

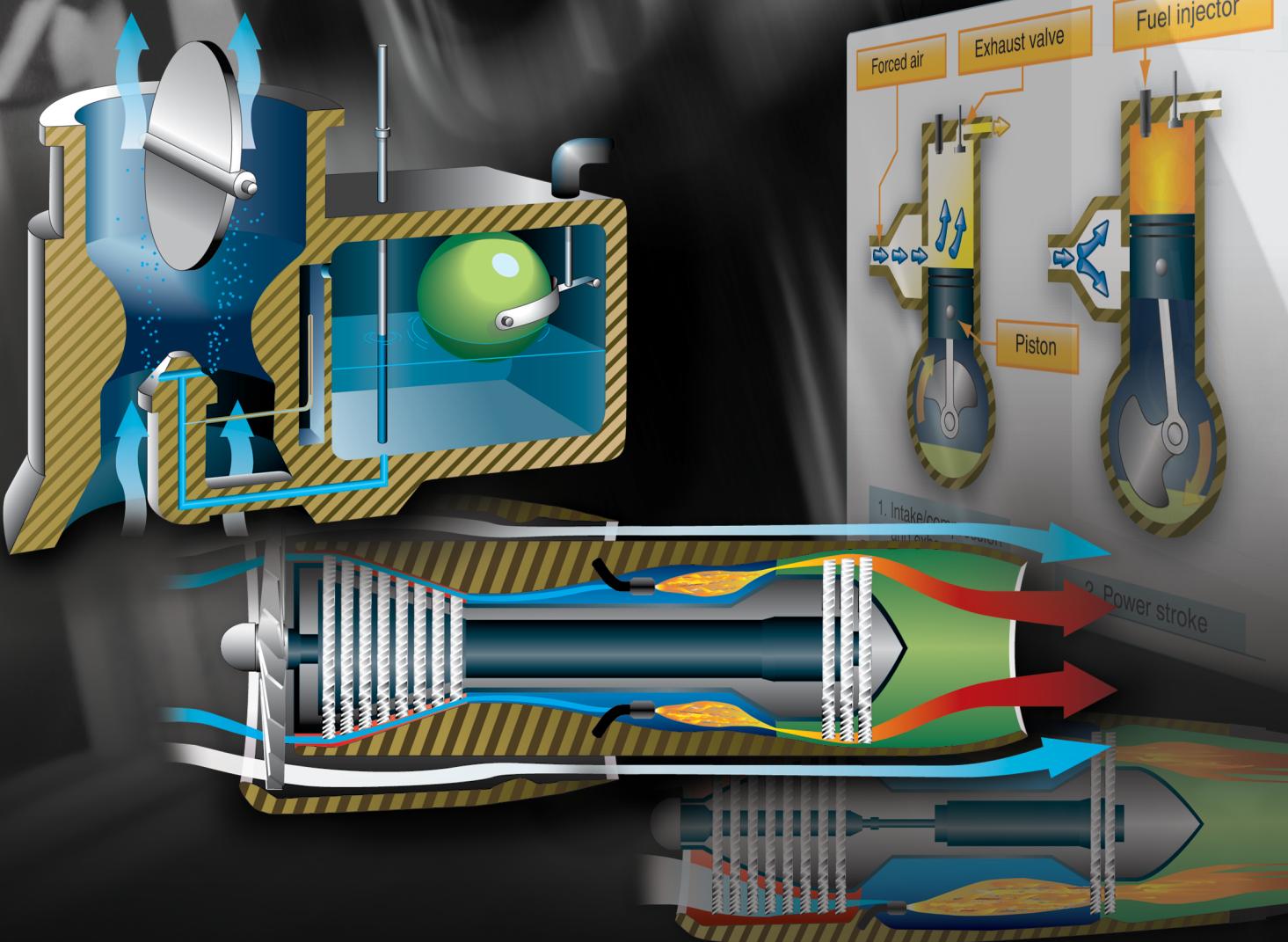
# Aircraft Systems

## Introduction

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

## Powerplant

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



## Reciprocating Engines

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

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

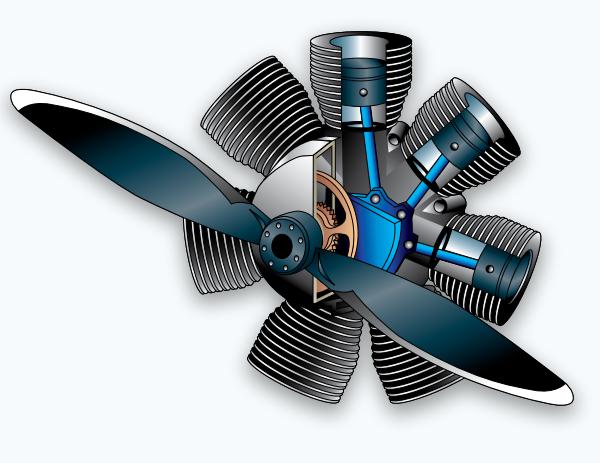
Reciprocating engines operate on the basic principle of converting chemical energy (fuel) into mechanical energy. This conversion occurs within the cylinders of the engine through the process of combustion. The two primary reciprocating engine designs are the spark ignition and the compression ignition.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

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

These two engine designs can be further classified as:

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

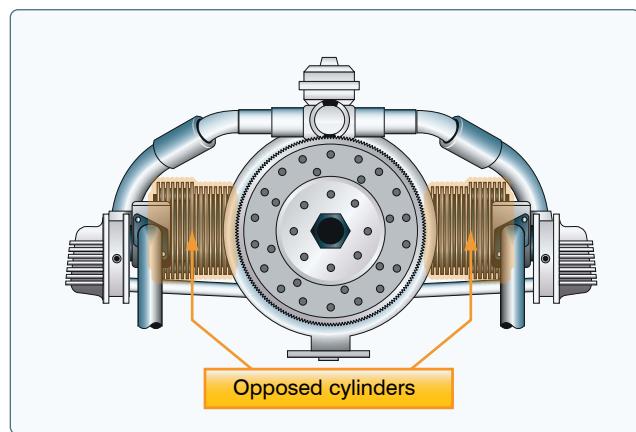
Radial engines were widely used during World War II and many are still in service today. With these engines, a row or rows of cylinders are arranged in a circular pattern around the crankcase. The main advantage of a radial engine is the favorable power-to-weight ratio. [Figure 7-1]



**Figure 7-1.** Radial engine.

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

Continued improvements in engine design led to the development of the horizontally-opposed engine, which remains the most popular reciprocating engines used on smaller aircraft. These engines always have an even number of cylinders, since a cylinder on one side of the crankcase “opposes” a cylinder on the other side. [Figure 7-2] The majority of these engines are air cooled and usually are mounted in a horizontal position when installed on fixed-wing airplanes. Opposed-type engines have high power-to-weight ratios because they have a comparatively small, lightweight crankcase. In addition, the compact cylinder arrangement reduces the engine’s frontal area and allows a streamlined installation that minimizes aerodynamic drag.



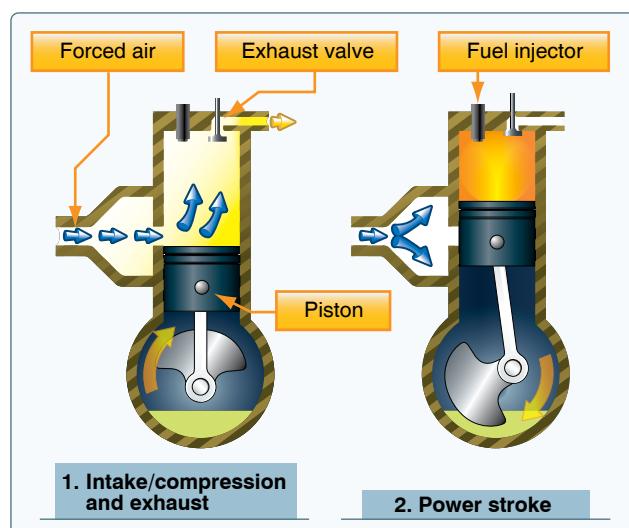
**Figure 7-2.** Horizontally opposed engine.

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

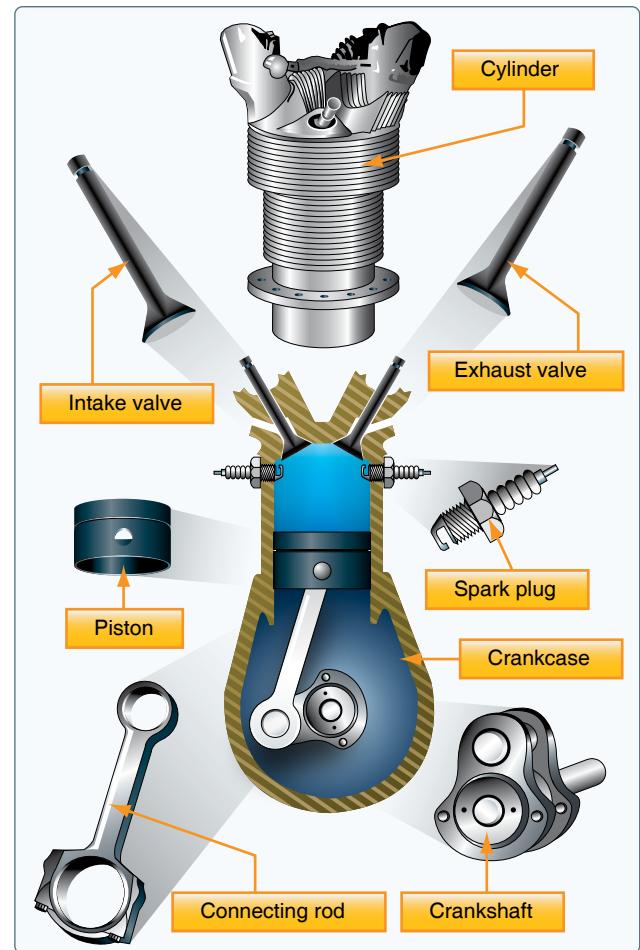
In a two-stroke engine, the conversion of chemical energy into mechanical energy occurs over a two-stroke operating cycle. The intake, compression, power, and exhaust processes occur in only two strokes of the piston rather than the more common four strokes. Because a two-stroke engine has a power stroke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

Recent advances in material and engine design have reduced many of the negative characteristics associated with two-stroke engines. Modern two-stroke engines often use conventional oil sumps, oil pumps, and full pressure fed lubrication systems. The use of direct fuel injection and pressurized air, characteristic of advanced compression ignition engines, make two-stroke compression ignition engines a viable alternative to the more common four-stroke spark ignition designs. [Figure 7-3]

Spark ignition four-stroke engines remain the most common design used in GA today. [Figure 7-4] The main parts of a spark ignition reciprocating engine include the cylinders, crankcase, and accessory housing. The intake/exhaust valves, spark plugs, and pistons are located in the cylinders. The crankshaft and connecting rods are located in the crankcase. The magnetos are normally located on the engine accessory housing.



**Figure 7-3.** Two-stroke compression ignition.



**Figure 7-4.** Main components of a spark ignition reciprocating engine.

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

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

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

Even when the engine is operated at a fairly low speed, the four-stroke cycle takes place several hundred times each minute. [Figure 7-5] In a four-cylinder engine, each cylinder operates on a different stroke. Continuous rotation of a crankshaft is maintained by the precise timing of the power strokes in each cylinder. Continuous operation of the engine depends on the simultaneous function of auxiliary systems, including the induction, ignition, fuel, oil, cooling, and exhaust systems.

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

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

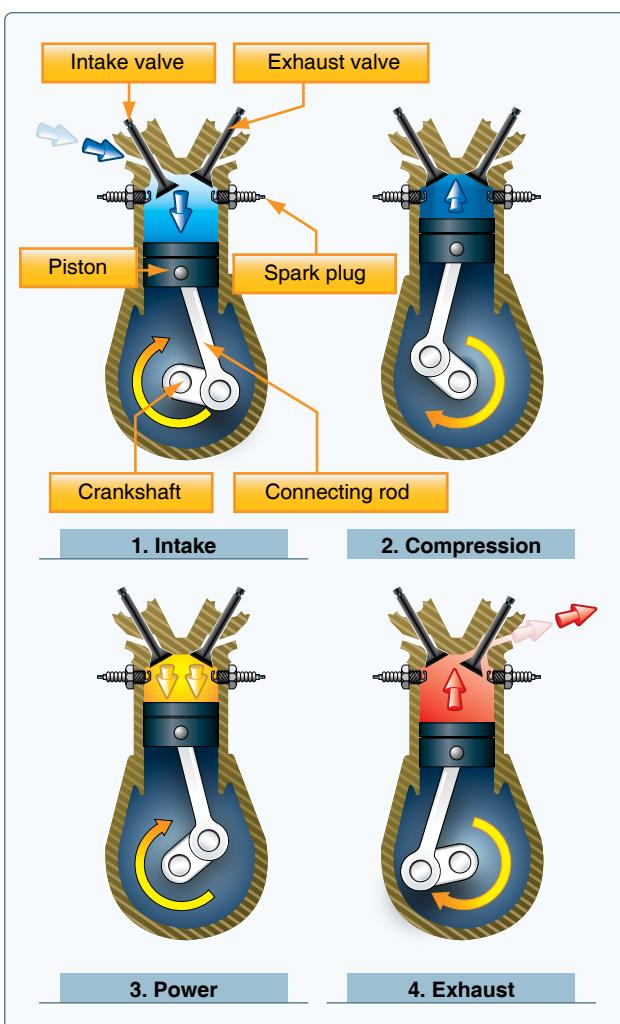
In 1999, Thielert formed Thielert Aircraft Engines (TAE) to design, develop, certify, and manufacture a brand-new Jet-A-burning diesel cycle engine (also known as jet-fueled piston engine) for the GA industry. By March 2001, the first prototype engine became the first certified diesel engine since World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

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

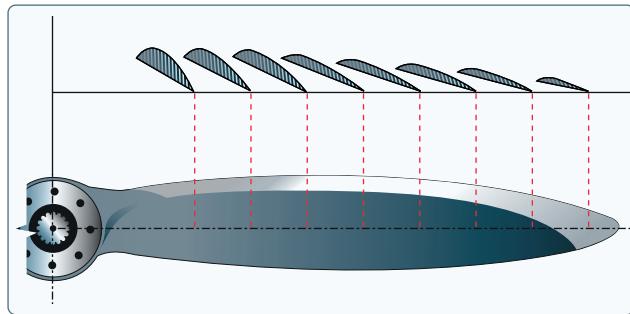
### Propeller

The propeller is a rotating airfoil, subject to induced drag, stalls, and other aerodynamic principles that apply to any airfoil. It provides the necessary thrust to pull, or in some cases push, the aircraft through the air. The engine power is used to rotate the propeller, which in turn generates thrust very similar to the manner in which a wing produces lift. The amount of thrust produced depends on the shape of the airfoil, the angle of attack (AOA) of the propeller blade, and the revolutions per minute (rpm) of the engine. The propeller itself is twisted so the blade angle changes from hub to tip. The greatest angle of incidence, or the highest pitch, is at the hub while the smallest angle of incidence or smallest pitch is at the tip. [Figure 7-6]

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



**Figure 7-5.** The arrows in this illustration indicate the direction of motion of the crankshaft and piston during the four-stroke cycle.



