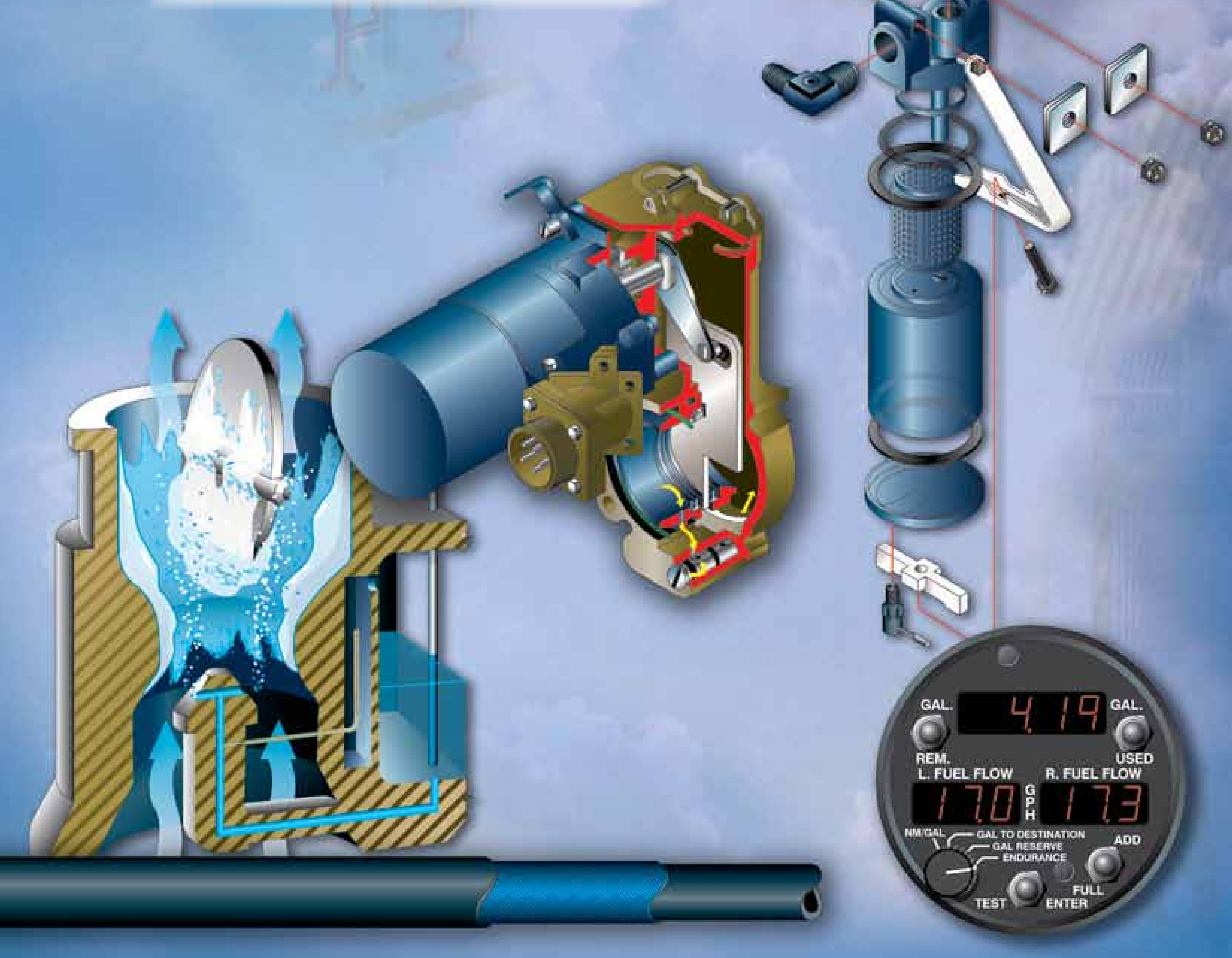
Chapter 14

Aircraft Fuel System

Basic Fuel System Requirements

All powered aircraft require fuel on board to operate the engine(s). A fuel system consisting of storage tanks, pumps, filters, valves, fuel lines, metering devices, and monitoring devices is designed and certified under strict Title 14 of the Code of Federal Regulations (14 CFR) guidelines. Each system must provide an uninterrupted flow of contaminant-free fuel regardless of the aircraft's attitude. Since fuel load can be a significant portion of the aircraft's weight, a sufficiently strong airframe must be designed. Varying fuel loads and shifts in weight during maneuvers must not negatively affect control of the aircraft in flight.



Each Federal Aviation Administration (FAA) certified aircraft is designed and constructed under FARs applicable to that type of aircraft. The certification airworthiness standards are found in 14 CFR as follows:

14 Part 23—Normal, Utility, Acrobatic, and Commuter Category Airplanes

14 Part 25—Transport Category Airplanes

14 Part 27—Normal Category Rotorcraft

14 Part 29—Transport Category Rotorcraft

14 Part 31—Manned Free Balloons

Additional information is found in 14 CFR part 33. It addresses airworthiness standards for engines and pertains mainly to engine fuel filter and intake requirements.

Under each 14 CFR part for a specific aircraft to be certified, paragraphs 951 through 1001 address very specific design criteria required to ensure the fuel system functions properly. These paragraphs from 14 CFR part 23, Normal, Utility, Acrobatic, and Commuter Category Airplanes, are summarized below. Airworthiness standards specified for air carrier and helicopter certification are similar. Although the technician is rarely involved with designing fuel systems, a review of these criteria gives insight into how an aircraft fuel system operates.

Each fuel system must be constructed and arranged to ensure fuel flow at a rate and pressure established for proper engine and auxiliary power unit (APU) functioning under each likely operating condition. This includes any maneuver for which certification is requested and during which the engine or APU may be in operation. *[Figure 14-1]* Each fuel system must be arranged so that no fuel pump can draw fuel from more than one tank at a time. There must also be a means to prevent the introduction of air into the system.

Figure 14-1. *Aircraft fuel systems must deliver fuel during any maneuver for which the aircraft is certified.*

Each fuel system for a turbine engine powered airplane must meet applicable fuel venting requirements. 14 CFR part 34 outlines requirements that fall under the jurisdiction of the Environmental Protection Agency (EPA). A turbine engine fuel system must be capable of sustained operation throughout its flow and pressure range even though the fuel has some water in it. The standard is that the engine continues to run using fuel initially saturated with water at 80 °F having 0.75 cubic centimeters (cm) of free water per gallon added to it and then cooled to the most critical condition for icing likely to be encountered in operation.

Fuel System Independence

Each fuel system for a multiengine airplane must be arranged so that, in at least one system configuration, the failure of any one component (other than a fuel tank) does not result in the loss of power of more than one engine or require immediate action by the pilot to prevent the loss of power of more than one engine.

If a single fuel tank (or series of fuel tanks interconnected to function as a single fuel tank) is used on a multiengine airplane, independent tank outlets for each engine, each incorporating a shut-off valve at the tank, must be provided. The shutoff valves may serve as firewall shutoff valves, which are also required. However, note that if the line between the valve and the engine compartment contains more than one quart of fuel (or any greater amount shown to be safe) that can escape into the engine compartment, an additional firewall shutoff valve is needed. Lines and any components from each tank outlet to each engine must be completely independent of each other.

The fuel tank must have at least two vents arranged to minimize the probability of both vents becoming obstructed simultaneously. The filler caps must be designed to minimize the probability of incorrect installation or in-flight loss.

Fuel System Lightning Protection

The fuel system must be designed and arranged to prevent the ignition of fuel vapor within the system by direct lightning strikes or swept lightning strokes (where highly probable). Swept strokes occur when the lightning strike is deformed by interaction with aerodynamic forces and propagates in a unique manner due to the material and shape of the airframe surfaces. Corona and streamering must also be inhibited at fuel vent outlets since they may ignite the fuel-air mixture. A corona is a luminous discharge that occurs as a result of an electrical potential difference between the aircraft and the surrounding area. Streamering is a branch-like ionized path that occurs in the presence of a direct stroke or under conditions when lightning strokes are imminent. *[Figure 14-2]*

Figure 14-2. *Lightning streamering at the wingtips of a jet fighter.*

Fuel Flow

The ability of the fuel system to provide fuel at a rate of flow and pressure sufficient for proper engine operation is vital in aircraft. Moreover, the fuel system must deliver the fuel at the aircraft attitude that is most critical with respect to fuel feed and quantity of unusable fuel. Tests are performed to demonstrate this performance. Fuel flowmeters are installed on most aircraft. During testing, the flowmeter is blocked and fuel must flow through or bypass the meter and still supply the engine at sufficient rate and pressure.

For gravity-flow fuel systems, the fuel flow rate must be 150 percent of the takeoff fuel consumption of the engine. For fuel pump systems, the fuel flow rate for each pump system (main and reserve supply) for each reciprocating engine must be 125 percent of the fuel flow required by the engine at the maximum takeoff power. However, the fuel pressure, with main and emergency pumps operating simultaneously, must not exceed the fuel inlet pressure limits of the engine. Auxiliary fuel systems and fuel transfer systems may operate under slightly different parameters. Turbine engine fuel systems must provide at least 100 percent required by the engine under each intended operating condition and maneuver.

On aircraft with multiple fuel tanks, performance is monitored when switching to a new tank once fuel has been depleted from a tank. For reciprocating, naturally aspirated, single-engine aircraft in level flight, 75 percent maximum continuous power must be obtainable in not more than 10 seconds. For turbocharged aircraft, 20 seconds is allowed. Twenty seconds is also allowed on multiengine aircraft.

Flow Between Interconnected Tanks

In a gravity feed fuel system with interconnected tank outlets, it must be impossible for enough fuel to flow between the tanks to cause an overflow of fuel from any tank vent under the conditions in 14 CFR part 23, section 23.959. If fuel can be pumped from one tank to another in flight, the fuel tank vents and the fuel transfer system must be designed so that no structural damage to any airplane component can occur because of overfilling of any tank.

Unusable Fuel Supply

The unusable fuel supply for each tank must be established. It cannot be less than that quantity at which the first evidence of malfunctioning appears under the most adverse fuel feed condition occurring under each intended operation and flight maneuver involving that tank. The effect on the usable fuel quantity as a result of a failure of any pump is also determined.

Fuel System Hot Weather Operation

Each fuel system must be free from vapor lock when using fuel at its critical temperature, with respect to vapor formation, when operating the airplane in all critical operating and environmental conditions for which approval is requested. For turbine fuel, the critical temperature must be 110 °F, –0°, +5 °F or the maximum outside air temperature for which approval is requested, whichever is more critical.

Fuel Tanks

Each fuel tank must be able to withstand, without failure, the vibration, inertia, fluid, and structural loads to which it may be subjected in operation. Fuel tanks with flexible liners must demonstrate that the liner is suitable for the particular application. The total usable capacity of any tank(s) must be enough for at least 30 minutes of operation at maximum continuous power. Each integral fuel tank must have adequate facilities for interior inspection and repair. Additionally, each fuel quantity indicator must be adjusted to account for the unusable fuel supply.

Fuel Tank Tests

Aircraft fuel tanks must be able to withstand the forces that are encountered throughout the entire spectrum of operation. Various tank testing standards exist. A main focus is to ensure that tanks are strong enough to remain fully operational and not deform when under various loads. Vibration resistance without leaking is also a concern. Tanks are tested under the most critical condition that may be encountered. Fuel tank supporting structure must be designed for the critical loads that could occur during flight or when landing with fuel pressure loads.

Fuel Tank Installation

Various standards exist for fuel tank installations. No fuel tank may be on the engine side of a firewall, and there must be at least ½-inch of clearance between the fuel tank and the firewall. Each tank must be isolated from personnel compartments of the aircraft by a fume-proof and fuel-proof enclosure that is vented and drained to the exterior of the airplane. Pressurization loads should not affect the tank(s). Each tank compartment must be ventilated and drained to prevent the accumulation of flammable fluids or vapors. Compartments adjacent to tanks must also be ventilated and drained.

Aircraft fuel tanks must be designed, located, and installed to retain fuel when subjected to inertia loads resulting from ultimate static load factors, and under conditions likely to occur when the airplane lands on a paved runway at a normal landing speed with the landing gear retracted. They must also retain fuel if one of the gear collapses or if an engine mount tears away. *[Figure 14-3]*

Figure 14-3. *Aircraft fuel tanks must be designed to retain fuel in the event of a gear-up landing. The fuel system drain valve should be located to prevent spillage.*

Many aircraft have fuel tanks that are not metal. Bladder fuel tanks have their own standards of construction and installation. As with metal tanks, there must be pads to prevent any chafing between each tank and its supports. The padding must be nonabsorbent or treated to prevent the absorption of fuel. Bladders must be supported so they are not required to support the entire fuel load. Surfaces adjacent to the liner must be smooth and free from projections that could cause wear. A positive pressure must be maintained within the vapor space of each bladder cell under any condition of operation, or it should be shown not to collapse under zero or negative pressure. Siphoning of fuel or collapse of bladder fuel cells should not result from improper securing or loss of the fuel filler cap. Bladder-type fuel cells must have a retaining shell at least equivalent to a metal fuel tank in structural integrity.

Fuel Tank Expansion Space

Each fuel tank must have an expansion space of not less than two percent of the tank capacity. This is waved if the tank vent discharges clear of the airplane, in which case no expansion space is required. It must be impossible to fill the expansion space inadvertently with the airplane in the normal ground attitude.

Fuel Tank Sump

Keeping contaminants out of the fuel delivered to the engine begins with the proper construction and installation of the fuel tank(s). Each tank must have a drainable sump with an effective capacity, in the normal ground and flight attitudes, of 0.25 percent of the tank capacity, or 1⁄16 gallon, whichever is greater. Each fuel tank must allow drainage of any hazardous quantity of water from any part of the tank to its sump with the airplane in the normal ground attitude. Reciprocating engine fuel systems must have a sediment bowl or chamber that is accessible for drainage. Its capacity must be 1 ounce for every 20 gallons of fuel on board. Each fuel tank outlet must be located so that water drains from all parts of the tank, except the sump, to the sediment bowl or chamber in the normal flight attitude.

Fuel Tank Filler Connection

Each fuel tank filler connection must be specifically marked. Aircraft with engines that use only gasoline fuel must have filler openings no larger than 2.36 inches in diameter. Turbine fuel aircraft filler openings must be no smaller than 2.95 inches. Spilled fuel must not enter the fuel tank compartment or any part of the airplane other than the tank itself. Each filler cap must provide a fuel-tight seal for the main filler opening. However, there may be small openings in the fuel tank cap for venting purposes or for the purpose of allowing passage of a fuel gauge through the cap. Fuel filling points must have a provision for electrically bonding the airplane to ground fueling equipment (except pressure fueling connection points).

Fuel Tank Vents and Carburetor Vapor Vents

To allow proper fuel flow, each fuel tank must be vented from the top part of the expansion space. Vent outlets must be located and constructed in a manner that minimizes the possibility of being obstructed by ice or other foreign matter. Siphoning of fuel during normal operation must not occur. Venting capacity must allow the rapid relief of excessive differences of pressure between the interior and exterior of the tank. The airspaces of tanks with interconnected outlets must also be interconnected. There must be no point in any vent line where moisture can accumulate either on the ground or during level flight (unless drainage is provided by an accessible drain valve).

Fuel tank vents may not terminate at a point where the discharge of fuel from the vent outlet constitutes a fire hazard or from which fumes may enter personnel compartments. The vents must be arranged to prevent the loss of fuel when the airplane is parked in any direction on a ramp having a one-percent slope. Fuel discharged because of thermal expansion is allowed.

Each carburetor with vapor elimination connections and each fuel injection engine employing vapor return provisions must have a separate vent line to lead vapors back to the top of one of the fuel tanks. If there is more than one tank and it is necessary to use these tanks in a definite sequence for any reason, the vapor vent line must lead back to the fuel tank to be used first, unless the relative capacities of the tanks are such that return to another tank is preferable.

For acrobatic category airplanes, excessive loss of fuel during acrobatic maneuvers, including short periods of inverted flight, must be prevented. It must be impossible for fuel to siphon from the vent when normal flight has been resumed after any acrobatic maneuver for which certification is requested.

Fuel Tank Outlet

There must be a fuel strainer for the fuel tank outlet or for the booster pump. On reciprocating-engine aircraft, the strainer must have 8 to 16 meshes per inch. The clear area of each fuel tank outlet strainer must be at least five times the area of the outlet line and the strainer diameter must be at least that of the fuel tank outlet. It must also be accessible for inspection and cleaning. Turbine-engine aircraft fuel strainers must prevent the passage of any object that could restrict fuel flow or damage any fuel system component.

Pressure Fueling Systems

Pressure fueling systems are used on many large, high-performance, and air carrier aircraft. Each pressure fueling system fuel manifold connection must have means to prevent the escape of hazardous quantities of fuel from the system if the fuel entry valve fails. A means for automatic shutoff must be provided to prevent the quantity of fuel in each tank from exceeding the maximum quantity approved for that tank. A means must also be provided to prevent damage to the fuel system in the event of failure of the automatic shutoff means prescribed in this section. All parts of the fuel system up to the tank that are subjected to fueling pressures must have a proof pressure of 1.33 times and an ultimate pressure of at least 2.0 times the surge pressure likely to occur during fueling.

Fuel Pumps

Fuel pumps are part of most aircraft fuel systems. Standards exist for main pumps and emergency pumps. Operation of any fuel pump may not affect engine operation by creating a hazard, regardless of the engine power or thrust setting or the functional status of any other fuel pump. On reciprocating engines, one main fuel pump must be engine-driven and there must be at least one for each engine. Turbine engines also require dedicated fuel pumps for each engine. Any pump required for operation is considered a main fuel pump. The power supply for the main pump for each engine must be independent of the power supply for each main pump for any other engine. There must also be a bypass feature for each positive displacement pump.

Emergency pumps are used and must be immediately available to supply fuel to the engine if any main pump fails. The power supply for each emergency pump must be independent of the power supply for each corresponding main pump. If both the main fuel pump and the emergency pump operate continuously, there must be a means to indicate a malfunction of either pump to the appropriate flight crew member.

Fuel System Lines and Fittings

Even aircraft fuel system fluid lines and fittings have standards to ensure proper fuel system operation. Each fuel line must be installed and supported to prevent excessive vibration and to withstand loads due to fuel pressure and accelerated flight conditions. Lines connected to components of the airplane, between which relative motion could exist, must have provisions for flexibility. Flexible hose assemblies are used when lines may be under pressure and subject to axial loads. Any hose that is used must be shown to be suitable for a particular application. Where high temperatures may exist during engine operation or after shutdown, fuel hoses must be capable of withstanding these temperatures.

Fuel System Components

Fuel system components in an engine nacelle or in the fuselage must be protected from damage that could result in spillage of enough fuel to constitute a fire hazard as a result of a wheels-up landing on a paved runway.

Fuel Valves and Controls

There must be a means to allow appropriate flight crew members to rapidly shut off the fuel to each engine individually in flight. No shutoff valve may be on the engine side of any firewall. There must be means to guard against inadvertent operation of each shutoff valve and means to reopen each valve rapidly after it has been closed. Each valve and fuel system control must be supported so that loads resulting from its operation, or from accelerated flight conditions, are not transmitted to the lines connected to the valve. Gravity and vibration should not affect the selected position of any valve.

Fuel valve handles and their connections to valve mechanisms must have design features that minimize the possibility of incorrect installation. Check valves must be constructed to preclude incorrect assembly or connection of the valve. Fuel tank selector valves must require a separate and distinct action to place the selector in the OFF position. The tank selector positions must be located in such a manner that it is impossible for the selector to pass through the OFF position when changing from one tank to another.

Fuel Strainer or Filter

In addition to fuel tank strainers already discussed, there must be a fuel strainer, or filter, between the fuel tank outlet and the inlet of either the fuel metering device or an engine-driven positive displacement pump, whichever is nearer the fuel tank outlet. This fuel strainer, or filter, must be accessible for draining and cleaning and must incorporate a screen or element that is easily removable. The fuel strainer should have a sediment trap and drain, except that it need not have a drain if the strainer or filter is easily removable for drain purposes. The fuel strainer should also be mounted so that its weight is not supported by the connecting lines. It should have the capacity to ensure that engine fuel system function is not impaired when fuel is contaminated to a degree that is greater than that established for the engine during its type certification. Commuter category airplanes must have a means to automatically maintain the fuel flow if ice clogs a filter.

Fuel System Drains

Aircraft fuel systems must be fitted with at least one drain to allow safe drainage of the entire fuel system with the airplane in its normal ground attitude. The drain must discharge the fuel clear of all parts of the aircraft. A readily accessible drain valve that can easily be opened and closed is required. It must have a manual or automatic means for locking in the closed position, and it must be observable that it is closed. Fuel should be collectible from the system drain valve so it can be examined. The location of the valve should be such that spillage is prevented should a gear up landing be made.

Fuel Jettisoning System

If an aircraft's design landing weight is less than that of the maximum takeoff weight, a situation could occur in which a landing is desired before sufficient fuel has burned off to lighten the aircraft. Fuel jettisoning systems are required on these aircraft so that fuel can be jettisoned in flight to avoid structural damage cause by landing the aircraft when it is too heavy. Fuel jettisoning systems are also referred to as fuel dump systems. *[Figure 14-4]*

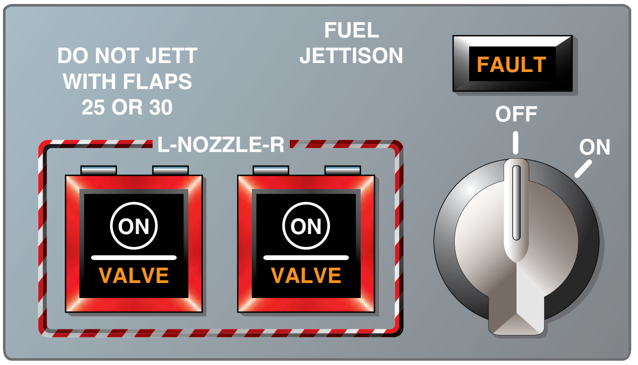


Figure 14-4. *The fuel jettison panel on a Boeing 767.*

Fuel jettisoning systems must meet several standards. The average rate of fuel jettisoning must be at least 1 percent of the maximum weight per minute, except that the time required to jettison the fuel need not be less than 10 minutes. Fuel jettisoning must be demonstrated at maximum weight with flaps and landing gear up and in a power-off glide at 1.4 VS_1. It must also be demonstrated during a climb with a critical engine inoperative and the remaining engines at maximum continuous power. Finally, the fuel jettisoning system must be performed during level flight at 1.4 VS_1 if the glide and climb tests show that this condition could be critical.

During the demonstration of the fuel jettisoning system, it must demonstrate that it operates without fire hazard. No fuel or fumes can enter any part of the aircraft. The fuel must discharge clear of any part of the aircraft and the jettisoning operation must not adversely affect the controllability of the airplane. *[Figure 14-5]* The system must be designed so that any reasonably probable single malfunction in the system does not result in a hazardous condition due to unsymmetrical jettisoning of, or inability to jettison, fuel. The fuel jettisoning valve must be designed to allow flight crewmembers to close the valve during any part of the jettisoning operation.

Figure 14-5. *Fuel being jettisoned free of the airframe on a transport category aircraft.*

On reciprocating-engine aircraft, the jettisoning system must be designed so that it is not possible to jettison the fuel in the tanks used for takeoff and landing below the level allowing 45 minutes of flight at 75 percent maximum continuous power. However, if there is an auxiliary control independent of the main jettisoning control, the system may be designed to jettison all the fuel. For turbine engine powered airplanes, the jettisoning system must be designed so that it is not possible to jettison fuel from the tanks used for takeoff and landing below the fuel level that would allow climb from sea level to 10,000 feet plus 45 minutes cruise at a speed for maximum range. If certain flight control configurations negatively affect jettisoning the fuel, a placard stating so must be posted next to the actuation control in the cockpit.

Types of Aviation Fuel

Each aircraft engine is designed to burn a certain fuel. Use only the fuel specified by the manufacturer. Mixing fuels is not permitted. There are two basic types of fuel discussed in this section: reciprocating-engine fuel (also known as gasoline or AVGAS) and turbine-engine fuel (also known as jet fuel or kerosene).

Reciprocating Engine Fuel—AVGAS

Reciprocating engines burn gasoline, also known as AVGAS. It is specially formulated for use in aircraft engines. Combustion releases energy in the fuel, which is converted into the mechanical motion of the engine. AVGAS of any variety is primarily a hydrocarbon compound refined from crude oil by fractional distillation. Aviation gasoline is different from the fuel refined for use in turbine-powered aircraft. AVGAS is very volatile and extremely flammable, with a low flash point. Turbine fuel is a kerosene-type fuel with a much higher flash point so it is less flammable.

Aircraft engines must perform throughout a wide range of demanding conditions. They must be lightweight and produce significant power in a wide range of atmospheric and engine operating temperatures. The gasoline used must support uninterrupted combustion throughout this range and must truly burn rather than explode or detonate. This ensures maximum power derivation and minimal engine wear. Over the years, AVGAS has been available in different formulas. These mostly correlate to how much energy can be produced without the fuel detonating. Larger, high-compression engines require fuel with a greater amount of potential power production without detonation than smaller low-compression engines.

Volatility

One of the most important characteristics of an aircraft fuel is its volatility. Volatility is a term used to describe how readily a substance changes from liquid into a vapor. For reciprocating engines, highly volatile fuel is desired. Liquid gasoline delivered to the engine induction system carburetor must vaporize in the carburetor to burn in the engine. Fuel with low volatility vaporizes slowly. This can cause hard engine starting, slow warm-up, and poor acceleration. It can also cause uneven fuel distribution to the cylinders and excessive dilution of the oil in the crankcase in engines equipped with oil dilution systems. However, fuel can also be too volatile, causing detonation and vapor lock.

AVGAS is a blend of numerous hydrocarbon compounds, each with different boiling points and volatility. A straight chain of volatile compounds creates a fuel that vaporizes easily for starting, but also delivers power through the acceleration and power ranges of the engine.

Vapor Lock

Vapor lock is a condition in which AVGAS vaporizes in the fuel line or other components between the fuel tank and the carburetor. This typically occurs on warm days on aircraft with engine-driven fuel pumps that suck fuel from the tank(s). Vapor lock can be caused by excessively hot fuel, low pressure, or excessive turbulence of the fuel traveling through the fuel system. In each case, liquid fuel vaporizes prematurely and blocks the flow of liquid fuel to the carburetor.

Aircraft gasoline is refined to have a vapor pressure be between 5.5 pounds per square inch (psi) and 7.0 psi at 100 °F. At this pressure, an aircraft fuel system is designed to deliver liquid fuel to the carburetor when drawn out of the tank by an engine-driven fuel pump. But temperatures in the fuel system can exceed 100 °F under the engine cowl on a hot day. Fuel may vaporize before it reaches the carburetor, especially if it is drawn up a line under a low pressure, or if it swirls while navigating a sharp bend in the tubing. To make matters worse, when an aircraft climbs rapidly, the pressure on the fuel in the tank decreases while the fuel is still warm. This causes an increase in fuel vaporization that can also lead to vapor lock.

Various steps can be taken to prevent vapor lock. The use of boost pumps located in the fuel tank that force pressurized liquid fuel to the engine is most common.

Carburetor Icing

As fuel vaporizes, it draws energy from its surroundings to change state from a liquid to a vapor. This can be a problem if water is present. When fuel vaporizes in the carburetor, water in the fuel-air mixture can freeze and deposit inside the carburetor and fuel induction system. The fuel discharge nozzle, throttle valve, venturi, or simply the walls of the induction system all can develop ice. As the ice builds, it restricts the fuel-air flow and causes loss of engine power. In severe cases, the engine stops running. *[Figure 14-6]*

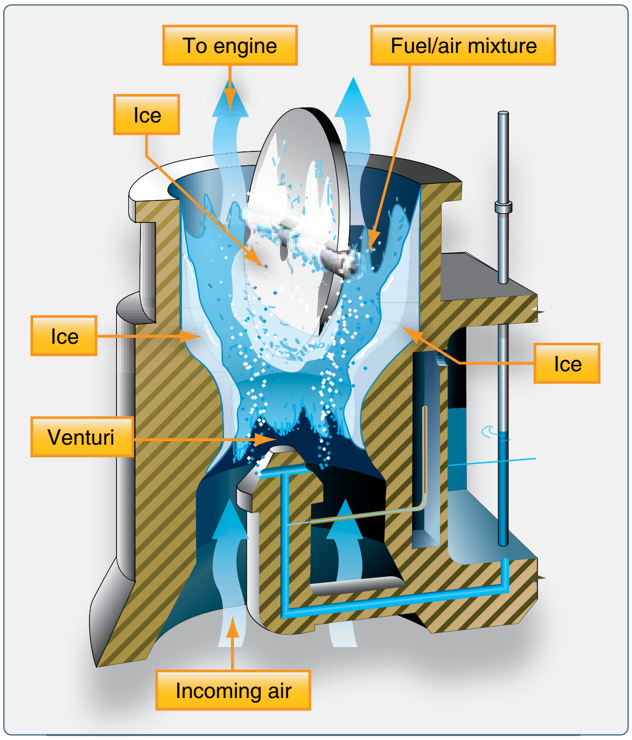


Figure 14-6. *An example of common areas where ice can form on a carburetor. The evaporation of volatile fuel takes energy from its surroundings to change state. As it does, water in the fuel-air mixture condenses and freezes.*

Carburetor icing is most common at ambient temperatures of 30–40 °F but can occur at much higher temperatures, especially in humid conditions. Most aircraft are equipped with carburetor heating to help eliminate this threat caused by the high volatility of the fuel and the presence of moisture. *[Figure 14-7]*

Aromatic Fuels

The aviation gasoline market is a relatively small part of the overall gasoline market. AVGAS producers are few. In years past, when this was less the case, considerable quantities of aromatic hydrocarbons were sometimes added to increase the rich mixture performance of AVGAS. It was used mainly in high horsepower reciprocating engines, such as military and transport category aircraft. Special hoses and seals were required for use of aromatic fuels. These additives are no longer available.

