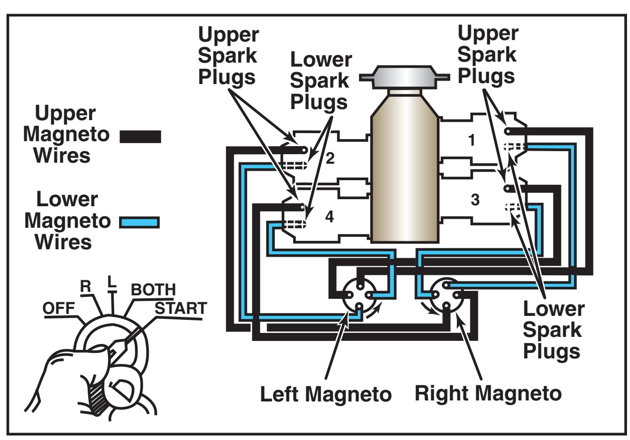


Figure 5-13. Ignition system components.

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

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

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

1. OFF
2. R—Right
3. L—Left
4. BOTH
5. START

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

You can identify a malfunctioning ignition system during the pretakeoff check by observing the decrease in r.p.m. that occurs when you first move the ignition switch from BOTH to RIGHT, and then from BOTH to LEFT. A small decrease in engine r.p.m. is normal during this check. The permissible decrease is listed in the AFM or POH. If the engine stops running when you switch to one magneto or if the r.p.m. drop exceeds the allowable limit, do not fly the airplane until the problem is corrected. The cause could be fouled plugs, broken or shorted wires between the magneto and the plugs, or improperly timed firing of the plugs. It should be noted that "no drop" in r.p.m. is not normal, and in that instance, the airplane should not be flown.

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

Loose or broken wires in the ignition system also can cause problems. For example, if the ignition switch is OFF, the magneto may continue to fire if the ignition switch ground wire is disconnected. If this occurs, the only way to stop the engine is to move the mixture lever to the idle cutoff position, then have the system checked by a qualified aviation maintenance technician.

COMBUSTION

During normal combustion, the fuel/air mixture burns in a very controlled and predictable manner. Although the process occurs in a fraction of a second, the mixture actually begins to burn at the point where it is ignited by the spark plugs, then burns away from the plugs until it is all consumed. This type of combustion causes a smooth buildup of temperature and pressure and ensures that the expanding gases deliver the maximum force to the piston at exactly the right time in the power stroke. [Figure 5-14]

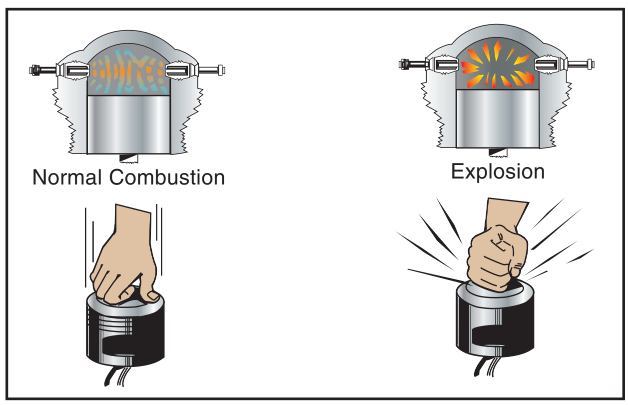


Figure 5-14. Normal combustion and explosive combustion.

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

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

Magneto—A self-contained, engine-driven unit that supplies electrical current to the spark plugs; completely independent of the airplane's electrical system. Normally, there are two magnetos per engine.

Detonation—An uncontrolled, explosive ignition of the fuel/air mixture within the cylinder's combustion chamber.

- Using a lower fuel grade than that specified by the aircraft manufacturer.
- Operating with extremely high manifold pressures in conjunction with low r.p.m.
- Operating the engine at high power settings with an excessively lean mixture.
- Detonation also can be caused by extended ground operations, or steep climbs where cylinder cooling is reduced.

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

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

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

Detonation and preignition often occur simultaneously and one may cause the other. Since either condition causes high engine temperature accompanied by a decrease in engine performance, it is often difficult to distinguish between the two. Using the recommended grade of fuel and operating the engine within its proper temperature, pressure, and r.p.m. ranges reduce the chance of detonation or preignition.

Preignition—The uncontrolled combustion of the fuel/air mixture in advance of the normal ignition.

FUEL SYSTEMS

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

The gravity-feed system utilizes the force of gravity to transfer the fuel from the tanks to the engine—for example, on high-wing airplanes where the fuel tanks are installed in the wings. This places the fuel tanks above the carburetor, and the fuel is gravity fed through the system and into the carburetor. If the design of the airplane is such that gravity cannot be used to transfer fuel, fuel pumps are installed—for example, on low-wing airplanes where the fuel tanks in the wings are located below the carburetor. [Figure 5-15]

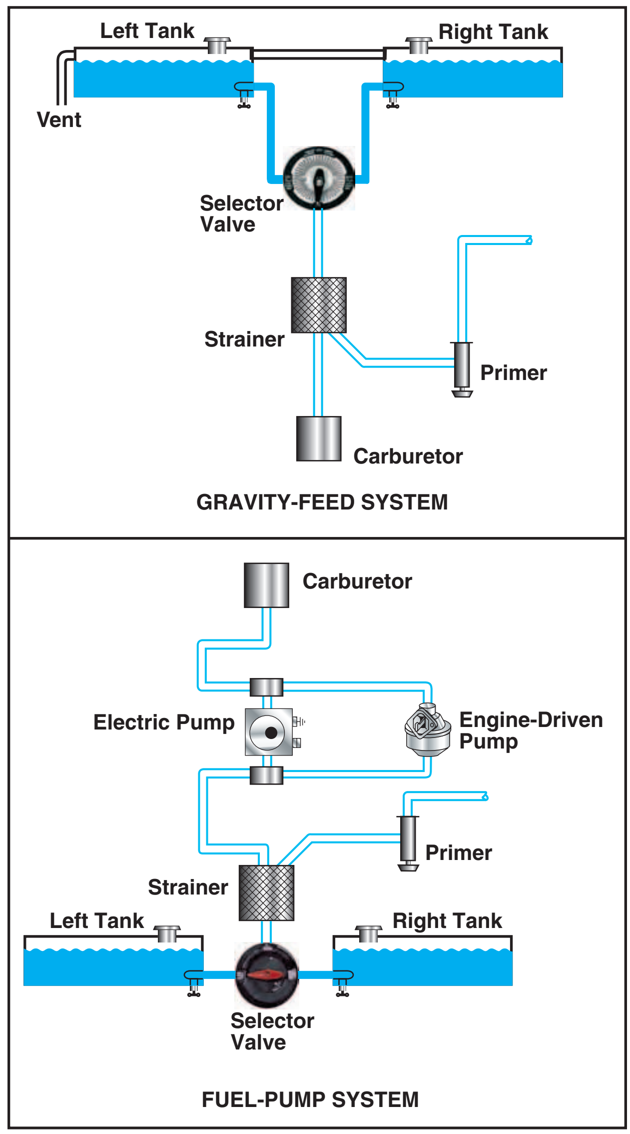


Figure 5-15. Gravity-feed and fuel-pump systems.