**Figure 7-6.** Changes in propeller blade angle from hub to tip.

throughout its entire length would be inefficient because as airspeed increases in flight, the portion near the hub would have a negative AOA while the blade tip would be stalled. Small aircraft are equipped with either one of two types of propellers: fixed-pitch or adjustable-pitch.

### Fixed-Pitch Propeller

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

There are two types of fixed-pitch propellers: climb and cruise. Whether the airplane has a climb or cruise propeller

installed depends upon its intended use. The climb propeller has a lower pitch, therefore less drag. Less drag results in higher rpm and more horsepower capability, which increases performance during takeoffs and climbs but decreases performance during cruising flight.

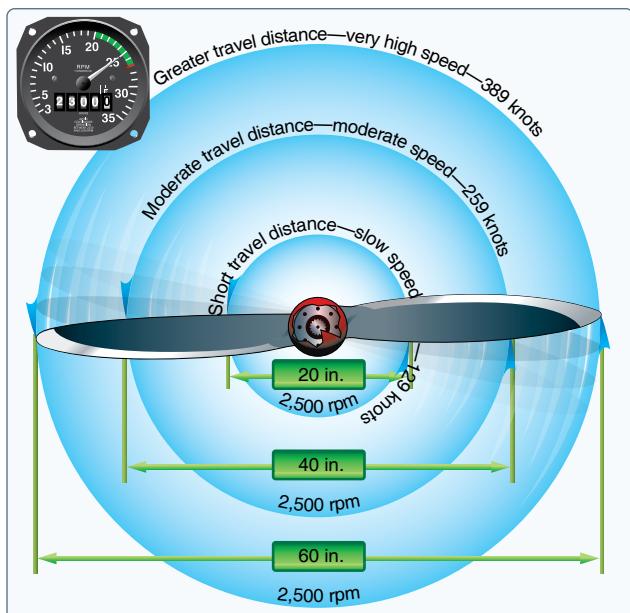
The cruise propeller has a higher pitch, therefore more drag. More drag results in lower rpm and less horsepower capability, which decreases performance during takeoffs and climbs but increases efficiency during cruising flight.

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

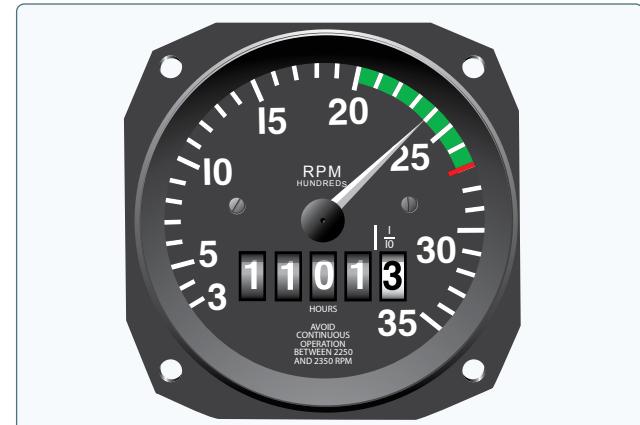
In a fixed-pitch propeller, the tachometer is the indicator of engine power. [Figure 7-8] A tachometer is calibrated in hundreds of rpm and gives a direct indication of the engine and propeller rpm. The instrument is color coded with a green arc denoting the maximum continuous operating rpm. Some tachometers have additional markings to reflect engine and/or propeller limitations. The manufacturer's recommendations should be used as a reference to clarify any misunderstanding of tachometer markings.

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

When operating altitude increases, the tachometer may not show correct power output of the engine. For example, 2,300 rpm at 5,000 feet produces less horsepower than 2,300 rpm at sea level because power output depends on air density. Air density decreases as altitude increases and a decrease in air



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



**Figure 7-8.** Engine rpm is indicated on the tachometer.

density (higher density altitude) decreases the power output of the engine. As altitude changes, the position of the throttle must be changed to maintain the same rpm. As altitude is increased, the throttle must be opened further to indicate the same rpm as at a lower altitude.

### **Adjustable-Pitch Propeller**

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

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

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

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

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

The propeller's constant-speed range, defined by the high and low pitch stops, is the range of possible blade angles for a constant-speed propeller. As long as the propeller blade angle is within the constant-speed range and not against either pitch stop, a constant engine rpm is maintained. If the propeller blades contact a pitch stop, the engine rpm

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

On aircraft equipped with a constant-speed propeller, power output is controlled by the throttle and indicated by a manifold pressure gauge. The gauge measures the absolute pressure of the fuel-air mixture inside the intake manifold and is more correctly a measure of manifold absolute pressure (MAP). At a constant rpm and altitude, the amount of power produced is directly related to the fuel-air mixture being delivered to the combustion chamber. As the throttle setting is increased, more fuel and air flows to the engine and MAP increases. When the engine is not running, the manifold pressure gauge indicates ambient air pressure (i.e., 29.92 inches mercury (29.92 "Hg)). When the engine is started, the manifold pressure indication decreases to a value less than ambient pressure (i.e., idle at 12 "Hg). Engine failure or power loss is indicated on the manifold gauge as an increase in manifold pressure to a value corresponding to the ambient air pressure at the altitude where the failure occurred. [Figure 7-9]

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.



**Figure 7-9.** Engine power output is indicated on the manifold pressure gauge.

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

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

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

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

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

### ***Propeller Overspeed in Piston Engine Aircraft***

On March 17, 2010, the Federal Aviation Administration (FAA) issued Special Airworthiness Information Bulletin (SAIB) CE-10-21. The subject was Propellers/Propulsors; Propeller Overspeed in Piston Engine Aircraft to alert operators, pilots, and aircraft manufacturers of concerns for an optimum response to a propeller overspeed in piston engine aircraft with variable pitch propellers. Although a SAIB is not regulatory in nature, the FAA recommends that the information be read and taken into consideration for the safety of flight.

The document explains that a single-engine aircraft experienced a propeller overspeed during cruise flight at 7,000 feet. The pilot reported that the application of throttle resulted in a propeller overspeed with no appreciable thrust. The pilot attempted to glide to a nearby airport and established the "best glide" speed of 110 knots, as published in the Pilot's

Operating Handbook (POH), but was unable to reach the airport and was forced to conduct an off-field landing.

It was further explained that a determination was made that the propeller experienced a failure causing the blade pitch change mechanism to move to the low pitch stop position. This caused the propeller to operate as a fixed-pitch propeller such that it changes rpm with changes in power and airspeed. The low pitch setting allows for maximum power during takeoff but can result in a propeller overspeed at a higher airspeed.

A performance evaluation of the flight condition was performed for the particular aircraft model involved in this incident. This evaluation indicated that an airspeed lower than the best glide speed would have resulted in increased thrust enabling the pilot to maintain level flight. There are numerous variables in aircraft, engines, and propellers that affect aircraft performance. For some aircraft models, the published best glide speed may not be low enough to generate adequate thrust for a given propeller installation in this situation (propeller blades at low pitch stop position).

The operators of aircraft with variable pitch propellers should be aware that in certain instances of propeller overspeed, the airspeed necessary to maintain level flight may be different than the speed associated with engine-out best glide speed. The appropriate emergency procedures should be followed to mitigate the emergency situation in the event of a propeller overspeed; however, pilots should be aware that some reduction in airspeed may result in the ability for continued safe flight and landing. The determination of an airspeed that is more suitable than engine-out best glide speed should only be conducted at a safe altitude when the pilot has time to determine an alternative course of action other than landing immediately.

### ***Induction Systems***

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

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

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

## Carburetor Systems

Aircraft carburetors are separated into two categories: float-type carburetors and pressure-type carburetors. Float-type carburetors, complete with idling, accelerating, mixture control, idle cutoff, and power enrichment systems, are the most common of the two carburetor types. Pressure-type carburetors are usually not found on small aircraft. The basic difference between a float-type and a pressure-type carburetor is the delivery of fuel. The pressure-type carburetor delivers fuel under pressure by a fuel pump.

In the operation of the float-type carburetor system, the outside air first flows through an air filter, usually located at an air intake in the front part of the engine cowling. This filtered air flows into the carburetor and through a venturi, a narrow throat in the carburetor. When the air flows through the venturi, a low-pressure area is created that forces the

fuel to flow through a main fuel jet located at the throat. The fuel then flows into the airstream where it is mixed with the flowing air. [Figure 7-10]

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

The float-type carburetor has several distinct disadvantages. First, they do not function well during abrupt maneuvers. Secondly, the discharge of fuel at low pressure leads to incomplete vaporization and difficulty in discharging fuel into some types of supercharged systems. The chief disadvantage of the float-type carburetor, however, is its icing tendency. Since the float-type carburetor must discharge

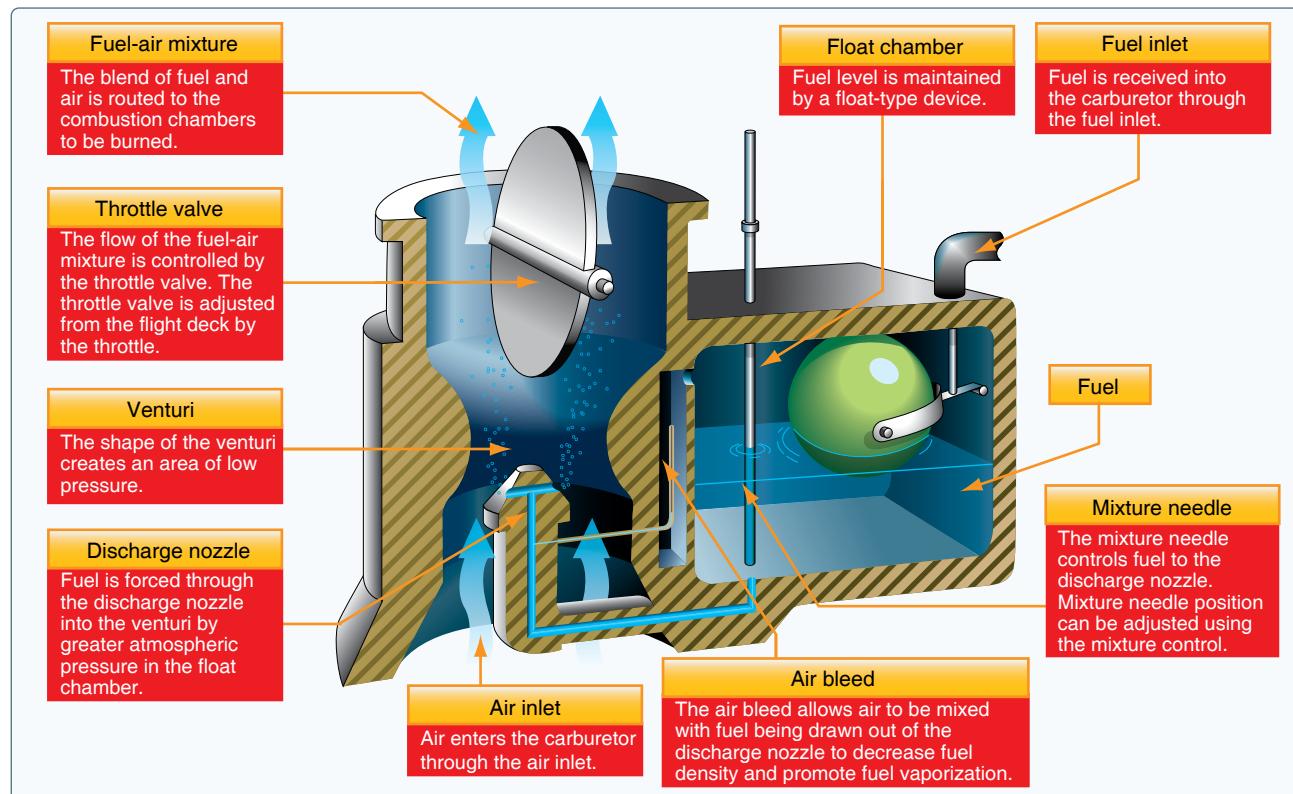


Figure 7-10. Float-type carburetor.

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

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

### Mixture Control

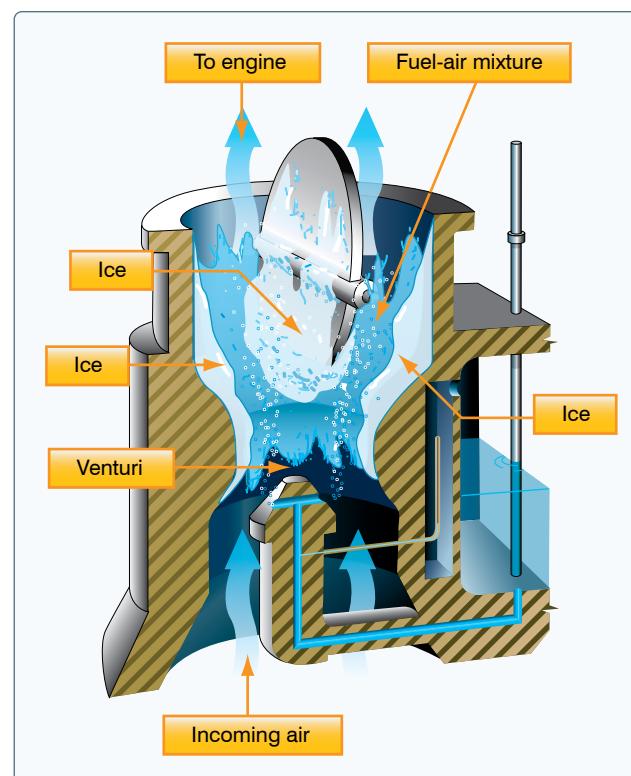
Carburetors are normally calibrated at sea-level air pressure where the correct fuel-air mixture ratio is established with the mixture control set in the FULL RICH position. However, as altitude increases, the density of air entering the carburetor decreases, while the density of the fuel remains the same. This creates a progressively richer mixture that can result in engine roughness and an appreciable loss of power. The roughness normally is due to spark plug fouling from excessive carbon buildup on the plugs. Carbon buildup occurs because the rich mixture lowers the temperature inside the cylinder, inhibiting complete combustion of the fuel. This condition may occur during the runup prior to takeoff at high-elevation airports and during climbs or cruise flight at high altitudes. To maintain the correct fuel-air mixture, the mixture must be leaned using the mixture control. Leaning the mixture decreases fuel flow, which compensates for the decreased air density at high altitude.

During a descent from high altitude, the fuel-air 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/or a loss of power. The best way to maintain the proper fuel-air mixture is to monitor the engine temperature and enrich the mixture as needed. Proper mixture control and better fuel economy for fuel-injected engines can be achieved by using an exhaust gas temperature (EGT) gauge. Since the process of adjusting the mixture can vary from one aircraft to another, it is important to refer to the airplane flight manual (AFM) or the POH to determine the specific procedures for a given aircraft.