Detonation

Detonation is the rapid, uncontrolled explosion of fuel due to high pressure and temperature in the combustion chamber. The fuel-air charge ignites and explodes before the ignition system spark lights it. Occasionally, detonation occurs when the fuel is ignited via the spark plug but explodes before it is finished burning.

The engine is not designed to withstand the forces caused by detonation. It is made to turn smoothly by having the fuel-air mixture burn in the combustion chamber and propagate directionally across the top of the piston. When it does so, a smooth transfer of the force developed by the burning fuel

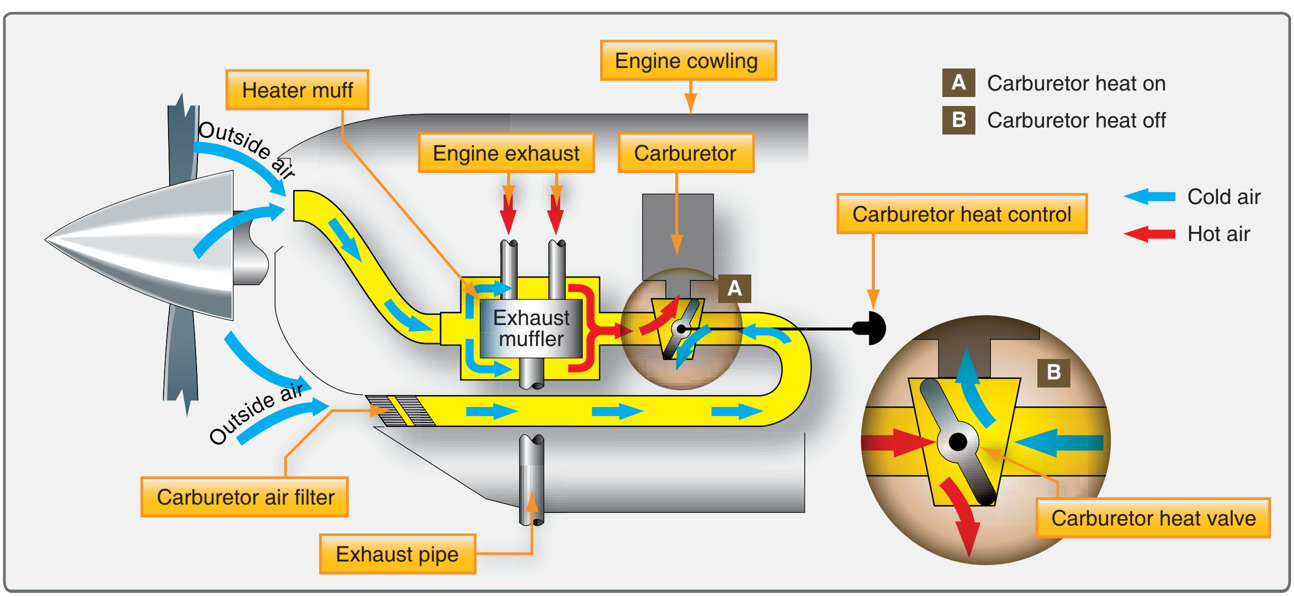


Figure 14-7. *To combat carburetor icing, air preheated by the exhaust manifold is directed into the carburetor via a push/pull control in the cockpit. The control changes the position of the air diverter butterfly in the carburetor heat valve box.*

pushes the piston down. Detonation of fuel instead sends a shock wave of force against the top of the piston, which in turn is transferred through the piston to the piston pin, to the connecting rod, and to the crankshaft. Valve operation is also affected by this shock wave. In short, the explosion of fuel detonating in the combustion chamber transfers the energy contained in the fuel harshly throughout the entire engine, causing damage.

Aviation fuels are refined and blended to avoid detonation. Each has an ignition point and burn speed at specific fuel-air mixture ratios that manufacturers rely on to design engines that can operate without detonation. An engine experiencing detonation in the field should be investigated. A pinging or knocking sound is a sign of detonation. This is often more difficult to detect in an aircraft than in an automobile due to propeller tip noise. Detonation causes an increase in cylinder head temperature.

If ignored or allowed to continue, detonation can eventually lead to engine failure. Causes of detonation include incorrect fuel, already high engine temperature at high power settings, such as takeoff, preignition of the fuel, extended operations with an extremely lean mixture, and operation at high revolutions per minute (rpm) with low airspeed.

Surface Ignition and Preignition

A sharp deposit or incandescent hot spot in the combustion chamber can cause fuel to ignite before the spark plug lights it. Detonation can cause such an area to form as can a cracked spark plug insulator or a sharp valve edge. The result could be ignition of the fuel before the piston is at the proper place during its movement toward top dead center of the compression stroke. The extended burn period of the fuel can increase temperatures and pressure in the combustion chamber to the point at which the fuel detonates. The repeated incorrect flame propagation and detonation can cause serious engine damage and eventual engine failure. *[Figure 14-8]*

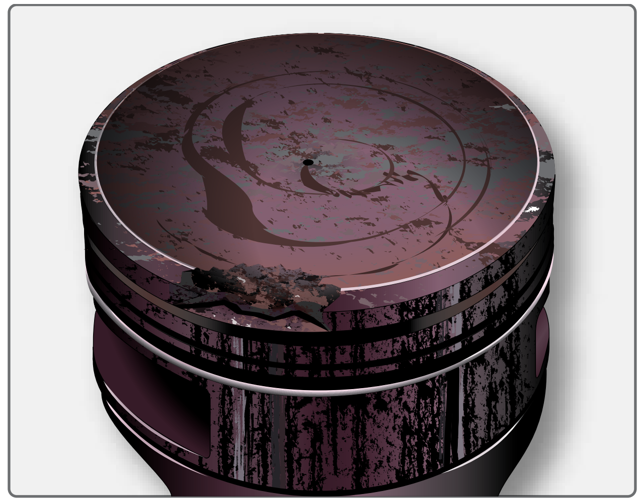


Figure 14-8. *Preignition can cause detonation and damage to the engine.*

Maintenance personnel should ensure that the correct fuel is being used, and that the engine is being operated correctly. Spark plugs and valves should be checked for wear. Signs of deposits and detonation must also be investigated and addressed.

Octane and Performance Number Rating

Octane ratings and performance numbers are given to fuels to describe their resistance to detonation. Fuels with high critical pressure and high octane or performance numbers have the greatest resistance. A referencing system is used to rate the fuel. A mixture of two hydrocarbons, iso-octane (C_8H_{18}) and heptane (C_7H_{16}), is used. Various ratios of the two hydrocarbons in a mixture result in proportional antidetonation properties. The more iso-octane there is in the mixture, the higher its resistance is to detonation.

When a fuel has the same critical pressure as a reference mixture of these two hydrocarbons, it is said to have an octane rating that is the same as the percentage of the iso-octane is this reference mixture. An 80 octane fuel has the same resistance to detonation as an 80 percent iso-octane, 20 percent heptane mixture; a 90 octane fuel has the same resistance to detonation as a 90 percent iso-octane, 10 percent heptane mixture; and a 100 octane fuel has the same resistance to detonation as 100 percent pure iso-octane. So, by comparing a fuel's tendency to detonate to reference mixtures of iso-octane and heptane, octane ratings from 80 to 100 can be established. The highest octane fuel possible with this system of measurement is 100 octane fuel.

To increase antidetonation characteristics of fuel, substances can be added. Tetraethyl lead (TEL) is the most common additive that increases the critical pressure and temperature of a fuel. However, additional additives, such as ethylene dibromide and tricresyl phosphate, must be also be added so that the TEL does not leave solid deposits in the combustion chamber.

The amount of TEL added to a fuel can be increased to raise the antidetonation characteristics from 80 to the 100 octane level and higher. References to octane characteristics above 100 percent iso-octane are made by referencing the antidetonation properties of the fuel to a mixture of pure iso-octane and specific quantities of TEL. The specific mixtures of iso-octane and TEL are assigned arbitrary octane numbers above 100. In addition to increasing the antidetonation characteristics of a fuel, TEL also lubricates the engine valves.

Performance numbers are also used to characterize the antidetonation characteristics of fuel. A performance number consists of two numbers (e.g., 80/87, 100/130, 115/145) in which higher numbers indicate a higher resistance to detonation. The first number indicates the octane rating of the fuel in a lean fuel-air mixture, and the second number indicates the octane rating of the fuel in a rich mixture.

Due to the small size of the worldwide aviation gasoline market, a single 100 octane low-lead fuel (100LL) is desired as the only AVGAS for all aircraft with reciprocating engines. This presents problems in engines originally designed to run on 80/87 fuel; the low lead 100 octane fuel still contains more lead than the 80 octane fuel. Spark plug fouling has been common and lower times between overhaul have occurred. Other engines designed for 91/96 fuel or 100/130 fuel operate satisfactorily on 100LL, which contains 2 milliliters of TEL per gallon (enough to lubricate the valves and control detonation). For environmental purposes, AVGAS with no TEL is sought for the aviation fleet of the future.

Fuel Identification

Aircraft and engine manufacturers designate approved fuels for each aircraft and engine. Consult manufacturer data and use only those fuel specified therein.

The existence of more than one fuel makes it imperative that fuel be positively identified and never introduced into a fuel system that is not designed for it. The use of dyes in fuel helps aviators monitor fuel type. 100LL AVGAS is the AVGAS most readily available and used in the United States. It is dyed blue. Some 100 octane or 100/130 fuel may still be available, but it is dyed green.

80/87 AVGAS is no longer available. It was dyed red. Many supplemental type certificates have been issued to engine and engine/airframe combinations that permit the use of automobile gasoline in engines originally designed for red AVGAS. A relatively new AVGAS fuel, 82UL (unleaded), has been introduced for use by this group of relatively low compression engines. It is dyed purple.

115/145 AVGAS is a fuel designed for large, high performance reciprocating engines from the World War II era. It is available only by special order from refineries, and is also dyed purple in color.

The color of fuel may be referred to in older maintenance manuals. All grades of jet fuel are colorless or straw colored. This distinguishes them from AVGAS of any kind that contains dye of some color. Should AVGAS fuel not be of a recognizable color, the cause should be investigated. Some color change may not affect the fuel. Other times, a color change may be a signal that fuels have been mixed or contaminated in some way. Do not release an aircraft for flight with unknown fuel onboard.

Identifying fuel and ensuring the correct fuel is delivered into storage tanks, fuel trucks, and aircraft fuel tanks is a process aided by labeling. Decals and markings using the same colors as the AVGAS colors are used. Delivery trucks and hoses are marked as are aircraft tank fuel caps and fill areas. Jet fuel fill hose nozzles are sized too large to fit into an AVGAS tank fill opening. *Figure 14-9* shows examples of color-coded fuel labeling.

Purity

The use of filters in the various stages of transfer and storage of AVGAS removes most foreign sediment from the fuel. Once in the aircraft fuel tanks, debris should settle into the fuel tank drain sumps to be removed before flight. Filters and strainers in the aircraft fuel system can successfully capture any remaining sediment.

The purity of aviation gasoline is compromised most often by water. Water also settles into the sumps given enough time. However, water is not removed by the aircraft's filters and strainers as easily as solid particles. It can enter the fuel even when the aircraft is parked on the ramp with the fuel caps in place. Air in the tank vapor space above the liquid fuel contains water vapor. Temperature fluctuations cause the water vapor to condense on the inner surface of the tanks and settle into the liquid fuel. Eventually, this settles to the sump, but some can remain in the fuel when the aircraft is to be flown.

Proper procedure for minimizing water entering aircraft fuel is to fill the aircraft fuel tanks immediately after each flight. This minimizes the size of the vapor space above the liquid fuel and the amount of air and associated water vapor present in the tank. When excessive water is drawn into the fuel system, it passes through carburetor jets where it can interrupt the smooth operation of the engine(s).

If water is entrained or dissolved in the fuel, it cannot be removed by draining the sump(s) and filter bowls before flight. However, there may be enough water for icing to be a concern. As the aircraft climbs and fuel is drawn out of the tanks, the fuel supply cools. Entrained and dissolved water in the fuel is forced out of solution and becomes free water. If cool enough, ice crystals form rather than liquid water. These can clog filters and disrupt fuel flow to the engines. Both AVGAS and jet fuel have this type of water impurity issue leading to icing that must be monitored and treated.

Fuel Type and Grade	Color of Fuel	Equipment Control Color	Pipe Banding and Marking	Refueler Decal
AVGAS 82UL	Purple	82UL AVGAS	AVGAS 82UL	82UL AVGAS
AVGAS 100	Green	100 AVGAS	AVGAS 100	100 AVGAS
AVGAS 100LL	Blue	100LL AVGAS	AVGAS 100LL	100LL AVGAS
JET A	Colorless or straw	JET A	JET A	JET A
JET A-1	Colorless or straw	JET A-1	JET A-1	JET A-1
JET B	Colorless or straw	JET B	JET B	JET B

Figure 14-9. *Color coded labeling and markings used on fueling equipment.*

Fuel anti-ice additives can be added to the bulk fuel and also directly into the aircraft fuel tank, usually during refueling. These are basically diethylene glycol solutions that work as antifreeze. They dissolve in free water as it comes out of the fuel and lower its freezing point. *[Figure 14-10]*

Figure 14-10. *Fuel anti-icing products, such as Prist®, act as antifreeze for any free water in aircraft fuel. They dissolve in the water and lower its freezing point to prevent ice crystals from disrupting fuel flow.*

Turbine Engine Fuels

Aircraft with turbine engines use a type of fuel different from that of reciprocating aircraft engines. Commonly known as jet fuel, turbine engine fuel is designed for use in turbine engines and should never be mixed with aviation gasoline or introduced into the fuel system of a reciprocating aircraft engine fuel system.

The characteristics of turbine engine fuels are significantly different from those of AVGAS. Turbine engine fuels are hydrocarbon compounds of higher viscosity with much lower volatility and higher boiling points than gasoline. In the distillation process from crude oil, the kerosene cut from which jet fuel is made condenses at a higher temperature than the naphtha or gasoline cuts. The hydrocarbon molecules of turbine engine fuels are composed of more carbon than are in AVGAS. *[Figure 14-11]*

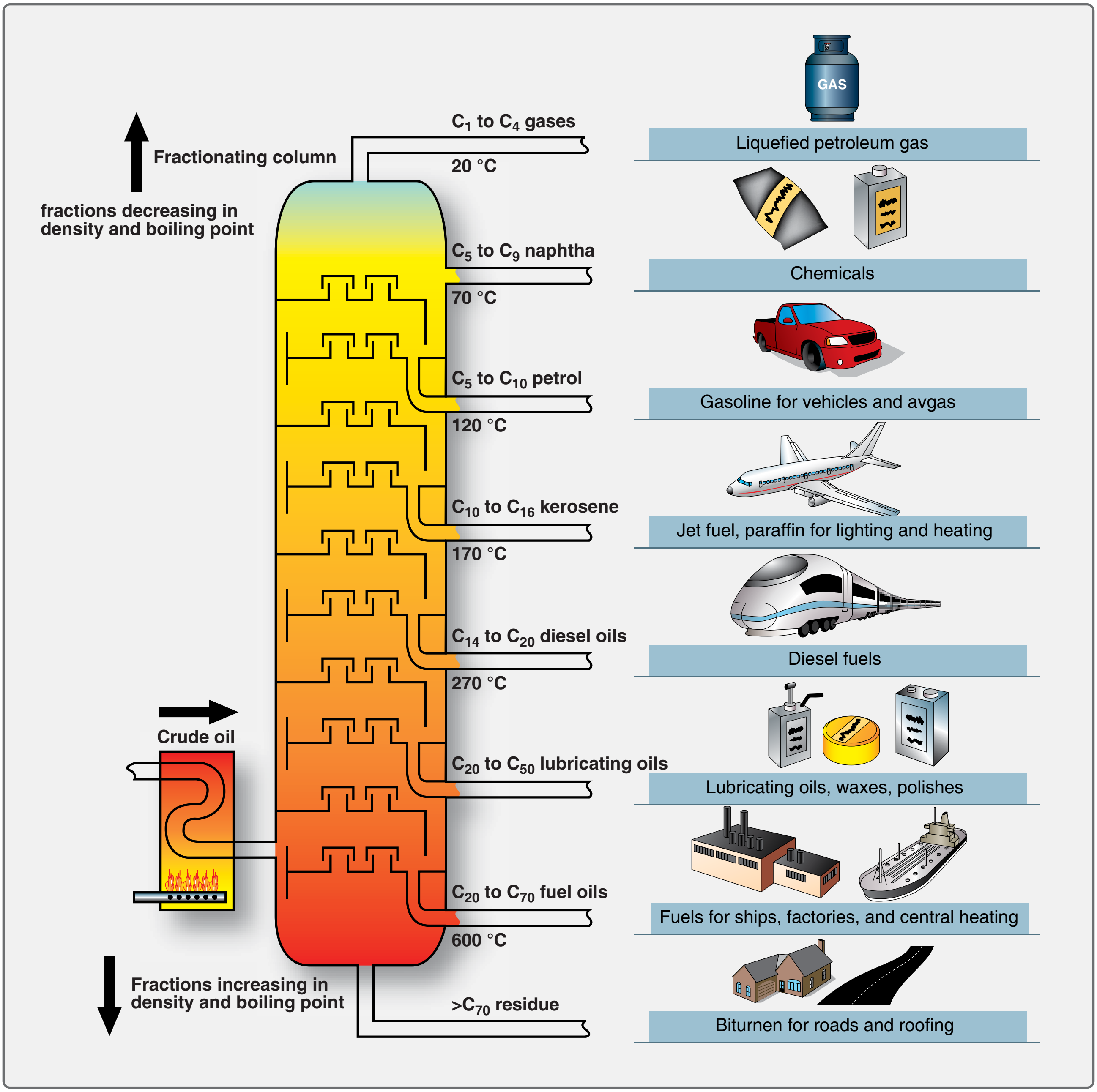


Figure 14-11. *Petroleum products are produced by distillation. Various fractions condense and are collected at different temperatures that correspond to the height of collection in the distillation tower. As can be seen, there are significant differences between turbine engine fuel and ordinary AVGAS.*

Turbine engine fuels sustain a continuous flame inside the engine. They typically have a higher sulfur content than gasoline, and various inhibitors are commonly added them. Used to control corrosion, oxidation, ice, and microbial and bacterial growth, these additives often are already in the fuel when it arrives at the airport for use.

Turbine Fuel Volatility

The choice of turbine engine fuel reflects consideration of conflicting factors. While it is desirable to use a fuel that is low in volatility to resist vapor lock and evaporation while in the aircraft's fuel tanks, turbine engine aircraft operate in cold environments. Turbine engines must start readily, and be able to restart while in flight. Fuel with high volatility makes this easier.

AVGAS has a relatively low maximum vapor pressure compared to automotive gasoline—only 7 psi. But the vapor pressure of Jet A is only 0.125 psi at standard atmospheric conditions. Jet B, a blend of Jet A and gasoline, has higher volatility with a vapor pressure between 2 and 3 psi.

Turbine Engine Fuel Types

Three basic turbine engine fuel types are available worldwide, although some countries have their own unique fuels. The first is Jet A. It is the most common turbine engine fuel available in the continental United States. Globally, Jet A-1 is the most popular. Both Jet A and Jet A-1 are fractionally distilled in the kerosene range. They have low volatility and low vapor pressure. Flashpoints range between 110 °F and 150 °F. Jet A freezes at –40 °F and Jet A-1 freezes at –52.6 °F. Most engine operations manuals permit the use of either Jet A or Jet A-1.

The third basic type of turbine engine fuel available is Jet B. It is a wide-cut fuel that is basically a blend of kerosene and gasoline. Its volatility and vapor pressure reflect this and fall between Jet A and AVGAS. Jet B is primarily available in Alaska and Canada due to its low freezing point of approximately –58 °F, and its higher volatility yields better cold weather performance.

Turbine Engine Fuel Issues

Purity issues related to turbine engine fuels are unique. While AVGAS experiences similar issues of solid particle contamination and icing concerns, the presence of water and fuel-consuming microbes is more prominent in jet fuel, which has different molecular structure and retains water in two principal ways. Some water is dissolved into the fuel. Other water also is entrained in the fuel, which is more viscous than AVGAS. The greater presence of water in jet fuel allows microbes to assemble, grow, and live on the fuel.

Since turbine engine fuels always contain water, microbial contamination is always a threat. The large tanks of many turbine engine aircraft have numerous areas where water can settle and microbes can flourish. Areas between the fuel tank and any water that may come to rest in the bottom of the tanks is where the microbes thrive. These microorganisms form a bio-film that can clog filters, corrode tank coatings, and degrade the fuel. They can be controlled somewhat with the addition of biocides to the fuel. *[Figure 14-12]* Anti-ice additives are also known to inhibit bacterial growth.

Since the microbes are sustained by fuel and water, best practices must be followed to keep the water in fuel to a minimum. Avoid having fuel in a storage tank for a prolonged period of time on or off the aircraft. Drain sumps and monitor the fuel for settled water. Investigate all incidents of water discovered in the fuel. In addition to water in jet fuel supporting the growth of microorganisms, it also poses a threat of icing. Follow the manufacturer's instructions for fuel handling procedures and fuel system maintenance.

Figure 14-12. *Biocides, such as these, are often added to jet fuel to kill microbes that live on hydrocarbons.*

Aircraft Fuel Systems

While each manufacturer designs its own fuel system, the basic fuel system requirements referenced at the beginning of this chapter yield fuel systems of similar design and function in the field. In the following sections are representative examples of various fuel systems in each class of aircraft discussed. Others are similar but not identical. Each aircraft fuel system must store and deliver clean fuel to the engine(s) at a pressure and flow rate able to sustain operations regardless of the operating conditions of the aircraft.

Small Single-Engine Aircraft Fuel Systems

Small single-engine aircraft fuel systems vary depending on factors, such as tank location and method of metering fuel to the engine. A high-wing aircraft fuel system can be designed differently from one on a low-wing aircraft. An aircraft engine with a carburetor has a different fuel system than one with fuel injection.

Gravity Feed Systems

High-wing aircraft with a fuel tank in each wing are common. With the tanks above the engine, gravity is used to deliver the fuel. A simple gravity feed fuel system is shown in *Figure 14-13*. The space above the liquid fuel is vented to maintain atmospheric pressure on the fuel as the tank empties. The two tanks are also vented to each other to ensure equal pressure when both tanks feed the engine. A single screened outlet on each tank feeds lines that connect to either a fuel shutoff valve or multiposition selector valve. The shutoff valve has two positions: fuel ON and fuel OFF. If installed,

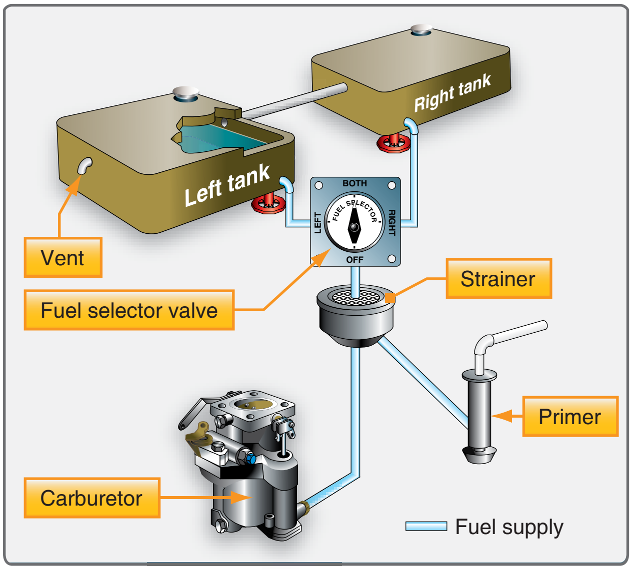


Figure 14-13. *The gravity-feed fuel system in a single-engine high-wing aircraft is the simplest aircraft fuel system.*

the selector valve provides four options: fuel shutoff to the engine; fuel feed from the right wing tank only; fuel feed from the left fuel tank only; fuel feed to the engine from both tanks simultaneously.

Downstream of the shutoff valve or selector valve, the fuel passes through a main system strainer. This often has a drain function to remove sediment and water. From there, it flows to the carburetor or to the primer pump for engine starting. Having no fuel pump, the gravity feed system is the simplest aircraft fuel system.

Pump Feed Systems

Low- and mid-wing single reciprocating engine aircraft cannot utilize gravity-feed fuel systems because the fuel tanks are not located above the engine. Instead, one or more pumps are used to move the fuel from the tanks to the engine. A common fuel system of this type is shown in *Figure 14-14*. Each tank has a line from the screened outlet to a selector valve. However, fuel cannot be drawn from both tanks simultaneously; if the fuel is depleted in one tank, the pump would draw air from that tank instead of fuel from the full tank. Since fuel is not drawn from both tanks at the same time, there is no need to connect the tank vent spaces together.

From the selector valve (LEFT, RIGHT, or OFF), fuel flows through the main strainer where it can supply the engine primer. Then, it flows downstream to the fuel pumps. Typically, one electric and one engine-driven fuel pump are arranged in parallel. They draw the fuel from the tank(s) and deliver it to the carburetor. The two pumps provide redundancy. The engine-driven fuel pump acts as the primary pump. The electric pump can supply fuel should the other fail.

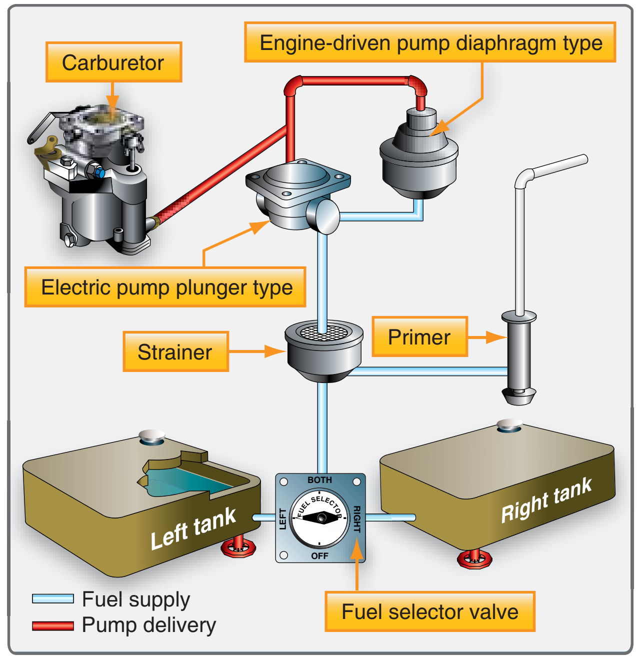


Figure 14-14. *A single reciprocating engine aircraft with fuel tanks located in wings below the engine uses pumps to draw fuel from the tanks and deliver it to the engine.*

The electric pump also supplies fuel pressure while starting and is used to prevent vapor lock during flight at high altitude.

High-Wing Aircraft With Fuel Injection System

Some high-wing, high-performance, single-engine general aviation aircraft are equipped with a fuel system that features fuel injection rather than a carburetor. It combines gravity flow with the use of a fuel pump(s). The Teledyne-Continental system is an example. *[Figure 14-15]*

NOTE: Fuel injection systems spray pressurized fuel into the engine intake or directly into the cylinders. Fuel without any air mixed in is required to provide a measured, continuous spray and smooth engine operation.

Fuel pressurized by an engine-driven pump is metered as a function of engine rpm on the Teledyne-Continental system. It is first delivered from the fuel tanks by gravity to two smaller accumulator or reservoir tanks. These tanks, one for each wing tank, consolidate the liquid fuel and have a relatively small airspace. They deliver fuel through a three-way selector valve (LEFT, RIGHT, or OFF). The selector valve also acts simultaneously as a diverter of air that has been separated out of the fuel in the engine-driven fuel pump and returned to the valve. It routes the air to the vent space above the fuel in the selected reservoir tank.