FUEL PUMPS

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

FUEL PRIMER

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

FUEL TANKS

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

FUEL GAUGES

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

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

FUEL SELECTORS

The fuel selector valve allows selection of fuel from various tanks. A common type of selector valve contains four positions: LEFT, RIGHT, BOTH, and OFF. Selecting the LEFT or RIGHT position allows fuel to feed only from that tank, while selecting the BOTH position feeds fuel from both tanks. The LEFT or RIGHT position may be used to balance the amount of fuel remaining in each wing tank. [Figure 5-16]

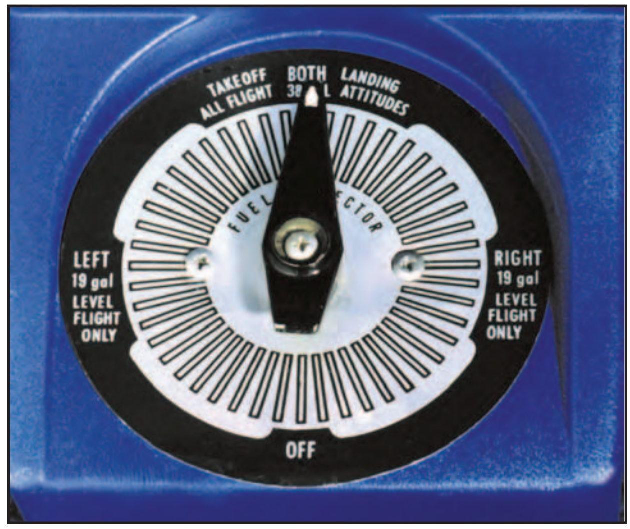


Figure 5-16. Fuel selector valve.

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

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

FUEL STRAINERS, SUMPS, AND DRAINS

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

The fuel strainer should be drained before each flight. Fuel samples should be drained and checked visually for water and contaminants. Water in the sump is hazardous because in cold weather the water can freeze and block fuel lines. In warm weather, it can flow into the carburetor and stop the engine. If water is present in the sump, it is likely there is more water in the fuel tanks, and you should continue to drain them until there is no evidence of water. In any event, never take off until you are certain that all water and contaminants have been removed from the engine fuel system.

Because of the variation in fuel systems, you should become thoroughly familiar with the systems that apply to your airplane. Consult the AFM or POH for specific operating procedures.

FUEL GRADES

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

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

The current method to identify aviation gasoline for aircraft with reciprocating engines is by the octane and performance number, along with the abbreviation AVGAS. These aircraft use AVGAS 80, 100, and 100LL. Although AVGAS 100LL performs the same as grade 100, the "LL" indicates it has a low lead content. Fuel for aircraft with turbine engines is classified as JET A, JET A-1, and JET B. Jet fuel is basically kerosene and has a distinctive kerosene smell.

Since use of the correct fuel is critical, dyes are added to help identify the type and grade of fuel. [Figure 5-17]

FUEL TYPE AND GRADE	COLOR OF FUEL	EQUIPMENT COLOR
AVGAS 80	RED	80 AVGAS
AVGAS 100	GREEN	100 AVGAS
AVGAS 100LL	BLUE	100LL AVGAS
JET A	COLORLESS OR STRAW	JET A

Figure 5-17. Aviation fuel color-coding system.

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

FUEL CONTAMINATION

Of the accidents attributed to powerplant failure from fuel contamination, most have been traced to:

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

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

Water may also remain in the fuel tanks after the drainage from the fuel strainer had ceased to show any trace of water. This residual water can be removed only by draining the fuel tank sump drains.

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

Fuel tanks should be filled after each flight, or at least after the last flight of the day to prevent moisture condensation within the tank. Another way to prevent fuel contamination is to avoid refueling from cans and drums. Refueling from cans or drums may result in fuel contamination.

The use of a funnel and chamois skin when refueling from cans or drums is hazardous under any conditions, and should be discouraged. In remote areas or in emergency situations, there may be no alternative to refueling from sources with inadequate anticontamination systems, and a chamois and funnel may be the only possible means of filtering fuel. However, the use of a chamois will not always ensure decontaminated fuel. Worn-out chamois will not filter water; neither will a new, clean chamois that is already water-wet or damp. Most imitation chamois skins will not filter water.

REFUELING PROCEDURES

Static electricity is formed by the friction of air passing over the surfaces of an airplane in flight and by the flow of fuel through the hose and nozzle during refueling. Nylon, dacron, or wool clothing is especially prone to accumulate and discharge static electricity from the person to the funnel or nozzle. To guard against the possibility of static electricity igniting fuel fumes, a ground wire should be attached to the aircraft before the fuel cap is removed from the tank. The refueling nozzle then should be grounded to the aircraft before refueling is begun, and should remain grounded throughout the refueling process. When a fuel truck is used, it should be grounded prior to the fuel nozzle contacting the aircraft.

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

1. Drum to ground.

2. Ground to aircraft.

3. Drum to aircraft.

4. Nozzle to aircraft before the fuel cap is removed.

When disconnecting, reverse the order.

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

STARTING SYSTEM

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

Electrical power for starting is usually supplied by an on-board battery, but can also be supplied by external power through an external power receptacle. When the battery switch is turned on, electricity is supplied to the main power bus through the battery solenoid. Both the starter and the starter switch draw current from the main bus, but the starter will not operate until the starting solenoid is energized by the starter switch being turned to the “start” position. When the starter switch is released from the “start” position, the solenoid removes power from the starter motor. The starter motor is protected from being driven by the engine through a clutch in the starter drive that allows the engine to run faster than the starter motor. [Figure 5-18]

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

OIL SYSTEMS

The engine oil system performs several important functions, including:

- Lubrication of the engine’s moving parts.

- Cooling of the engine by reducing friction.

- Removing heat from the cylinders.

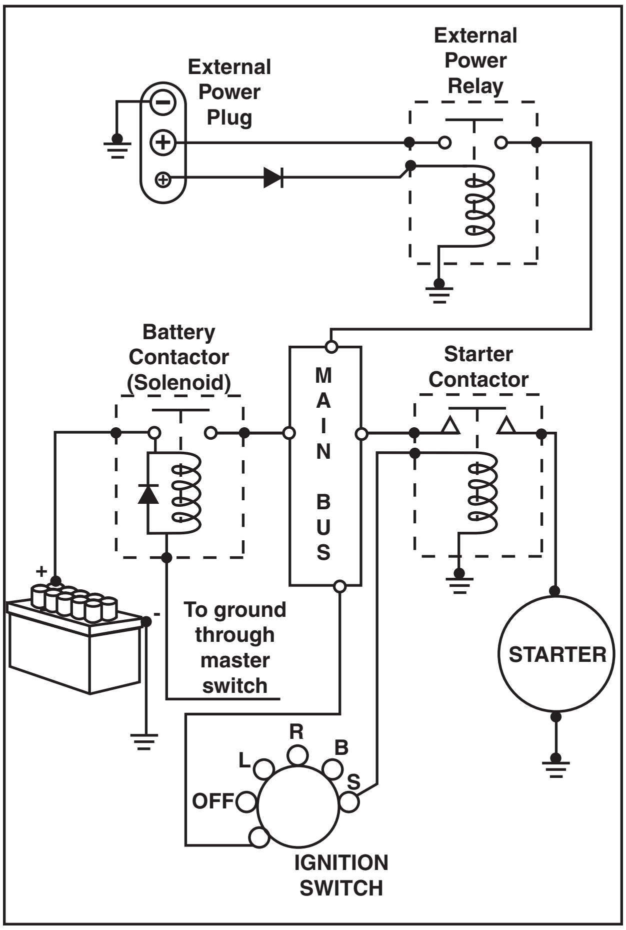


Figure 5-18. Typical starting circuit.

- Providing a seal between the cylinder walls and pistons.

- Carrying away contaminants.