### Carburetor Icing

As mentioned earlier, one disadvantage of the float-type carburetor is its icing tendency. Carburetor ice occurs due to the effect of fuel vaporization and the decrease in air pressure in the venturi, which causes a sharp temperature drop in the carburetor. If water vapor in the air condenses when the carburetor temperature is at or below freezing, ice may form on internal surfaces of the carburetor, including the throttle valve. [Figure 7-11]

The reduced air pressure, as well as the vaporization of fuel, contributes to the temperature decrease in the carburetor. Ice generally forms in the vicinity of the throttle valve and in the venturi throat. This restricts the flow of the fuel-air mixture and reduces power. If enough ice builds up, the engine may cease to operate. Carburetor ice is most likely to occur when temperatures are below 70 degrees Fahrenheit ( $^{\circ}\text{F}$ ) or 21 degrees Celsius ( $^{\circ}\text{C}$ ) and the relative humidity is above 80 percent. Due to the sudden cooling that takes place in the carburetor, icing can occur even in outside air temperatures as high as 100  $^{\circ}\text{F}$  ( $38^{\circ}\text{C}$ ) and humidity as low as 50 percent. This temperature drop can be as much as 60 to 70 absolute (versus relative) Fahrenheit degrees ( $70 \times 100/180 = 38.89$



**Figure 7-11.** The formation of carburetor ice may reduce or block fuel-air flow to the engine.

Celsius degrees) (Remember there are 180 Fahrenheit degrees from freezing to boiling versus 100 degrees for the Celsius scale.) Therefore, an outside air temperature of 100 F (38 C), a temperature drop of an absolute 70 F degrees (38.89 Celsius degrees) results in an air temperature in the carburetor of 30 F (-1 C). [Figure 7-12]

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

### **Carburetor Heat**

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

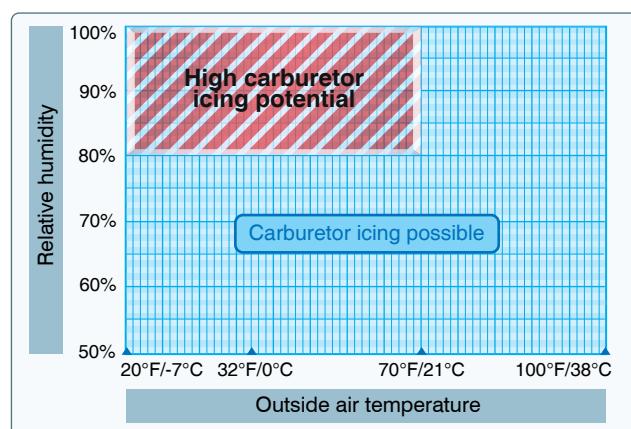
When conditions are conducive to carburetor icing during flight, periodic checks should be made to detect its

presence. If detected, full carburetor heat should be applied immediately, and it should be left in the ON position until the pilot is certain 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. If installed, a carburetor temperature gauge is useful in determining when to use carburetor heat.

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

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

It is imperative for a pilot to recognize carburetor ice when it forms during flight to prevent a loss in power, altitude, and/or airspeed. 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 further reduce power and may cause 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.



**Figure 7-12.** Although carburetor ice is most likely to form when the temperature and humidity are in ranges indicated by this chart, carburetor icing is possible under conditions not depicted.

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

### Carburetor Air Temperature Gauge

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

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

### Outside Air Temperature Gauge

Most aircraft are also equipped with an outside air temperature (OAT) gauge calibrated in both degrees

Celsius and Fahrenheit. It provides the outside or ambient air temperature for calculating true airspeed and is useful in detecting potential icing conditions.

### Fuel Injection Systems

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

A fuel injection system usually incorporates six basic components: an engine-driven fuel pump, a fuel-air control unit, a fuel manifold (fuel distributor), discharge nozzles, an auxiliary fuel pump, and fuel pressure/flow indicators. [Figure 7-13]

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

This control unit, which essentially replaces the carburetor, meters fuel based on the mixture control setting and sends it to the fuel manifold valve at a rate controlled by the throttle.

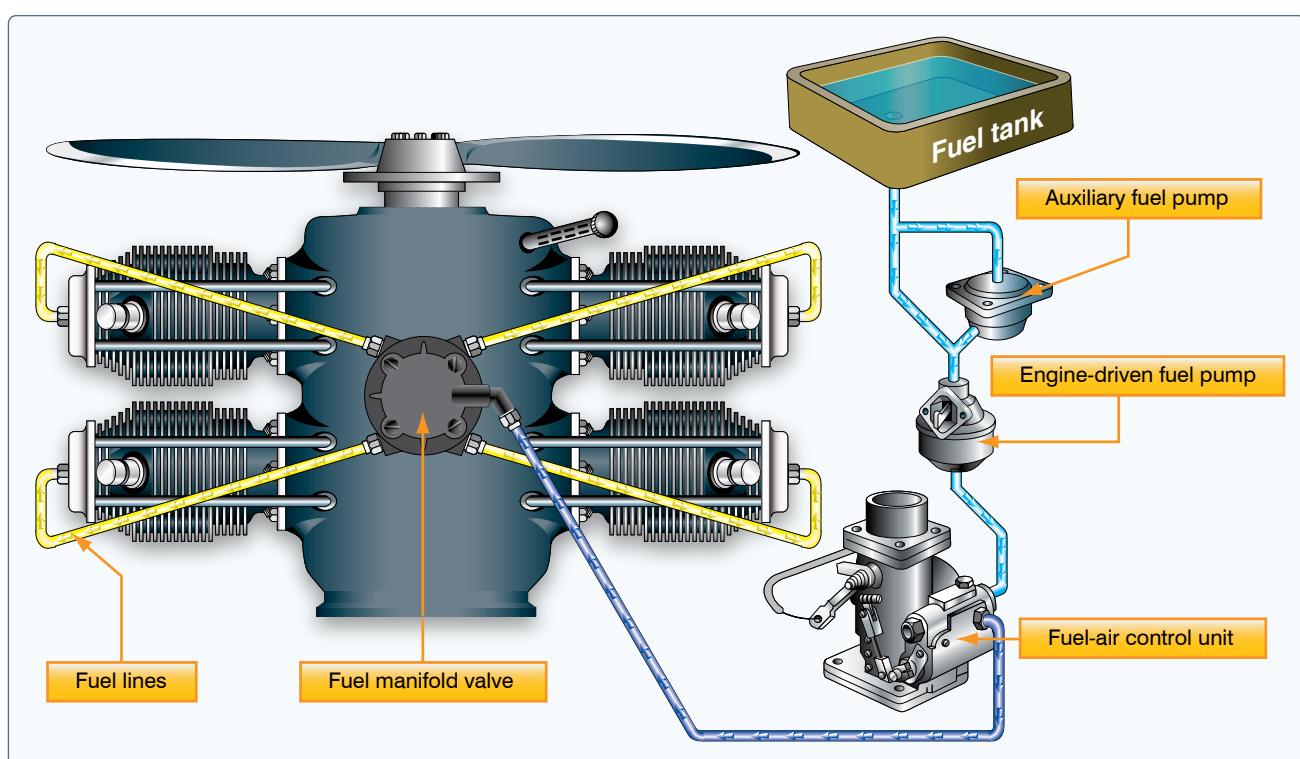


Figure 7-13. Fuel injection system.

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.

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

The following are advantages of using fuel injection:

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

The following are disadvantages of using fuel injection:

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

## Superchargers and Turbosuperchargers

To increase an engine's horsepower, manufacturers have developed forced induction systems called supercharger and turbosupercharger systems. They both compress the intake air to increase its density. The key difference lies in the power supply. A supercharger relies on an engine-driven air pump or compressor, while a turbocharger gets its power from the exhaust stream that runs through a turbine, which in turn spins the compressor. Aircraft with these systems have a manifold pressure gauge, which displays MAP within the engine's intake manifold.

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

As a normally aspirated aircraft climbs, it eventually reaches an altitude where the MAP is insufficient for a normal climb. This altitude limit is known as the aircraft's service ceiling, and it is directly affected by the engine's ability to produce power. If the induction air entering the engine is pressurized,

or boosted, by either a supercharger or a turbosupercharger, the aircraft's service ceiling can be increased. With these systems, an aircraft can fly at higher altitudes with the advantage of higher true airspeeds and the increased ability to circumnavigate adverse weather.

### Superchargers

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

For example, at 8,000 feet, a typical engine may be able to produce 75 percent of the power it could produce at mean sea level (MSL) because the air is less dense at the higher altitude. The supercharger compresses the air to a higher density allowing a supercharged engine to produce the same manifold pressure at higher altitudes as it could produce at sea level. Thus, an engine at 8,000 feet MSL could still produce 25 "Hg of manifold pressure whereas, without a supercharger, it could only produce 22 "Hg. Superchargers are especially valuable at high altitudes (such as 18,000 feet) where the air density is 50 percent that of sea level. The use of a supercharger in many cases will supply air to the engine at the same density it did at sea level.

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

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

Single-stage, single-speed superchargers are found on many high-powered radial engines and use an air intake that faces forward so the induction system can take full advantage of

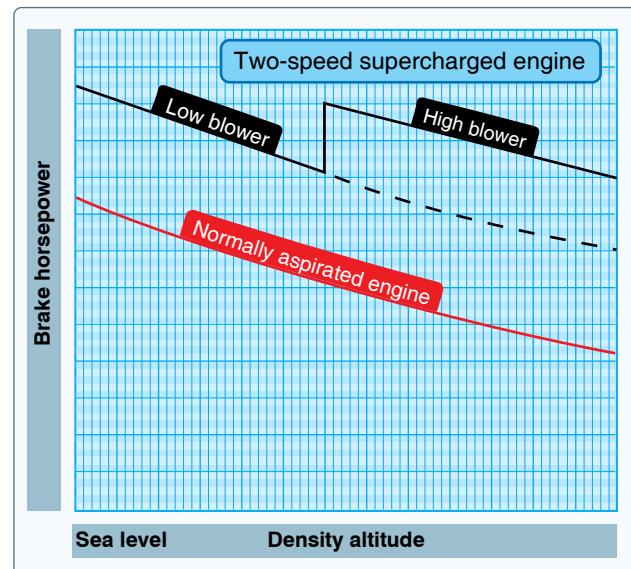
the ram air. Intake air passes through ducts to a carburetor, where fuel is metered in proportion to the airflow. The fuel-air charge is then ducted to the supercharger, or blower impeller, which accelerates the fuel-air mixture outward. Once accelerated, the fuel-air mixture passes through a diffuser, where air velocity is traded for pressure energy. After compression, the resulting high pressure fuel-air mixture is directed to the cylinders.

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

Under normal operations, takeoff is made with the supercharger in the low blower position. In this mode, the engine performs as a ground-boosted engine, and the power output decreases as the aircraft gains altitude. However, once the aircraft reaches a specified altitude, a power reduction is made, and the supercharger control is switched to the high blower position. The throttle is then reset to the desired manifold pressure. An engine equipped with this type of supercharger is called an altitude engine. [Figure 7-14]

### Turbosuperchargers

The most efficient method of increasing horsepower in an engine is by using a turbosupercharger or turbocharger.



**Figure 7-14.** Power output of normally aspirated engine compared to a single-stage, two-speed supercharged engine.

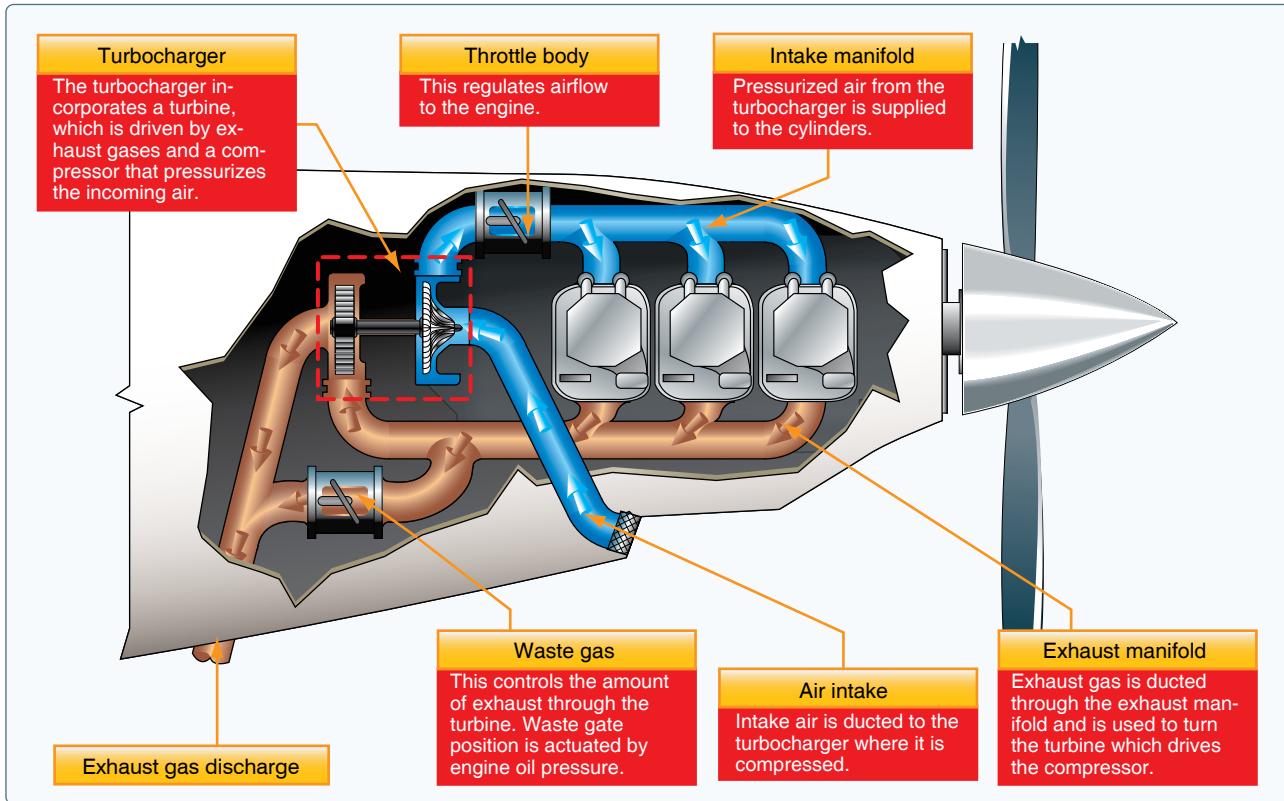
Installed on an engine, this booster uses the engine's exhaust gases to drive an air compressor to increase the pressure of the air going into the engine through the carburetor or fuel injection system to boost power at higher altitude.

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

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

Turbochargers increase the pressure of the engine's induction air, which allows the engine to develop sea level or greater horsepower at higher altitudes. A turbocharger is comprised of two main elements: a compressor and turbine. The compressor section houses an impeller that turns at a high rate of speed. As induction air is drawn across the impeller blades, the impeller accelerates the air, allowing a large volume of air to be drawn into the compressor housing. The impeller's action subsequently produces high-pressure, high-density air that is delivered to the engine. To turn the impeller, the engine's exhaust gases are used to drive a turbine wheel that is mounted on the opposite end of the impeller's drive shaft. By directing different amounts of exhaust gases to flow over the turbine, more energy can be extracted, causing the impeller to deliver more compressed air to the engine. The waste gate, essentially an adjustable butterfly valve installed in the exhaust system, is used to vary the mass of exhaust gas flowing into the turbine. When closed, most of the exhaust gases from the engine are forced to flow through the turbine. When open, the exhaust gases are allowed to bypass the turbine by flowing directly out through the engine's exhaust pipe. [Figure 7-15]

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



**Figure 7-15.** Turbocharger components.

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

Although an automatic waste gate system is less likely to experience an overboost condition, it can still occur. If takeoff power is applied while the engine oil temperature is below its normal operating range, the cold oil may not flow out of the

waste gate actuator quickly enough to prevent an overboost. To help prevent overboosting, advance the throttle cautiously to prevent exceeding the maximum manifold pressure limits.