An electric auxiliary fuel pump draws fuel through the selector valve. It forces the fuel through the strainer, making

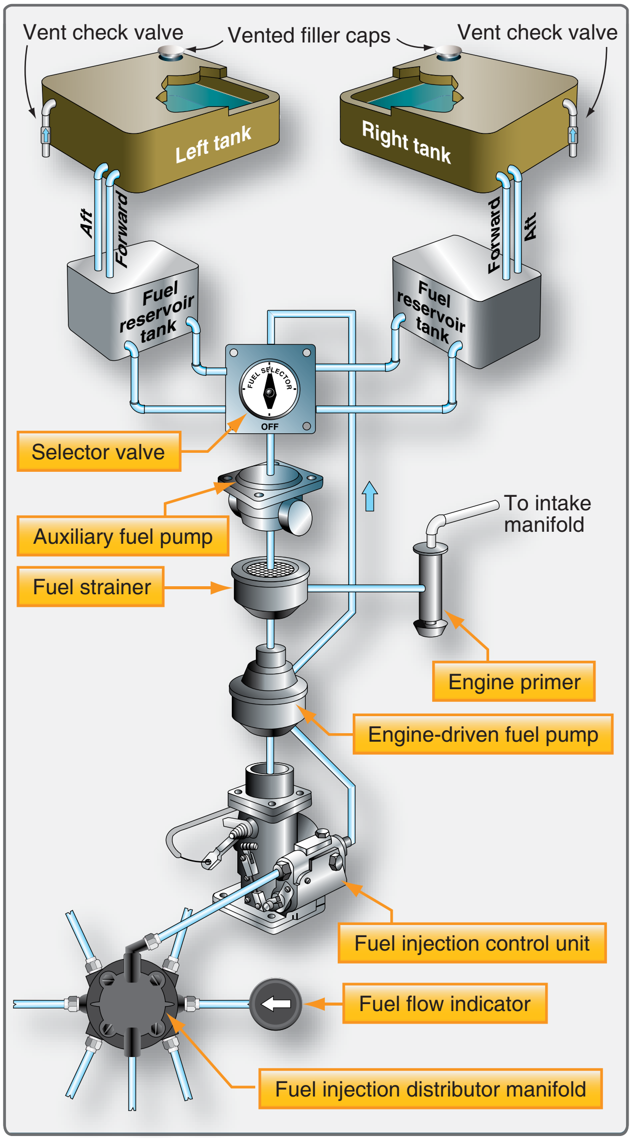


Figure 14-15. *A Teledyne-Continental fuel system featuring fuel injection used on high-wing, high-performance single-engine aircraft.*

it available for the primer pump and the engine-driven fuel pump. This pump is typically used for starting and as a backup should the engine-driven pump fail. It is controlled by a switch in the cockpit and does not need to be operating to allow the engine-driven fuel pump access to the fuel.

The engine-driven fuel pump intakes the pressurized fuel from the electrically driven pump or from the reservoir tanks if the electric pump is not operating. It supplies a higher-than-needed volume of fuel under pressure to the fuel control. Excess fuel is returned to the pump, which pumps it through the selector valve into the appropriate reservoir tank. Fuel vapor is also returned to tanks by the pump. The fuel control unit meters the fuel according to engine rpm and mixture control inputs from the cockpit.

The fuel control delivers the fuel to the distribution manifold, which divides it and provides equal, consistent fuel flow for individual fuel injector in each cylinder. *[Figure 14-16]* A fuel flow indicator tapped off of the distribution manifold provides feedback in cockpit. It senses fuel pressure but is displayed on a dial calibrated in gallons per hour.

Figure 14-16. *A fuel distribution manifold for a fuel-injected engine.*

Small Multiengine (Reciprocating) Aircraft Fuel Systems

Low-Wing Twin

The fuel system on a small, multiengine aircraft is more complicated than a single-engine aircraft but contains many of the same elements. An example system used on a low-wing aircraft is illustrated in *Figure 14-17*. It features the main fuel tanks in the wing tips and auxiliary tanks in the wing structure. A boost pump is located at the outlet of each main tank. This pressurizes the entire fuel system from the tank to the injectors eliminating the possibility of vapor lock. An engine can operate with just its boost pump running in the event the engine-driven injection pump fails. Typically, the boost pumps are used to prime and start the engine.

Two selector valves are required on twin-engine aircraft, one for each engine. The right selector valve receives fuel from a main tank on either side of the aircraft and directs it to the right engine. The left selector valve also receives fuel from either main tank and directs it to the left engine. This allows fuel to crossfeed from one side of the aircraft to the opposite engine if desired. The selector valves can also direct fuel from the auxilliary tank to the engine on the same side. Crossfeed of fuel from auxilliary tanks is not possible. From the outlet of the selector valve, fuel flows to the strainer. On some aircraft, the strainer is built into the selector valve unit. From the strainer, fuel flows to the engine-driven fuel pump.

The engine-driven fuel pump is an assembly that also contains a vapor separator and a pressure regulating valve with an adjustment screw. The vapor separator helps

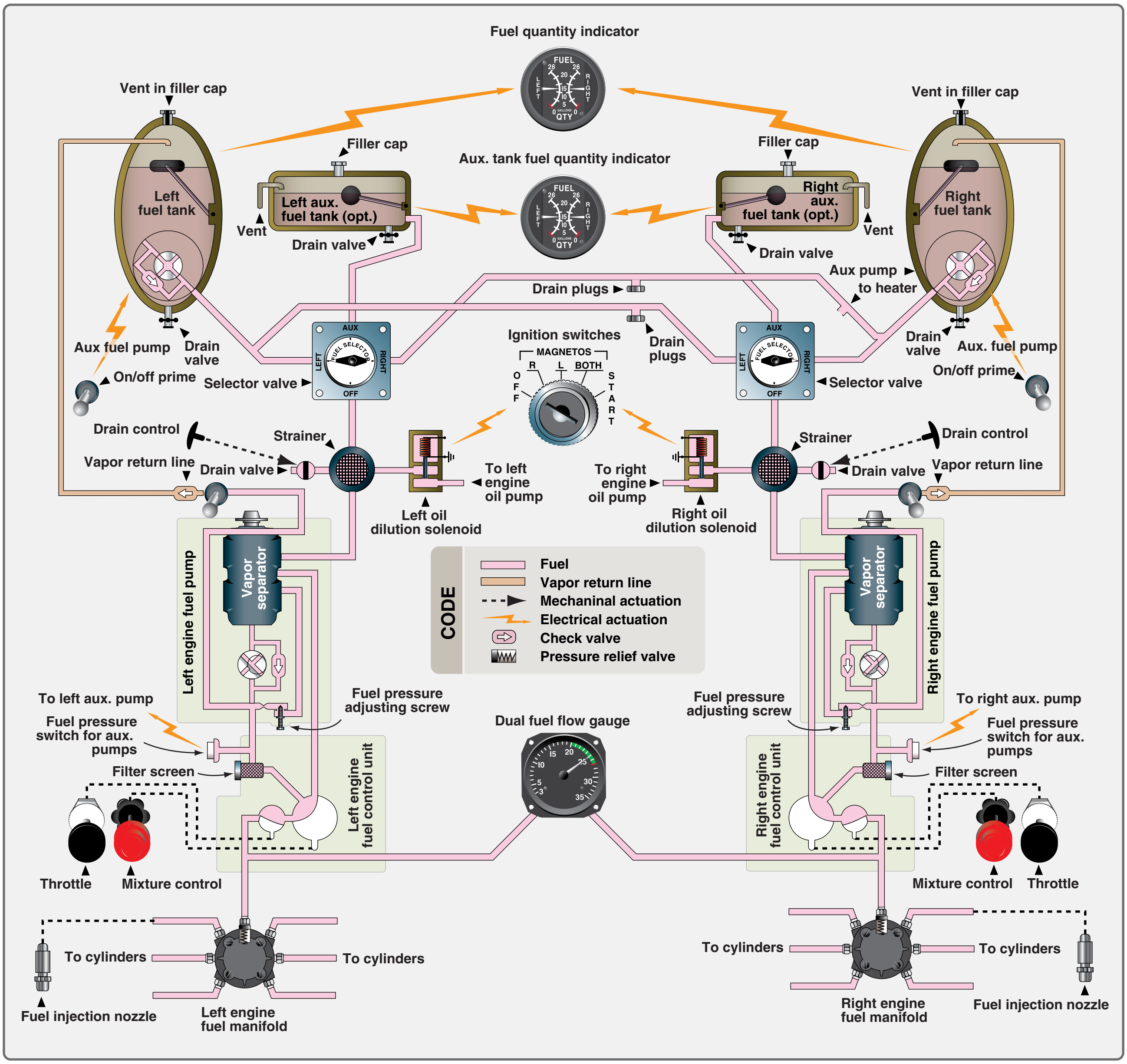


Figure 14-17. *A low-wing, twin-engine, light aircraft fuel system.*

eliminate air from the fuel. It returns a small amount of fuel and any vapor present back to the main fuel tank. The pump supplies pressurized fuel to the fuel control. The fuel control, one for each engine, responds to throttle and mixture control settings from the cockpit and supplies the proper amount of fuel to the fuel manifold. The manifold divides the fuel and sends it to an injector in each cylinder. A fuel pressure gauge is placed between the fuel control unit outlet and the manifold to monitor the injector-applied pressure that indicates engine power.

High-Wing Twin

A simplified system on a high-wing, twin-engine aircraft that combines gravity feed with an electric fuel pump is illustrated in *Figure 14-18*. Directly downstream of the selector valves are the fuel strainers and then an electric fuel pump for each engine. This pump draws fuel from the selected tank and sends it under pressure to the inlet side of the fuel injection metering unit. The metering unit for each engine provides the proper flow of fuel to the distribution manifold which feeds the injectors.

Large Reciprocating-Engine Aircraft Fuel Systems

Large, multiengine transport aircraft powered by reciprocating radial engines are no longer produced. However, many are still in operation. They are mostly carbureted and share many features with the light aircraft systems previously discussed.

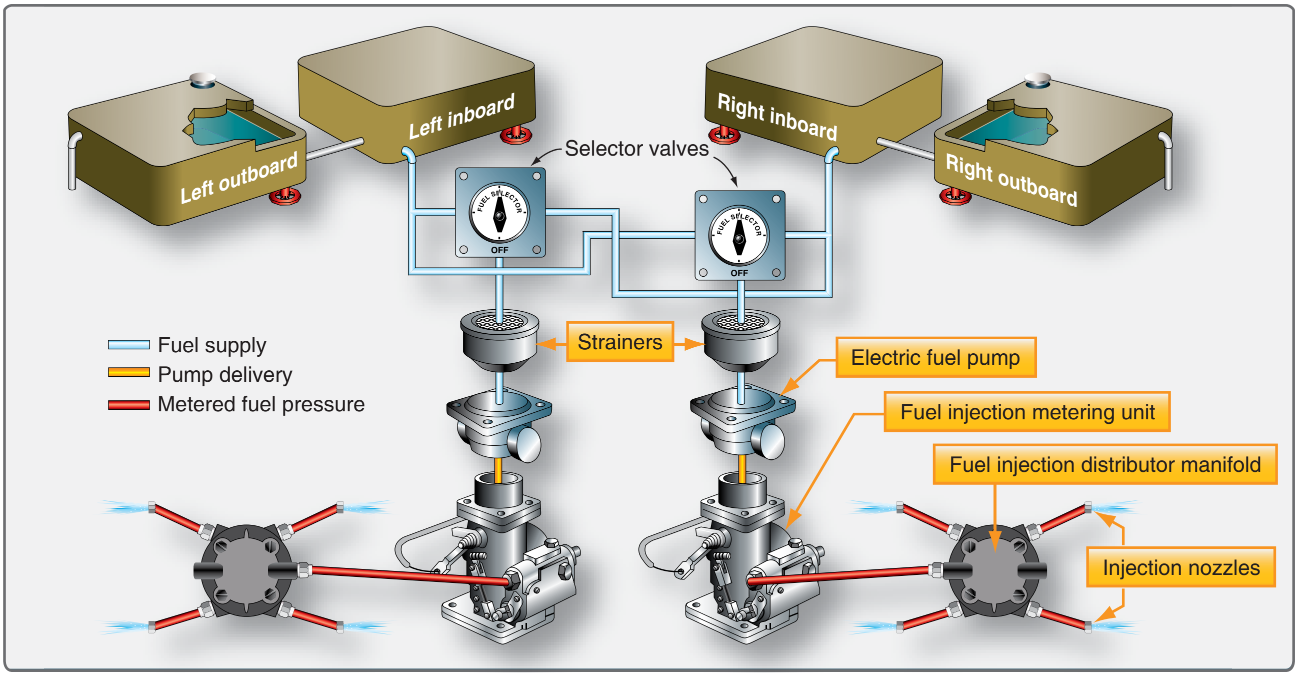


Figure 14-18. *A simple high-wing fuel injection fuel system for a light twin reciprocating-engine aircraft.*

Figure 14-19 shows the fuel system of a DC-3. A selector valve for each engine allows an engine-driven pump to pull fuel from the main tank or an auxiliary tank. The fuel passes through a strainer before reaching the pump where it is delivered to the engine. The outlet of the pump can feed either engine through the use of a crossfeed line with valves controlled in the cockpit. A hand-operated wobble pump located upstream of the strainer is used to prime the system for starting. Fuel vapor lines run from the pressure carburetor to the vent space in the main and auxilliary tanks. Fuel pressure gauges are tapped off of the carburetor for power indication.

The hand-operated wobble pumps were replaced by electric pumps on later model aircraft. A fuel pressure warning light tapped in downstream of the engine-driven fuel pump alerts the crew should fuel pressure decline.

Not all large, old aircraft have this fuel system. This is merely an example. Others aircraft share similar features and possess unique features of their own. The same is true for small reciprocating-engine aircraft. There are many systems that share features with those described above, but they also differ in some ways. Always consult the manufacturer's data when working on aircraft fuel systems and follow all instructions for service and repair. The fuel system of an aircraft provides the life blood for engine operation and must be maintained with the highest discretion.

Jet Transport Aircraft Fuel Systems

Fuel systems on large transport category jet aircraft are complex with some features and components not found in reciprocating-engine aircraft fuel systems. They typically contain more redundancy and facilitate numerous options from which the crew can choose while managing the aircraft's fuel load. Features like an onboard APU, single point pressure refueling, and fuel jettison systems, which are not needed on smaller aircraft, add to the complexity of an airliner fuel system.

Jet transport fuel systems can be regarded as a handful of fuel subsystems as follows:

1. Storage
2. Vent
3. Distribution
4. Feed
5. Indicating

Most transport category aircraft fuel systems are very much alike. Integral fuel tanks are the norm with much of each wing's structure sealed to enable its use as a fuel tank. Center wing section or fuselage tanks are also common. These may be sealed structure or bladder type. Jet transport aircraft carry tens of thousands of pounds of fuel on board. *Figure 14-20* shows a diagram of a Boeing 777 fuel tank configuration with tank capacities.

Note that there are optional fuel storage configurations available on the same model airliner. For example, airlines expecting to use an aircraft on transoceanic flights may order the aircraft with long-range auxiliary tanks. These

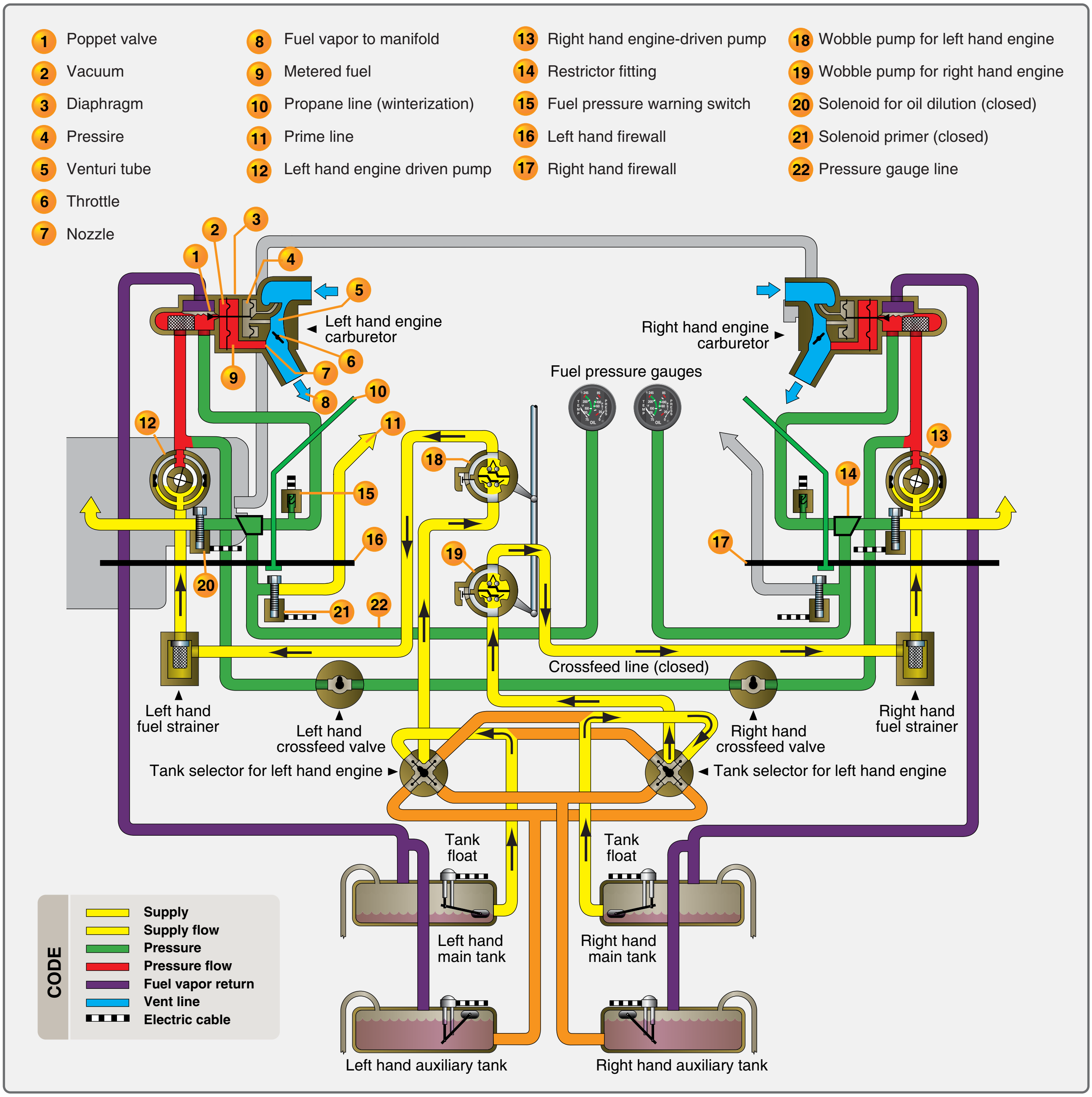


Figure 14-19. *DC-3 fuel system.*

additional tanks, usually located in the fuselage section of the aircraft, can alter fuel management logistics in addition to complicating the fuel system.

In addition to main and auxiliary fuel tanks, surge tanks may also be found on jet transports. These normally empty tanks located in the wing structure outboard of the main wing tanks are used for fuel overflow. A check valve allows the one-way drainage of fuel back into the main tanks. Surge tanks are also use for fuel system venting.

Transport category fuel systems require venting similar to reciprocating engine aircraft fuel systems. A series of vent tubing and channels exists that connects all tanks to vent space in the surge tanks (if present) or vent overboard. Venting must be configured to ensure the fuel is vented regardless of the attitude of the aircraft or the quantity of fuel on board. This sometimes requires the installation of various check valves, float valves, and multiple vent locations in the same tank. *Figure 14-21* shows the fuel vent system of a Boeing 737.

A transport category aircraft fuel distribution subsystem consists of the pressure fueling components, defueling components, transfer system, and fuel jettison or dump system. Single-point pressure fueling at a fueling station

Tank	Gallons	Pounds*
Left main tank	9,560	64,000
Right main tank	9,560	64,000
Center tank	26,100	174,900
Total	45,200	302,900

* Usable fuel at level attitude
Fuel density = 6.7 pounds per U.S. gallon.

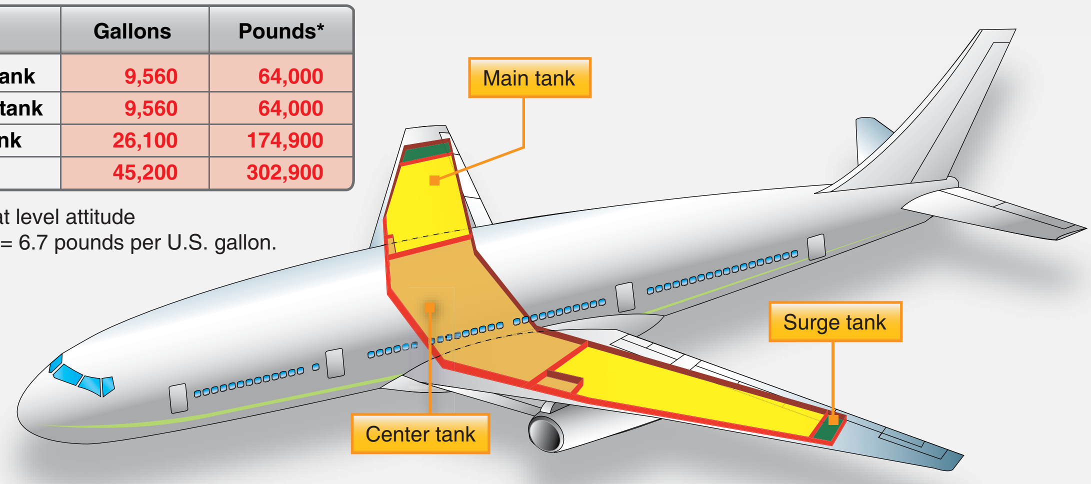


Figure 14-20. *Boeing 777 fuel tank locations and capacities.*

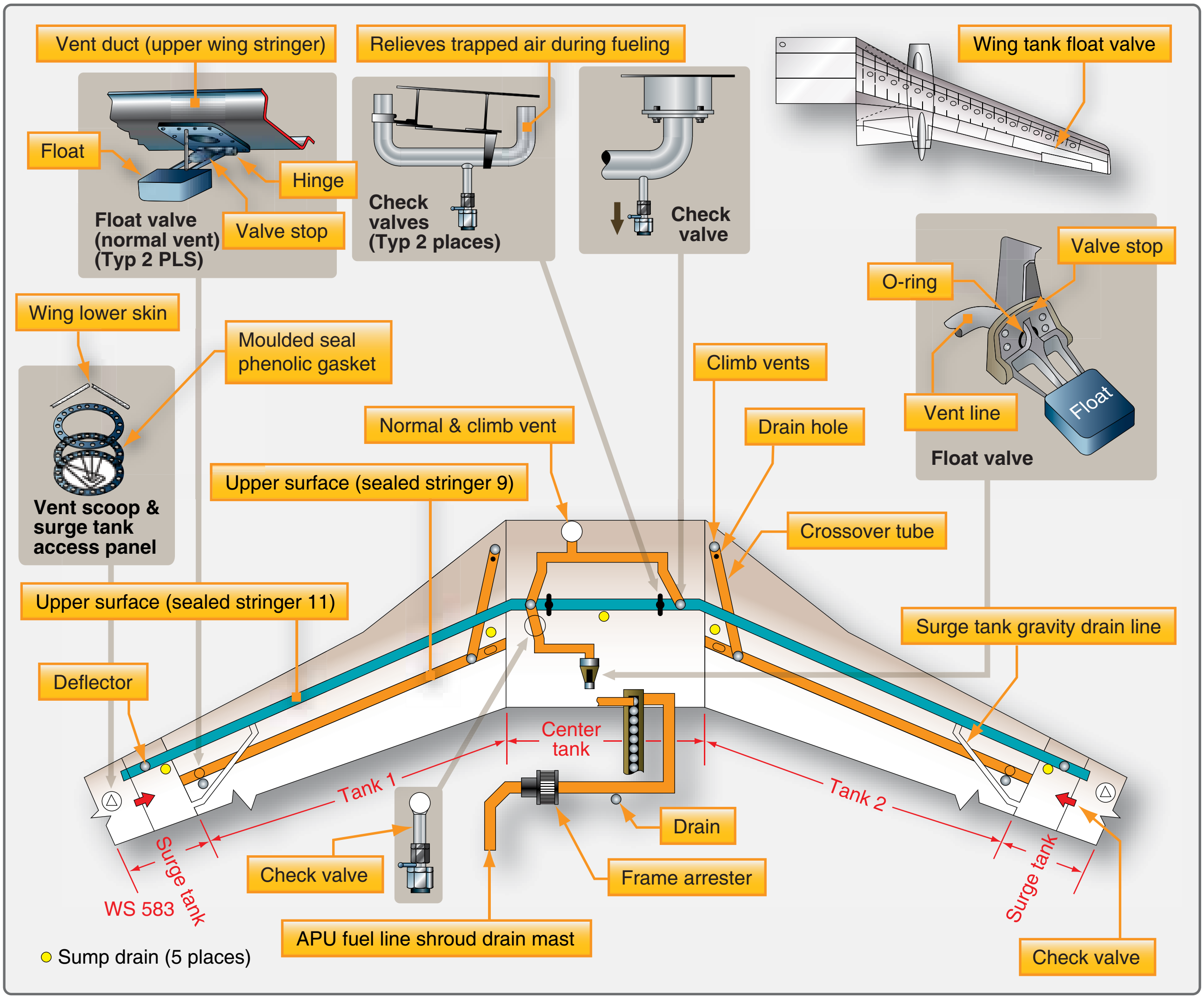


Figure 14-21. *A fuel vent system with associated float and check valves that stop fuel and keep the tanks vented regardless of the aircraft attitude.*

accessible by ramp refueling trucks allows all aircraft fuel tanks to be filled with one connection of the fuel hose. Leading and trailing edge wing locations are common for these stations. *Figure 14-22* shows an airliner fueling station with the fueling rig attached.

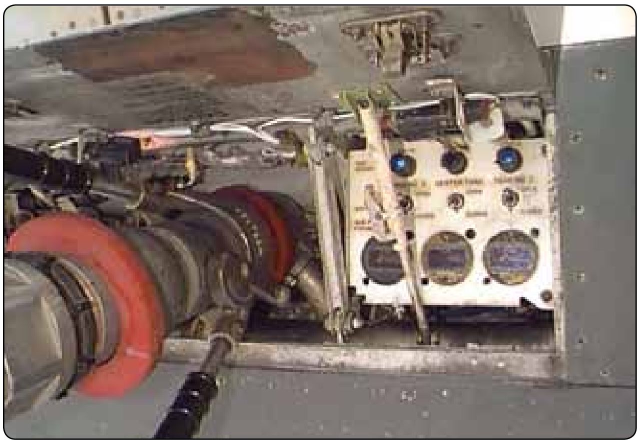


Figure 14-22. *A central pressure refueling station on a transport category aircraft allows all fuel tanks to be filled from one position.*

To fuel with pressure refueling, a hose nozzle is attached at the fueling station and valves to the tanks required to be filled are opened. These valves are called fueling valves or refueling valves depending upon the manufacturer's preference. Various automatic shutoff systems have been designed to close tank fueling valves before the tanks overfill or are damaged. Gauges on the refueling panel allow refueling personnel to monitor progress.

Occasionally, defueling the aircraft is required for an inspection or repair. The same fueling station is used, and the hose from the fuel truck is connected to same receptacle used to fuel the aircraft. To allow fuel to exit the aircraft, a defueling valve is opened. Fuel can either be pumped out of the aircraft using the boost pumps located in the tanks that need to be emptied, or the pump in the refueling truck can be used to draw the fuel out of the tanks. Control over the operation is maintained by positioning various shutoff and crossfeed valves, as well as the defuel valve so that fuel travels from the tank to the fueling station and into the truck. The fuel transfer system is a series of plumbing and valves that permits movement of fuel from one tank to another on board the aircraft. In-tank fuel boost pumps move the fuel into a manifold and, by opening the fuel valve (or refueling valve) for the desired tank, the fuel is transferred. Not all jet transports have such fuel transfer capability. Through the use of a fuel feed manifold and crossfeed valves, some aircraft simply allow engines to be run off fuel from any tank as a means for managing fuel location.

Figure 14-23 shows the fuel system diagram for a DC-10. Dedicated transfer boost pumps move fuel into a transfer manifold. Opening the fuel valve on one of the tanks transfers the fuel into that tank. The transfer manifold and boost pumps are also used to jettison fuel overboard by opening the proper dump valves with a transfer boost pump(s) operating. Additionally, the transfer system can function to supply the engines if the normal engine fuel feed malfunctions.

The fuel feed subsystem is sometimes considered part of the fuel distribution system. It is the heart of the fuel system since it delivers fuel to the engines. Jet transport aircraft supply fuel to the engines via in-tank fuel boost pumps, usually two per tank. They pump fuel under pressure through a shutoff valve for each engine. A manifold or connecting tubing typically allows any tank to supply any engine through the use of crossfeed valves. Boost pump bypasses allow fuel flow should a pump fail. Note that the engines are designed to be able to run without any fuel boost pumps operating. But, each engine's shutoff valve must be open to allow flow to the engines from the tanks.

Most jet transport fuel feed systems, or the engine fuel systems, have some means for heating the fuel usually through an exchange with hot air or hot oil taken from the engine. *Figure 14-24* shows the fuel cooled oil cooler (FCOC) on a Rolls Royce RB211 engine, which not only heats the fuel but also cools the engine oil.