Reciprocating engines use either a wet-sump or dry-sump oil system. In a dry-sump system, the oil is contained in a separate tank, and circulated through the engine by pumps. In a wet-sump system, the oil is located in a sump, which is an integral part of the engine. [Figure 5-19]

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

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

The oil pressure gauge provides a direct indication of the oil system operation. It measures the pressure in

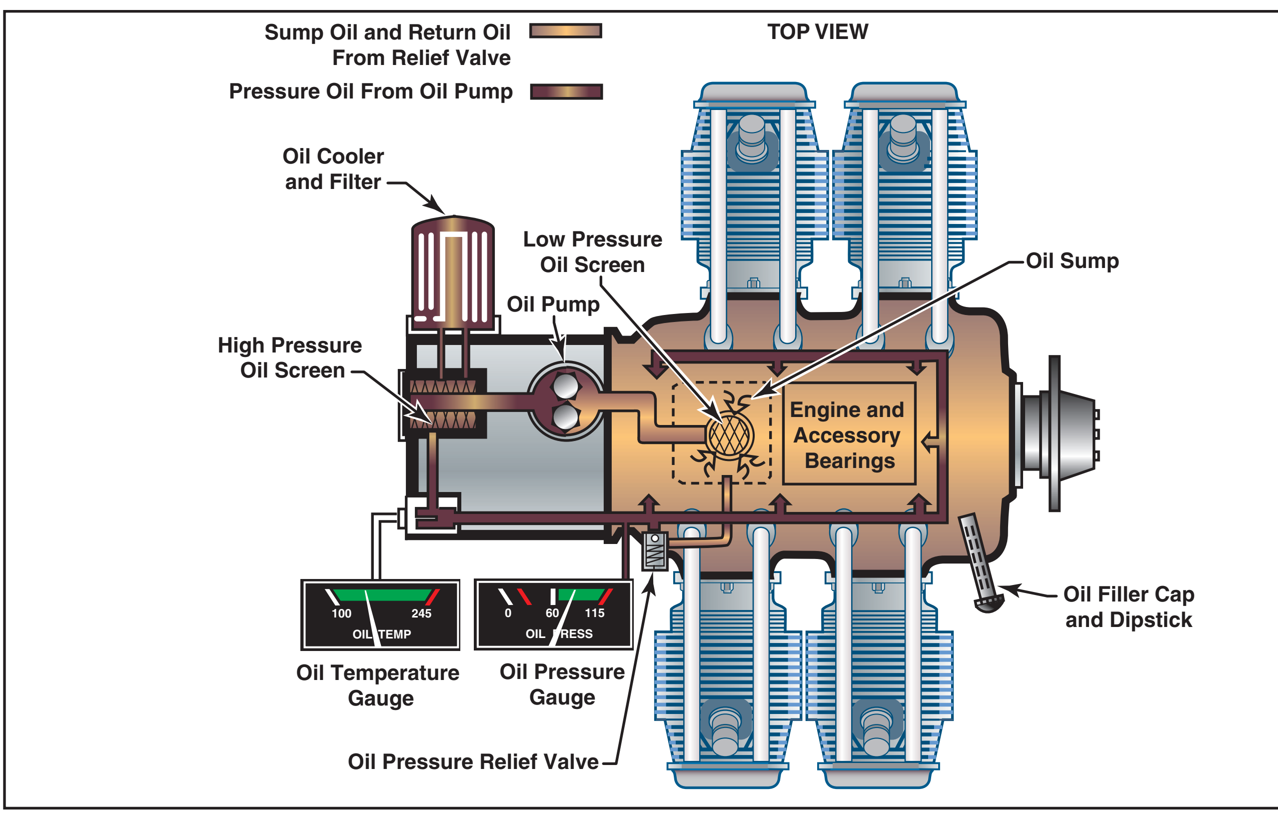


Figure 5-19. Wet-sump oil system.

pounds per square inch (p.s.i.) of the oil supplied to the engine. Green indicates the normal operating range, while red indicates the minimum and maximum pressures. There should be an indication of oil pressure during engine start. Refer to the AFM/POH for manufacturer limitations.

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

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

The oil filler cap and dipstick (for measuring the oil quantity) are usually accessible through a panel in the engine cowling. If the quantity does not meet the manufacturer's recommended operating levels, oil should be added. The AFM, POH, or placards near the access panel provide information about the correct oil type and weight, as well as the minimum and maximum oil quantity. [Figure 5-20]

Figure 5-20. Always check the engine oil level during the preflight inspection.

ENGINE COOLING SYSTEMS

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

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

Air cooling is accomplished by air flowing into the engine compartment through openings in front of the engine cowling. Baffles route this air over fins attached to the engine cylinders, and other parts of the engine, where the air absorbs the engine heat. Expulsion of the hot air takes place through one or more openings in the lower, aft portion of the engine cowling. [Figure 5-21]

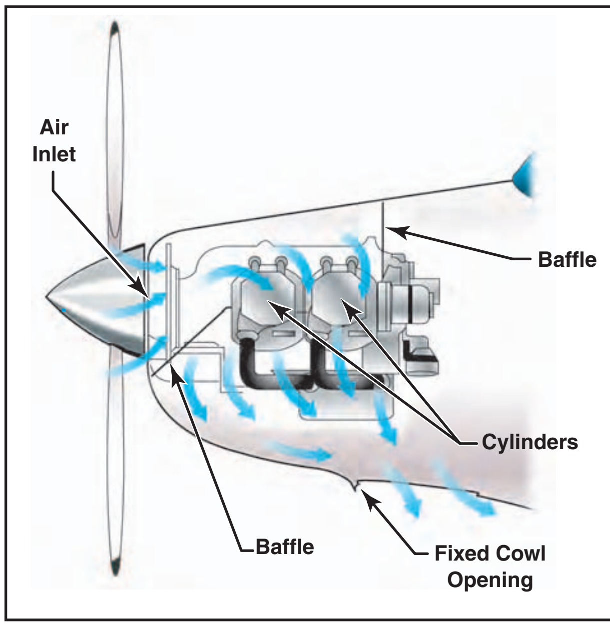


Figure 5-21. Outside air aids in cooling the engine.

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

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

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

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

The oil temperature gauge gives an indirect and delayed indication of rising engine temperature, but can be used for determining engine temperature if this is the only means available.

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

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

EXHAUST SYSTEMS

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

Cowl Flaps—Shutter-like devices arranged around certain air-cooled engine cowlings, which may be opened or closed to regulate the flow of air around the engine.

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

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

Some exhaust systems have an exhaust gas temperature probe. This probe transmits the exhaust gas temperature (EGT) to an instrument in the cockpit. The EGT gauge measures the temperature of the gases at the exhaust manifold. This temperature varies with the ratio of fuel to air entering the cylinders and can be used as a basis for regulating the fuel/air mixture. The EGT gauge is highly accurate in indicating the correct mixture setting. When using the EGT to aid in leaning the fuel/air mixture, fuel consumption can be reduced. For specific procedures, refer to the manufacturer's recommendations for leaning the mixture.

ELECTRICAL SYSTEM

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

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

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

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

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

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

The electrical system is turned on or off with a master switch. Turning the master switch to the ON position provides electrical energy to all the electrical equipment circuits with the exception of the ignition system. Equipment that commonly uses the electrical system for its source of energy includes:

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

Many airplanes are equipped with a battery switch that controls the electrical power to the airplane in a manner similar to the master switch. In addition, an alternator switch is installed which permits the pilot to exclude the alternator from the electrical system in the event of alternator failure. [Figure 5-22]

Figure 5-22. On this master switch, the left half is for the alternator and the right half is for the battery.