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

### High Altitude Performance

As an aircraft equipped with a turbocharging system climbs, the waste gate is gradually closed to maintain the maximum allowable manifold pressure. At some point, the waste gate is fully closed and further increases in altitude cause the manifold pressure to decrease. This is the critical altitude,

which is established by the aircraft or engine manufacturer. When evaluating the performance of the turbocharging system, be aware that if the manifold pressure begins decreasing before the specified critical altitude, the engine and turbocharging system should be inspected by a qualified aviation maintenance technician (AMT) to verify that the system is operating properly.

## Ignition System

In a spark ignition engine, the ignition system provides a spark that ignites the fuel-air mixture in the cylinders and is made up of magnetos, spark plugs, high-tension leads, and an ignition switch. [Figure 7-16]

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

Most standard certificated aircraft incorporate a dual ignition system with two individual magnetos, separate sets of wires, and spark plugs to increase reliability of the ignition system. Each magneto operates independently to fire one of the two spark plugs in each cylinder. The firing of two spark plugs improves combustion of the fuel-air mixture and results in a

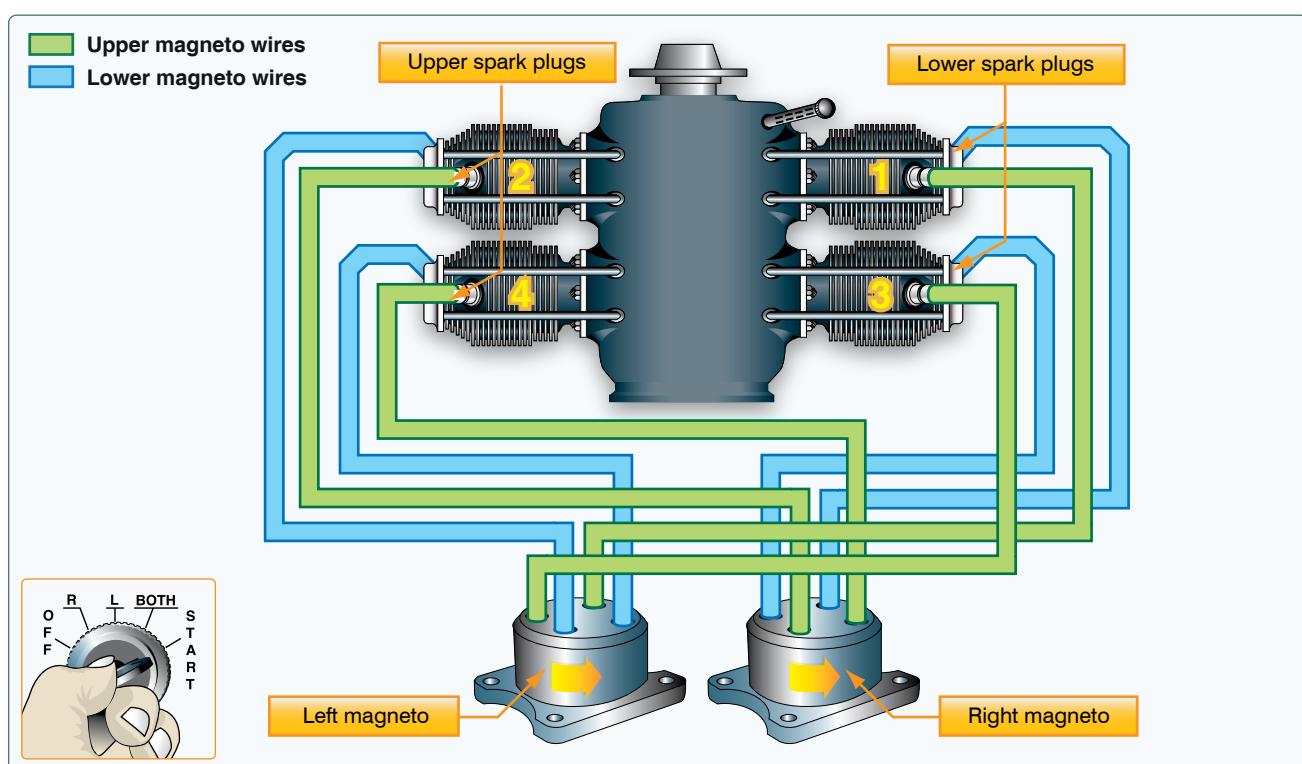
slightly higher power output. If one of the magnetos fails, the other is unaffected. The engine continues to operate normally, although a slight decrease in engine power can be expected. The same is true if one of the two spark plugs in a cylinder fails.

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

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

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

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



**Figure 7-16.** Ignition system components.

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 rpm is not normal, and in that instance, the aircraft should not be flown.

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

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

## Oil Systems

The engine oil system performs several important functions:

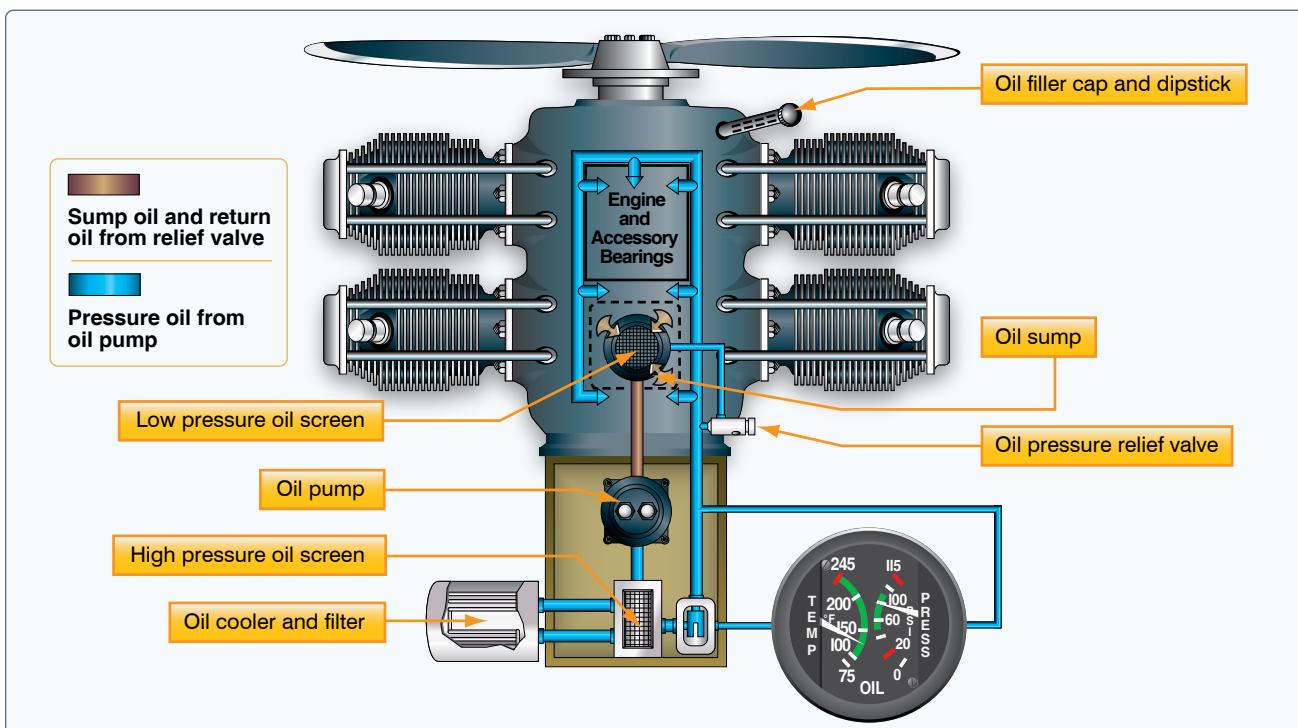
- Lubrication of the engine’s moving parts
- Cooling of the engine by reducing friction
- Removing heat from the cylinders
- Providing a seal between the cylinder walls and pistons
- Carrying away contaminants

Reciprocating engines use either a wet-sump or a dry-sump oil system. In a wet-sump system, the oil is located in a sump that is an integral part of the engine. In a dry-sump system, the oil is contained in a separate tank and circulated through the engine by pumps. [Figure 7-17]

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

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

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



**Figure 7-17.** Wet-sump oil system.

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

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

The oil filler cap and dipstick (for measuring the oil quantity) are usually accessible through a panel in the engine cowling. If the quantity does not meet the manufacturer's recommended operating levels, oil should be added. The AFM/POH or placards near the access panel provide information about the correct oil type and weight, as well as the minimum and maximum oil quantity. [Figure 7-18]

## Engine Cooling Systems

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

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



**Figure 7-18.** Always check the engine oil level during the preflight inspection.

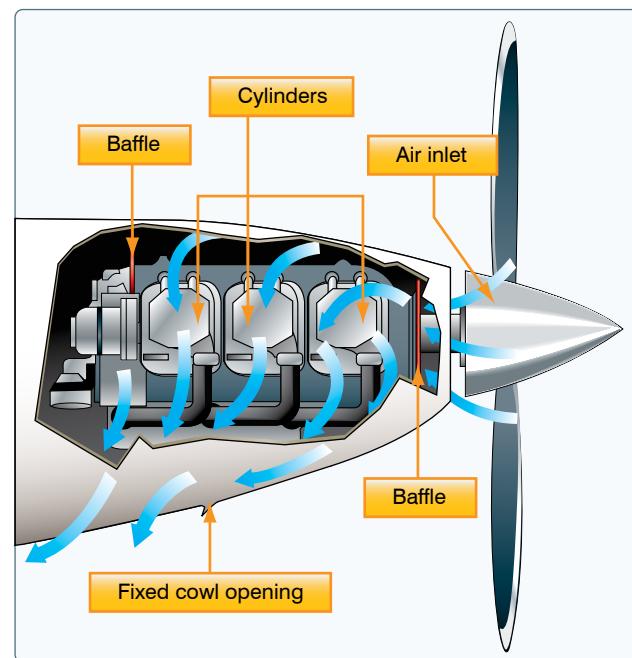
Air cooling is accomplished by air flowing into the engine compartment through openings in front of the engine cowling. Baffles route this air over fins attached to the engine cylinders, and other parts of the engine, where the air absorbs the engine heat. Expulsion of the hot air takes place through one or more openings in the lower, aft portion of the engine cowling. [Figure 7-19]

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

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

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

Under normal operating conditions in aircraft not equipped with cowl flaps, the engine temperature can be controlled



**Figure 7-19.** Outside air aids in cooling the engine.

by changing the airspeed or the power output of the engine. High engine temperatures can be decreased by increasing the airspeed and/or reducing the power.

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

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

## Exhaust Systems

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

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

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

Some exhaust systems have an EGT probe. This probe transmits the EGT to an instrument in the flight deck. The EGT gauge measures the temperature of the gases at the exhaust manifold. This temperature varies with the ratio of fuel to air entering the cylinders and can be used as a basis for regulating the fuel-air mixture. The EGT gauge is highly accurate in indicating the correct fuel-air 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 fuel-air mixture.

## Starting System

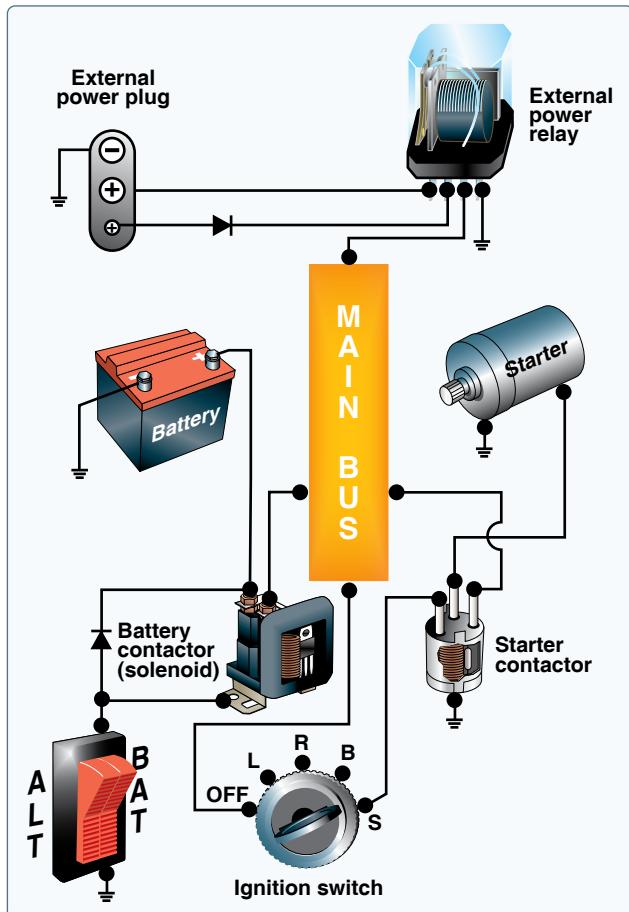
Most small aircraft use a direct-cranking electric starter system. This system consists of a source of electricity, wiring, switches, and solenoids to operate the starter and a starter motor. Most aircraft have starters that automatically engage and disengage when operated, but some older aircraft have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

Electrical power for starting is usually supplied by an onboard battery, but can also be supplied by external power through an external power receptacle. When the battery switch is turned on, electricity is supplied to the main power bus bar through the battery solenoid. Both the starter and the starter switch draw current from the main bus bar, but the starter will not operate until the starting solenoid is energized by the starter switch being turned to the "start" position. When the starter switch is released from the "start" position, the solenoid removes power from the starter motor. The starter motor is protected from being driven by the engine through a clutch in the starter drive that allows the engine to run faster than the starter motor. [Figure 7-20]

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

## Combustion

During normal combustion, the fuel-air mixture burns in a very controlled and predictable manner. In a spark ignition engine, the process occurs in a fraction of a second. The mixture actually begins to burn at the point where it is ignited

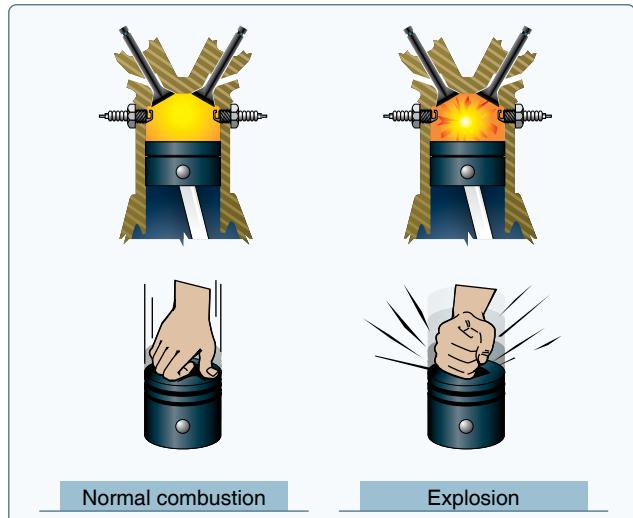


**Figure 7-20.** Typical starting circuit.

by the spark plugs. It then burns away from the plugs until it is completely consumed. This type of combustion causes a smooth build-up of temperature and pressure and ensures that the expanding gases deliver the maximum force to the piston at exactly the right time in the power stroke. [Figure 7-21] Detonation is an uncontrolled, explosive ignition of the fuel-air mixture within the cylinder's combustion chamber. It causes excessive temperatures and pressures which, if not corrected, can quickly lead to failure of the piston, cylinder, or valves. In less severe cases, detonation causes engine overheating, roughness, or loss of power.