Fuel indicating systems on jet transport aircraft monitor a variety of parameters, some not normally found on general aviation aircraft. Business jet aircraft share many of these features. True fuel flow indicators for each engine are used as the primary means for monitoring fuel delivery to the engines. A fuel temperature gauge is common as are fuel filter bypass warning lights. The temperature sensor is usually located in a main fuel tank. The indicator is located on the instrument panel or is displayed on a multifunction display (MFD). These allow the crew to monitor the fuel temperature during high altitude flight in extremely frigid conditions. The fuel filters have bypasses that permit fuel flow around the filters if clogged. Indicator light(s) illuminate in the cockpit when this occurs.

Low fuel pressure warning lights are also common on jet transport aircraft. The sensors for these are located in the boost pump outlet line. They give an indication of possible boost pump failure.

Fuel quantity gauges are important features on all aircraft. Indications exist for all tanks on a transport category aircraft. Often, these use a capacitance type fuel quantity indication system and a fuel totalizer as is discussed later in this chapter.

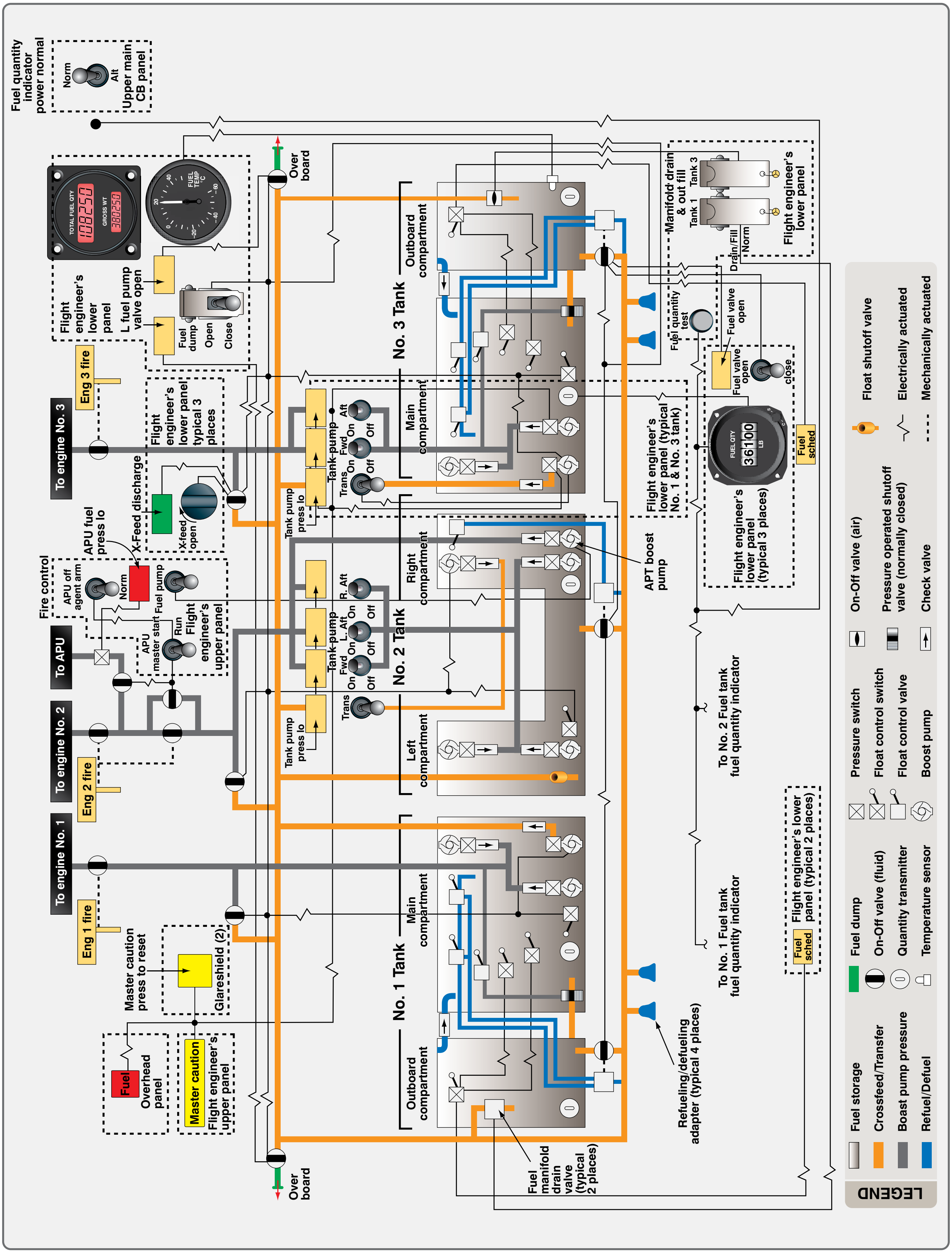


Figure 14-23. *The fuel distribution systems, components, and cockpit controls of a DC-10 airliner. Note: Fuel transfer system components and lines are used to complete the fuel dump system, the refuel/defuel system, back-up fuel delivery system, and the fuel storage system.*

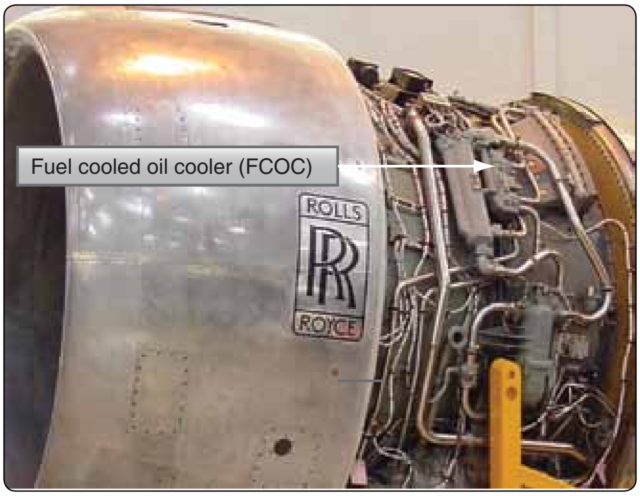


Figure 14-24. *Jet transport aircraft fly at high altitudes where temperatures can reach –50 °F. Most have fuel heaters somewhere in the fuel system to help prevent fuel icing. This fuel-cooled oil cooler on an RB211 turbofan engine simultaneously heats the fuel while cooling the oil.*

The location of fuel instrumentation varies depending on the type of cockpit displays utilized on the aircraft.

Helicopter Fuel Systems

Helicopter fuel systems vary. They can be simple or complex depending on the aircraft. Always consult the manufacturer's manuals for fuel system description, operation, and maintenance instructions.

Typically, a helicopter has only one or two fuel tanks located near the center of gravity (CG) of the aircraft, which is near the main rotor mast. Thus, the tank, or tanks, are usually located in or near the aft fuselage. Some helicopter fuel tanks are mounted above the engine allowing for gravity fuel feed. Others use fuel pumps and pressure feed systems.

Fundamentally, helicopter fuel systems differ little from those on fixed-wing aircraft. Gravity-feed systems have vented fuel tanks with an outlet strainer and shutoff valve. Fuel flows from the tank through a main filter to the carburetor. *[Figure 14-25]*

A slightly more complex system for a light turbine-powered helicopter is shown in *Figure 14-26*. Two in-tank electric boost pumps send fuel through a shutoff valve rather than a selector valve, since there is only one fuel tank. It flows through an airframe filter to an engine filter and then to the engine-driven fuel pump. The fuel tank is vented and contains an electrically operated sump drain valve. A pressure gauge is used to monitor boost pump output pressure and differential pressure switches warn of fuel filter restrictions. Fuel quantity is derived through the use of two in-tank fuel probes with transmitters.

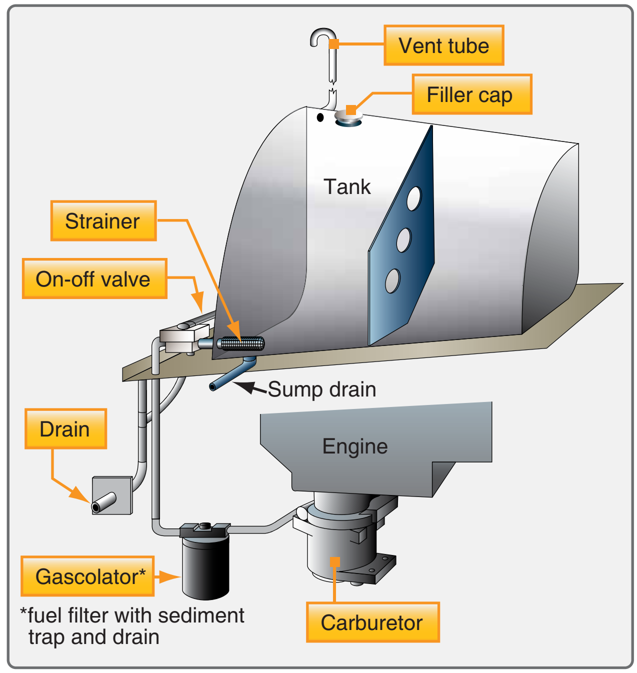


Figure 14-25. *A simple, gravity-feed fuel system on a Robinson helicopter.*

Larger, heavy, multiengine transport helicopters have complex fuel systems similar to jet transport fixed-wing aircraft. They may feature multiple fuel tanks, crossfeed systems, and pressure refueling.

Fuel System Components

To better understand aircraft fuel systems and their operation, the following discussion of various components of aircraft fuel systems is included.

Fuel Tanks

There are three basic types of aircraft fuel tanks: rigid removable tanks, bladder tanks, and integral fuel tanks. The type of aircraft, its design and intended use, as well as the age of the aircraft determine which fuel tank is installed in an aircraft. Most tanks are constructed of noncorrosive material(s). They are typically made to be vented either through a vent cap or a vent line. Aircraft fuel tanks have a low area called a sump that is designed as a place for contaminants and water to settle. The sump is equipped with a drain valve used to remove the impurities during preflight walk-around inspection. *[Figure 14-27]* Most aircraft fuel tanks contain some sort of baffling to subdue the fuel from shifting rapidly during flight maneuvers. Use of a scupper constructed around the fuel fill opening to drain away any spilled fuel is also common.

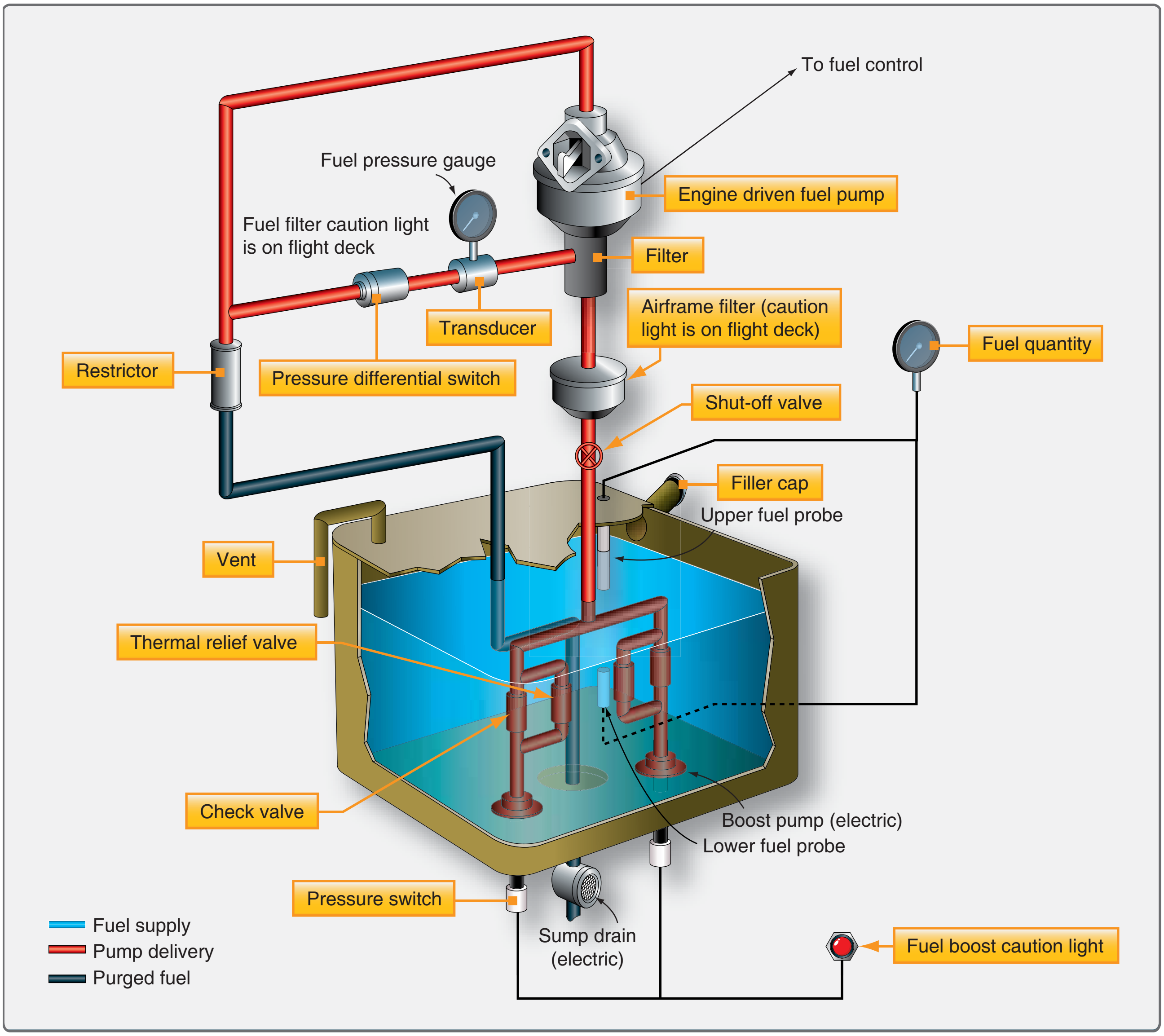


Figure 14-26. *A pressure-feed fuel system on a light turbine-powered helicopter.*

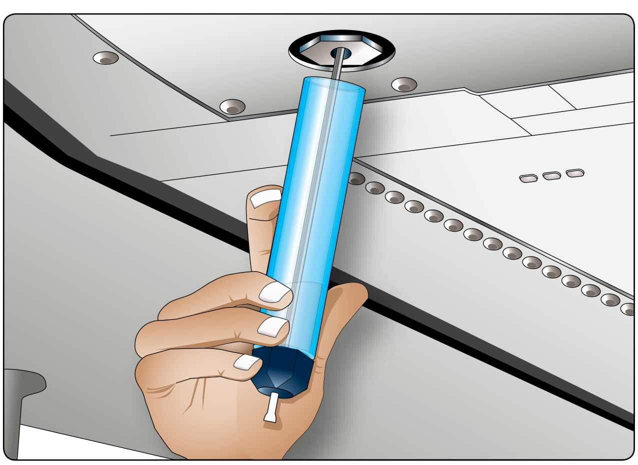


Figure 14-27. *Sumping a fuel tank with a fuel strainer that is designed to collect the sump drain material in the clear cylinder to be examined for the presence of contaminants.*

Rigid Removable Fuel Tanks

Many aircraft, especially older ones, utilize an obvious choice for fuel tank construction. A rigid tank is made from various materials, and it is strapped into the airframe structure. The tanks are often riveted or welded together and can include baffles, as well as the other fuel tank features described above. They typically are made from 3003 or 5052 aluminum alloy or stainless steel and are riveted and seam welded to prevent leaks. Many early tanks were made of a thin sheet steel coated with a lead/tin alloy called terneplate. The terneplate tanks have folded and soldered seams. *Figure 14-28* shows the parts of a typical rigid removable fuel tank.

Regardless of the actual construction of removable metal tanks, they must be supported by the airframe and held in place with some sort of padded strap arrangement to resist

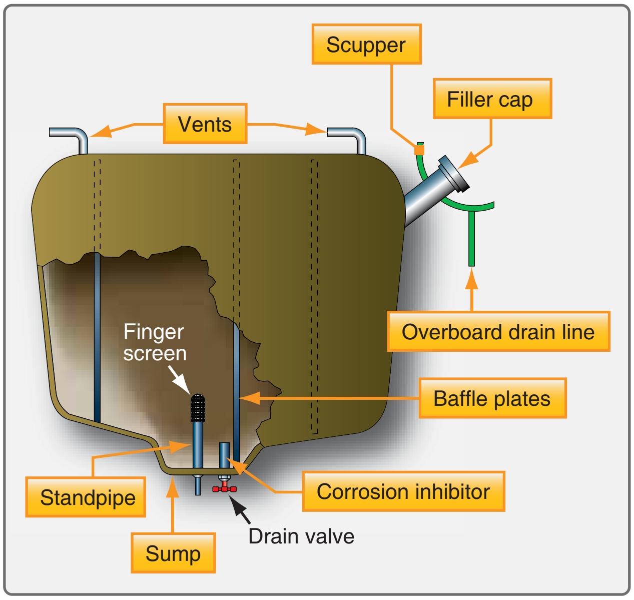


Figure 14-28. *A typical rigid removable aircraft fuel tank and its parts.*

Figure 14-30. *A fuselage tank for a light aircraft.*

shifting in flight. The wings are the most popular location for fuel tanks. *Figure 14-29* shows a fuel tank bay in a wing root with the tank straps. Some tanks are formed to be part of the leading edge of the wing. These are assembled using electric resistance welding and are sealed with a compound that is poured into the tank and allowed to cure. Many fuselage tanks also exist. *[Figure 14-30]* In all cases, the structural integrity of the airframe does not rely on the tank(s) being installed, so the tanks are not considered integral.

Figure 14-29. *A fuel tank bay in the root of a light aircraft wing on a stand in a paint booth. Padded straps hold the fuel tank securely in the structure.*

Note that as new materials are tested and used in aircraft, fuel tanks are being constructed out of materials other than aluminum, steel, and stainless steel. *Figure 14-31* shows a rigid removable fuel tank

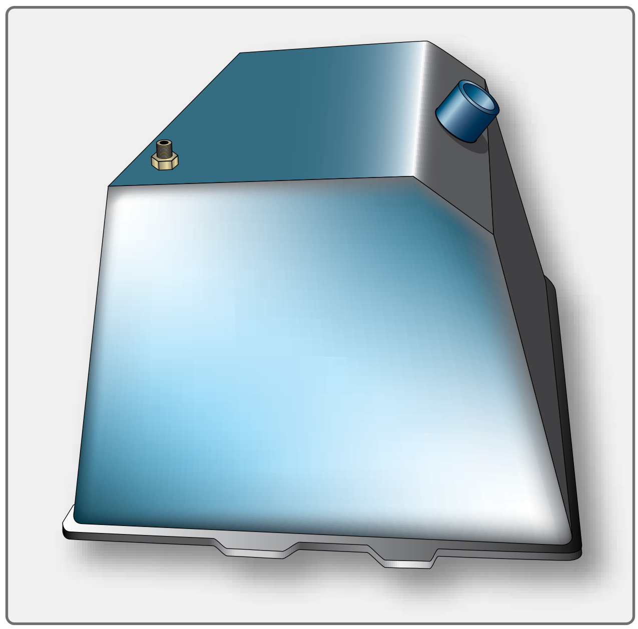


Figure 14-31. *A composite tank from a Challenger ultralight aircraft.*

from an ultralight category aircraft that is constructed from Vipel® isophthalic polyester UL 1316/UL 1746 resin and composite. Its seamless, lightweight construction may lead to the use of this type of tank in other aircraft categories in the future.

Being able to remove and repair, or replace, a fuel tank can be a great convenience if a leak or malfunction with the tank exists. Repairs to fuel tanks must be done in accordance with manufacturer's specifications. It is especially critical to follow all safety procedures when welding repairs are performed. Fuel vapors must be removed from the tank to prevent explosion. This typically involves washing out the tank with water and detergent, as well as some number of minutes that steam or water should be run through the tank (time varies by manufacturer). Once repaired, fuel tanks need to be pressure checked, usually while installed in the airframe, to prevent distortion while under pressure.

Bladder Fuel Tanks

A fuel tank made out of a reinforced flexible material called a bladder tank can be used instead of a rigid tank. A bladder tank contains most of the features and components of a rigid tank but does not require as large an opening in the aircraft skin to install. The tank, or fuel cell as it is sometimes called, can be rolled up and put into a specially prepared structural bay or cavity through a small opening, such as an inspection opening. Once inside, it can be unfurled to its full size. Bladder tanks must be attached to the structure with clips or other fastening devices. They should lie smooth and unwrinkled in the bay. It is especially important that no wrinkles exist on the bottom surface so that fuel contaminants are not blocked from settling into the tank sump. *[Figure 14-32]*

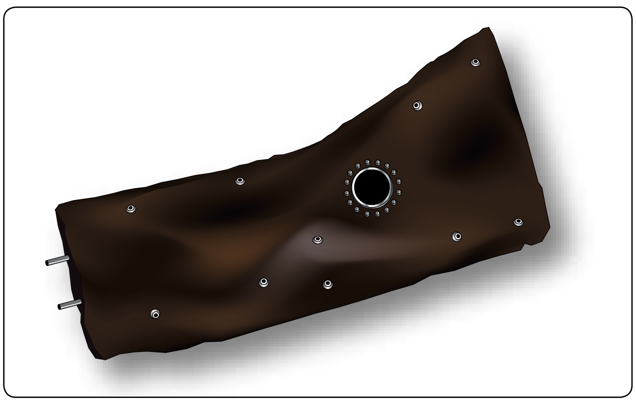


Figure 14-32. *A bladder fuel tank for a light aircraft.*

Bladder fuel tanks are used on aircraft of all size. They are strong and have a long life with seams only around installed features, such as the tank vents, sump drain, filler spout, etc. When a bladder tank develops a leak, the technician can patch it following manufacturer's instructions. The cell can also be removed and sent to a fuel tank repair station familiar with and equipped to perform such repairs.

The soft flexible nature of bladder fuel tanks requires that they remain wet. Should it become necessary to store a bladder tank without fuel in it for an extended period of time, it is common to wipe the inside of the tank with a coating of clean engine oil. Follow the manufacturer's instructions for the dry storage procedures for fuel cells.

Integral Fuel Tanks

On many aircraft, especially transport category and high-performance aircraft, part of the structure of the wings or fuselage is sealed with a fuel resistant two-part sealant to form a fuel tank. The sealed skin and structural members provide the highest volume of space available with the lowest weight. This type of tank is called an integral fuel tank since it forms a tank as a unit within the airframe structure.

Integral fuel tanks in the otherwise unused space inside the wings are most common. Aircraft with integral fuel tanks in the wings are said to have wet wings. For fuel management purposes, sometimes a wing is sealed into separate tanks and may include a surge tank or an overflow tank, which is normally empty but sealed to hold fuel when needed.

When an aircraft maneuvers, the long horizontal nature of an integral wing tank requires baffling to keep the fuel from sloshing. The wing ribs and box beam structural members serve as baffles and others may be added specifically for that purpose. Baffle check valves are commonly used. These valves allow fuel to move to the low, inboard sections of the tank but prevent it from moving outboard. They ensure that the fuel boost pumps located in the bottom of the tanks at the lowest points above the sumps always have fuel to pump regardless of aircraft attitude. *[Figure 14-33]*

Integral fuel tanks must have access panels for inspection and repairs of the tanks and other fuel system components. On large aircraft, technicians physically enter the tank for maintenance. Transport category aircraft often have more than a dozen oval access panels or tank plates on the bottom surface of the wing for this purpose. *[Figure 14-34A]* These aluminum panels are each sealed into place with an O-ring and an aluminum gasket for electrostatic bonding. An outer clamp ring is tightened to the inner panel with screws, as shown in *Figure 14-34B.*

When entering and performing maintenance on an integral fuel tank, all fuel must be emptied from the tank and strict safety procedures must be followed. Fuel vapors must be purged from the tank and respiratory equipment must be used by the technician. A full-time spotter must be positioned just outside of the tank to assist if needed.

Aircraft using integral fuel tanks normally have sophisticated fuel systems that include in-tank boost pumps. There are usually at least two pumps in each tank that deliver fuel to the engine(s) under positive pressure. On various aircraft, these in-tank boost pumps are also used to transfer fuel to other tanks, jettison fuel, and defuel the aircraft.

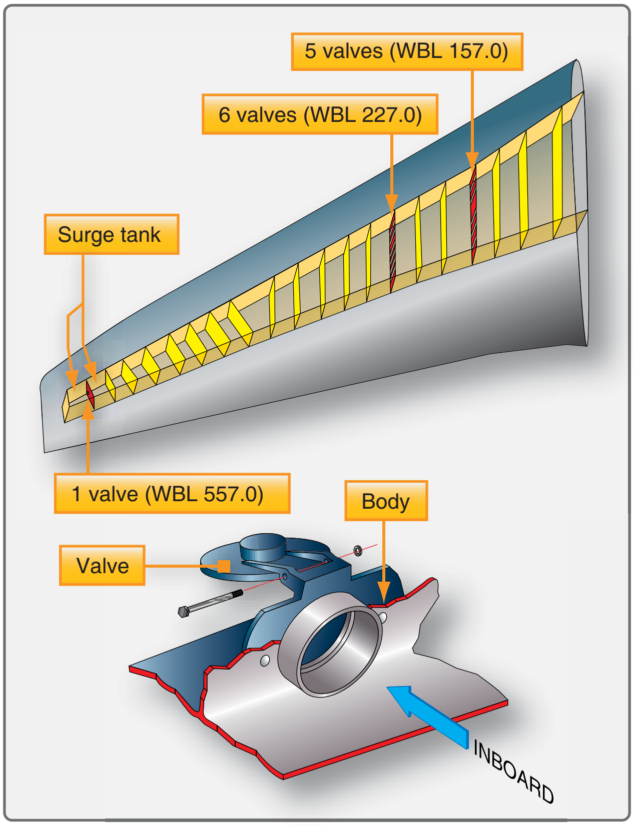


Figure 14-33. *Baffle check valves are installed in the locations shown in the integral tank rib structure of a Boeing 737 airliner. Fuel is prevented from flowing outboard during maneuvers. The tank boost pumps are located inboard of WBL 157.*

Fuel Lines and Fittings

Aircraft fuel lines can be rigid or flexible depending on location and application. Rigid lines are often made of aluminum alloy and are connected with Army/Navy (AN) or military standard (MS) fittings. However, in the engine compartment, wheel wells, and other areas, subject to damage from debris, abrasion, and heat, stainless steel lines are often used.

Flexible fuel hose has a synthetic rubber interior with a reinforcing fiber braid wrap covered by a synthetic exterior. *[Figure 14-35]* The hose is approved for fuel and no other hose should be substituted. Some flexible fuel hose has a braided stainless steel exterior. *[Figure 14-36]* The diameters of all fuel hoses and line are determined by the fuel flow requirements of the aircraft fuel system. Flexible hoses are used in areas where vibration exists between components, such as between the engine and the aircraft structure.

Sometimes manufacturers wrap either flexible or rigid fuel lines to provide even further protection from abrasion and especially from fire. A fire sleeve cover is held over the line with steel clamps at the end fittings. *[Figure 14-37]*

As mentioned, aircraft fuel line fitting are usually either AN or MS fittings. Both flared and flareless fitting are used. Problems with leaks at fittings can occur. Technicians are cautioned to not overtighten a leaky fitting. If the proper torque does not stop a leak, depressurize the line, disconnect the fitting and visually inspect it for a cause. The fitting or line should be replaced if needed. Replace all aircraft fuel lines and fittings with approved replacement parts from the manufacturer. If a line is manufactured in the shop, approved components must be used.

Several installation procedures for fuel hoses and rigid fuel lines exist. Hoses should be installed without twisting. The writing printed on the outside of the hose is used as a lay line to monitor fuel hose twist. Separation should be maintained between all fuel hoses and electrical wiring. Never clamp wires to a fuel line. When separation is not possible, always route the fuel line below any wiring. If a fuel leak develops, it does not drip onto the wires.

Metal fuel lines and all aircraft fuel system components need to be electrically bonded and grounded to the aircraft structure. This is important because fuel flowing through the fuel system generates static electricity that must have a place to flow to ground rather than build up. Special bonded cushion clamps are used to secure rigid fuel lines in place. They are supported at intervals shown in *Figure 14-38.*

All fuel lines should be supported so that there is no strain on the fittings. Clamp lines so that fittings are aligned. Never draw two fittings together by threading. They should thread easily and a wrench should be used only for tightening. Additionally, a straight length of rigid fuel line should not be made between two components or fitting rigidly mounted to the airframe. A small bend is needed to absorb any strain from vibration or expansion and contraction due to temperature changes.

Fuel Valves

There are many fuel valve uses in aircraft fuel systems. They are used to shut off fuel flow or to route the fuel to a desired location. Other than sump drain valves, light aircraft fuel systems may include only one valve, the selector valve. It incorporates the shutoff and selection features into a single valve. Large aircraft fuel systems have numerous valves. Most simply open and close and are know by different names related to their location and function in the fuel system (e.g., shutoff valve, transfer valve, crossfeed valve). Fuel valves can be manually operated, solenoid operated, or operated by electric motor.