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

A bus bar is used as a terminal in the airplane electrical system to connect the main electrical system to the equipment using electricity as a source of power. This simplifies the wiring system and provides a common point from which voltage can be distributed throughout the system. [Figure 5-23]

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

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

Ammeters are designed with the zero point in the center of the face and a negative or positive indication on either side. [Figure 5-24] When the pointer of the ammeter on the left is on the plus side, it shows the charging rate of the battery. A minus indication means more current is being drawn from the battery than is being replaced. A full-scale minus deflection indicates a malfunction of the alternator/generator. A full-scale positive deflection indicates a malfunction of the regulator. In either case, consult the AFM or POH for appropriate action to be taken.

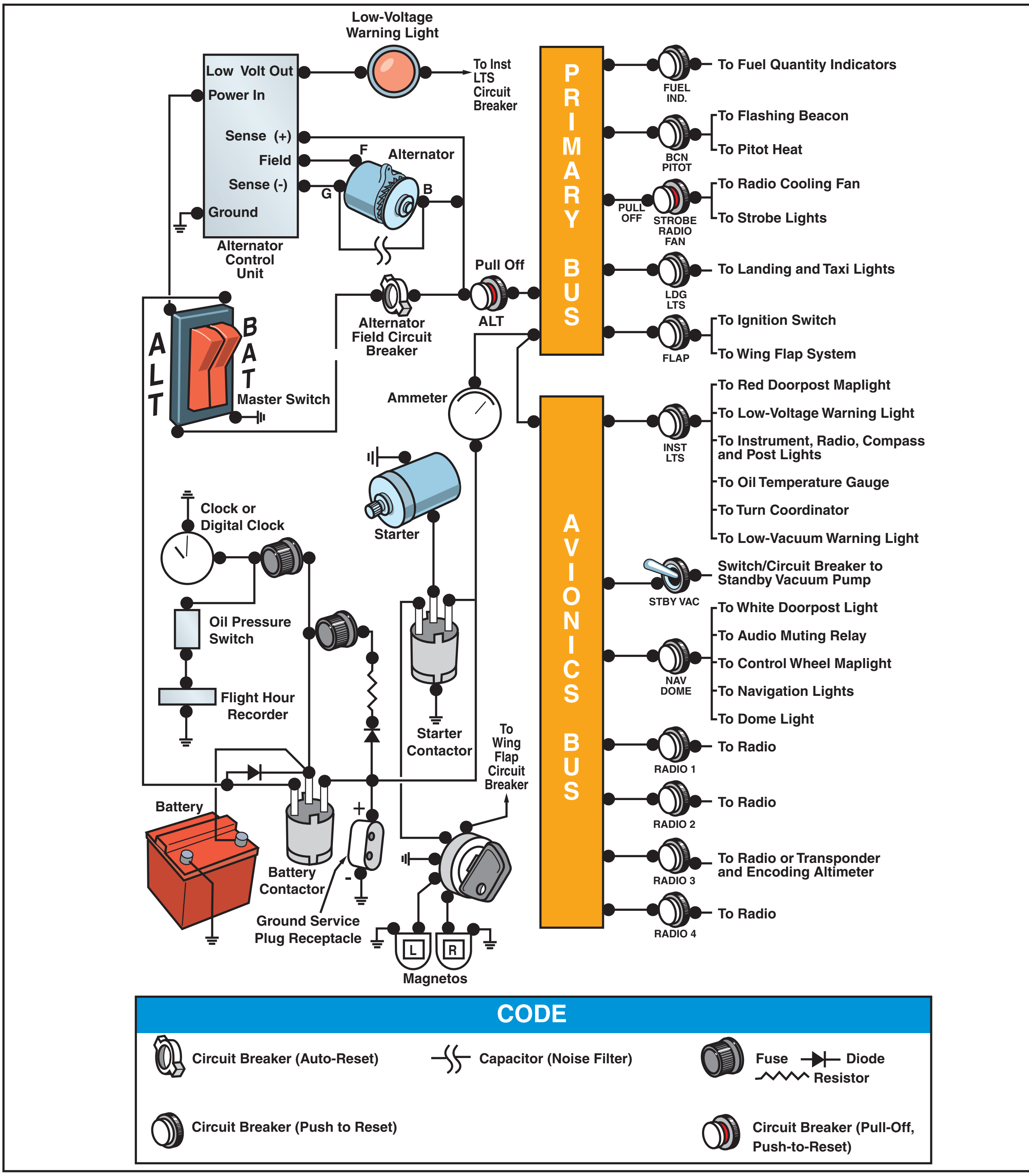


Figure 5-23. Electrical system schematic.

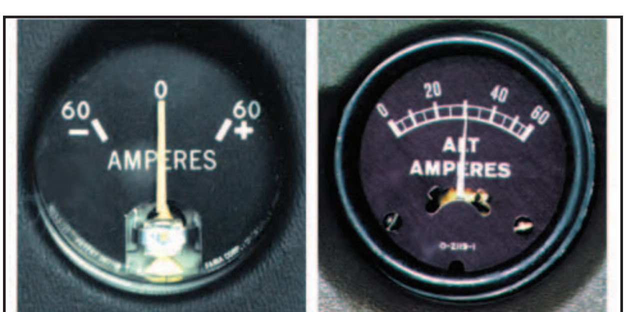


Figure 5-24. Ammeter and loadmeter.

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

Another electrical monitoring indicator is a loadmeter. This type of gauge, illustrated on the right in figure 5-24, has a scale beginning with zero and shows the load being placed on the alternator/generator. The loadmeter reflects the total percentage of the load placed on the generating capacity of the electrical system by the electrical accessories and battery. When all electrical components are turned off, it reflects only the amount of charging current demanded by the battery.

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

HYDRAULIC SYSTEMS

There are multiple applications for hydraulic use in airplanes, depending on the complexity of the airplane. For example, hydraulics are often used on small airplanes to operate wheel brakes, retractable landing gear, and some constant-speed propellers. On large airplanes, hydraulics are used for flight control surfaces, wing flaps, spoilers, and other systems.

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

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

A mineral-based fluid is the most widely used type for small airplanes. This type of hydraulic fluid, which is a kerosene-like petroleum product, has good lubricating properties, as well as additives to inhibit foaming and prevent the formation of corrosion. It is quite stable chemically, has very little viscosity change with temperature, and is dyed for identification. Since several types of hydraulic fluids are commonly used, make sure your airplane is serviced with the type specified by the manufacturer. Refer to the AFM, POH, or the Maintenance Manual. [Figure 5-25]

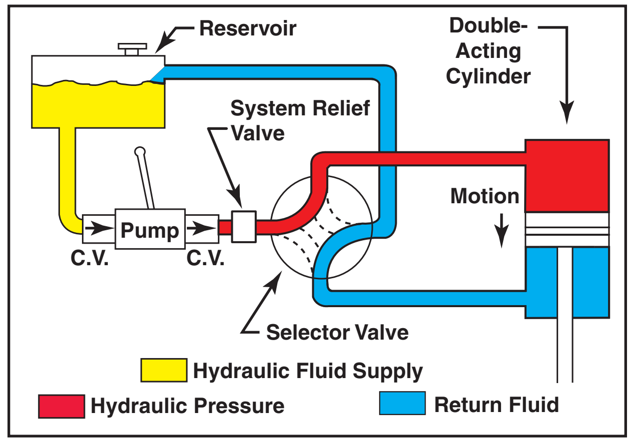


Figure 5-25. Basic hydraulic system.

LANDING GEAR

The landing gear forms the principal support of the airplane on the surface. 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 5-26]

Figure 5-26. The landing gear supports the airplane during the takeoff run, landing, taxiing, and when parked.

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

TRICYCLE LANDING GEAR AIRPLANES

A tricycle gear airplane has three main advantages:

Servo—A motor or other form of actuator which receives a small signal from the control device and exerts a large force to accomplish the desired work.