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

- Use of a lower fuel grade than that specified by the aircraft manufacturer
- Operation of the engine with extremely high manifold pressures in conjunction with low rpm
- Operation of the engine at high power settings with an excessively lean mixture



**Figure 7-21.** Normal combustion and explosive combustion.

- Maintaining extended ground operations or steep climbs in which cylinder cooling is reduced

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

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

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

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

## Full Authority Digital Engine Control (FADEC)

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

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

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

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

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

## Turbine Engines

An aircraft turbine engine consists of an air inlet, compressor, combustion chambers, a turbine section, and exhaust. Thrust is produced by increasing the velocity of the air flowing through the engine. Turbine engines are highly desirable aircraft powerplants. They are characterized by smooth operation and a high power-to-weight ratio, and they use readily available jet fuel. Prior to recent advances in material, engine design, and manufacturing processes, the use of turbine engines in small/light production aircraft was cost prohibitive. Today, several aviation manufacturers are producing or plan to produce small/light turbine-powered aircraft. These smaller turbine-powered aircraft typically seat between three and seven passengers and are referred to as very light jets (VLJs) or microjets. [Figure 7-22]

### Types of Turbine Engines

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

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

### Turbojet

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



Figure 7-22. Eclipse 500 VLJ.

the combustion chamber. The combustion chamber contains the fuel inlet and igniter for combustion. The expanding air drives a turbine, which is connected by a shaft to the compressor, sustaining engine operation. The accelerated exhaust gases from the engine provide thrust. This is a basic application of compressing air, igniting the fuel-air mixture, producing power to self-sustain the engine operation, and exhaust for propulsion. [Figure 7-23]

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

### Turboprop

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

of the turboprop engine is normally available in the altitude range of 25,000 feet to the tropopause. [Figure 7-24]

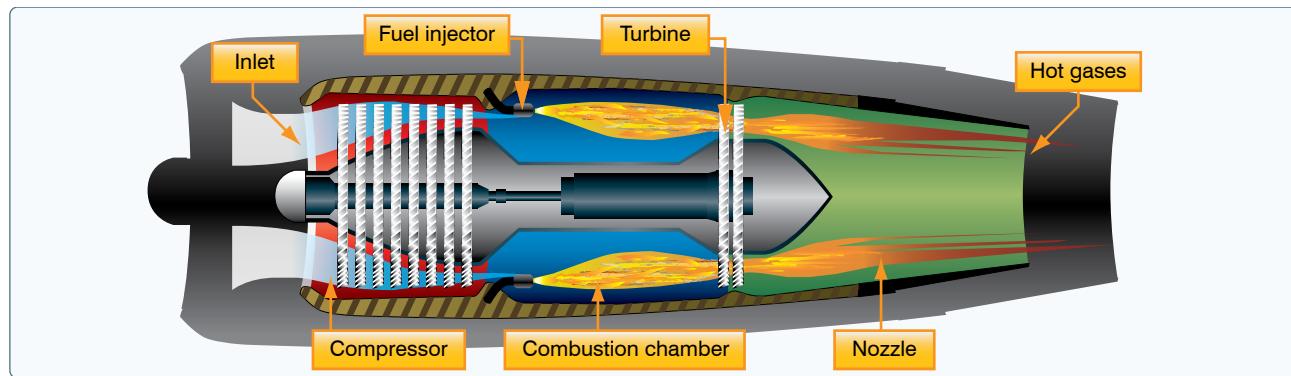
### Turbofan

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

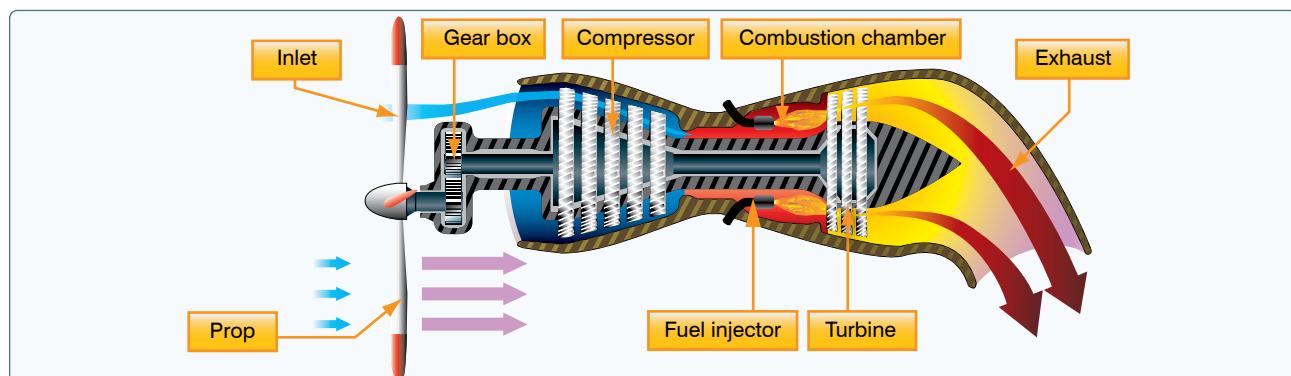
The inlet air that passes through a turbofan engine is usually divided into two separate streams of air. One stream passes through the engine core, while a second stream bypasses the engine core. It is this bypass stream of air that is responsible for the term "bypass engine." A turbofan's bypass ratio refers to the ratio of the mass airflow that passes through the fan divided by the mass airflow that passes through the engine core. [Figure 7-25]

### Turboshaft

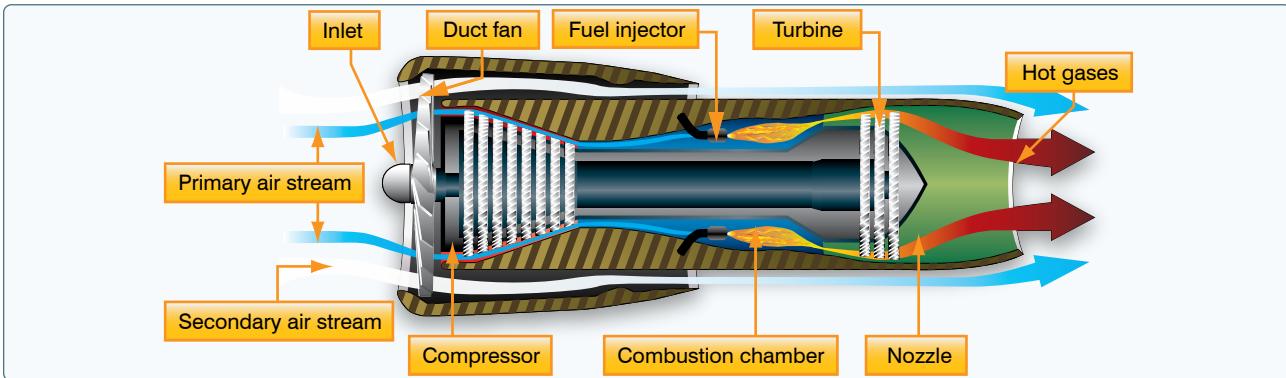
The fourth common type of jet engine is the turboshaft. [Figure 7-26] It delivers power to a shaft that drives something other than a propeller. The biggest difference between a turbojet and turboshaft engine is that on a



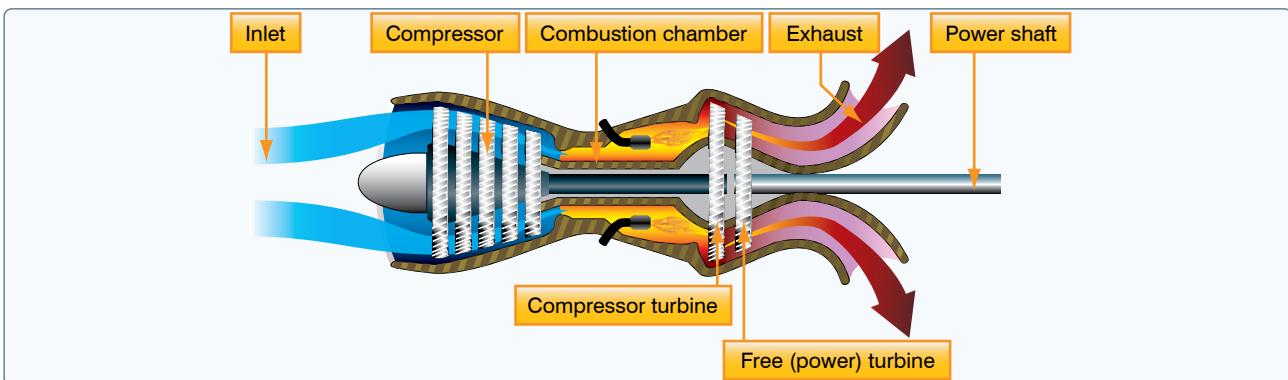
**Figure 7-23.** Turbojet engine.



**Figure 7-24.** Turboprop engine.



**Figure 7-25.** Turbofan engine.



**Figure 7-26.** Turboshaft engine.

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

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

### Turbine Engine Instruments

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

### Exhaust Gas Temperature (EGT)

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

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

### Torquemeter

Turboprop/turboshaft engine power output is measured by the torquemeter. Torque is a twisting force applied to a shaft. The torquemeter measures power applied to the shaft.

Turboprop and turboshaft engines are designed to produce torque for driving a propeller. Torquemeters are calibrated in percentage units, foot-pounds, or psi.

### ***N<sub>1</sub> Indicator***

N<sub>1</sub> represents the rotational speed of the low pressure compressor and is presented on the indicator as a percentage of design rpm. After start, the speed of the low pressure compressor is governed by the N<sub>1</sub> turbine wheel. The N<sub>1</sub> turbine wheel is connected to the low pressure compressor through a concentric shaft.

### ***N<sub>2</sub> Indicator***

N<sub>2</sub> represents the rotational speed of the high pressure compressor and is presented on the indicator as a percentage of design rpm. The high pressure compressor is governed by the N<sub>2</sub> turbine wheel. The N<sub>2</sub> turbine wheel is connected to the high pressure compressor through a concentric shaft. [Figure 7-27]

## **Turbine Engine Operational Considerations**

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

### ***Engine Temperature Limitations***

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

### ***Thrust Variations***

Turbine engine thrust varies directly with air density. As air density decreases, so does thrust. Additionally, because air density decreases with an increase in temperature, increased

temperatures also results in decreased thrust. While both turbine and reciprocating powered engines are affected to some degree by high relative humidity, turbine engines will experience a negligible loss of thrust, while reciprocating engines a significant loss of brake horsepower.

### ***Foreign Object Damage (FOD)***

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

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

### ***Turbine Engine Hot/Hung Start***

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

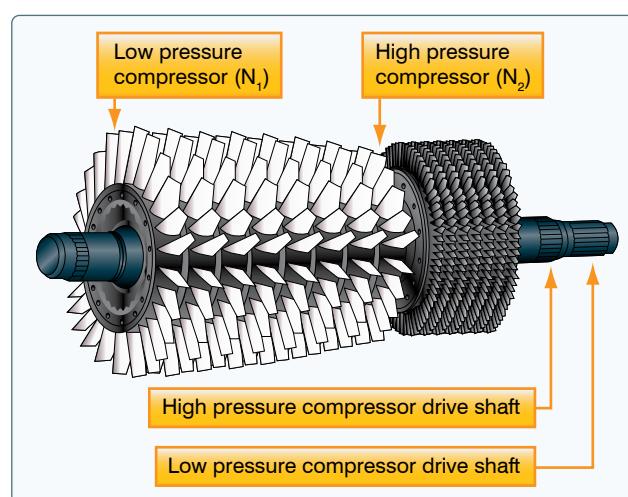
If the engine fails to accelerate to the proper speed after ignition or does not accelerate to idle rpm, a hung or false start has occurred. A hung start may be caused by an insufficient starting power source or fuel control malfunction.

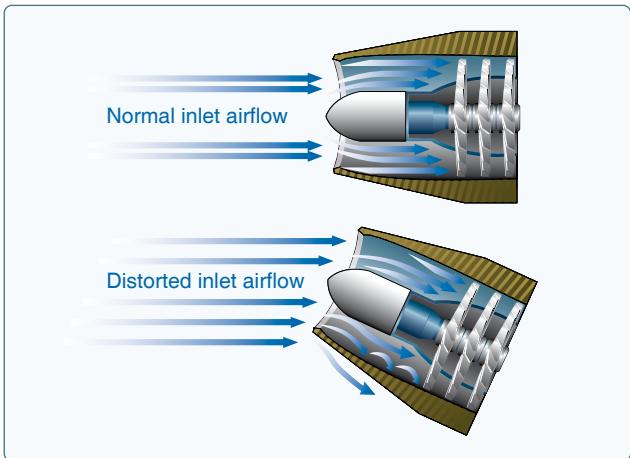
### ***Compressor Stalls***

Compressor blades are small airfoils and are subject to the same aerodynamic principles that apply to any airfoil. A compressor blade has an AOA that 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 AOA to the approaching inlet air.

A compressor stall is an imbalance between the two vector quantities, inlet velocity, and compressor rotational speed. Compressor stalls occur when the compressor blades' AOA exceeds the critical AOA. 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 7-28]

**Figure 7-27. Dual-spool axial-flow compressor.**





**Figure 7-28.** Comparison of normal and distorted airflow into the compressor section.

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

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

### Flameout

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

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

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

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

### Performance Comparison

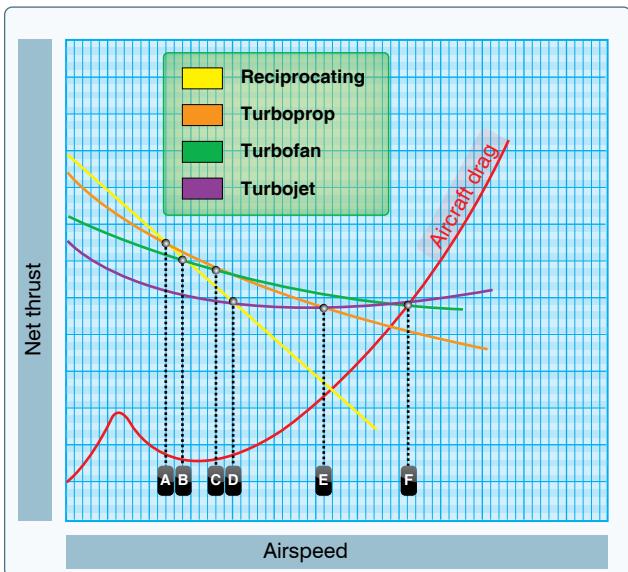
It is possible to compare the performance of a reciprocating powerplant and different types of turbine engines. For the comparison to be accurate, thrust horsepower (usable horsepower) for the reciprocating powerplant must be used rather than brake horsepower, and net thrust must be used for the turbine-powered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

When comparing performance, the following definitions are useful:

- Brake horsepower (BHP)—the horsepower actually delivered to the output shaft. Brake horsepower is the actual usable horsepower.
- Net thrust—the thrust produced by a turbojet or turbofan engine.
- Thrust horsepower (THP)—the horsepower equivalent of the thrust produced by a turbojet or turbofan engine.