A feature of all aircraft fuel valves is a means for positively identifying the position of the valve at all times. Hand-operated valves accomplish this through the use of detents

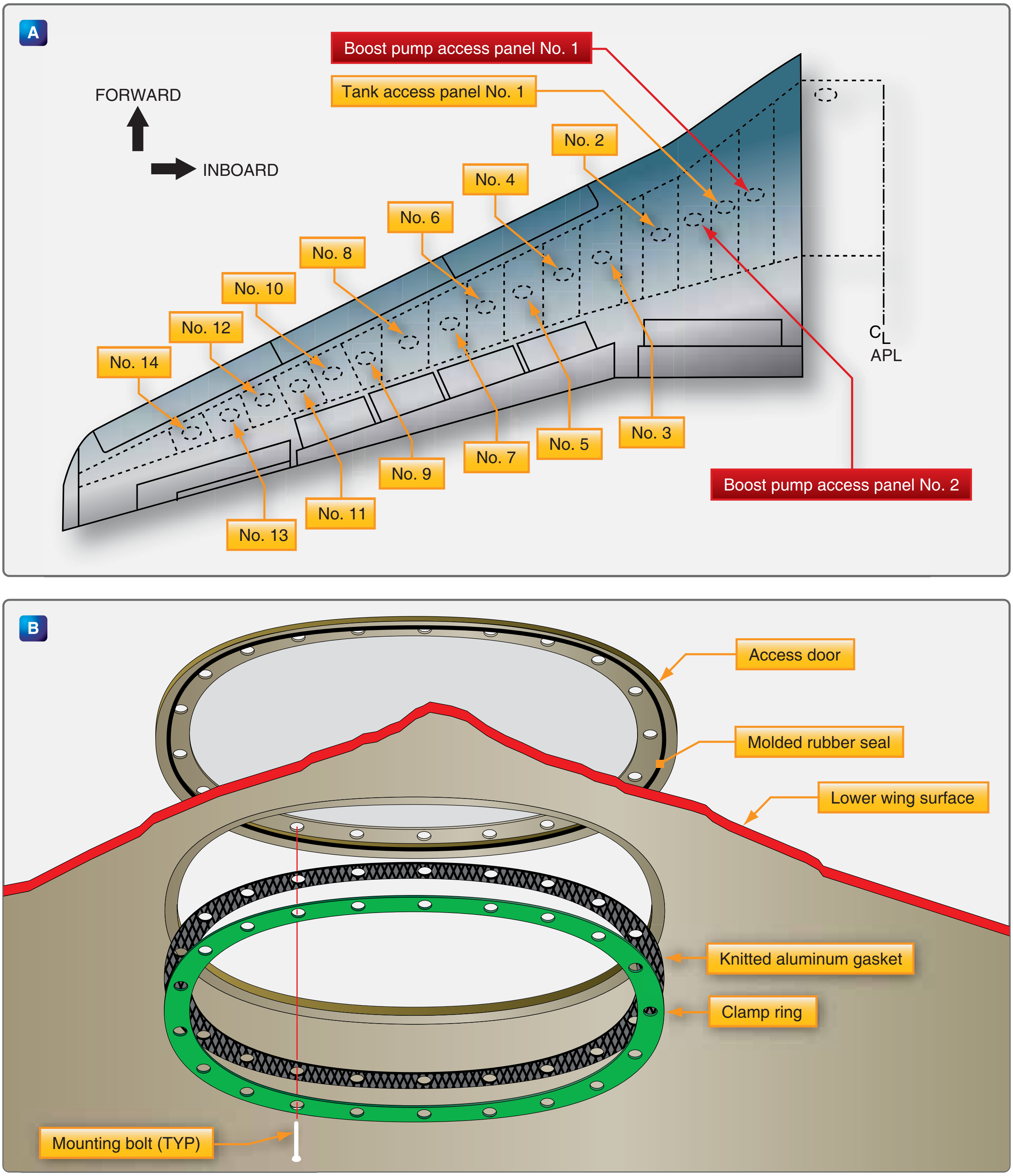


Figure 14-34. *Fuel tank access panel locations on a Boeing 737 (A), and typical fuel tank access panel seals (B).*

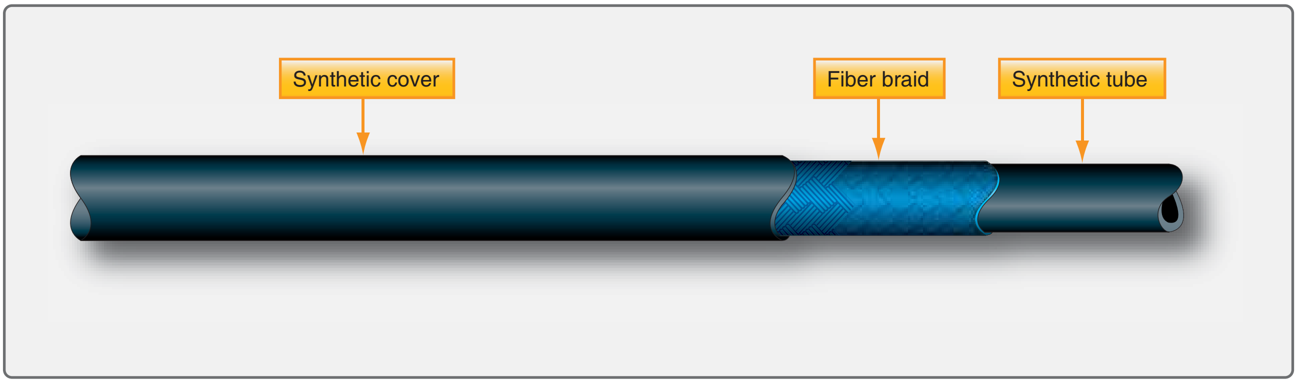


Figure 14-35. *A typical flexible aircraft fuel line with braided reinforcement.*

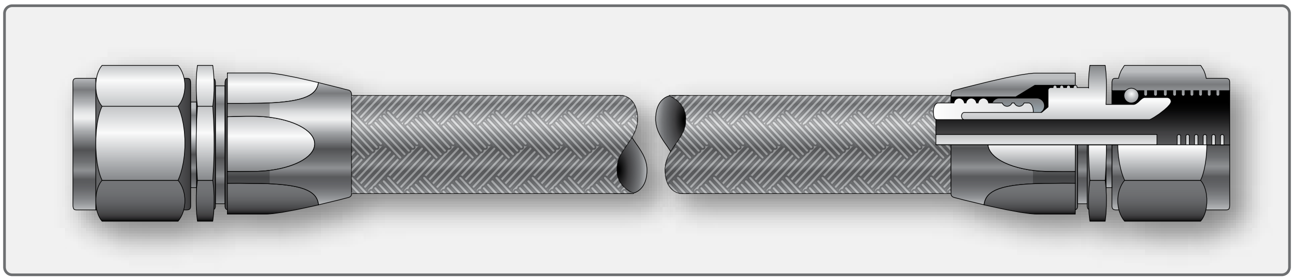


Figure 14-36. *A braided stainless steel exterior fuel line with fittings.*

Figure 14-37. *Exterior fuel hose wrap that protects from fire, as well as abrasion, shown with the clamps and pliers used to install it.*

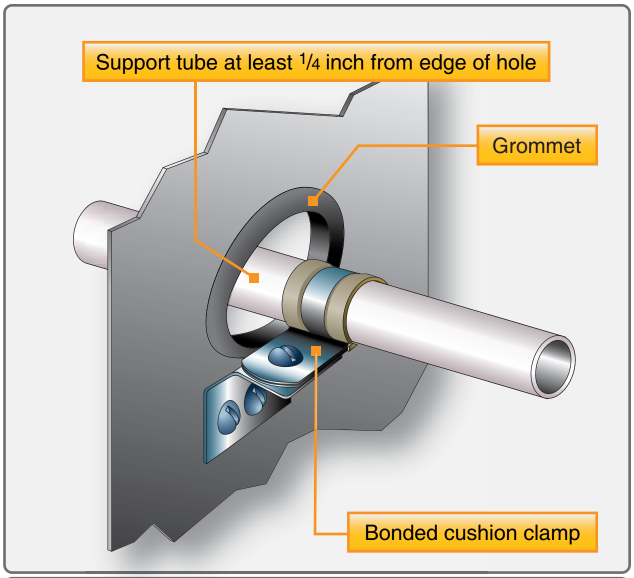
into which a spring-loaded pin or similar protrusion locates when the valve is set in each position. Combined with labels and a directional handle, this makes it easy to identify by feel and by sight that the valve is in the desired position. *[Figure 14-39]* Motor- and solenoid-operated valves use position annunciator lights to indicate valve position in addition to the switch position. Flight management system (FMS) fuel pages also display the position of the fuel valves graphically in diagrams called up on the flat screen monitors. *[Figure 14-40]* Note that many valves have an exterior position handle, or lever, that indicates valve position. When maintenance personnel directly observe the valve, it can be manually positioned by the technician using this same lever. *[Figure 14-41]*

Hand-Operated Valves

There are three basic types of hand-operated valves used in aircraft fuel systems. The cone-type valve and the poppet-type valve are commonly used in light general aviation aircraft as fuel selector valves. Gate valves are used on transport category aircraft as shutoff valves. While many are motor operated, there are several applications in which gate valves are hand operated.

Cone Valves

A cone valve, also called a plug valve, consists of a machined valve housing into which a rotatable brass or nylon cone is set. The cone is manually rotated by the pilot with an attached handle. Passageways are machined through the



Tubing OD (inch)	Approximate distance between supports (inches)
1/8 to 3/16	9
1/4 to 5/16	12
3/8 to 1/2	16
5/8 to 3/4	22
7 to 1 1/4	30
1 1/2 to 2	40

Figure 14-38. *Rigid metallic fuel lines are clamped to the airframe with electrically bonded cushion clamps at specified intervals.*

cone so that, as it is rotated, fuel can flow from the selected source to the engine. This occurs when the passageway aligns with the desired fuel input port machined into the housing. *Figure 14-42* shows a cross sectional view of a cone valve. The cone can also be rotated to a position so that the passageway(s) does not align with any fuel input port. This is the fuel OFF position of the valve.

Poppet Valves

Selector valves are also commonly the poppet type. As the handle is rotated in this valve, a cam on the attached shaft lifts the poppet off the seat of the desired port being selected. At the same time, spring-assisted poppets close off the ports that are not selected. Detents lock the valve into position when the cam pushes a poppet fully off of its seat. There is also a positive detent when the cam engages none of the poppets, which is the OFF position of the valve. *[Figure 14-43]* Note that a similar mechanism is use in some selector valves, but balls are used instead of poppets.

Manually-Operated Gate Valves

A single selector valve is not used in complex fuel systems of transport category aircraft. Fuel flow is controlled with a series of ON/OFF, or shutoff, type valves that are plumbed

Figure 14-39. *Detents for each position, an indicating handle, and labeling aid the pilot in knowing the position of the fuel valve.*

Figure 14-40. *The graphic depiction of the fuel system on this electronic centralized aircraft monitor (ECAM) fuel page includes valve position information.*

Figure 14-41. *This motor-operated gate valve has a red position indicating lever that can be used by maintenance personnel to identify the position of the valve. The lever can be moved by the technician to position the valve.*

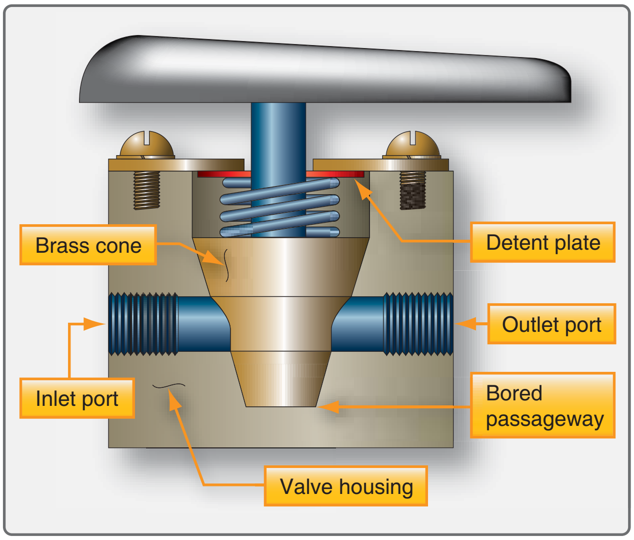


Figure 14-42. *A cone valve is open when the bored cone aligns the inlet and the outlet ports. It shuts off the flow when the un-bored portion of the cone is aligned with the inlet port(s).*

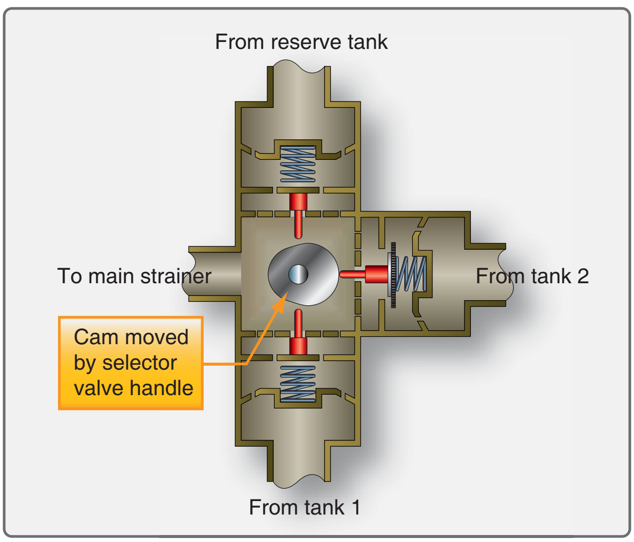


Figure 14-43. *The internal mechanism of a poppet-type fuel selector valve.*

between system components. Hand-operated gate valves can be used, especially as fire control valves, requiring no electrical power to shutoff fuel flow when the emergency fire handle is pulled. The valves are typically positioned in the fuel feed line to each engine. Hand-operated gate valves are also featured as ground-operated defuel valves and boost pump isolation valves, which shut off the fuel to the inlet of the boost pump, allowing it to be changed without emptying the tank.

Gate valves utilize a sealed gate or blade that slides into the path of the fuel, blocking its flow when closed. *Figure 14-44* shows a typical hand-operated gate valve. When the handle is rotated, the actuating arm inside the valve

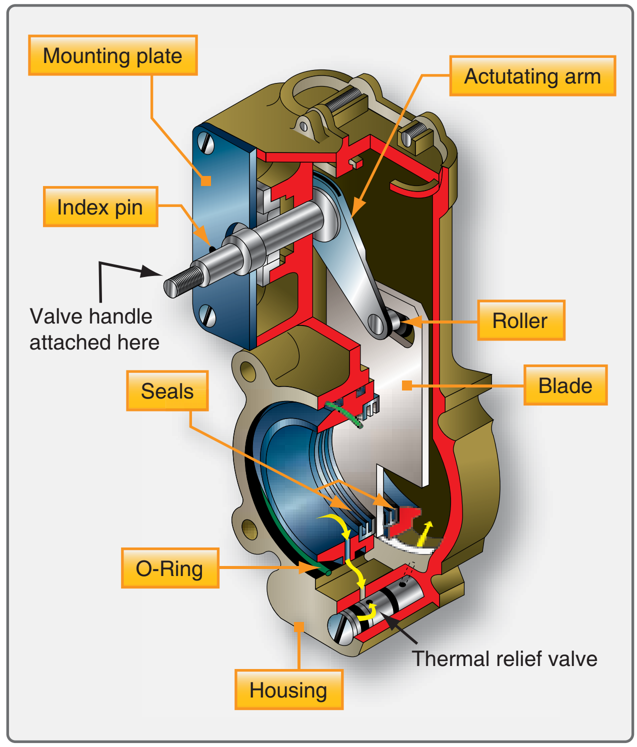


Figure 14-44. *A hand-operated gate valve used in transport category aircraft fuel systems.*

moves the gate blade down between seals and into the fuel flow path. A thermal relief bypass valve is incorporated to relieve excess pressure buildup against the closed gate due to temperature increases.

Motor-Operated Valves

The use of electric motors to operate fuel system valves is common on large aircraft due to the remote location from the cockpit of fuel system components. The types of valves used are basically the same as the manually operated valves, but electric motors are used to actuate the units. The two most common electric motor operated fuel valves are the gate valve and the plug-type valve.

The motor-operated gate valve uses a geared, reversible electric motor to turn the actuating arm of the valve that moves the fuel gate into or out of the path of the fuel. As with the manually operated gate valve, the gate or blade is sealed. A manual override lever allows the technician to observe the position of the valve or manually position it. *[Figure14-45]* Less common is the use of a motorized plug-type fuel valve; an electric motor is used to rotate the plug or drum rather than it being rotated manually. Regardless of the type of valve used, large aircraft fuel system valves either allow fuel to flow or shut off flow.

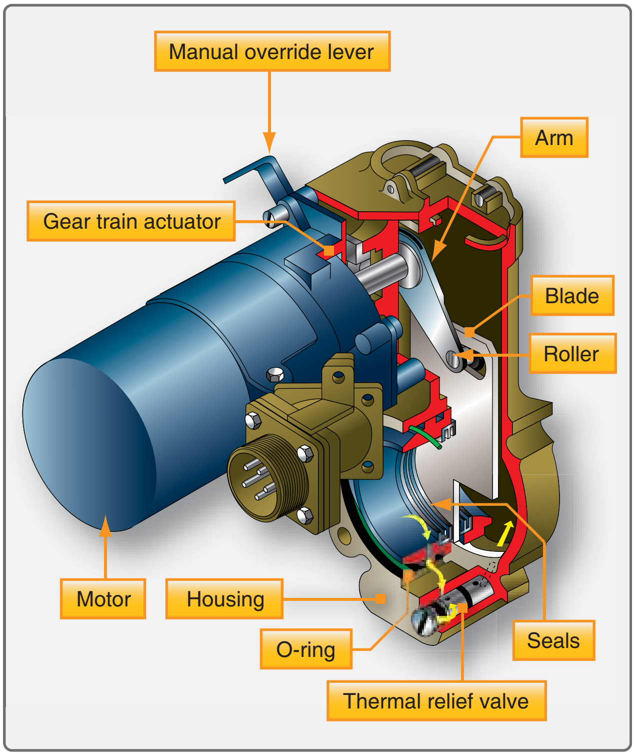


Figure 14-45. *An electric motor-driven gate valve commonly used in large aircraft fuel systems.*

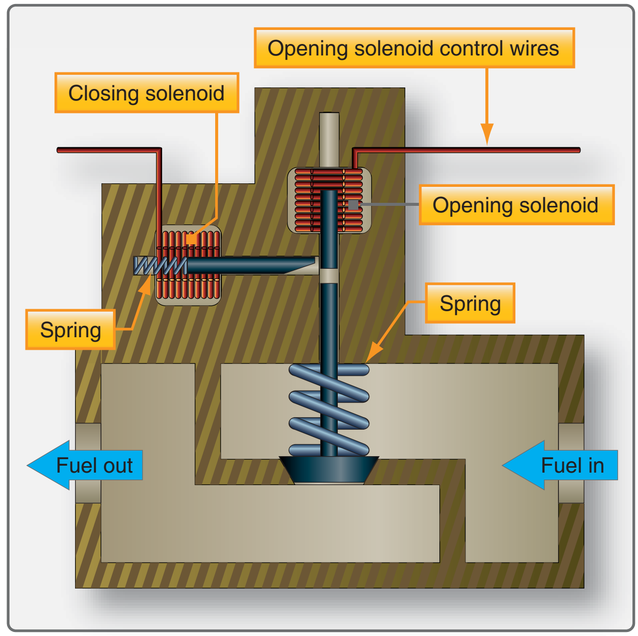


Figure 14-46. *A solenoid-operated fuel valve uses the magnetic force developed by energized solenoids to open and close a poppet.*

Solenoid-Operated Valves

An additional way to operate a remotely located fuel valve is through the use of electric solenoids. A poppet-type valve is opened via the magnetic pull developed when an opening solenoid is energized. A spring forces a locking stem into a notch in the stem of the poppet to lock the valve in the open position. Fuel then flows through the opening vacated by the poppet. To close the poppet and shut off fuel flow, a closing solenoid is energized. Its magnetic pull overcomes the force of the locking stem spring and pulls the locking stem out of the notch in the poppet stem. A spring behind the poppet forces it back onto its seat. A characteristic of solenoid-operated fuel valves is that they open and close very quickly. *[Figure 14-46]*

Fuel Pumps

Other than aircraft with gravity-feed fuel systems, all aircraft have at least one fuel pump to deliver clean fuel under pressure to the fuel metering device for each engine. Engine-driven pumps are the primary delivery device. Auxiliary pumps are used on many aircraft as well. Sometimes known as booster pumps or boost pumps, auxiliary pumps are used to provide fuel under positive pressure to the engine-driven pump and during starting when the engine-driven pump is not yet up to speed for sufficient fuel delivery. They are also used to back up the engine-driven pump during takeoff and at high altitude to guard against vapor lock. On many large aircraft, boost pumps are used to move fuel from one tank to another.

There are many different types of auxiliary fuel pumps in use. Most are electrically operated, but some hand-operated pumps are found on older aircraft. A discussion of the various pump types found in the aviation fleet follows.

Hand-Operated Fuel Pumps

Some older reciprocating engine aircraft have been equipped with hand-operated fuel pumps. They are used to back up the engine-driven pump and to transfer fuel from tank to tank. The wobble pumps, as they are known, are double-acting pumps that deliver fuel with each stroke of the pump handle. They are essentially vane-type pumps that have bored passages in the center of the pump, allowing a back-and-forth motion to pump the fuel rather than a full revolution of the vanes as is common in electrically driven or engine-driven vane-type pumps.

Figure 14-47 illustrates the mechanism found in a wobble pump. As the handle is moved down from where it is shown, the vane on the left side of the pump moves up, and the vane on the right side of the pump moves down. As the left vane moves up, it draws fuel into chamber A. Because chambers A and D are connected through the bored center, fuel is also drawn into chamber D. At the same time, the right vane forces fuel out of chamber B, through the bored passage in the center of the pump, into chamber C and out the fuel outlet through the check valve at the outlet of chamber C. When the handle is moved up again, the left vane moves down, forcing fuel out of chambers A and D because the check valve at the inlet of the A chamber prevents fuel from flowing back through the fuel inlet. The right vane moves up simultaneously and draws fuel into chambers B and C.

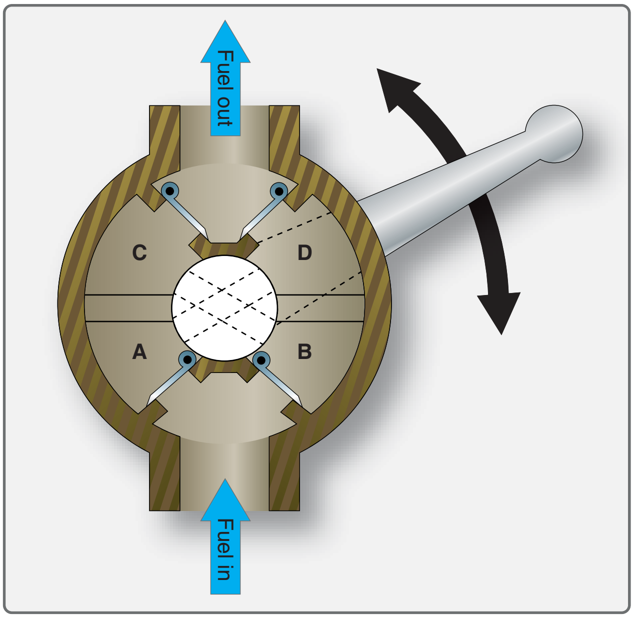


Figure 14-47. *A hand-operated wobble pump used for engine starting and fuel transfer on older transport category aircraft.*

While simple with little to go wrong, a hand-operated pump requires fuel lines to be run into the cockpit to the pump, creating a potential hazard that can be avoided by the use of an electrically driven pump. Modern light reciprocating-engine aircraft usually use electric auxiliary pumps, but they often make use of a simple hand pump for priming the engine(s) during starting. These simple devices are single-acting piston pumps that pull fuel into the pump cylinder when the primer knob is pulled aft. When pushed forward, the fuel is pumped through lines to the engine cylinders. *[Figure 14-48]*

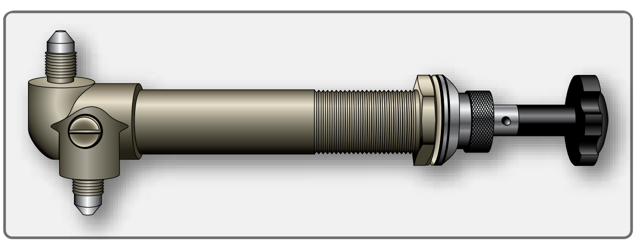


Figure 14-48. *This engine primer pump is a hand-operated piston type. It is mounted in the instrument panel and extends through the firewall where fuel intake and delivery lines are attached to the fittings on the left.*

Centrifugal Boost Pumps

The most common type of auxiliary fuel pump used on aircraft, especially large and high-performance aircraft, is the centrifugal pump. It is electric motor driven and most frequently is submerged in the fuel tank or located just outside of the bottom of the tank with the inlet of the pump extending into the tank. If the pump is mounted outside the tank, a pump removal valve is typically installed so the pump can be removed without draining the fuel tank. *[Figure 14-49]*

A centrifugal boost pump is a variable displacement pump. It takes in fuel at the center of an impeller and expels it to the outside as the impeller turns. *[Figure 14-50]* An outlet check valve prevents fuel from flowing back through the pump. A fuel feed line is connected to the pump outlet. A bypass valve may be installed in the fuel feed system to allow the engine-driven pump to pull fuel from the tank if the boost pump is not operating. The centrifugal boost pump is used to supply the engine-driven fuel pump, back up the engine-driven fuel pump, and transfer fuel from tank to tank if the aircraft is so designed.

Some centrifugal fuel pumps operate at more than one speed, as selected by the pilot, depending on the phase of aircraft operation. Single-speed fuel pumps are also common. Centrifugal fuel pumps located in fuel tanks ensure positive pressure throughout the fuel system regardless of temperature, altitude, or flight attitude thus preventing vapor lock. Submerged pumps have fuel proof covers for the electric motor since the motor is in the fuel. Centrifugal pumps mounted on the outside of the tank do not require this but have some sort of inlet that is located in the fuel. This can be a tube in which a shutoff valve is located so the pump can be changed without draining the tank. The inlet of both types of centrifugal pump is covered with a screen to prevent the ingestion of foreign matter. *[Figure 14-51]*

Ejector Pumps

Fuel tanks with in-tank fuel pumps, such as centrifugal pumps, are constructed to maintain a fuel supply to the pump inlet at all times. This ensures that the pump does not cavitate and that the pump is cooled by the fuel. The section of the fuel tank dedicated for the pump installation may be partitioned off with baffles that contain check valves, also known as flapper valves. These allow fuel to flow inboard to the pump during maneuvers but does not allow it to flow outboard.