1. It allows more forceful application of the brakes during landings at high speeds without resulting in the airplane nosing over.

2. It permits better forward visibility for the pilot during takeoff, landing, and taxiing.

3. It tends to prevent ground looping (swerving) by providing more directional stability during ground operation since the airplane's center of gravity (CG) is forward of the main wheels. The forward CG, therefore, tends to keep the airplane moving forward in a straight line rather than ground looping.

Nosewheels are either steerable or castering. Steerable nosewheels are linked to the rudders by cables or rods, while castering nosewheels are free to swivel. In both cases, you steer the airplane using the rudder pedals. However, airplanes with a castering nosewheel may require you to combine the use of the rudder pedals with independent use of the brakes.

TAILWHEEL LANDING GEAR AIRPLANES

On tailwheel airplanes, two main wheels, which are attached to the airframe ahead of its center of gravity, support most of the weight of the structure, while a tailwheel at the very back of the fuselage provides a third point of support. This arrangement allows adequate ground clearance for a larger propeller and is more desirable for operations on unimproved fields. [Figure 5-27]

The main drawback with the tailwheel landing gear is that the center of gravity is behind the main gear. This makes directional control more difficult while on the ground. If you allow the airplane to swerve while rolling on the ground at a speed below that at which the rudder has sufficient control, the center of gravity will attempt to get ahead of the main gear. This may cause the airplane to ground loop.

Figure 5-27. Tailwheel landing gear.

Another disadvantage for tailwheel airplanes is the lack of good forward visibility when the tailwheel is on or near the surface. Because of the associated hazards, specific training is required in tailwheel airplanes.

FIXED AND RETRACTABLE LANDING GEAR

Landing gear can also be classified as either fixed or retractable. A fixed gear always remains extended and has the advantage of simplicity combined with low maintenance. A retractable gear is designed to streamline the airplane by allowing the landing gear to be stowed inside the structure during cruising flight. [Figure 5-28]

BRAKES

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

AUTOPILOT

Autopilots are designed to control the aircraft and help reduce the pilot's workload. The limitations of the autopilot depend on the complexity of the system. The

Figure 5-28. Fixed and retractable gear airplanes.

STANDARD ATMOSPHERIC PRESSURE			
Altitude (ft)	Pressure (p.s.i.)	Altitude (ft)	Pressure (p.s.i.)
Sea Level	14.7	16,000	8.0
2,000	13.7	18,000	7.3
4,000	12.7	20,000	6.8
6,000	11.8	22,000	6.2
8,000	10.9	24,000	5.7
10,000	10.1	26,000	5.2
12,000	9.4	28,000	4.8
14,000	8.6	30,000	4.4

The altitude where the standard air pressure is equal to 10.9 p.s.i can be found at 8,000 feet.

At an altitude of 28,000 feet, standard atmospheric pressure is 4.8 p.s.i. By adding this pressure to the cabin pressure differential of 6.1 p.s.i.d., a total air pressure of 10.9 p.s.i. is obtained.

Figure 5-29. Standard atmospheric pressure chart.

common features available on an autopilot are altitude and heading hold. More advanced systems may include a vertical speed and/or indicated airspeed hold mode. Most autopilot systems are coupled to navigational aids.

An autopilot system consists of servos that actuate the flight controls. The number and location of these servos depends on the complexity of the system. For example, a single-axis autopilot controls the aircraft about the longitudinal axis and a servo actuates the ailerons. A three-axis autopilot controls the aircraft about the longitudinal, lateral, and vertical axes; and three different servos actuate the ailerons, the elevator, and the rudder.

The autopilot system also incorporates a disconnect safety feature to automatically or manually disengage the system. Autopilots can also be manually overridden. Because autopilot systems differ widely in their operation, refer to the autopilot operating instructions in the AFM or POH.

PRESSURIZED AIRPLANES

When an airplane is flown at a high altitude, it consumes less fuel for a given airspeed than it does for the same speed at a lower altitude. In other words, the airplane is more efficient at a high altitude. In addition, bad weather and turbulence may be avoided by flying in the relatively smooth air above the storms. Because of the advantages of flying at high altitudes, many modern general aviation-type airplanes are being designed to operate in that environment. It is important that pilots transitioning to such sophisticated equipment be familiar with at least the basic operating principles.

A cabin pressurization system accomplishes several functions in providing adequate passenger comfort and safety. It maintains a cabin pressure altitude of approximately 8,000 feet at the maximum designed cruising altitude of the airplane, and prevents rapid changes of cabin altitude that may be uncomfortable or cause injury to passengers and crew. In addition, the pressurization system permits a reasonably fast exchange of air from the inside to the outside of the cabin. This is necessary to eliminate odors and to remove stale air. [Figure 5-29]

Pressurization of the airplane cabin is an accepted method of protecting occupants against the effects of hypoxia. Within a pressurized cabin, occupants can be transported comfortably and safely for long periods of time, particularly if the cabin altitude is maintained at 8,000 feet or below, where the use of oxygen equipment is not required. The flight crew in this type of airplane must be aware of the danger of accidental loss of cabin pressure and must be prepared to deal with such an emergency whenever it occurs.

In the typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit that is capable of containing air under a pressure higher than outside atmospheric pressure. On aircraft powered by turbine engines, bleed air from the engine compressor section is used to pressurize the cabin. Superchargers may be used on older model turbine powered airplanes to pump air into the sealed fuselage. Piston-powered airplanes may use air supplied from each engine turbocharger through a sonic venturi (flow limiter). Air is released from the fuselage by a device called an outflow valve. The outflow valve, by regulating the air exit, provides a constant inflow of air to the pressurized area. [Figure 5-30]

To understand the operating principles of pressurization and air-conditioning systems, it is necessary to become familiar with some of the related terms and definitions, such as:

- **Aircraft altitude**—the actual height above sea level at which the airplane is flying.

- **Ambient temperature**—the temperature in the area immediately surrounding the airplane.

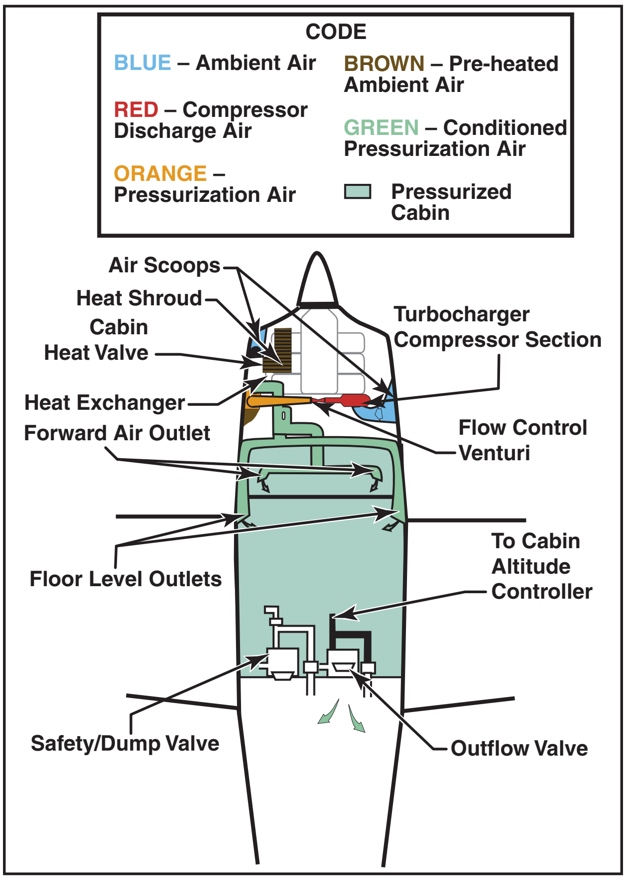


Figure 5-30. High performance airplane pressurization system.