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

*Figure 7-29 shows how four types of engines compare in net thrust as airspeed is increased. This figure is for explanatory*



**Figure 7-29.** Engine net thrust versus aircraft speed and drag. Points A through F are explained in the text below.

purposes only and is not for specific models of engines. The following are the four types of engines:

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

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

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

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

maximum speed than aircraft equipped with a turboprop or reciprocating powerplant.

## Airframe Systems

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

## Fuel Systems

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

### Gravity-Feed System

The gravity-feed system utilizes the force of gravity to transfer the fuel from the tanks to the engine. For example, on high-wing airplanes, the fuel tanks are installed in the wings. This places the fuel tanks above the carburetor, and the fuel is gravity fed through the system and into the carburetor. If the design of the aircraft is such that gravity cannot be used to transfer fuel, fuel pumps are installed. For example, on low-wing airplanes, the fuel tanks in the wings are located below the carburetor. [Figure 7-30]

### Fuel-Pump System

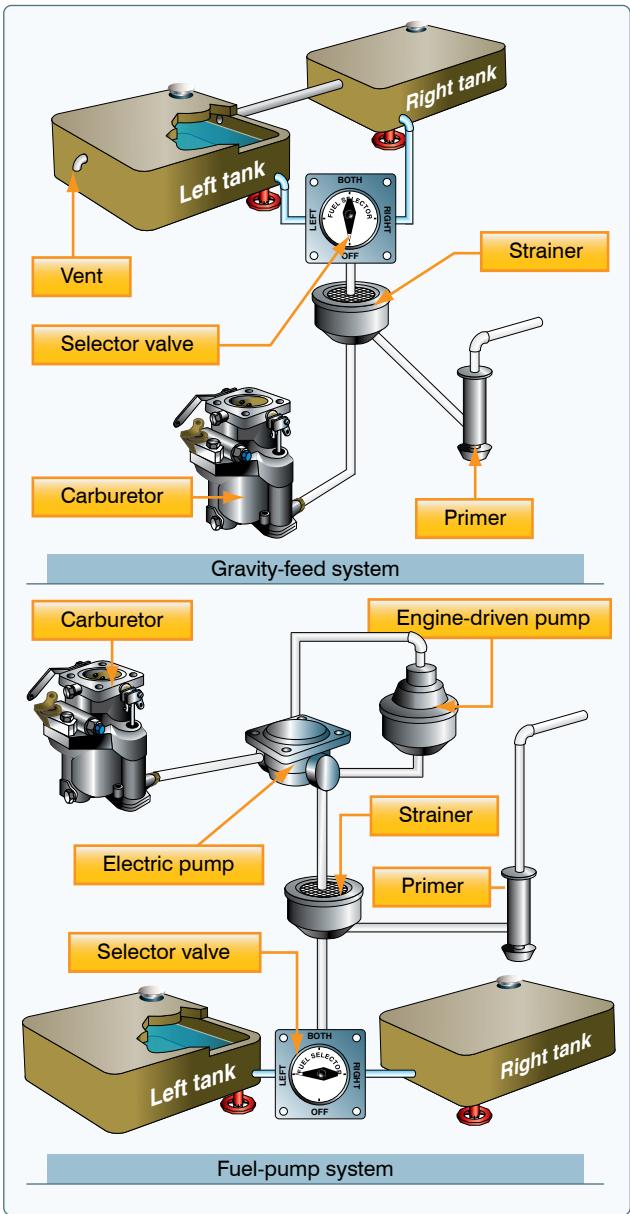
Aircraft with fuel-pump systems have two fuel pumps. The main pump system is engine driven with an electrically-driven auxiliary pump provided for use in engine starting and in the event the engine pump fails. The auxiliary pump, also known as a boost pump, provides added reliability to the fuel system.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

### Fuel Primer

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

### 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.



**Figure 7-30.** Gravity-feed and fuel-pump systems.

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

### Fuel Gauges

The fuel quantity gauges indicate the amount of fuel measured by a sensing unit in each fuel tank and is displayed in gallons or pounds. Aircraft certification rules require

accuracy in fuel gauges only when they read “empty.” Any reading other than “empty” should be verified. Do not depend solely on the accuracy of the fuel quantity gauges. Always visually check the fuel level in each tank during the preflight inspection, and then compare it with the corresponding fuel quantity indication.

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

### Fuel Selectors

The fuel selector valve allows selection of fuel from various tanks. A common type of selector valve contains four positions: LEFT, RIGHT, BOTH, and OFF. Selecting the LEFT or RIGHT position allows fuel to feed only from the respective 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 7-31]

Fuel placards 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 does not only cause the engine to stop, but running for prolonged periods on one tank causes an unbalanced fuel load between tanks. Running a tank completely dry may allow air to enter the fuel system and cause vapor lock, which makes it difficult to restart the engine. On fuel-injected engines, the fuel becomes so hot it vaporizes in the fuel line, not allowing fuel to reach the cylinders.



**Figure 7-31.** Fuel selector valve.

## Fuel Strainers, Sumps, and Drains

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

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

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

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

## Fuel Grades

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

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

The current method identifies AVGAS for aircraft with reciprocating engines by the octane and performance number, along with the abbreviation AVGAS. These aircraft use AVGAS 80, 100, and 100LL. Although AVGAS 100LL

performs the same as grade 100, the "LL" indicates it has a low lead content. Fuel for aircraft with turbine engines is classified as JET A, JET A-1, and JET B. Jet fuel is basically kerosene and has a distinctive kerosene smell. Since use of the correct fuel is critical, dyes are added to help identify the type and grade of fuel. [Figure 7-32]

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

Special Airworthiness Information Bulleting (SAIB) NE-11-15 advises that grade 100VLL AVGAS is acceptable for use on aircraft and engines. 100VLL meets all performance requirements of grades 80, 91, 100, and 100LL; meets the approved operating limitations for aircraft and engines certificated to operate with these other grades of AVGAS; and is basically identical to 100LL AVGAS. The lead content of 100VLL is reduced by about 19 percent. 100VLL is blue like 100LL and virtually indistinguishable.

## Fuel Contamination

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

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

Fuel should be drained from the fuel strainer quick drain and from each fuel tank sump into a transparent container and then checked for dirt and water. When the fuel strainer is being drained, water in the tank may not appear until all the fuel has been drained from the lines leading to the tank. This indicates that water remains in the tank and is not forcing the fuel out of the fuel lines leading to the fuel strainer. Therefore, drain enough fuel from the fuel strainer to be certain that fuel is being drained from the tank. The amount depends on

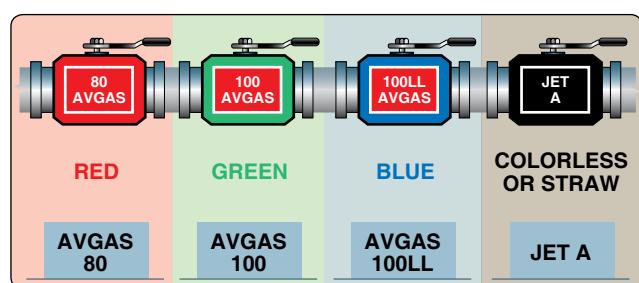


Figure 7-32. Aviation fuel color-coding system.

the length of fuel line from the tank to the drain. If water or other contaminants are found in the first sample, drain further samples until no trace appears.

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

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

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

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

### **Fuel System Icing**

Ice formation in the aircraft fuel system results from the presence of water in the fuel system. This water may be undissolved or dissolved. One condition of undissolved water is entrained water that consists of minute water particles suspended in the fuel. This may occur as a result of mechanical agitation of free water or conversion of dissolved water through temperature reduction. Entrained water settles out in time under static conditions and may or may not be drained during normal servicing, depending on the rate at which it is converted to free water. In general, it is not likely that all entrained water can ever be separated from fuel under field conditions. The settling rate depends on a series of factors including temperature, quiescence, and droplet size.

The droplet size varies depending upon the mechanics of formation. Usually, the particles are so small as to be invisible to the naked eye, but in extreme cases, can cause slight haziness in the fuel. Water in solution cannot be removed except by dehydration or by converting it through temperature reduction to entrained, then to free water.

Another condition of undissolved water is free water that may be introduced as a result of refueling or the settling of entrained water that collects at the bottom of a fuel tank. Free water is usually present in easily detected quantities at the bottom of the tank, separated by a continuous interface from the fuel above. Free water can be drained from a fuel tank through the sump drains, which are provided for that purpose. Free water, frozen on the bottom of reservoirs, such as the fuel tanks and fuel filter, may render water drains useless and can later melt releasing the water into the system thereby causing engine malfunction or stoppage. If such a condition is detected, the aircraft may be placed in a warm hangar to reestablish proper draining of these reservoirs, and all sumps and drains should be activated and checked prior to flight.

Entrained water (i.e., water in solution with petroleum fuels) constitutes a relatively small part of the total potential water in a particular system, the quantity dissolved being dependent on fuel temperature and the existing pressure and the water volatility characteristics of the fuel. Entrained water freezes in mid fuel and tends to stay in suspension longer since the specific gravity of ice is approximately the same as that of AVGAS.

Water in suspension may freeze and form ice crystals of sufficient size such that fuel screens, strainers, and filters may be blocked. Some of this water may be cooled further as the fuel enters carburetor air passages and causes carburetor metering component icing, when conditions are not otherwise conducive to this form of icing.

### **Prevention Procedures**

The use of anti-icing additives for some aircraft has been approved as a means of preventing problems with water and ice in AVGAS. Some laboratory and flight testing indicates that the use of hexylene glycol, certain methanol derivatives, and ethylene glycol mononethyl ether (EGME) in small concentrations inhibit fuel system icing. These tests indicate that the use of EGME at a maximum 0.15 percent by volume concentration substantially inhibits fuel system icing under most operating conditions. The concentration of additives in the fuel is critical. Marked deterioration in additive effectiveness may result from too little or too much additive. Pilots should recognize that anti-icing additives are in no way a substitute or replacement for carburetor heat. Aircraft operating instructions involving the use of carburetor heat should be adhered to at all times when operating under atmospheric conditions conducive to icing.

## Refueling Procedures

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

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

1. Drum to ground
2. Ground to aircraft
3. Drum to aircraft or nozzle to aircraft before removing the fuel cap

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.

## Heating System

There are many different types of aircraft heating systems that are available depending on the type of aircraft. Regardless of which type or the safety features that accompany them, it is always important to reference the specific aircraft operator's manual and become knowledgeable about the heating system. Each has different repair and inspection criteria that should be precisely followed.

### Fuel Fired Heaters

A fuel fired heater is a small mounted or portable space-heating device. The fuel is brought to the heater by using piping from a fuel tank, or taps into the aircraft's fuel system. A fan blows air into a combustion chamber, and a spark plug or ignition device lights the fuel-air mixture. A built-in safety

switch prevents fuel from flowing unless the fan is working. Outside the combustion chamber, a second, larger diameter tube conducts air around the combustion tube's outer surface, and a second fan blows the warmed air into tubing to direct it towards the interior of the aircraft. Most gasoline heaters can produce between 5,000 and 50,000 British Thermal Units (BTU) per hour.

Fuel fired heaters require electricity to operate and are compatible with a 12-volt and 24-volt aircraft electrical system. The heater requires routine maintenance, such as regular inspection of the combustion tube and replacement of the igniter at periodic intervals. Because gasoline heaters are required to be vented, special care must be made to ensure the vents do not leak into the interior of the aircraft. Combustion byproducts include soot, sulfur dioxide, carbon dioxide, and some carbon monoxide. An improperly adjusted, fueled, or poorly maintained fuel heater can be dangerous.

### Exhaust Heating Systems

Exhaust heating systems are the simplest type of aircraft heating system and are used on most light aircraft. Exhaust heating systems are used to route exhaust gases away from the engine and fuselage while reducing engine noise. The exhaust systems also serve as a heat source for the cabin and carburetor.

The risks of operating an aircraft with a defective exhaust heating system include carbon monoxide poisoning, a decrease in engine performance, and an increased potential for fire. Because of these risks, technicians should be aware of the rate of exhaust heating system deterioration and should thoroughly inspect all areas of the exhaust heating system to look for deficiencies inside and out.

### Combustion Heater Systems

Combustion heaters or surface combustion heaters are often used to heat the cabin of larger, more expensive aircraft. This type of heater burns the aircraft's fuel in a combustion chamber or tube to develop required heat, and the air flowing around the tube is heated and ducted to the cabin. A combustion heater is an airtight burner chamber with a stainless-steel jacket. Fuel from the aircraft fuel system is ignited and burns to provide heat. Ventilation air is forced over the airtight burn chamber picking up heat, which is then dispersed into the cabin area.

When the heater control switch is turned on, airflow, ignition, and fuel are supplied to the heater. Airflow and ignition are constant within the burner chamber while the heater control switch is on. When heat is required, the temperature control is advanced, activating the thermostat. The thermostat (which

senses ventilation air temperature) turns on the fuel solenoid allowing fuel to spray into the burner chamber. Fuel mixes with air inside the chamber and is ignited by the spark plug, producing heat.

The by-product, carbon monoxide, leaves the aircraft through the heater exhaust pipe. Air flowing over the outside of the burner chamber and inside the jacket of the heater absorbs the heat and carries it through ducts into the cabin. As the thermostat reaches its preset temperature, it turns off the fuel solenoid and stops the flow of fuel into the burner chamber. When ventilation air cools to the point that the thermostat again turns the fuel solenoid on, the burner starts again.

This method of heat is very safe as an overheat switch is provided on all combustion heaters, which is wired into the heater's electrical system to shut off the fuel in the case of malfunction. In the unlikely event that the heater fuel solenoid, located at the heater, remains open or the control switches fail, the remote fuel solenoid and/or fuel pump is shut off by the mechanical overheat switch, stopping all fuel flow to the system.

As opposed to the fuel fired cabin heaters that are used on most single-engine aircraft, it is unlikely for carbon monoxide poisoning to occur in combustion heaters. Combustion heaters have low pressure in the combustion tube that is vented through its exhaust into the air stream. The ventilation air on the outside of the combustion chamber is of higher pressure than on the inside, and ram air increases the pressure on the outside of the combustion tube. In the event a leak would develop in the combustion chamber, the higher-pressure air outside the chamber would travel into the chamber and out the exhaust.