Some aircraft use ejector pumps to help ensure that liquid fuel is always at the inlet of the pump. A relatively small diameter line circulates pump outflow back into the section of the tank where the pump is located. The fuel is directed through a venturi that is part of the ejector. As the fuel rushes through the venturi, low pressure is formed. An inlet, or line that originates outside of the tank pump area, allows fuel to be drawn into the ejector assembly where it is pumped into the fuel pump tank section. Together, with baffle check valves, ejector pumps keep a positive head of fuel at the inlet of the pump. *[Figure 14-52]*

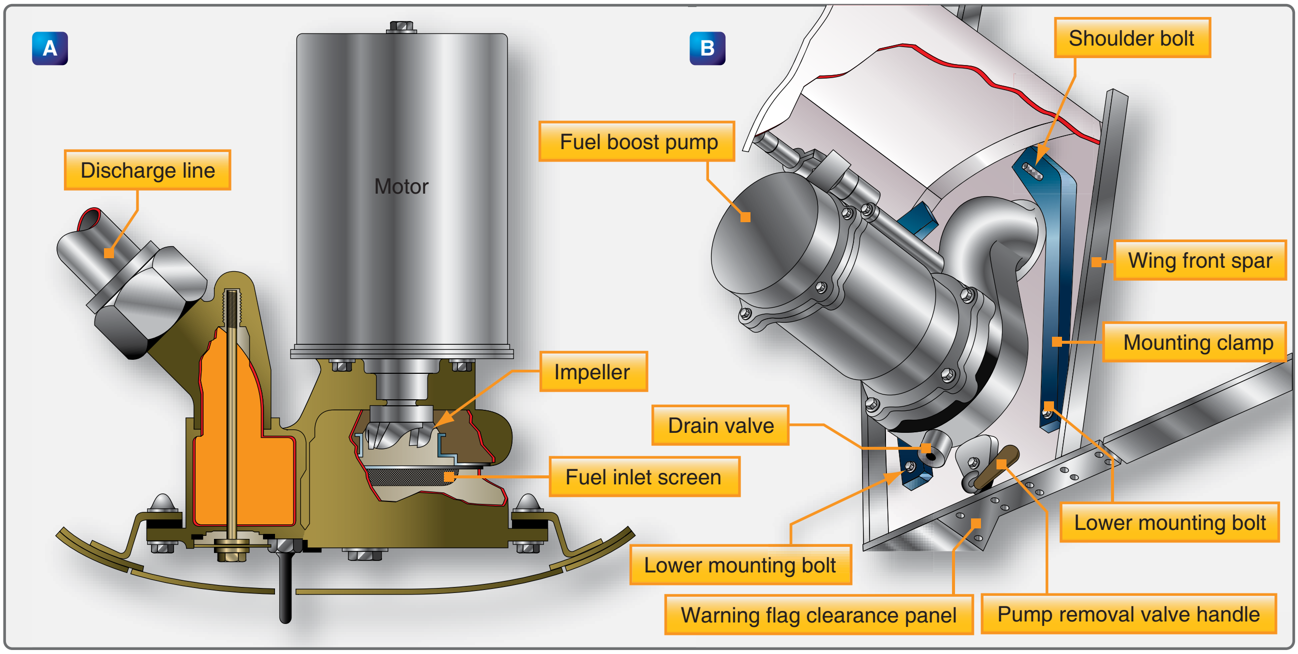


Figure 14-49. *A centrifugal fuel boost pump can be submersed in the fuel tank (A) or can be attached to the outside of the tank with inlet and outlet plumbing extending into the tank (B). The pump removal valve handle extends below the warning flag clearance panel to indicate the pump inlet is closed.*

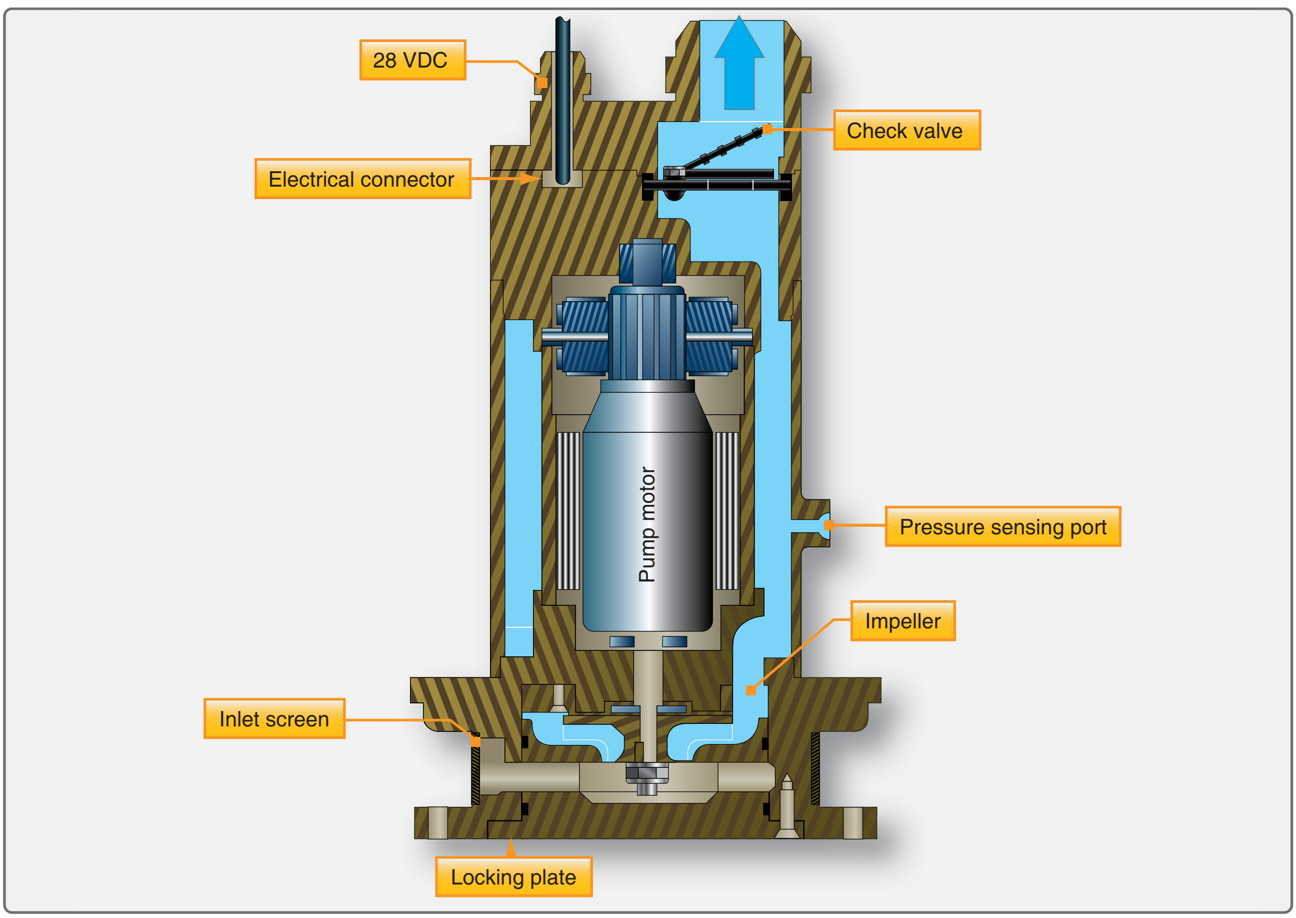


Figure 14-50. *The internal workings of a centrifugal fuel boost pump. Fuel is drawn into the center of the impeller through a screen. It is moved to the outside of the case by the impeller and out the fuel outlet tube.*

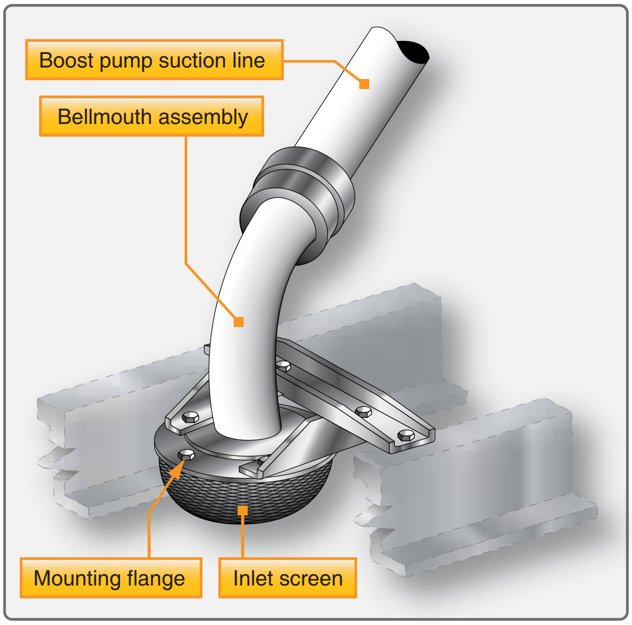


Figure 14-51. *A typical fuel boost pump inlet screen installation for a centrifugal pump mounted outside of the bottom of the tank.*

Pulsating Electric Pumps

General aviation aircraft often make use of smaller, less expensive auxiliary fuel pumps. The pulsating electric pump, or plunger-type fuel pump, is common. It is usually used in the same manner as a centrifugal fuel pump on larger aircraft, except it is located downstream of the fuel tank outlets. The pulsating electric fuel pump is plumbed in parallel with the engine-driven pump. During starting, it provides fuel before the engine-driven fuel pump is up to speed, and it can be used during takeoff as a backup. It also can be used at high altitudes to prevent vapor lock.

The pulsating electric pump uses a plunger to draw fuel in and push fuel out of the pump. It is powered by a solenoid that alternates between being energized and de-energized, which moves the plunger back and forth in a pulsating motion. *Figure 14-53* shows the internal workings of the pump. When switched ON, current travels through the solenoid coils, which pull the steel plunger down between the coils. Any fuel in chamber C is forced through the small check valve in the center of the plunger and into chamber D. When positioned between the solenoid, the plunger is far enough away from the magnet that it no longer attracts it, and the pivot allows the contacts to open. This disrupts the current to the solenoid. The calibrated spring shown under the plunger is then strong enough to push the plunger up from between the solenoid coils. As the plunger rises, it pushes fuel in chamber D out the pump outlet port. Also as the plunger rises, it draws fuel into chamber C and through the check valve into chamber C. As the plunger rises, the magnet is attracted to it and the upward motion closes the points. This allows current flow to the solenoid coils, and the process begins again with the plunger pulled down between the coils, the magnet releasing, and the points opening.

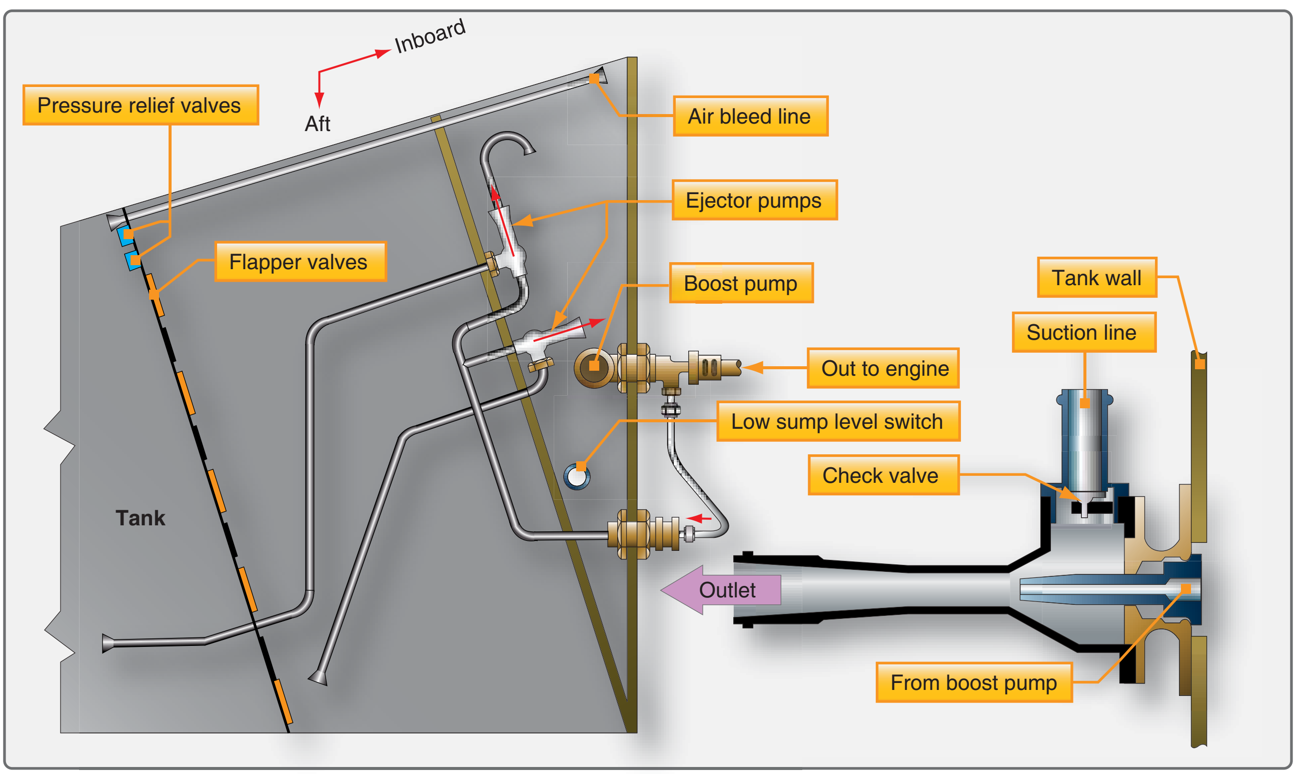


Figure 14-52. *An ejector pump uses a venturi to draw fuel into the boost pump sump area of the fuel tank.*

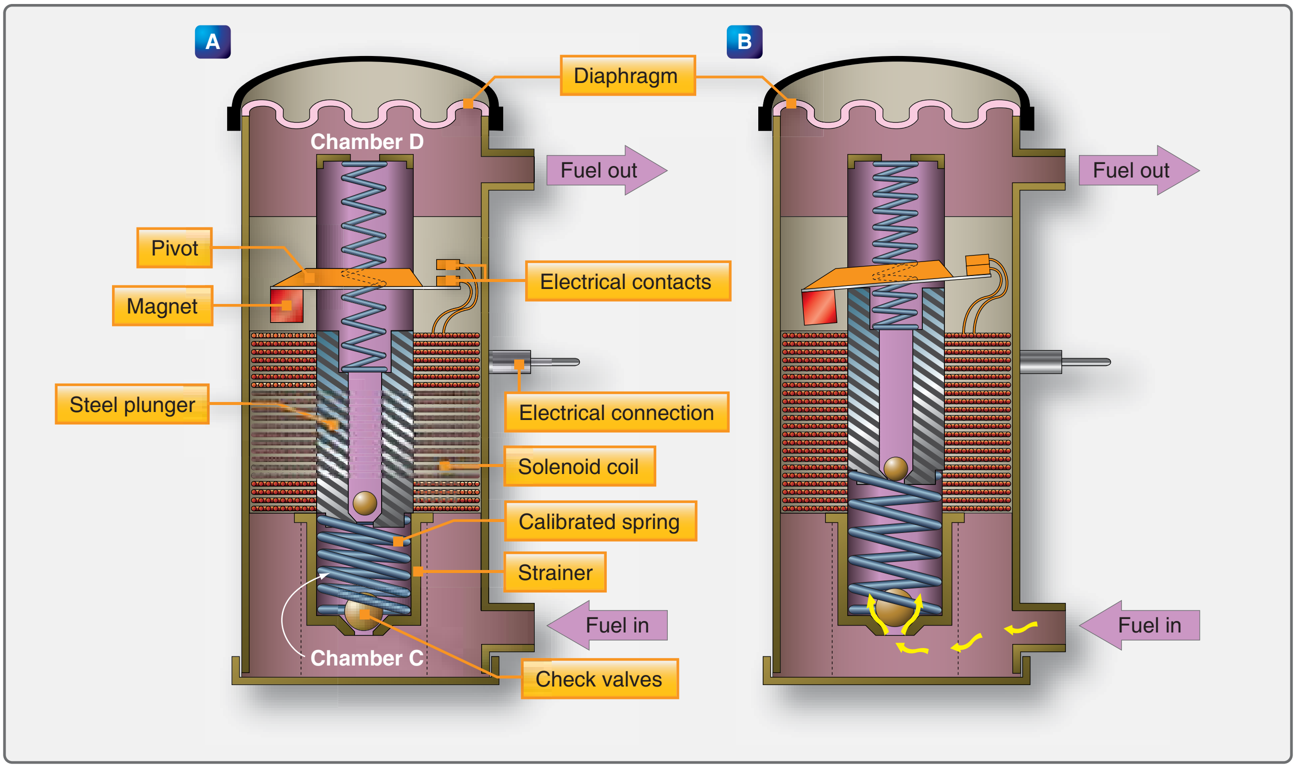


Figure 14-53. *A pulsating electric auxiliary fuel pump is used on many light reciprocating engine aircraft. In A, the pump is shown with its solenoid coil energized, which draws the plunger down between the coil. This opens the breaker points allowing the calibrated spring to push the plunger upwards, thus pumping fuel out the outlet B. This cycle repeats at a speed related to the fuel pressure buildup at the pump outlet.*

The single-acting pulsating electric fuel pump responds to the pressure of the fuel at its outlet. When fuel is needed, the pump cycles rapidly with little pressure at the pump outlet. As fuel pressure builds, the pump slows because the calibrated spring meets this resistance while attempting to force the piston upwards. A spring in the center of the plunger dampens its motion. A diaphragm between the chamber D fuel and an airspace at the top of the pump dampens the output fuel pulses.

Vane-Type Fuel Pumps

Vane-type fuel pumps are the most common types of fuel pumps found on reciprocating-engine aircraft. They are used as both engine-driven primary fuel pumps and as auxiliary or boost pumps. Regardless, the vane-type pump is a constant displacement pump that moves a constant volume of fuel with each revolution of the pump. When used as an auxiliary pump, an electric motor rotates the pump shaft. On engine-driven applications, the vane pump is typically driven by the accessory gear box.

As with all vane pumps, an eccentric rotor is driven inside a cylinder. Slots on the rotor allow vanes to slide in and out and be held against the cylinder wall by a central floating spacer pin. As the vanes rotate with the eccentric rotor, the volume space created by the cylinder wall, the rotor, and the vanes increases and then decreases. An inlet port is located where the vanes create an increasing volume space, and fuel is drawn into the pump. Further around in the rotation, the space created becomes smaller. An outlet port located there causes fuel to be forced from the cylinder. *[Figure 14-54]*

The fuel metering device for the engine delivers more fuel than it needs to operate. However, the constant volume of a vane pump can be excessive. To regulate flow, most vane pumps have an adjustable pressure relief feature. It uses pressure built up at the outlet of the pump to lift a valve off its seat, which returns excess fuel to the inlet side of the pump. *Figure 14-55* shows a typical vane type fuel pump with this adjustable pressure relief function. By setting the relief at a certain pressure above the engine fuel metering device air intake pressure, the correct volume of fuel is delivered. The relief pressure is set via the pressure adjustment screw which tensions the relief valve spring.

During engine starting, or if the vane pump is inoperative, fuel must be able to flow through the pump to the fuel metering device. This is accomplished with the use of a bypass valve inside the pump. A lightly sprung plate under the relief valve overcomes spring pressure whenever the pump's inlet fuel

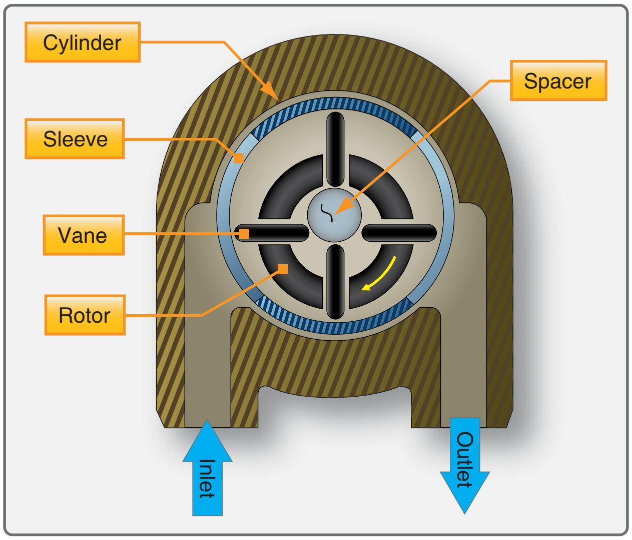


Figure 14-54. *The basic mechanism of a vane-type fuel pump.*

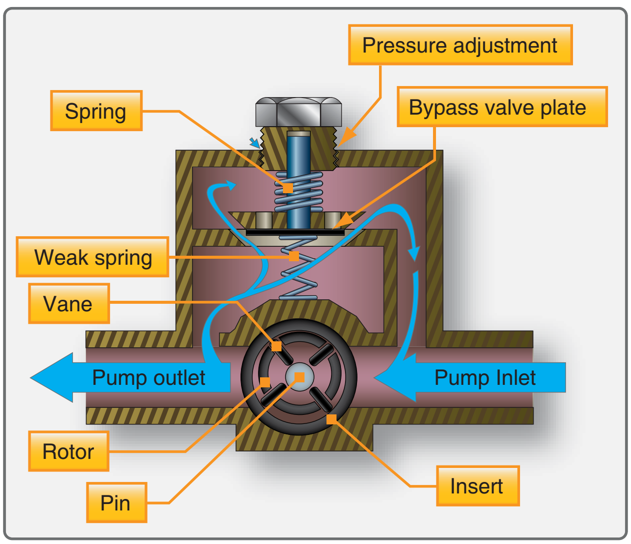


Figure 14-55. *The pressure relief valve in a vane-type fuel pump.*

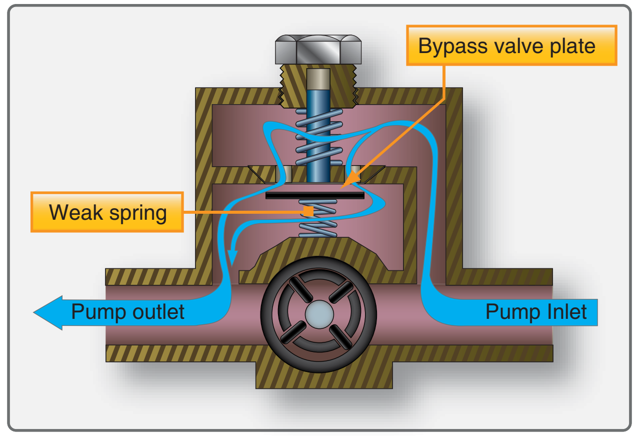


Figure 14-56. *The bypass feature in a vane-type fuel pump allows fuel to flow through the pump during starting or when the pump is inoperative.*

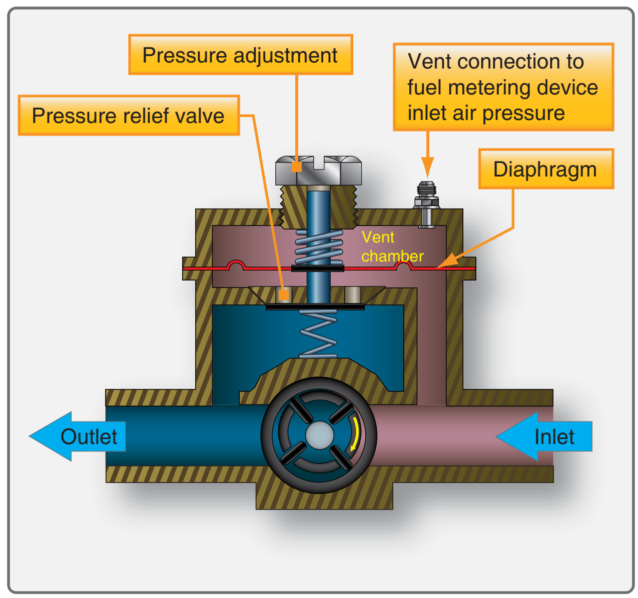


Figure 14-57. *A compensated vane pump is used in engine-driven applications. The fuel metering device inlet air pressure is connected to the vent chamber in the pump. The diaphragm assists or resists the relief valve mechanism depending on the pressure sensed in this chamber.*

pressure is greater than the outlet fuel press. The plate moves down and fuel can flow through the pump. *[Figure 14-56]*

Compensated vane-type fuel pumps are used when the vane pump is the engine-driven primary fuel pump. The relief valve setting varies automatically to provide the correct delivery of fuel as the air inlet pressure of the fuel metering device changes due to altitude or turbocharger outlet pressure. A vent chamber above a diaphragm attached to the relief mechanism is connected to the inlet air pressure source. As air pressure varies, the diaphragm assists or resists the relief valve spring pressure, resulting in proper fuel delivery for the condition at the fuel metering device. *[Figure 14-57]*

Fuel Filters

Two main types of fuel cleaning device are utilized on aircraft. Fuel strainers are usually constructed of relatively coarse wire mesh. They are designed to trap large pieces of debris and prevent their passage through the fuel system. Fuel strainers do not inhibit the flow of water. Fuel filters generally are usually fine mesh. In various applications, they can trap fine sediment that can be only thousands of an inch in diameter and also help trap water. The technician should be aware that the terms "strainer" and "filter" are sometimes used interchangeably. Micronic filters are commonly used on turbine-powered aircraft. This is a type of filter that captures extremely fine particles in the range of 10–25 microns. A micron is $1/1{,}000$ of a millimeter. *[Figure 14-58]*

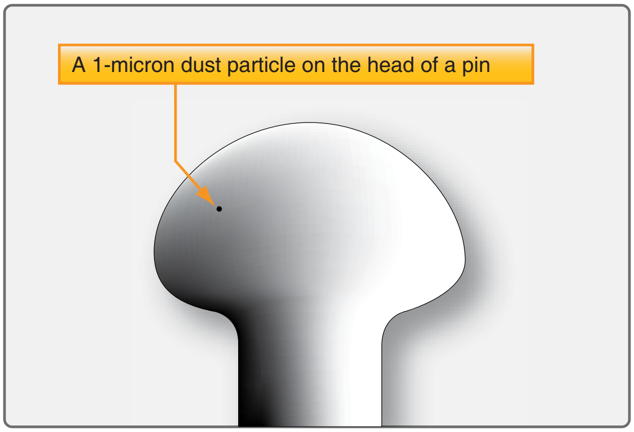


Figure 14-58. *Size comparison of 1-micron dust particle and pin head.*

All aircraft fuel systems have filters and strainers to ensure that the fuel delivered to the engine(s) is free from contaminants. The first of these is encountered at the outlet of the fuel tank. A sump is used to encourage the collection of debris in the lowest part of the tank, which can then be drained off before flight. The actual tank outlet for the fuel is positioned above this sump. Some type of screen is used to trap contaminants attempting to flow out of the tank into the fuel system. Finger screens are common on light aircraft. They effectively increase the area of the fuel tank outlet, allowing a large amount of debris to be trapped while still permitting fuel to flow. *Figure 14-59* illustrates finger screens that are screwed into a fitting welded in the tank outlet.

Figure 14-59. *Fuel tank outlet finger strainers are used in light aircraft.*

Fuel tank outlet screens on aircraft with more complex fuel systems are similarly designed. When in-tank boost pumps are used, the tank outlet strainer is located at the inlet to the boost pump as was shown in *Figure 14-51*. The screen's large area allows debris capture while still permitting sufficient fuel flow for operation. Regularly scheduled inspection and cleaning of these strainers are required.

An additional main strainer for the aircraft fuel system is required between the fuel tank outlet and the fuel metering device (in a carburetor or fuel-injection system). It is normally located between the fuel tank and the engine-driven fuel pump at the low point in the fuel system and is equipped with a drain for preflight sampling and draining. On light aircraft, the main strainer may be in the form of a gascolator. A gascolator is a fuel strainer, or filter, that also incorporates a sediment collection bowl. The bowl is traditionally glass to allow quick visual checks for contaminants; however, many gascolators also have opaque bowls. A gascolator has a drain, or the bowl can be removed to inspect and discard trapped debris and water. *[Figure 14-60]*

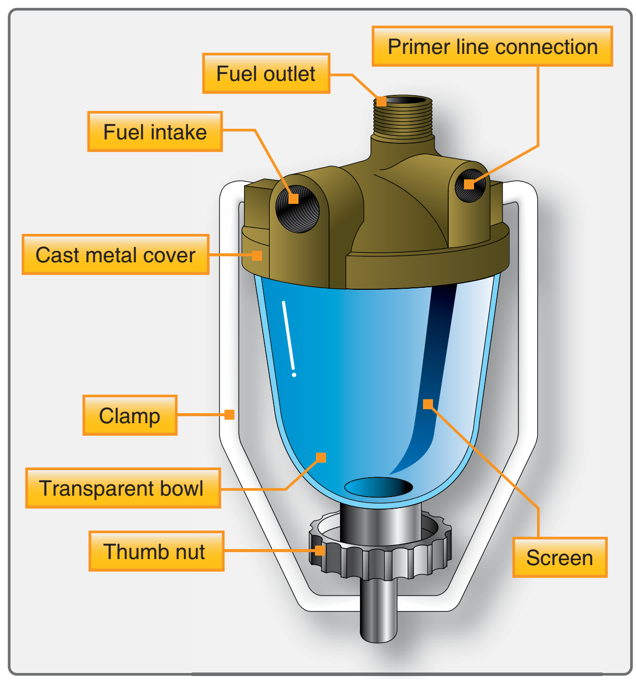


Figure 14-60. *A gascolator is the main fuel strainer between the fuel tanks and the fuel metering device on many light aircraft.*

The main fuel strainer is often mounted at a low point on the engine firewall. The drain is accessible through an easy-access panel, or it simply extends through the bottom engine cowling. As with most filters or strainers, fuel is allowed to enter the unit but must travel up through the filtering element to exit. Water, which is heavier than fuel, becomes trapped and collects in the bottom of the bowl. Other debris too large to pass through the element also settles in the strainer bowl.

Higher performance light aircraft may have a main filter/strainer. *[Figure 14-61]* On twin-engine aircraft, there is a main strainer for each engine. As with single-engine aircraft, a strainer is often mounted low on the engine firewall in each nacelle.