- **Ambient pressure**—the pressure in the area immediately surrounding the airplane.
- **Cabin altitude**—used to express cabin pressure in terms of equivalent altitude above sea level.
- **Differential pressure**—the difference in pressure between the pressure acting on one side of a wall and the pressure acting on the other side of the wall. In aircraft air-conditioning and pressurizing systems, it is the difference between cabin pressure and atmospheric pressure.

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

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

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

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

Several instruments are used in conjunction with the pressurization controller. The cabin differential pressure gauge indicates the difference between inside and outside pressure. This gauge should be monitored to assure that the cabin does not exceed the maximum allowable differential pressure. A cabin altimeter is also provided as a check on the performance of the system. In some cases, these two instruments are combined into one. A third instrument indicates the cabin rate of climb or descent. A cabin rate-of-climb instrument and a cabin altimeter are illustrated in Figure 5-31 on page 5-26.

Decompression is defined as the inability of the airplane's pressurization system to maintain its designed pressure differential. This can be caused by a malfunction in the pressurization system or structural damage to the airplane. Physiologically, decompressions fall into two categories; they are:

- **Explosive Decompression**—Explosive decompression is defined as a change in cabin pressure faster than the lungs can decompress; therefore, it is possible that lung damage may occur. Normally, the time required to release air from the lungs without restrictions, such as masks, is 0.2 seconds. Most authorities consider any decompression that occurs in less than 0.5 seconds as explosive and potentially dangerous.

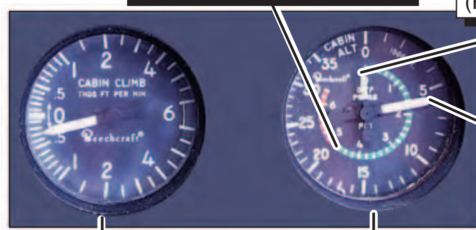


Figure 5-31. Cabin pressurization instruments.

- **Rapid Decompression**—Rapid decompression is defined as a change in cabin pressure where the lungs can decompress faster than the cabin; therefore, there is no likelihood of lung damage.

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

The primary danger of decompression is hypoxia. Unless proper utilization of oxygen equipment is accomplished quickly, unconsciousness may occur in a very short time. The period of useful consciousness is considerably shortened when a person is subjected to a rapid decompression. This is due to the rapid reduction of pressure on the body—oxygen in the lungs is exhaled rapidly. This in effect reduces the partial pressure of oxygen in the blood and therefore reduces the pilot's effective performance time by one-third to one-fourth its normal time. For this reason, the oxygen mask should be worn when flying at very high altitudes (35,000 feet or higher). It is recommended that the crewmembers select the 100 percent oxygen setting on the oxygen regulator at high altitude if the airplane is equipped with a demand or pressure demand oxygen system.

Another hazard is being tossed or blown out of the airplane if near an opening. For this reason, individuals near openings should wear safety harnesses or seatbelts at all times when the airplane is pressurized and they are seated.

Another potential hazard during high altitude decompressions is the possibility of evolved gas decompression sicknesses. Exposure to wind blasts and extremely cold temperatures are other hazards one might have to face.

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

OXYGEN SYSTEMS

Most high altitude airplanes come equipped with some type of fixed oxygen installation. If the airplane does not have a fixed installation, portable oxygen equipment must be readily accessible during flight. The portable equipment usually consists of a container, regulator, mask outlet, and pressure gauge. Aircraft oxygen is usually stored in high pressure system containers of 1,800 – 2,200 pounds per square inch (p.s.i.). When the ambient temperature surrounding an oxygen cylinder decreases, pressure within that cylinder will decrease because pressure varies directly with temperature if the volume of a gas remains constant. If a drop in indicated pressure on a supplemental oxygen cylinder is noted, there is no reason to suspect depletion of the oxygen supply, which has simply been compacted due to storage of the containers in an unheated area of the aircraft. High pressure oxygen containers should be marked with the p.s.i. tolerance (i.e., 1,800 p.s.i.) before filling the container to that pressure. The containers should be supplied with aviation oxygen only, which is 100 percent pure oxygen. Industrial oxygen is not intended for breathing and may contain impurities, and medical oxygen contains water vapor that can freeze in the regulator when exposed to cold temperatures. To assure safety, oxygen system periodic inspection and servicing should be done.

An oxygen system consists of a mask and a regulator that supplies a flow of oxygen dependent upon cabin altitude. Regulators approved for use up to 40,000 feet are designed to provide zero percent cylinder oxygen and 100 percent cabin air at cabin altitudes of 8,000 feet or less, with the ratio changing to 100 percent oxygen and zero percent cabin air at approximately 34,000 feet cabin altitude. Regulators approved up to 45,000 feet are designed to provide 40 percent cylinder oxygen and 60 percent cabin air at lower altitudes, with the ratio changing to 100 percent at the higher altitude. Pilots should avoid flying above 10,000 feet without oxygen during the day and above 8,000 feet at night. [Figure 5-32]

Figure 5-32. Oxygen system regulator.

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

MASKS

There are numerous types of oxygen masks in use that vary in design detail. It would be impractical to discuss all of the types in this handbook. It is important that the masks used be compatible with the particular oxygen system involved. Crew masks are fitted to the user's face with a minimum of leakage. Crew masks usually contain a microphone. Most masks are the oronasal-type, which covers only the mouth and nose.

Passenger masks may be simple, cup-shaped rubber moldings sufficiently flexible to obviate individual fitting. They may have a simple elastic head strap or the passenger may hold them to the face.

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

DILUTER DEMAND OXYGEN SYSTEMS

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

PRESSURE DEMAND OXYGEN SYSTEMS

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

CONTINUOUS FLOW OXYGEN SYSTEM

Continuous flow oxygen systems are usually provided for passengers. The passenger mask typically has a reservoir bag, which collects oxygen from the continuous flow oxygen system during the time when the mask user is exhaling. The oxygen collected in the reservoir bag allows a higher aspiratory flow rate during the inhalation cycle, which reduces the amount of air dilution. Ambient air is added to the supplied oxygen during inhalation after the reservoir bag oxygen supply is depleted. The exhaled air is released to the cabin. [Figure 5-33]

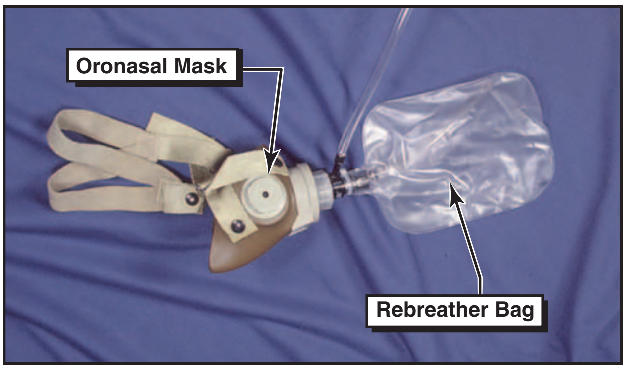


Figure 5-33. Continuous flow mask and rebreather bag.

SERVICING OF OXYGEN SYSTEMS

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

ICE CONTROL SYSTEMS

Ice control systems installed on aircraft consist of anti-ice and de-ice equipment. Anti-icing equipment is designed to prevent the formation of ice, while de-icing equipment is designed to remove ice once it has formed. Ice control systems protect the leading edge of wing and tail surfaces, pitot and static port openings, fuel tank vents, stall warning devices, windshields, and propeller blades. Ice detection lighting may also be installed on some airplanes to determine the extent of structural icing during night flights. Since many airplanes are not certified for flight in icing conditions, refer to the AFM or POH for details.