### Bleed Air Heating Systems

Bleed air heating systems are used on turbine-engine aircraft. Extremely hot compressor bleed air is ducted into a chamber where it is mixed with ambient or re-circulated air to cool the air to a useable temperature. The air mixture is then ducted into the cabin. This type of system contains several safety features to include temperature sensors that prevent excessive heat from entering the cabin, check valves to prevent a loss of compressor bleed air when starting the engine and when full power is required, and engine sensors to eliminate the bleed system if the engine becomes inoperative.

### Electrical System

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

- Alternator/generator

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

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

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

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

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

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

- Position lights
- Anticollision lights
- Landing lights
- Taxi lights
- Interior cabin lights
- Instrument lights
- Radio equipment
- Turn indicator
- Fuel gauges

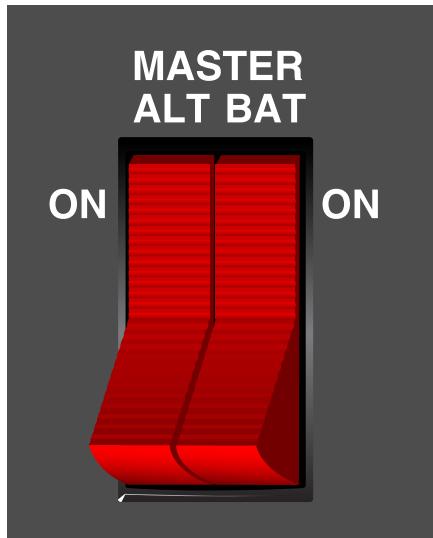
- Electric fuel pump
- Stall warning system
- Pitot heat
- Starting motor

Many aircraft are equipped with a battery switch that controls the electrical power to the aircraft in a manner similar to the master switch. In addition, an alternator switch is installed that permits the pilot to exclude the alternator from the electrical system in the event of alternator failure. [Figure 7-33]

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

A bus bar is used as a terminal in the aircraft electrical system to connect the main electrical system to the equipment using electricity as a source of power. This simplifies the wiring system and provides a common point from which voltage can be distributed throughout the system. [Figure 7-34]

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



**Figure 7-33.** On this master switch, the left half is for the alternator and the right half is for the battery.

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

Ammeters are designed with the zero point in the center of the face and a negative or positive indication on either side. [Figure 7-35] When the pointer of the ammeter is on the plus side, it shows the charging rate of the battery. A minus indication means more current is being drawn from the battery than is being replaced. A full-scale minus deflection indicates a malfunction of the alternator/generator. A full-scale positive deflection indicates a malfunction of the regulator. In either case, consult the AFM/POH for appropriate action to be taken.

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

Another electrical monitoring indicator is a loadmeter. This type of gauge has a scale beginning with zero and shows the load being placed on the alternator/generator. [Figure 7-35] The loadmeter reflects the total percentage of the load placed on the generating capacity of the electrical system by the electrical accessories and battery. When all electrical components are turned off, it reflects only the amount of charging current demanded by the battery.

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

## Hydraulic Systems

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

A basic hydraulic system consists of a reservoir, pump (either hand, electric, or engine-driven), a filter to keep the fluid clean, a selector valve to control the direction of flow, a relief valve to relieve excess pressure, and an actuator. [Figure 7-36]

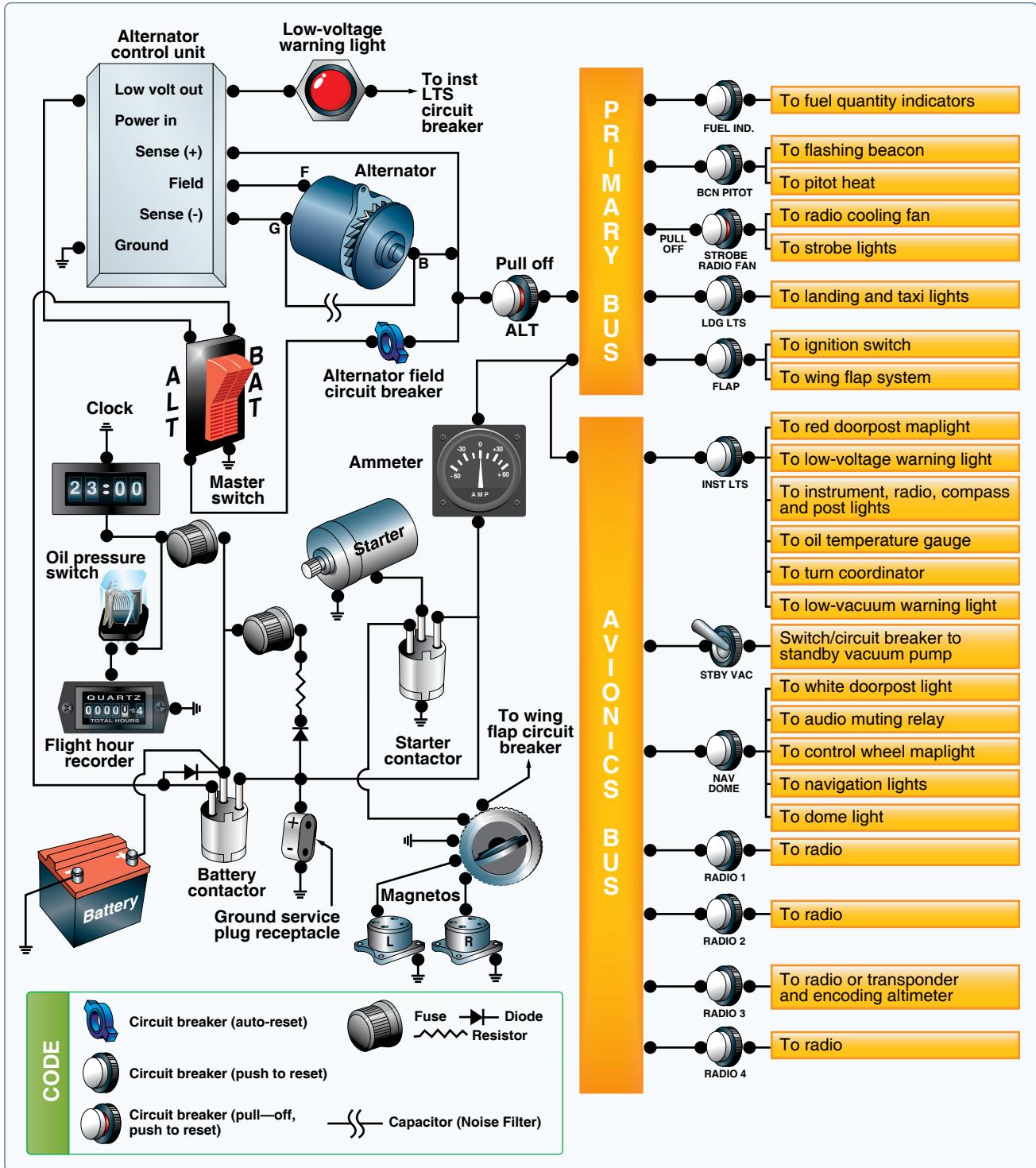
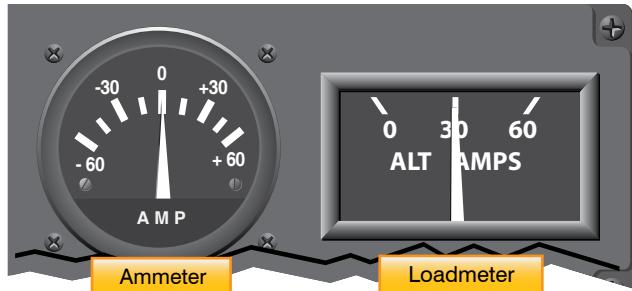


Figure 7-34. Electrical system schematic.

The hydraulic fluid is pumped through the system to an actuator or servo. A servo is a cylinder with a piston inside that turns fluid power into work and creates the power needed to move an aircraft system or flight control. Servos can be either single-acting or double-acting, based on the needs of the system. This means that the fluid can be applied to one

or both sides of the servo, depending on the servo type. A single-acting servo provides power in one direction. The selector valve allows the fluid direction to be controlled. This is necessary for operations such as the extension and retraction of landing gear during which the fluid must work in two different directions. The relief valve provides an outlet



**Figure 7-35.** Ammeter and loadmeter.

for the system in the event of excessive fluid pressure in the system. Each system incorporates different components to meet the individual needs of different aircraft.

A mineral-based hydraulic fluid is the most widely used type for small aircraft. This type of hydraulic fluid, a kerosene-like petroleum product, has good lubricating properties, as well as additives to inhibit foaming and prevent the formation of corrosion. It is chemically stable, has very little viscosity change with temperature, and is dyed for identification. Since several types of hydraulic fluids are commonly used, an aircraft must be serviced with the type specified by the manufacturer. Refer to the AFM/POH or the Maintenance Manual.

### Landing Gear

The landing gear forms the principal support of an aircraft on the surface. The most common type of landing gear consists of wheels, but aircraft can also be equipped with floats for water operations or skis for landing on snow. [Figure 7-37] The landing gear on small aircraft consists of three wheels: two main wheels (one located on each side of the fuselage) and a third wheel positioned either at the front or rear of the



**Figure 7-37.** The landing gear supports the airplane during the takeoff run, landing, taxiing, and when parked.

airplane. Landing gear employing a rear-mounted wheel is called conventional landing gear. Airplanes with conventional landing gear are often referred to as tailwheel airplanes. When the third wheel is located on the nose, it is called a nosewheel, and the design is referred to as a tricycle gear. A steerable nosewheel or tailwheel permits the airplane to be controlled throughout all operations while on the ground.

### Tricycle Landing Gear

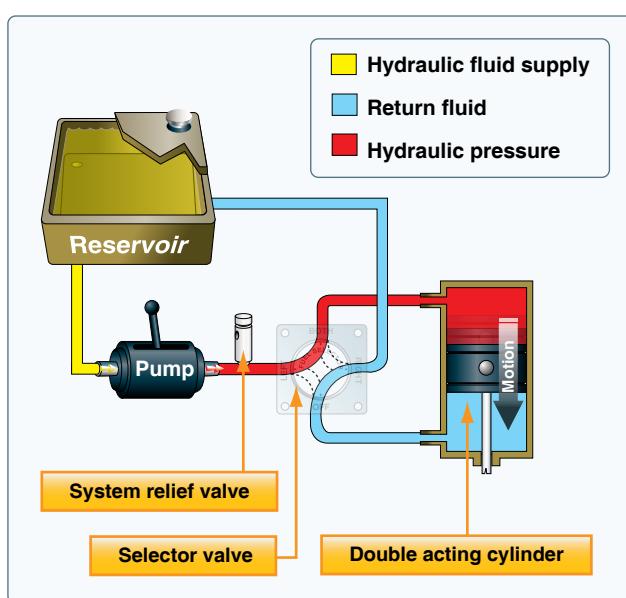
There are three advantages to using tricycle landing gear:

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

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

### Tailwheel Landing Gear

Tailwheel landing gear airplanes have two main wheels attached to the airframe ahead of its CG that support most of the weight of the structure. A tailwheel at the very back of the fuselage provides a third point of support. This arrangement



**Figure 7-36.** Basic hydraulic system.

allows adequate ground clearance for a larger propeller and is more desirable for operations on unimproved fields. [Figure 7-38]

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

Diminished forward visibility when the tailwheel is on or near the ground is a second disadvantage of tailwheel landing gear airplanes. Because of these disadvantages, specific training is required to operate tailwheel airplanes.

### **Fixed and Retractable Landing Gear**

Landing gear can also be classified as either fixed or retractable. Fixed landing gear always remains extended and has the advantage of simplicity combined with low



Figure 7-38. Tailwheel landing gear.

maintenance. Retractable landing gear is designed to streamline the airplane by allowing the landing gear to be stowed inside the structure during cruising flight. [Figure 7-39]

### **Brakes**

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

### **Pressurized Aircraft**

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

In a typical pressurization system, the cabin, flight compartment, and baggage compartments are incorporated into a sealed unit capable of containing air under a pressure higher than outside atmospheric pressure. On aircraft powered by turbine engines, bleed air from the engine compressor section is used to pressurize the cabin. Superchargers may be used on older model turbine-powered aircraft to pump air into the sealed fuselage. Piston-powered aircraft may use air supplied from each engine turbocharger through a sonic venturi (flow limiter). Air is released from the fuselage by



Figure 7-39. Fixed (left) and retractable (right) gear airplanes.

a device called an outflow valve. By regulating the air exit, the outflow valve allows for a constant inflow of air to the pressurized area. [Figure 7-40]

A cabin pressurization system typically maintains a cabin pressure altitude of approximately 8,000 feet at the maximum designed cruising altitude of an aircraft. This prevents rapid changes of cabin altitude that may be uncomfortable or cause 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 7-41]

Pressurization of the aircraft cabin is necessary in order to protect occupants against 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 aircraft must be aware of the danger of accidental loss of cabin pressure and be prepared to deal with such an emergency whenever it occurs.

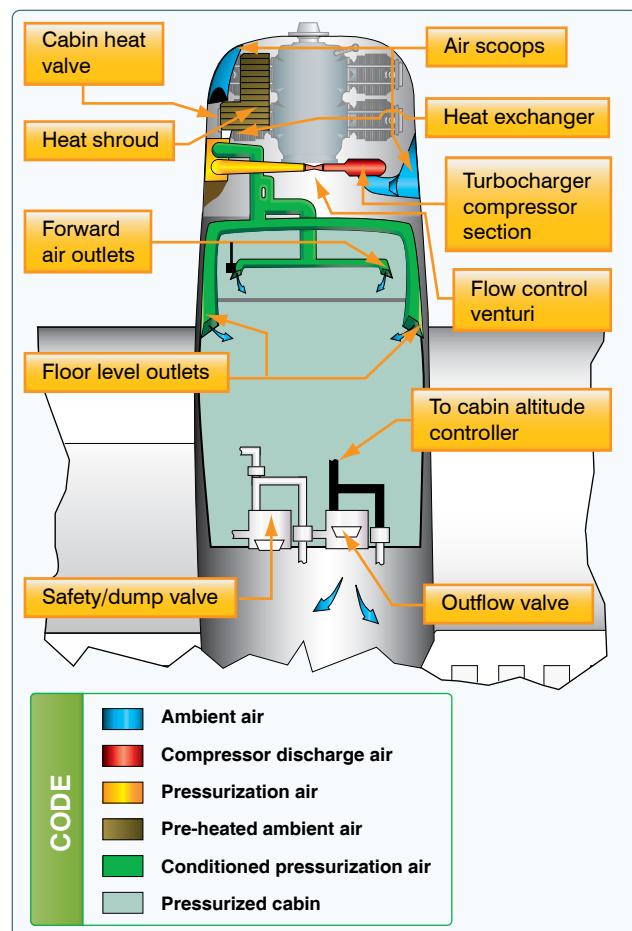


Figure 7-40. High performance airplane pressurization system.

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

Figure 7-41. Standard atmospheric pressure chart.

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

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

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

The cabin pressure regulator controls cabin pressure to a selected value in the isobaric range and limits cabin pressure to a preset differential value in the differential range. When an aircraft reaches the altitude at which the difference between the pressure inside and outside the cabin is equal to the highest differential pressure for which the fuselage structure is designed, a further increase in aircraft altitude will result

in a corresponding increase in cabin altitude. Differential control is used to prevent the maximum differential pressure, for which the fuselage was designed, from being exceeded. This differential pressure is determined by the structural strength of the cabin and often by the relationship of the cabin size to the probable areas of rupture, such as window areas and doors.