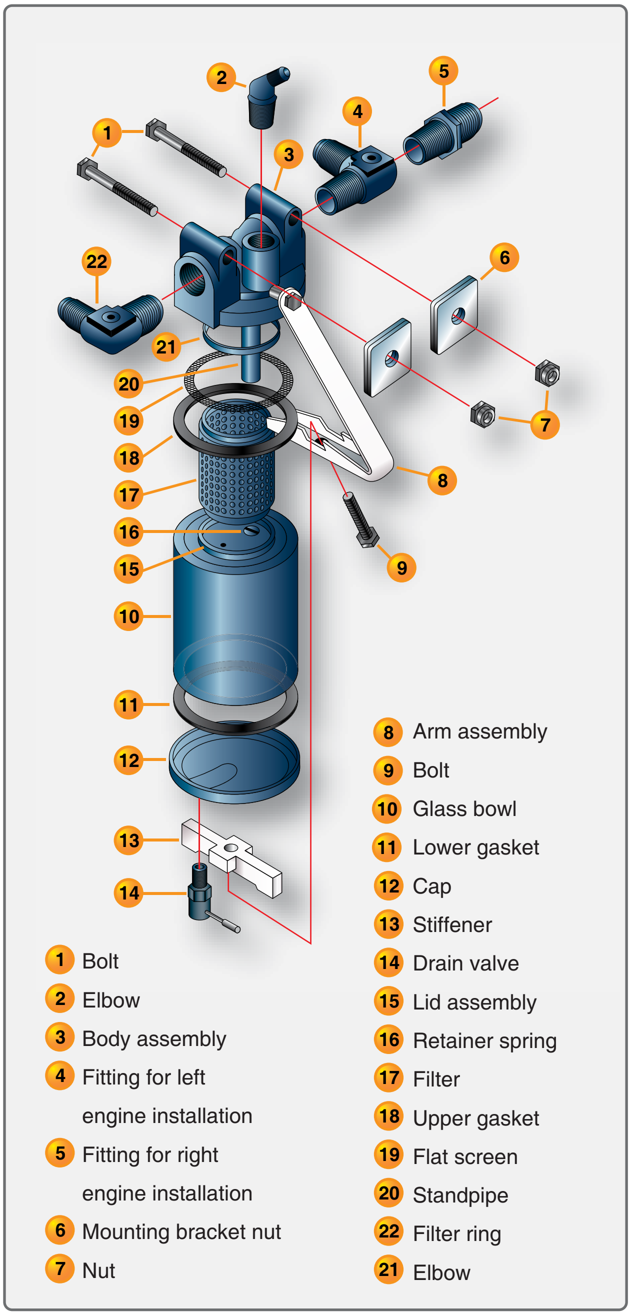


Figure 14-61. *A filter assembly on a light twin reciprocating-engine aircraft.*

Other larger fuel filters have double-screen construction. A cylindrical structural screen is wrapped with a fine mesh material through which inlet fuel must pass. Inside the cylinder is an additional cone-shaped screen. Fuel must pass up through the cone to get to the filter outlet. The mesh used in this filter assembly prevents water and particles from exiting the filter bowl. The contaminants collect at the bottom to be drained off through a drain valve. *[Figure 14-62]*

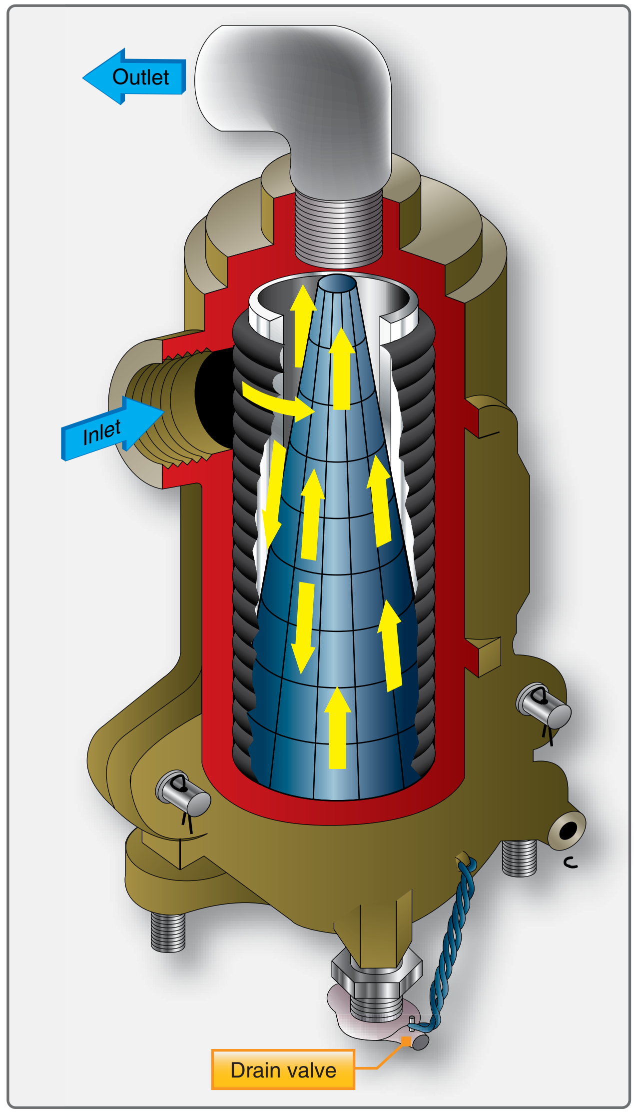


Figure 14-62. *A large-area double-screen filter passes fuel through the outer cylindrical mesh and the inner conical mesh.*

Turbine engine fuel control units are extremely close tolerance devices. It is imperative that fuel delivered to them is clean and contaminant free. The used of micronic filters makes this possible. The changeable cellulose filter mesh type shown in *Figure 14-63* can block particles 10–200 microns in size and absorbs water if it is present. The small size of the mesh raises the possibility of the filter being blocked by debris or water. Therefore, a relief valve is included in the filter assembly that bypasses fuel through the unit should pressure build up from blockage.

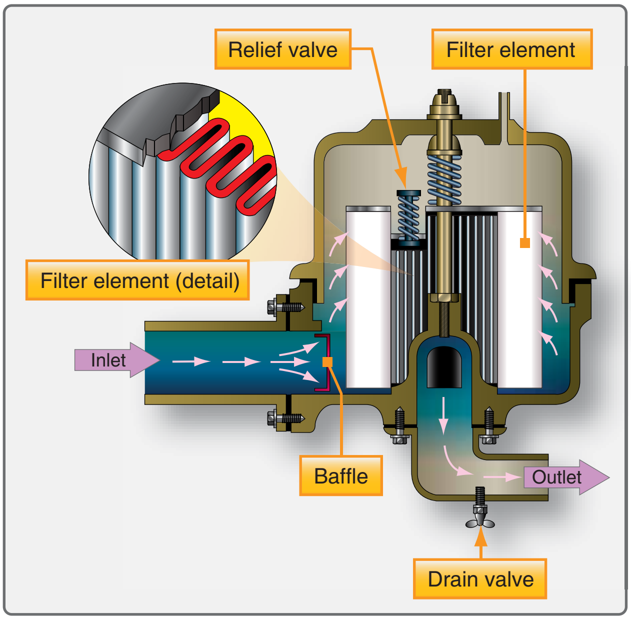


Figure 14-63. *A typical micronic fuel filter with changeable cellulose filter element.*

Fuel filters are often used between the engine-driven fuel pump and the fuel metering device on reciprocating, as well as turbine-engine aircraft. While these are technically part of the engine fuel system, a common type used on turbine engines is discussed here. It is also a micronic filter. It uses finely meshed disks or wafers stacked on a central core. These filters are able to withstand the higher pressure found in the engine fuel system downstream of the engine-driven pump. *[Figure 14-64]*

Indication of a filter blockage may also appear in the cockpit through the use of a bypass-activated switch or a pressure differential switch. The bypass valve physically activates a switch that closes the circuit to the annunciator in the first type. The differential pressure type indicator compares the input pressure of the fuel filter to the output pressure. A circuit is completed when a preset difference occurs. Thus, an indicator is illuminated should a blockage cause the bypass to open or the inlet and outlet pressures to vary significantly. Fuel temperature can also be monitored for the possibility of a blockage caused by frozen water. *[Figure 14-65]*

Fuel Heaters and Ice Prevention

Turbine powered aircraft operate at high altitude where the temperature is very low. As the fuel in the fuel tanks cools, water in the fuel condenses and freezes. It may form ice crystals in the tank or as the fuel/water solution slows and contacts the cool filter element on its way through fuel filter to the engine(s). The formation of ice on the filter element blocks the flow of fuel through the filter. A valve in the filter unit bypasses unfiltered fuel when this occurs. Fuel heaters are used to warm the fuel so that ice does not form. These heat exchanger units also heat the fuel sufficiently to melt any ice that has already formed.

The most common types of fuel heaters are air/fuel heaters and oil/fuel heaters. An air/fuel heater uses warm compressor bleed air to heat the fuel. An oil/fuel exchanger heats the fuel with hot engine oil. This latter type is often referred to as a fuel-cooled oil cooler (FCOC). *[Figure 14-24]*

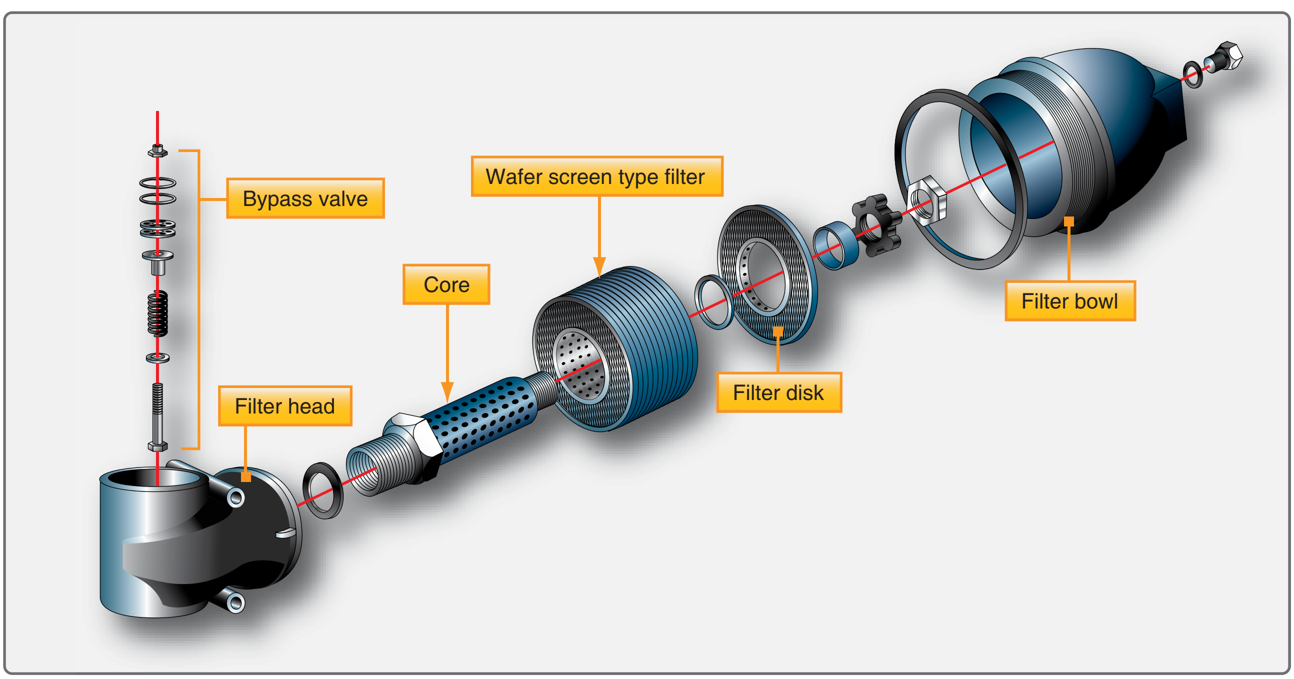


Figure 14-64. *A micronic wafer filter uses multiple screen wafers through which fuel must pass to exit the filter through the core. A spring loaded bypass valve in the filter housing unseats when the filter is clogged to continue delivery of fuel.*

Fuel heaters often operate intermittently as needed. A switch in the cockpit can direct the hot air or oil through the unit or block it. The flight crew uses the information supplied by the filter bypass indicating lights and fuel temperature gauge *[Figure 14-65]* to know when to heat the fuel. Fuel heaters can also be automatic. A built-in thermostatic device opens or closes a valve that permits the hot air or hot oil to flow into the unit to cool the fuel. *[Figure 14-66]*

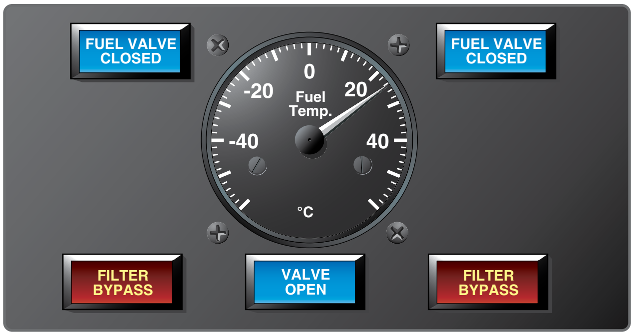


Figure 14-65. *A Boeing 737 cockpit fuel panel showing illuminated valve position indicators and fuel filter bypass lights. The fuel temperature in tank No.1 is also indicated.*

Note that some aircraft have a hydraulic fluid cooler in one of the aircraft fuel tanks. The fluid helps warm the fuel as it cools in this type of full-time heat exchanger.

Fuel System Indicators

Aircraft fuel systems utilize various indicators. All systems are required to have some sort of fuel quantity indicator. Fuel flow, pressure, and temperature are monitored on many aircraft. Valve position indicators and various warning lights and annunciations are also used.

Fuel Quantity Indicating Systems

All aircraft fuel systems must have some form of fuel quantity indicator. These devices vary widely depending on the complexity of the fuel system and the aircraft on which they are installed. Simple indicators requiring no electrical power were the earliest type of quantity indicators and are still in use today. The use of these direct reading indicators is possible only on light aircraft in which the fuel tanks are in close proximity to the cockpit. Other light aircraft and larger aircraft require electric indicators or electronic capacitance-type indicators.

A sight glass is a clear glass or plastic tube open to the fuel tank that fills with fuel to the same level as the fuel in the tank. It can be calibrated in gallons or fractions of a full tank that can be read by the pilot. Another type of sight gauge makes use of a float with an indicating rod attached to it. As the float moves up and down with the fuel level in the tank, the portion of the rod that extends through the fuel cap indicates the quantity of fuel in the tank. *[Figure 14-67]* These two mechanisms are combined in yet another simple fuel quantity indicator in which the float is attached to a rod that moves up or down in a calibrated cylinder. *[Figure 14-68]*

More sophisticated mechanical fuel quantity gauges are common. A float that follows the fuel level remains the primary sensing element, but a mechanical linkage is connected to move a pointer across the dial face of an instrument. This can be done with a crank and pinion arrangement that drives the pointer with gears, or with a magnetic coupling, to the pointer. *[Figure 14-69]*

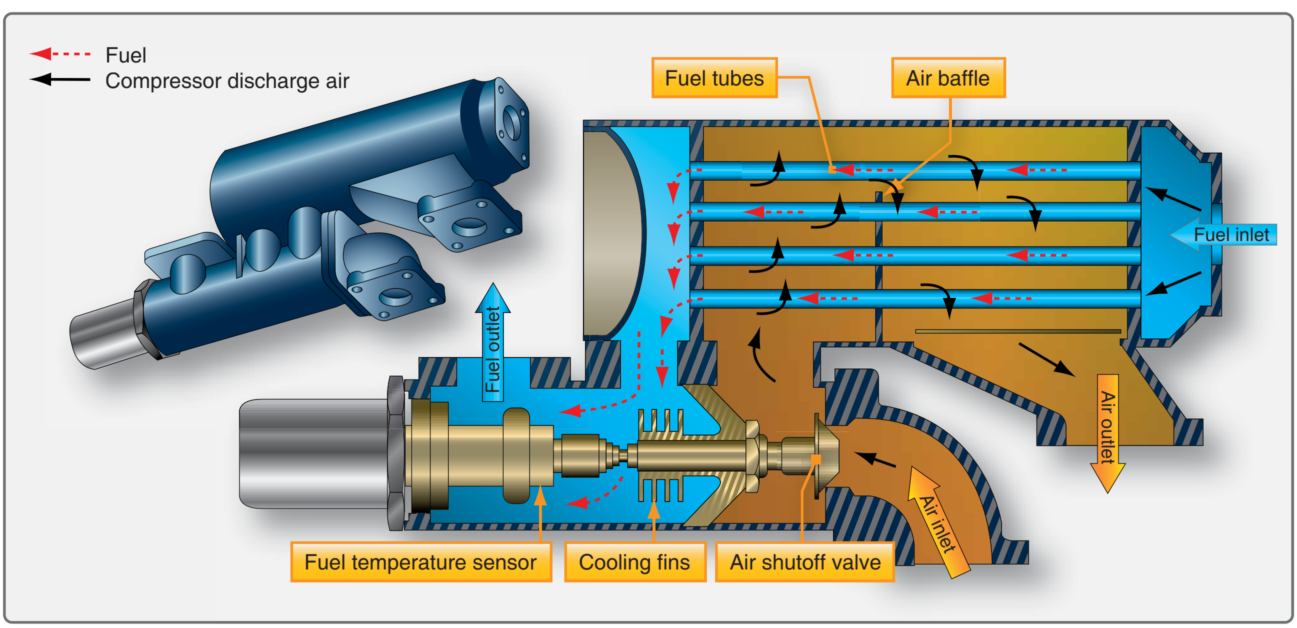


Figure 14-66. *An air-fuel heat exchanger uses engine compressor bleed air to warm the fuel on many turbine engine powered aircraft.*

Figure 14-67. *The fuel quantity indicator on this Piper Cub is a float attached to a rod that protrudes through the fuel cap.*

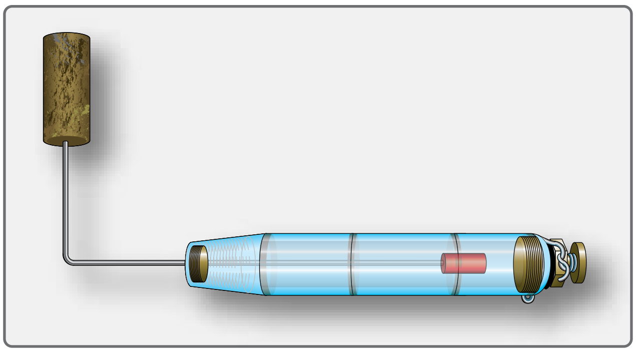


Figure 14-68. *A float-type sight gauge fuel quantity indicator.*

Electric fuel quantity indicators are more common than mechanical indicators in modern aircraft. Most of these units operate with direct current (DC) and use variable resistance in a circuit to drive a ratiometer-type indicator. The movement of a float in the tank moves a connecting arm to the wiper on a variable resistor in the tank unit. This resistor is wired in series with one of the coils of the ratiometer-type fuel gauge in the instrument panel. Changes to the current flowing through the tank unit resistor change the current flowing through one of the coils in the indicator. This alters the magnetic field in which the indicating pointer pivots. The calibrated dial indicates the corresponding fuel quantity. *[Figure 14-70]*

Digital indicators are available that work with the same variable resistance signal from the tank unit. They convert the variable resistance into a digital display in the cockpit instrument head. *[Figure 14-71]* Fully digital instrumentation systems, such as those found in a glass cockpit aircraft, convert the variable resistance into a digital signal to be processed in a computer and displayed on a flat screen panel.

Large and high-performance aircraft typically utilize electronic fuel quantity systems. These more costly systems have the advantage of having no moving parts in the tank sending units. Variable capacitance transmitters are installed in the fuel tanks extending from the top to the bottom of each tank in the usable fuel. Several of these tank units, or fuel probes as they are sometimes called, may be installed in a large tank. *[Figure 14-72]* They are wired in parallel. As the level of the fuel changes, the capacitance of each unit changes. The capacitance transmitted by all of the probes in a tank is totaled and compared in a bridge circuit by a microchip computer in the tank's digital fuel quantity indicator in the cockpit. As the aircraft maneuvers, some probes are in more fuel than others due to the attitude of the aircraft. The indication remains steady, because the total capacitance transmitted by all of the probes remains the same. A trimmer is used to match the capacitance output with the precalibrated quantity indicator.

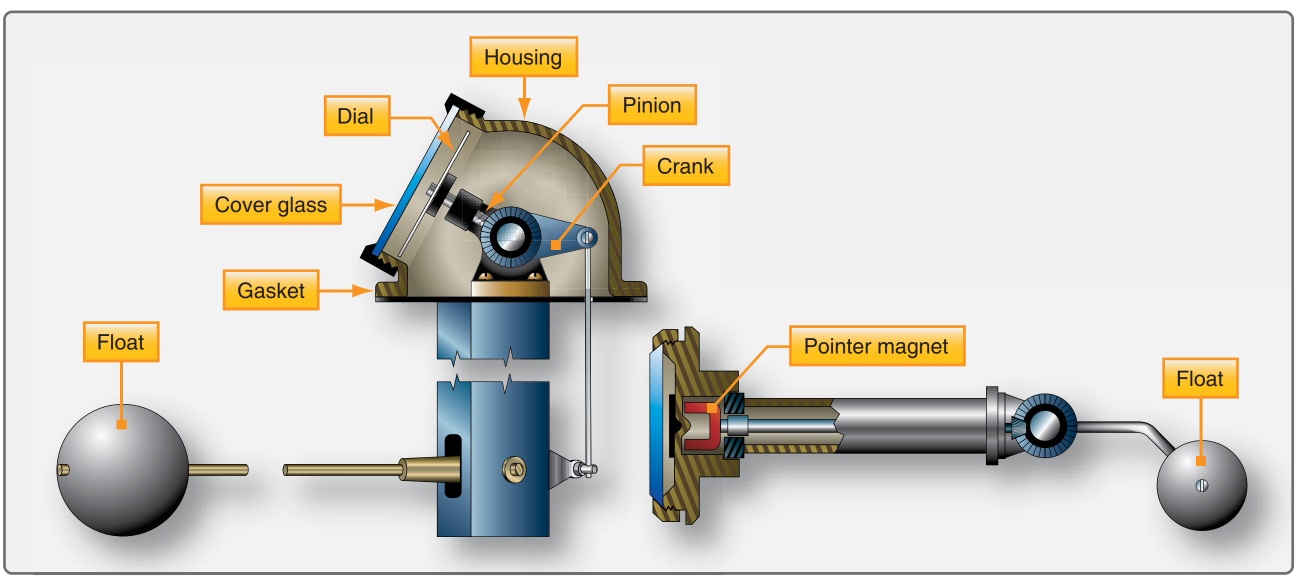


Figure 14-69. *Simple mechanical fuel indicators used on light aircraft with fuel tanks in close proximity to the pilot.*

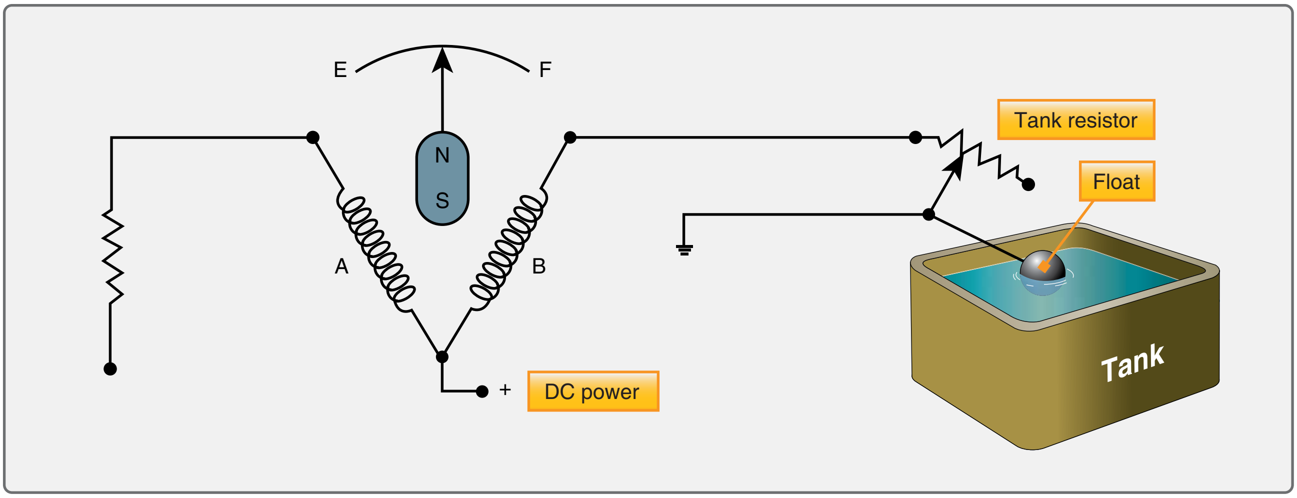


Figure 14-70. *A DC electric fuel quantity indicator uses a variable resistor in the tank unit, which is moved by a float arm.*

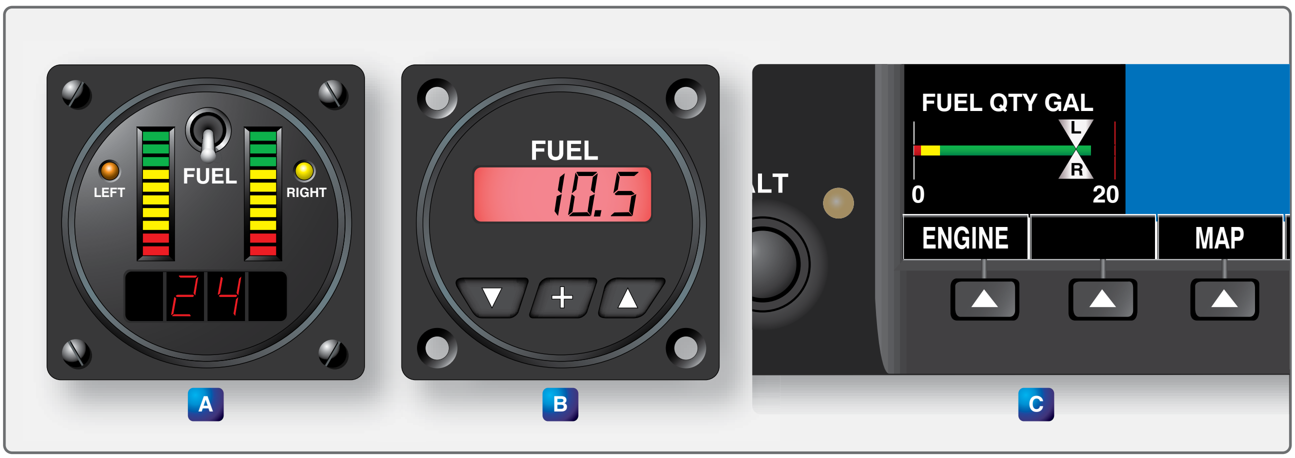


Figure 14-71. *Digital fuel quantity gauges that work off of variable resistance from the tank unit are shown in A and B. The fuel quantity indication of a Garmin G-1000 flat screen display is shown in C.*

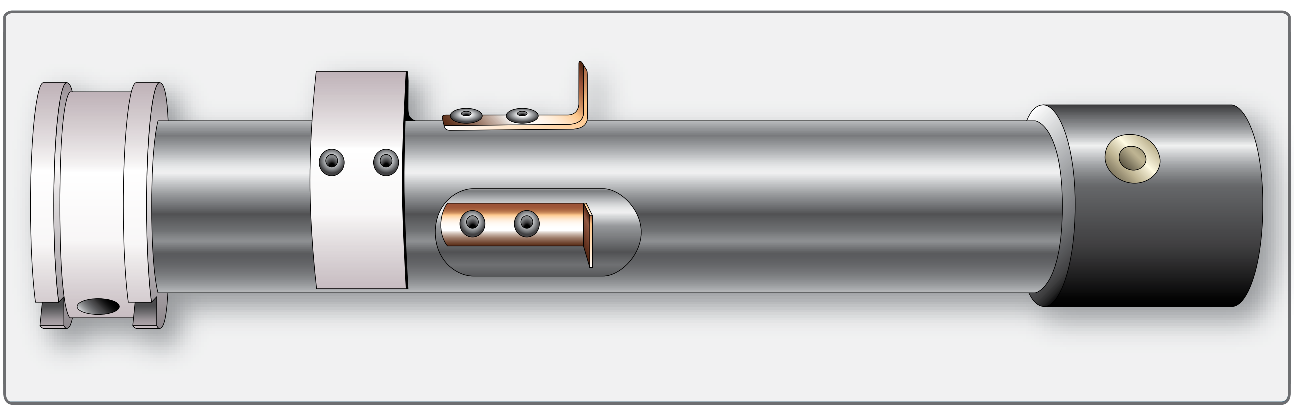


Figure 14-72. *A fuel tank transmitter for a capacitance-type fuel quantity indicating system.*

A capacitor is a device that stores electricity. The amount it can store depends on three factors: the area of its plates, the distance between the plates, and the dielectric constant of the material separating the plates. A fuel tank unit contains two concentric plates that are a fixed distance apart. Therefore, the capacitance of a unit can change if the dielectric constant of the material separating the plates varies. The units are open at the top and bottom so they can assume the same level of fuel as is in the tanks. Therefore, the material between the plates is either fuel (if the tank is full), air (if the tank is empty), or some ratio of fuel and air depending on how much fuel remains in the tank. *Figure 14-73* shows a simplified illustration of this construction.

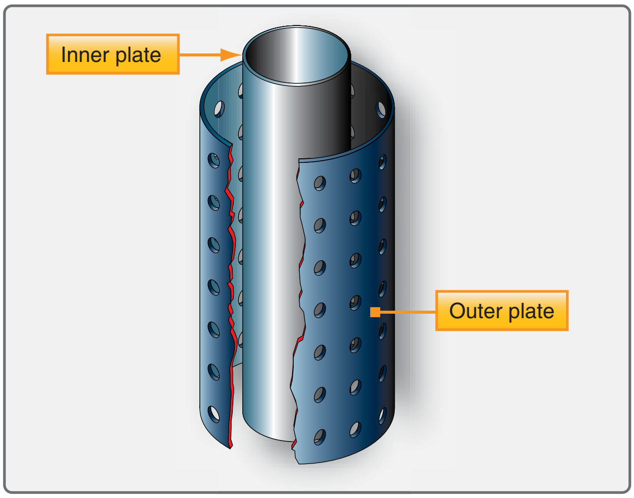


Figure 14-73. *The capacitance of tank probes varies in a capacitance-type fuel tank indicator system as the space between the inner and outer plates is filled with varying quantities of fuel and air depending on the amount of fuel in the tank.*

The bridge circuit that measures the capacitance of the tank units uses a reference capacitor for comparison. When voltage is induced into the bridge, the capacitive reactance of the tank probes and the reference capacitor can be equal or different. The magnitude of the difference is translated into an indication of the fuel quantity in the tank calibrated in pounds. *Figure 14-74* represents the nature of this comparison bridge circuit.