AIRFOIL ICE CONTROL

Inflatable de-icing boots consist of a rubber sheet bonded to the leading edge of the airfoil. When ice builds up on the leading edge, an engine-driven pneumatic pump inflates the rubber boots. Some turboprop aircraft divert engine bleed air to the wing to inflate the rubber boots. Upon inflation, the ice is cracked and should fall off the leading edge of the wing. De-icing boots are controlled from the cockpit by a switch and can be operated in a single cycle or allowed to cycle at automatic, timed intervals. It is important that de-icing boots are used in accordance with the manufacturer's recommendations. If they are allowed to cycle too often, ice can form over the contour of the boot and render the boots ineffective. [Figure 5-34]

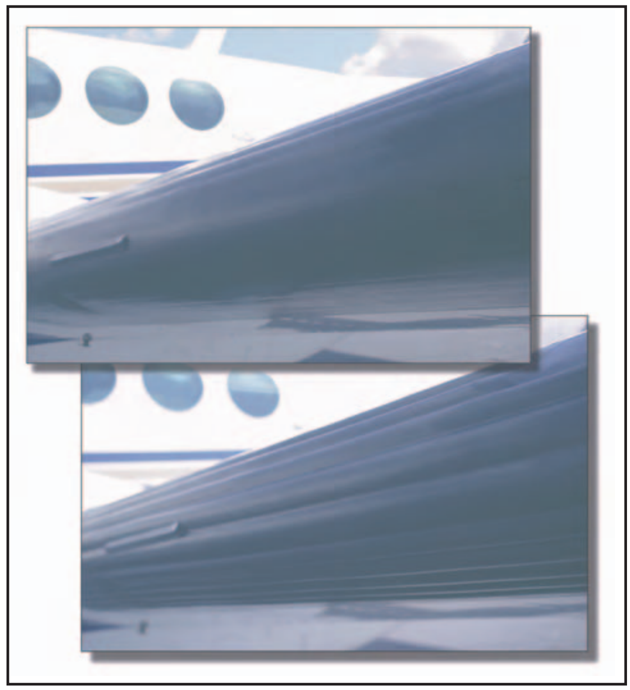


Figure 5-34. De-icing boots on the leading edge of the wing.

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

Proper maintenance and care of de-icing boots is important for continued operation of this system. They need to be carefully inspected prior to a flight.

Another type of leading edge protection is the thermal anti-ice system installed on airplanes with turbine engines. This system is designed to prevent the buildup of ice by directing hot air from the compressor section of the engine to the leading edge surfaces. The system is activated prior to entering icing conditions. The hot air heats the leading edge sufficiently to prevent the formation of ice.

An alternate type of leading edge protection that is not as common as thermal anti-ice and de-icing boots is known as a weeping wing. The weeping-wing design uses small holes located in the leading edge of the wing. A chemical mixture is pumped to the leading edge and weeps out through the holes to prevent the formation and buildup of ice.

WINDSCREEN ICE CONTROL

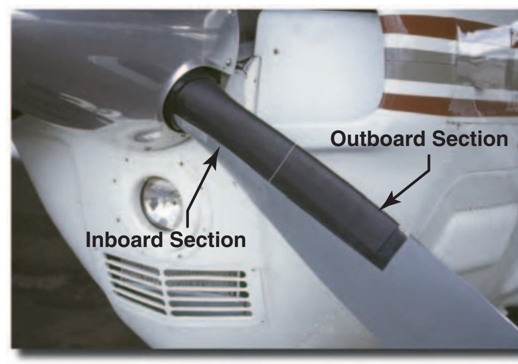
There are two main types of windscreen anti-ice systems. The first system directs a flow of alcohol to the windscreen. By using it early enough, the alcohol will prevent ice from building up on the windshield. The rate of alcohol flow can be controlled by a dial in the cockpit according to procedures recommended by the airplane manufacturer.

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

PROPELLER ICE CONTROL

Propellers are protected from icing by use of alcohol or electrically heated elements. Some propellers are equipped with a discharge nozzle that is pointed toward the root of the blade. Alcohol is discharged from the nozzles, and centrifugal force makes the alcohol flow down the leading edge of the blade. This prevents ice from forming on the leading edge of the propeller. Propellers can also be fitted with propeller anti-ice boots. The propeller boot is divided into two sections—the inboard and the outboard sections. The boots are grooved to help direct the flow of alcohol, and they are also imbedded with electrical wires that carry current for heating the propeller. The prop anti-ice system can be monitored for proper operation by monitoring the prop anti-ice ammeter. During the preflight inspection, check the propeller boots for proper operation. If a boot fails to heat one blade, an unequal blade loading can result, and may cause severe propeller vibration. [Figure 5-35]

PROP ANTI-ICE AMMETER
When the system is operating, the prop ammeter will show in the normal operating range. As each boot section cycles, the ammeter will fluctuate.



PROP ANTI-ICE BOOT
The boot is divided into two sections: inboard and outboard. When the anti-ice is operating, the inboard section heats on each blade, and then cycles to the outboard section. If a boot fails to heat properly on one blade, unequal ice loading may result, causing severe vibration.

Figure 5-35. Prop ammeter and anti-ice boots.

OTHER ICE CONTROL SYSTEMS

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

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

TURBINE ENGINES

The turbine engine produces thrust by increasing the velocity of the air flowing through the engine. It consists of an air inlet, compressor, combustion chambers, turbine section, and exhaust. [Figure 5-36] The turbine engine has the following advantages over a reciprocating engine: less vibration, increased aircraft performance, reliability, and ease of operation.

TYPES OF TURBINE ENGINES

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

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

TURBOJET

The turbojet engine contains four sections: compressor, combustion chamber, turbine section, and exhaust. The compressor section passes inlet air at a high rate of speed to the combustion chamber. The combustion chamber contains the fuel inlet and igniter for combustion. The expanding air drives a turbine, which is connected by a shaft to the compressor, sustaining engine operation. The accelerated exhaust gases from the engine provide thrust. This is a basic application of compressing air, igniting the fuel-air mixture, producing power to self-sustain the engine operation, and exhaust for propulsion.

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

TURBOPROP

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

TURBOFAN

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

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

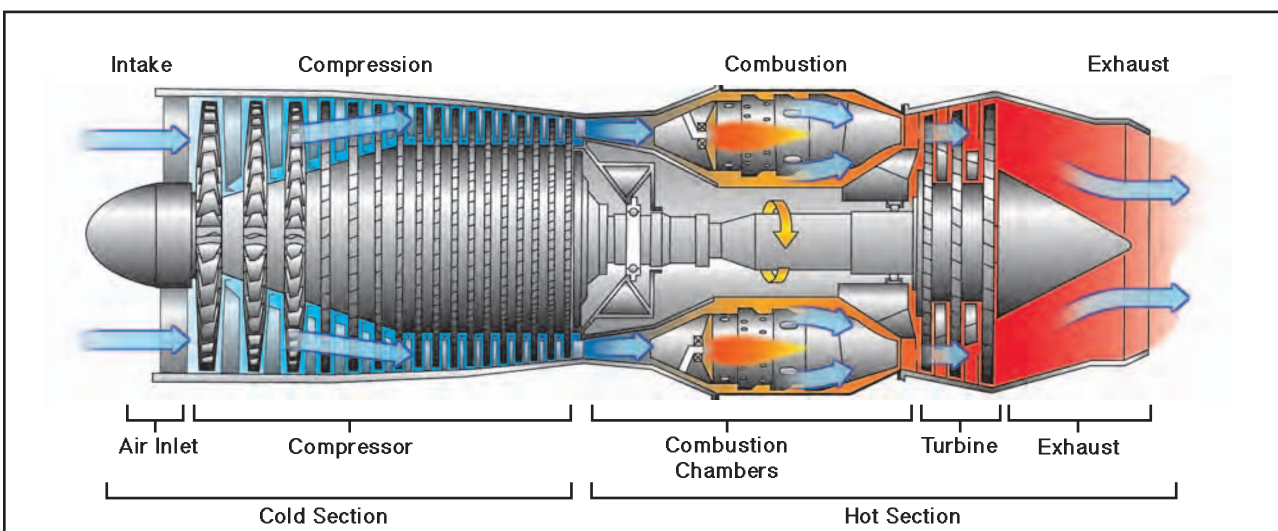


Figure 5-36. Basic components of a turbine engine.