The cabin air pressure safety valve is a combination pressure relief, vacuum relief, and dump valve. The pressure relief valve prevents cabin pressure from exceeding a predetermined differential pressure above ambient pressure. The vacuum relief prevents ambient pressure from exceeding cabin pressure by allowing external air to enter the cabin when ambient pressure exceeds cabin pressure. The flight deck control switch actuates the dump valve. When this switch is positioned to ram, a solenoid valve opens, causing the valve to dump cabin air into the 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 7-42*.

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

Physiologically, decompressions fall into the following two categories:

- Explosive decompression—a change in cabin pressure faster than the lungs can decompress, possibly resulting in lung damage. Normally, the time required to release air from the lungs without restrictions, such as masks, is 0.2 seconds. Most authorities consider any decompression that occurs in less than 0.5 seconds to be explosive and potentially dangerous.
- Rapid decompression—a change in cabin pressure in which the lungs decompress faster than the cabin.

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

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



**Figure 7-42.** Cabin pressurization instruments.

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

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

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

## Oxygen Systems

Crew and passengers use oxygen systems, in conjunction with pressurization systems, to prevent hypoxia. Regulations require, at a minimum, flight crews have and use supplemental oxygen after 30 minutes exposure to cabin pressure altitudes between 12,500 and 14,000 feet. Use of supplemental oxygen is required immediately upon exposure to cabin pressure altitudes above 14,000 feet. Every aircraft occupant, above 15,000 feet cabin pressure altitude, must have supplemental oxygen. However, based on a person's physical characteristics and condition, a person may feel the effects of oxygen deprivation at much lower altitudes. Some people flying above 10,000 feet during the day may experience disorientation due to the lack of adequate oxygen. At night, especially when fatigued, these effects may occur as low as 5,000 feet. Therefore, for optimum protection, pilots are encouraged to use supplemental oxygen above 10,000 feet cabin altitude during the day and above 5,000 feet at night.

Most high altitude aircraft come equipped with some type of fixed oxygen installation. If the aircraft does not have a fixed installation, portable oxygen equipment must be readily accessible during flight. The portable equipment usually consists of a container, regulator, mask outlet, and pressure gauge. Aircraft oxygen is usually stored in high pressure system containers of 1,800–2,200 psi. When the ambient temperature surrounding an oxygen cylinder decreases, pressure within that cylinder decreases because pressure varies directly with temperature if the volume of a gas remains constant. A drop in the indicated pressure of a supplemental oxygen cylinder may be due to the container

being stored in an unheated area of the aircraft rather than an actual depletion of the oxygen supply. High pressure oxygen containers should be marked with the psi tolerance (i.e., 1,800 psi) before filling the container to that pressure. The containers should be supplied with oxygen that meets or exceeds SAE AS8010 (as revised), Aviator's Breathing Oxygen Purity Standard. To assure safety, periodic inspection and servicing of the oxygen system should be performed.

An oxygen system consists of a mask or cannula and a regulator that supplies a flow of oxygen dependent upon cabin altitude. Most regulators approved for use up to 40,000 feet are designed to provide zero percent cylinder oxygen and 100 percent cabin air at cabin altitudes of 8,000 feet or less, with the ratio changing to 100 percent oxygen and zero percent cabin air at approximately 34,000 feet cabin altitude. [Figure 7-43] Most 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 be aware of the danger of fire when using oxygen. Materials that are nearly fireproof in ordinary air may be susceptible to combustion in oxygen. Oils and greases may ignite if exposed to oxygen and cannot be used for sealing the valves and fittings of oxygen equipment. Smoking during any kind of oxygen equipment use is prohibited. Before each flight, the pilot should thoroughly inspect and test all oxygen equipment. The inspection should include a thorough examination of the aircraft oxygen equipment, including available supply, an operational check of the system, and assurance that the supplemental oxygen is readily accessible. The inspection should be accomplished with clean hands and should include a visual inspection of the mask and tubing for tears, cracks, or deterioration; the regulator for valve and lever condition and positions; oxygen quantity; and the location and functioning of oxygen pressure gauges, flow indicators, and connections. The mask should be donned and the system should be tested. After any oxygen use, verify that all components and valves are shut off.



Figure 7-43. Oxygen system regulator.

## Oxygen Masks

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

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

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

## Cannula

A cannula is an ergonomic piece of plastic tubing that runs under the nose to administer oxygen to the user. [Figure 7-44] Cannulas are typically more comfortable than masks, but may not provide an adequate flow of oxygen as reliably as masks when operating at higher altitudes. Airplanes certified to older regulations had cannulas installed with an on-board

oxygen system. However, current regulations require aircraft with oxygen systems installed and certified for operations above 18,000 feet to be equipped with oxygen masks instead of cannulas. Many cannulas have a flow meter in the oxygen supply line. If equipped, a periodic check of the green flow detector should be a part of the pilot's regular scan.

## Diluter-Demand Oxygen Systems

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

## Pressure-Demand Oxygen Systems

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

## Continuous-Flow Oxygen System

Continuous-flow oxygen systems are usually provided for passengers. The passenger mask typically has a reservoir bag that collects oxygen from the continuous-flow oxygen system during the time when the mask user is exhaling. The oxygen collected in the reservoir bag allows a higher respiratory flow rate during the inhalation cycle, which reduces the amount of air dilution. Ambient air is added to the supplied oxygen during inhalation after the reservoir bag oxygen supply is depleted. The exhaled air is released to the cabin. [Figure 7-45]

## Electrical Pulse-Demand Oxygen System

Portable electrical pulse-demand oxygen systems deliver oxygen by detecting an individual's inhalation effort and provide oxygen flow during the initial portion of inhalation. Pulse demand systems do not waste oxygen during the



Figure 7-44. Cannula with green flow detector.



**Figure 7-45.** Continuous flow mask and rebreather bag.

breathing cycle because oxygen is only delivered during inhalation. Compared to continuous-flow systems, the pulse-demand method of oxygen delivery can reduce the amount of oxygen needed by 50–85 percent. Most pulse-demand oxygen systems also incorporate an internal barometer that automatically compensates for changes in altitude by increasing the amount of oxygen delivered for each pulse as altitude is increased. [Figure 7-46]

### Pulse Oximeters

A pulse oximeter is a device that measures the amount of oxygen in an individual's blood, in addition to heart rate. This non-invasive device measures the color changes that red blood cells undergo when they become saturated with oxygen. By transmitting a special light beam through a fingertip to evaluate the color of the red cells, a pulse oximeter can calculate the degree of oxygen saturation within one percent of directly measured blood oxygen. Because of their portability and speed, pulse oximeters are very useful for pilots operating in nonpressurized aircraft above 12,500 feet where supplemental oxygen is required. A pulse oximeter permits crewmembers and passengers of an aircraft to evaluate their actual need for supplemental oxygen. [Figure 7-47]

### Servicing of Oxygen Systems

Before servicing any aircraft with oxygen, consult the specific aircraft service manual to determine the type of equipment required and procedures to be used. Certain precautions should be observed whenever aircraft oxygen



**Figure 7-46.** EDS-011 portable pulse-demand oxygen system.

systems are to be serviced. Oxygen system servicing should be accomplished only when the aircraft is located outside of the hangars. Personal cleanliness and good housekeeping are imperative when working with oxygen. Oxygen under pressure creates spontaneous results when brought in contact with petroleum products. 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,



**Figure 7-47.** Onyx pulse oximeter.

and dirt. Aircraft with permanently installed oxygen tanks usually require two persons to accomplish servicing of the system. One should be stationed at the service equipment control valves, and the other stationed where he or she can observe the aircraft system pressure gauges. Oxygen system servicing is not recommended during aircraft fueling operations or while other work is performed that could provide a source of ignition. Oxygen system servicing while passengers are on board the aircraft is not recommended.

## Anti-Ice and Deice Systems

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

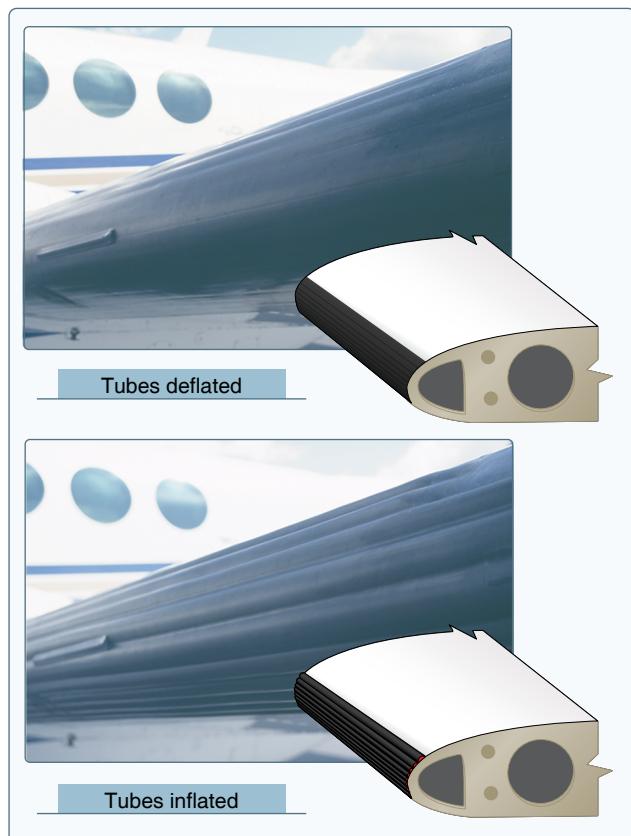
Most light aircraft have only a heated pitot tube and are not certified for flight in icing. These light aircraft have limited cross-country capability in the cooler climates during late fall, winter, and early spring. Noncertified aircraft must exit icing conditions immediately. Refer to the AFM/POH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

### Airfoil Anti-Ice and Deice

Inflatable deicing boots consist of a rubber sheet bonded to the leading edge of the airfoil. When ice builds up on the leading edge, an engine-driven pneumatic pump inflates the rubber boots. Many turboprop aircraft divert engine bleed air to the wing to inflate the rubber boots. Upon inflation, the ice is cracked and should fall off the leading edge of the wing. Deicing boots are controlled from the flight deck by a switch and can be operated in a single cycle or allowed to cycle at automatic, timed intervals. [Figure 7-48]

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

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



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

also incorporate an annunciator light to indicate proper boot operation.

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

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

An alternate type of leading edge protection that is not as common as thermal anti-ice and deicing boots is known

as a weeping wing. The weeping-wing design uses small holes located in the leading edge of the wing to prevent the formation and build-up of ice. An antifreeze solution is pumped to the leading edge and weeps out through the holes. Additionally, the weeping wing is capable of deicing an aircraft. When ice has accumulated on the leading edges, application of the antifreeze solution chemically breaks down the bond between the ice and airframe, allowing aerodynamic forces to remove the ice. [Figure 7-49]

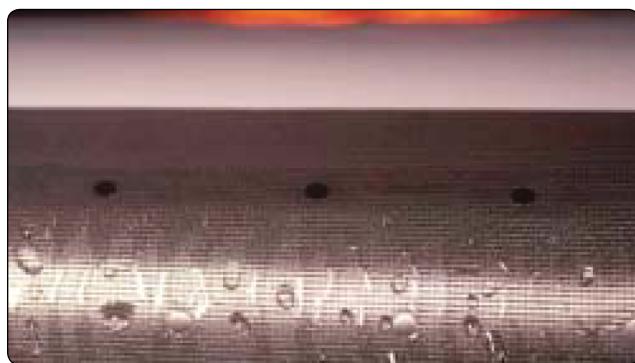
### Windscreen Anti-Ice

There are two main types of windscreen anti-ice systems. The first system directs a flow of alcohol to the windscreens. If used early enough, the alcohol prevents ice from building up on the windscreens. The rate of alcohol flow can be controlled by a dial in the flight deck according to procedures recommended by the aircraft manufacturer.

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

### Propeller Anti-Ice

Propellers are protected from icing by the use of alcohol or electrically heated elements. Some propellers are equipped with a discharge nozzle that is pointed toward the root of the blade. Alcohol is discharged from the nozzles, and centrifugal force drives the alcohol down the leading edge of the blade. The boots are also grooved to help direct the flow of alcohol. This prevents ice from forming on the leading edge of the propeller. Propellers can also be fitted with propeller anti-ice boots. The propeller boot is divided into two sections—the



**Figure 7-49.** TKS weeping wing anti-ice/deicing system.

inboard and the outboard sections. The boots are imbedded with electrical wires that carry current for heating the propeller. The prop anti-ice system can be monitored for proper operation by monitoring the prop anti-ice ammeter. During the preflight inspection, check the propeller boots for proper operation. If a boot fails to heat one blade, an unequal blade loading can result and may cause severe propeller vibration. [Figure 7-50]

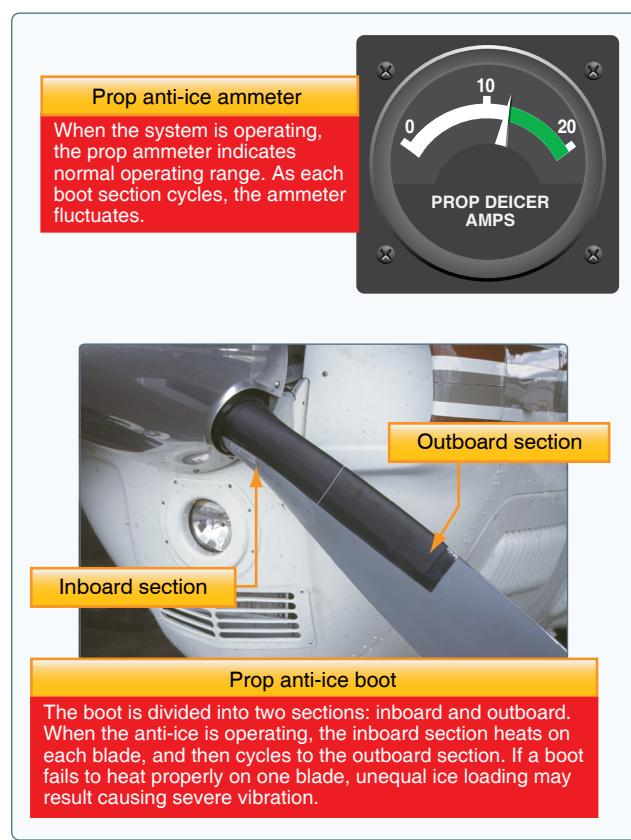
### Other Anti-Ice and Deice Systems

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

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

## Chapter Summary

All aircraft have a requirement for essential systems such as the engine, propeller, induction, ignition systems as well as the fuel, lubrication, cooling, electrical, landing gear, and



**Figure 7-50.** Prop ammeter and anti-ice boots.

environmental control systems to support flight. Understanding the aircraft systems of the aircraft being flown is critical to its safe operation and proper maintenance. Consult the AFM/POH for specific information pertaining to the aircraft being flown. Various manufacturer and owners group websites can also be a valuable source of additional information.