TURBOSHAFT

The fourth common type of jet engine is the turboshaft. It delivers power to a shaft that drives something other than a propeller. The biggest difference between a turbojet and turboshaft engine is that on a turboshaft engine, most of the energy produced by the expanding gases is used to drive a turbine rather than produce thrust. Many helicopters use a turboshaft gas turbine engine. In addition, turboshaft engines are widely used as auxiliary power units on large aircraft.

PERFORMANCE COMPARISON

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

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

Net Thrust— The thrust produced by a turbojet or turbofan engine.

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

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

Figure 5-37 shows how four types of engines compare in net thrust as airspeed is increased. This figure is for explanatory purposes only and is not for specific models of engines. The four types of engines are:

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

The comparison is made by plotting the performance curve for each engine, which shows how maximum aircraft speed varies with the type of engine used. Since the graph is only a means of comparison, numerical values for net thrust, aircraft speed, and drag are not included.

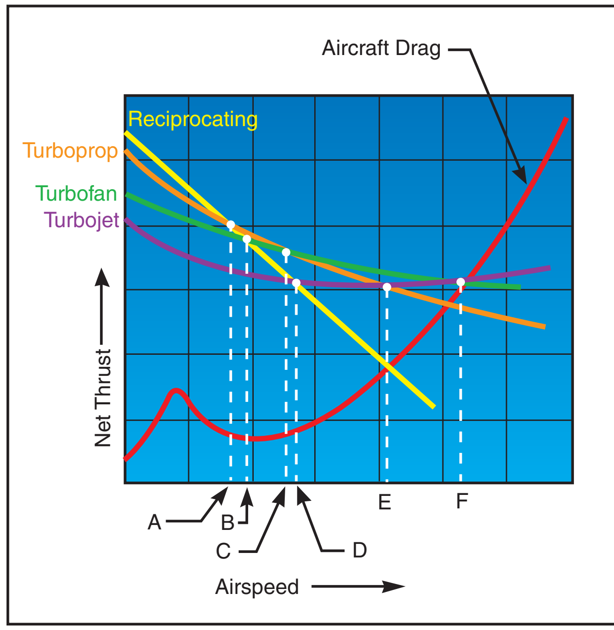


Figure 5-37. Engine net thrust versus aircraft speed and drag.

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

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

TURBINE ENGINE INSTRUMENTS

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

ENGINE PRESSURE RATIO

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

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

EXHAUST GAS TEMPERATURE

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

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

TORQUEMETER

Turboprop/turboshaft engine power output is measured by the torquemeter. Torque is a twisting force applied to a shaft. The torquemeter measures power applied to the shaft. Turboprop and turboshaft engines are designed to produce torque for driving a propeller. Torquemeters are calibrated in percentage units, foot-pounds, or pounds per square inch.

N_1 INDICATOR

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

N_2 INDICATOR

N_2 represents the rotational speed of the high pressure compressor and is presented on the indicator as a percentage of design r.p.m. The high pressure compressor is governed by the N_2 turbine wheel. The N_2 turbine wheel is connected to the high pressure compressor through a concentric shaft. [Figure 5-38]

Concentric Shaft—One shaft inside another shaft having a common core.

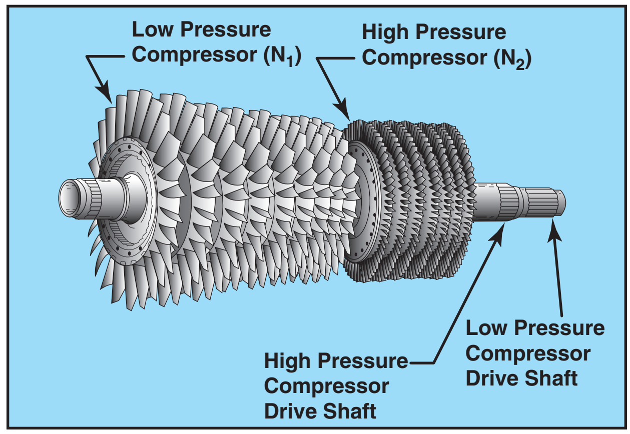


Figure 5-38. Dual-spool axial-flow compressor.

TURBINE ENGINE OPERATIONAL CONSIDERATIONS

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

ENGINE TEMPERATURE LIMITATIONS

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

THRUST VARIATIONS

Turbine engine thrust varies directly with air density. As air density decreases, so does thrust. While both turbine and reciprocating powered engines are affected to some degree by high relative humidity, turbine engines will experience a negligible loss of thrust, while reciprocating engines a significant loss of brake horsepower.

FOREIGN OBJECT DAMAGE

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

Prevention of FOD is a high priority. Some engine inlets have a tendency to form a vortex between the ground and the inlet during ground operations. A vortex dissipater may be installed on these engines.

Other devices, such as screens and/or deflectors, may also be utilized. Preflight procedures include a visual inspection for any sign of FOD.

TURBINE ENGINE HOT/HUNG START

A hot start is when the EGT exceeds the safe limit. Hot starts are caused by too much fuel entering the combustion chamber, or insufficient turbine r.p.m. Any time an engine has a hot start, refer to the AFM, POH, or an appropriate maintenance manual for inspection requirements.

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

COMPRESSOR STALLS

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

A compressor stall can be described as an imbalance between the two vector quantities, inlet velocity and compressor rotational speed. Compressor stalls occur when the compressor blades' angle of attack exceeds the critical angle of attack. At this point, smooth airflow is interrupted and turbulence is created with pressure fluctuations. Compressor stalls cause air flowing in the compressor to slow down and stagnate, sometimes reversing direction. [Figure 5-39]

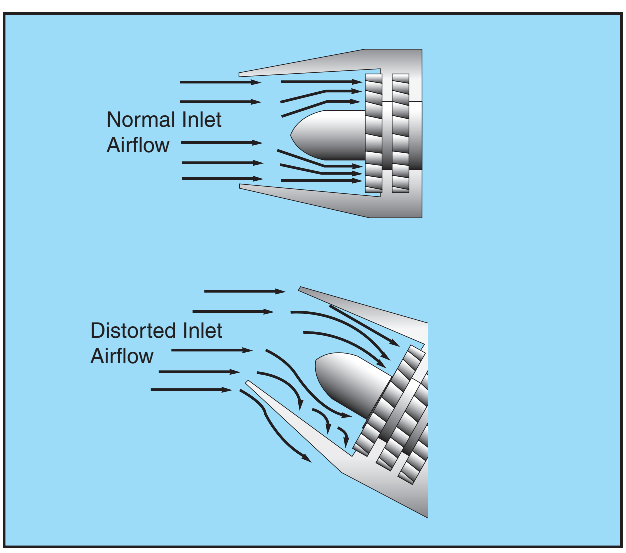


Figure 5-39. Comparison of normal and distorted airflow into the compressor section.

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

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

FLAMEOUT

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

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

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

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