The use of tank unit capacitors, a reference capacitor, and a microchip bridge circuit in the fuel quantity indicators is complicated by the fact that temperature affects the dielectric constant of the fuel. A compensator unit (mounted low in the tank so it is always covered with fuel) is wired into the bridge circuit. It modifies current flow to reflect temperature variations of the fuel, which affect fuel density and thus capacitance of the tank units. *[Figure 14-75]* An amplifier is also needed in older systems. The amplitude of the electric signals must be increased to move the servo

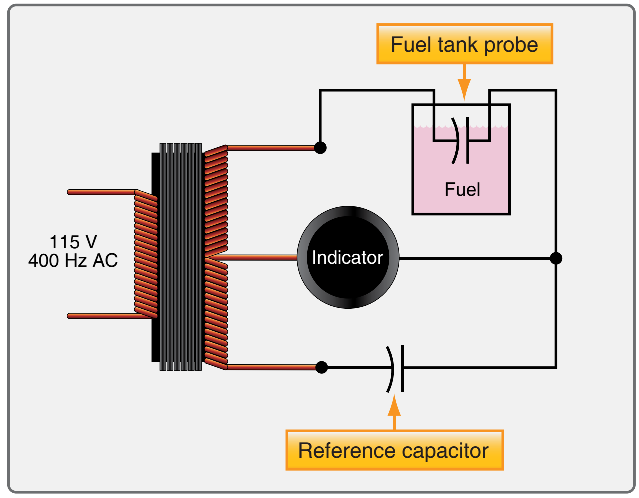


Figure 14-74. *A simplified capacitance bridge for a fuel quantity system.*

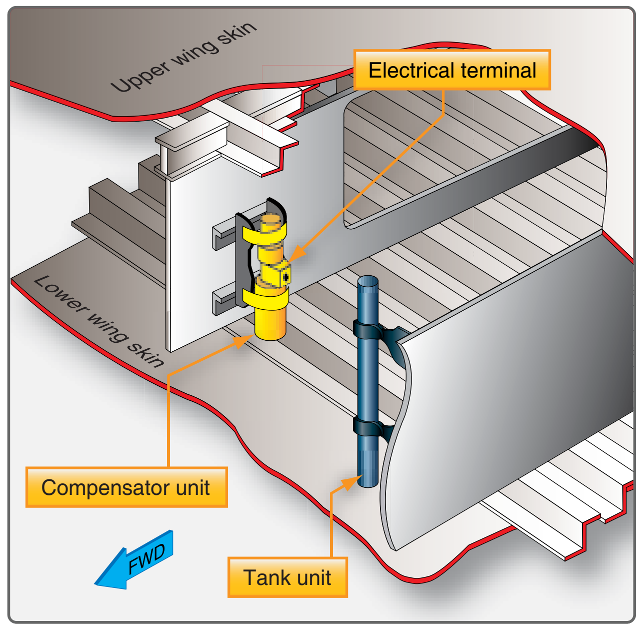


Figure 14-75. *A fuel quantity tank unit and compensator unit installed inside a wing tank.*

motor in the analog indicator. Additionally, the dielectric constant of different turbine-engine fuels approved for a particular aircraft may also vary. Calibration is required to overcome this.

A fuel summation unit is part of the capacitance-type fuel quantity indication system. It is used to add the tank quantities from all indicators. This total aircraft fuel quantity can be used by the crew and by flight management computers for calculating optimum airspeed and engine performance limits for climb, cruise, descent, etc. Capacitance-type fuel quantity system test units are available for troubleshooting and ensuring proper functioning and calibration of the indicating system components.

Many aircraft with capacitance-type fuel indicating systems also use a mechanical indication system to cross-check fuel quantity indications and to ascertain the amount of fuel onboard the aircraft when electrical power is not available. A handful of fuel measuring sticks, or drip sticks, are mounted throughout each tank. When pushed and rotated, the drip stick can be lowered until fuel begins to exit the hole on the bottom of each stick. This is the point at which the top of the stick is equal to the height of the fuel. The sticks have a calibrated scale on them. By adding the indications of all of the drip sticks and converting to pounds or gallons via a chart supplied by the manufacturer, the quantity of the fuel in the tank can be ascertained. *[Figure 14-76]*

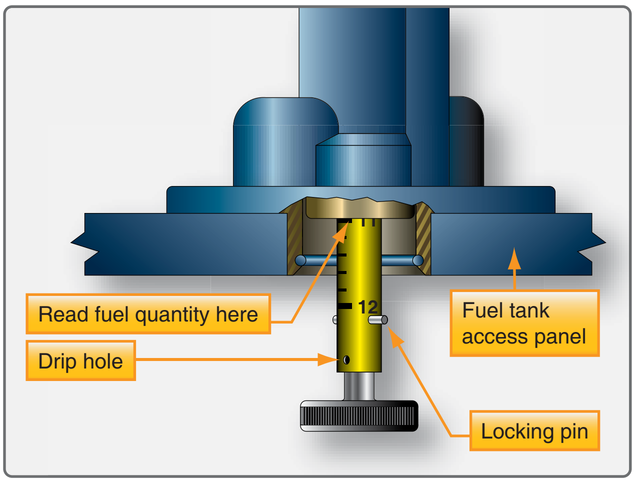


Figure 14-76. *A fuel drip stick is lowered from the fuel tank bottom until fuel drips out the hole at the bottom. By reading the calibrated scale and adding readings from all tank drip sticks, a chart can be consulted to arrive at the total fuel quantity on the aircraft by weight or by volume.*

Fuel Flowmeters

A fuel flowmeter indicates an engine's fuel use in real time. This can be useful to the pilot for ascertaining engine performance and for flight planning calculations. The types of fuel flow meter used on an aircraft depends primarily on the powerplant being used and the associated fuel system.

Measuring fuel flow accurately is complicated by the fact that the fuel mass changes with temperature or with the type of fuel used in turbine engines. In light aircraft with reciprocating engines, systems have been devised to measure fuel volume. The actual mass of fuel flowing to the engine is based on an assumption of the average weight of the fuel per unit volume.

The simplest fuel flow sensing device is used in conjunction with fuel injection systems installed on horizontally opposed reciprocating engines. A pressure gauge is used but it is calibrated in gallons per hour or pounds per hour. The amount of fuel that is flowing through the fuel injectors has a direct relationship to the pressure drop across the fuel injector orifices. Therefore, monitoring fuel pressure at the injector(s) closely approximates fuel flow and provides useful flow information for mixture control and flight planning.

There is a major limitation to the use of fuel pressure as a flow indicator. Should an injector become clogged, fuel flow is reduced. However, the pressure gauge indicates a higher fuel pressure (and greater fuel flow) due to the restriction. Operators must be aware of this potential condition and check the flowmeter against EGT to determine the nature of the elevated indication. *[Figure 14-77]*

Large reciprocating engine fuel systems may use a vane-type fuel flow meter that measures the volume of the fuel consumed by the engine. The fuel flow unit is typically located between the engine-driven fuel pump and the carburetor. The entire volume of fuel delivered to the engine is made to pass through the flowmeter. Inside, the fuel pushes against the vane, which counters the force of the fuel flow with a calibrated spring. The vane shaft rotates varying degrees matching the fuel flow rate through the unit. An autosyn transmitter deflects the pointer on the cockpit fuel flow gauge the same amount as the vane deflects. The dial face of the indicator is calibrated in gallons per hour or pounds per hour based on an average weight of fuel.

Since fuel fed to the engine must pass through the flowmeter unit, a relief valve is incorporated to bypass the fuel around the vane should it malfunction and restrict normal fuel flow. The vane chamber is eccentric. As more fuel pushes against the vane, it rotates further around in the chamber. The volume of the chamber gradually increases to permit the greater flow of fuel without restriction or pressure buildup. *[Figure 14-78]*

Turbine-engine aircraft experience the greatest range of fuel density from temperature variation and fuel composition. An elaborate fuel flow device is used on these aircraft. It measures fuel mass for accurate fuel flow indication in the cockpit. The mass flow indicator takes advantage of the direct relationship between fuel mass and viscosity. Fuel is swirled by a cylindrical impeller that rotates at a fixed speed. The outflow deflects a turbine just downstream of the impeller. The turbine is held with calibrated springs. Since the impeller motor swirls the fuel at a fixed rate, any variation of the turbine deflection is caused by the volume and viscosity of the fuel. The viscosity component represents the mass of the fuel. *[Figure 14-79]*

An alternating current (AC) synchro system is part of the mass fuel flowmeter. It is used to position a pointer against the cockpit indicator scale calibrated in pounds per hour.

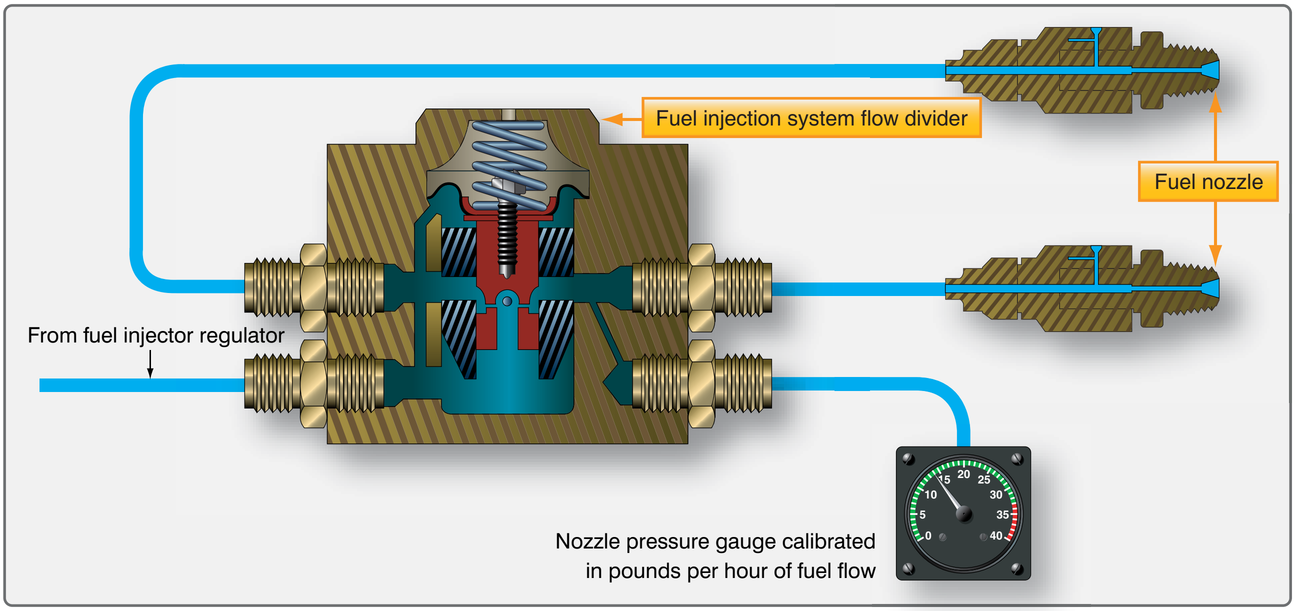


Figure 14-77. *The pressure drop across the fuel injector nozzles is used to represent fuel flow in light reciprocating-engine aircraft.*

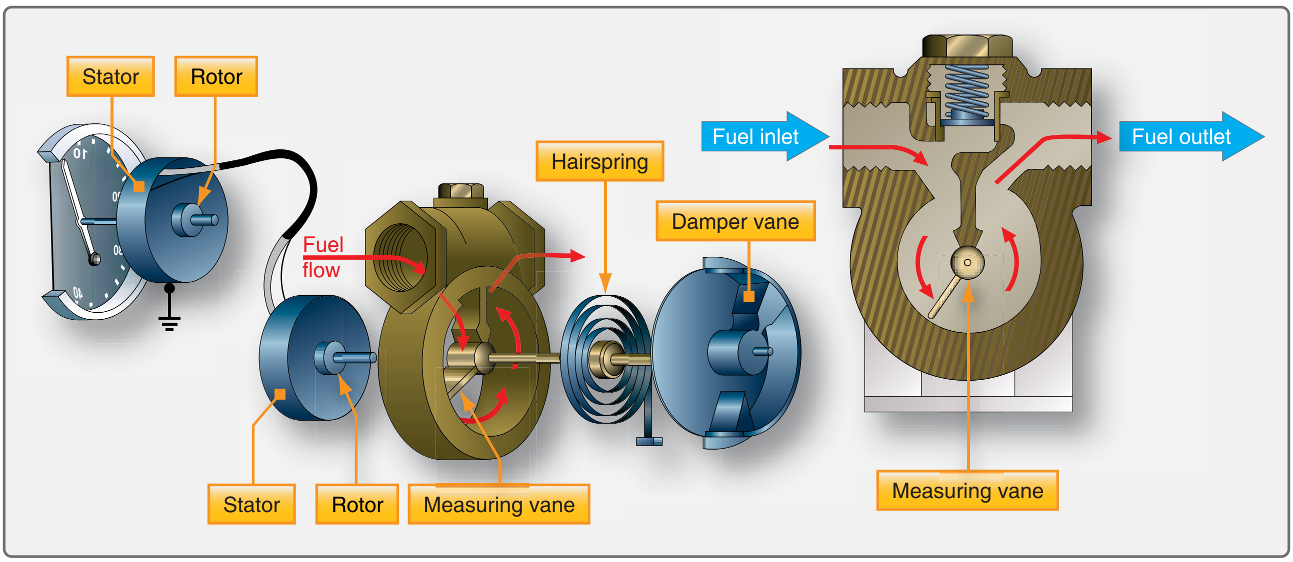


Figure 14-78. *A vane-type fuel flow meter. Greater flow volume increases deflection of the vane against a calibrated spring. An autosyn transmitter replicates the vane shaft rotation on the cockpit indicator that is calibrated in gallons or pounds of fuel flow per hour.*

With accurate fuel flow knowledge, numerous calculations can be performed to aid the pilot's situational awareness and flight planning. Most high-performance aircraft have a fuel totalizer that electronically calculates and displays information, such as total fuel used, total fuel remaining onboard the aircraft, total range and flight time remaining at the present airspeed, rate of fuel consumption, etc. On light aircraft, it is common to replace the original analog fuel indicators with electronic gauges containing similar capabilities and built-in logic. Some of these fuel computers, as they are called, integrate global positioning satellite (GPS) location information. *[Figure 14-80]* Aircraft with fully digital cockpits process fuel flow data in computers and display a wide array of fuel flow related information on demand.

Relatively new types of fuel flow sensors/transmitters are available in new aircraft and for retrofit to older aircraft. One type of device found in home-built and experimental aircraft uses a turbine that rotates in the fuel flow. The higher the flow rate is, the faster the turbine rotates. A Hall effect transducer is used to convert the speed of the turbine to an electrical signal to be used by an advanced fuel gauge similar to a fuel computer to produce a variety of calculated readouts and warnings. The turbine in this unit is in line with the fuel flow, but is fail safe to allow adequate fuel flow without interruption should the unit malfunction. *[Figure 14-81]*

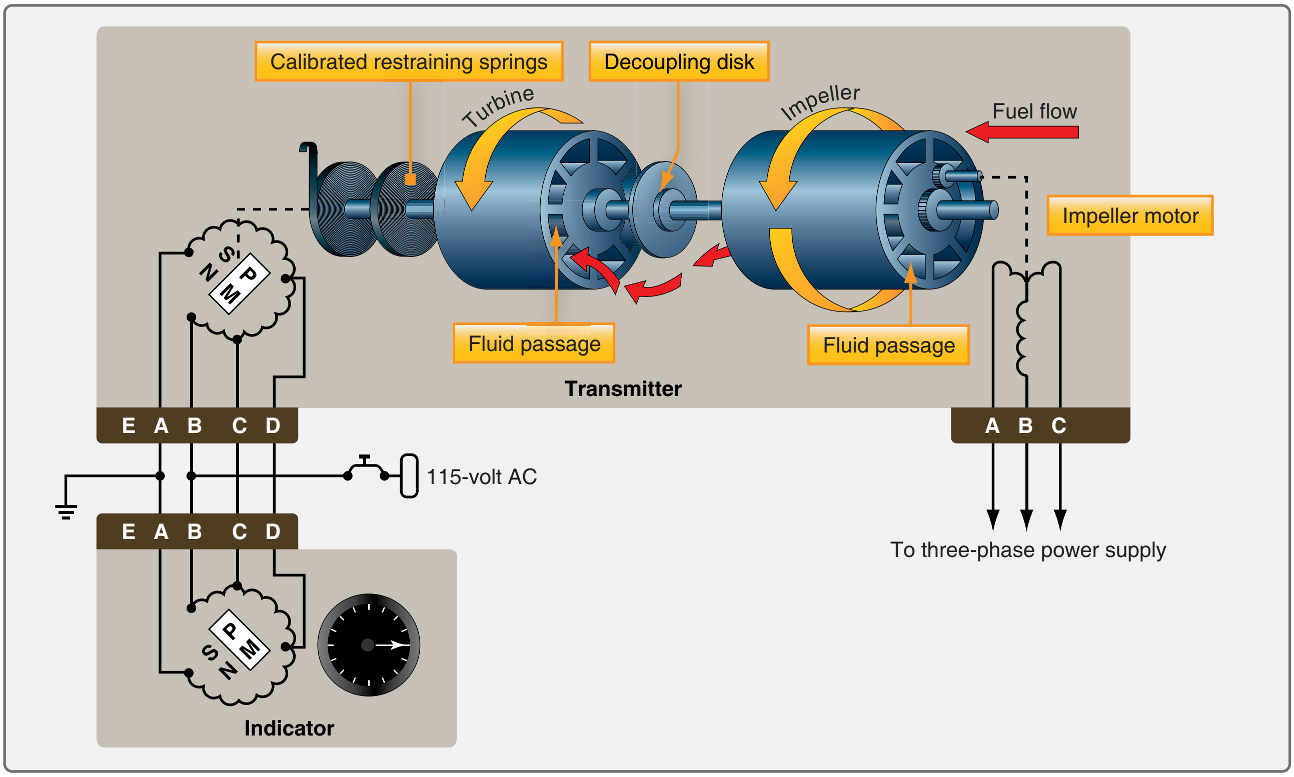


Figure 14-79. *A mass flow fuel flow indicating system used on turbine-engine aircraft uses the direct relationship between viscosity and mass to display fuel flow in pounds per hour.*

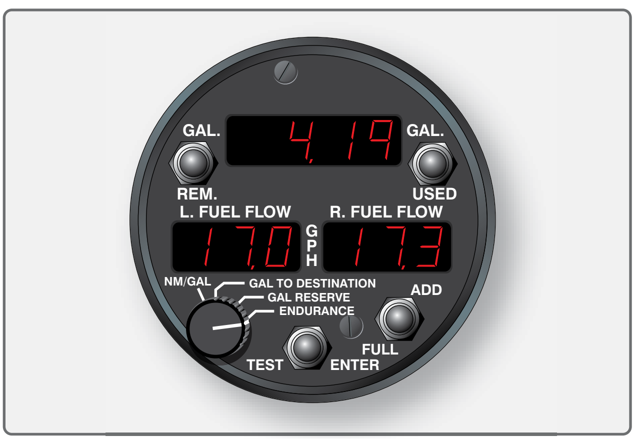


Figure 14-80. *A modern fuel management gauge uses a microprocessor to display fuel flow and numerous other fuel consumption related calculations.*

Another fuel flow sensor used primarily on light aircraft also detects the spinning velocity of a turbine in the fuel path. It too has a failsafe design should the turbine malfunction. In this unit, notches in the rotor interrupt an infrared light beam between an LED and phototransistor that creates a signal proportional to the amount fuel flow. *[Figure 14-82]* This type of sensor may be coupled with an electronic indicator.

Increasing use of microprocessors and computers on aircraft enable the integration of fuel temperature and other compensating factors to produce highly accurate fuel flow information. Fuel flow sensing with digital output facilitates this with a high degree of reliability. Thermal dispersion technology provides flow sensing with no moving parts and digital output signals. The sensor consists of two resistance temperature detectors (RTDs). One is a reference RTD that measures the temperature of the fuel. The other is the active RTD. It is heated by an adjacent element to a temperature higher than the fuel. As the fuel flows, the active element cools proportionally to the fuel flow. The temperature difference between the two RTDs is highest at no flow.

The RTDs are connected to an electronic assembly that supplies power to the heater and uses sensing circuitry and a microprocessor to control a constant temperature difference between the heated and unheated RTDs. The electrical current to the heater is proportional to the mass flow of the fuel. As mentioned, the reference RTD is used as a temperature sensor to provide a temperature output and allow for temperature compensation of the flow measurement. *[Figure 14-83]*

Fuel Temperature Gauges

As previously mentioned, monitoring fuel temperature can inform the pilot when fuel temperature approaches that which could cause ice to form in the fuel system, especially at the fuel filter. Many large and high-performance turbine aircraft use a resistance type electric fuel temperature

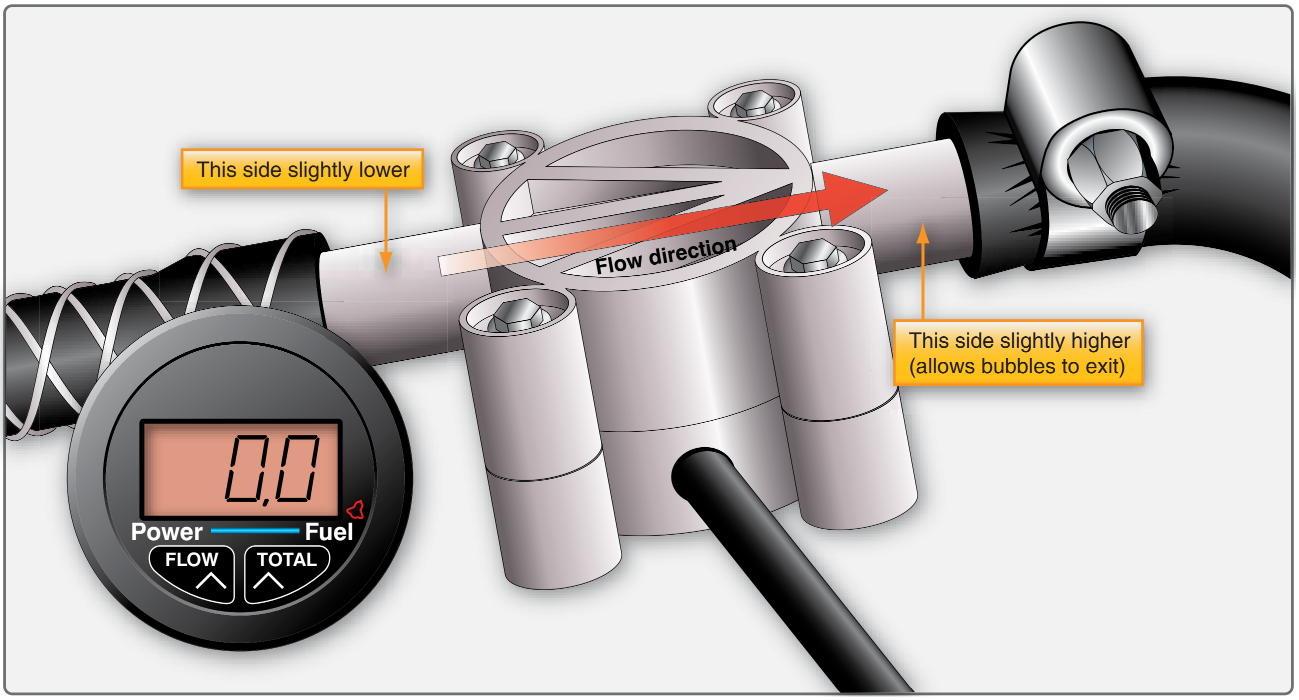


Figure 14-81. *A transducer and microprocessor for control functions are located in the base of this turbine fuel flow sensor. The gauge is menu driven with numerous display options.*

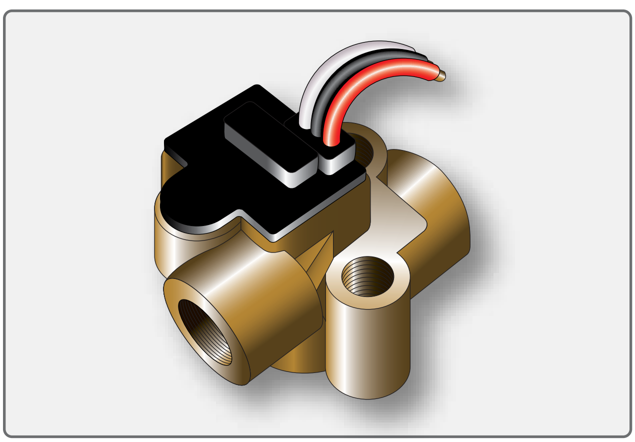


Figure 14-82. *A turbine flow transducer in this fuel flow sensor produces a current pulse signal from an opto-electronic pickup with a preamplifier.*

Figure 14-83. *Fuel flow sensing units using thermal dispersion technology have no moving parts and output digital signals.*

sender in a main fuel tank for this purpose. It can display on a traditional ratiometer gauge *[Figure 14-65]* or can be input into a computer for processing and digital display. A low fuel temperature can be corrected with the use of a fuel heater if the aircraft is so equipped. Also as mentioned, fuel temperature can be integrated into fuel flow processing calculations. Viscosity differences at varying fuel temperatures that affect fuel flow sensing accuracy can be corrected via microprocessors and computers.

Fuel Pressure Gauges

Monitoring fuel pressure can give the pilot early warning of a fuel system related malfunction. Verification that the fuel system is delivering fuel to the fuel metering device can be critical. Simple light reciprocating-engine aircraft typically utilize a direct reading Bourdon tube pressure gauge. It is connected into the fuel inlet of the fuel metering device with a line extending to the back of the gauge in the cockpit instrument panel. A more complex aircraft may have a sensor with a transducer located at the fuel inlet to the metering device that sends electrical signals to a cockpit gauge. *[Figure 14-84]* In aircraft equipped with an auxiliary pump for starting and to backup the engine-driven pump, the fuel pressure gauge indicates the auxilliary pump pressure until the engine is started. When the auxiliary pump is switched off, the gauge indicates the pressure developed by the engine-driven pump.

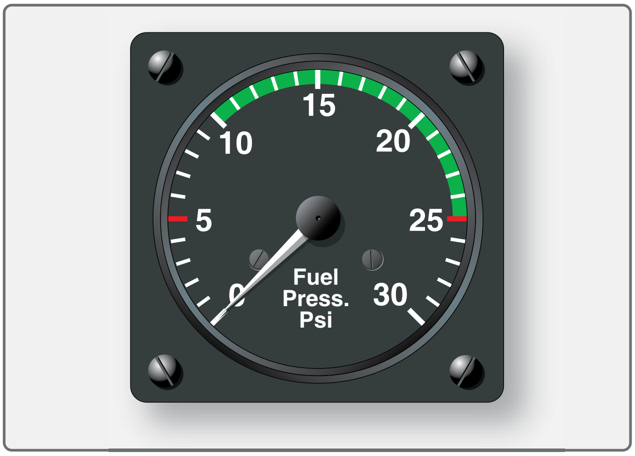


Figure 14-84. *A typical fuel gauge that uses a signal from a sensing transducer to display fuel inlet pressure at the metering device.*

More complex and larger reciprocating engine aircraft may use a differential fuel pressure gauge. It compares fuel inlet pressure to the air inlet pressure at the fuel metering device. A bellows type pressure gauge is normally used. *[Figure 14- 85]*

Figure 14-85. *A differential fuel pressure gauge used on complex and high-performance reciprocating-engine aircraft compares the fuel inlet pressure to the air inlet pressure at the fuel metering device.*

Modern aircraft may use a variety of sensors including solid state types and those with digital output signals or signals that are converted to digital output. These can be processed in the instrument gauge microprocessor, if so equipped, or in a computer and sent to the display unit. *[Figure 14-86]*

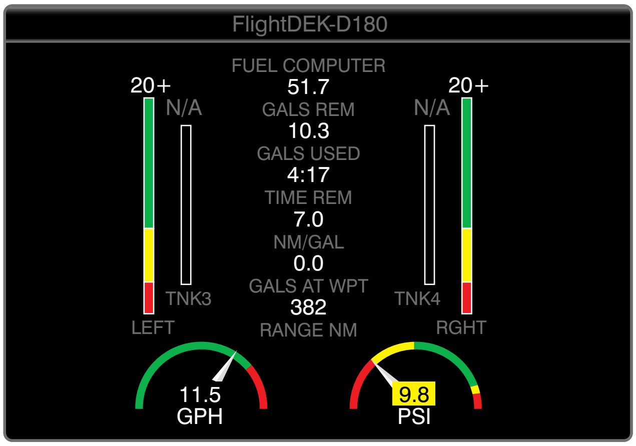


Figure 14-86. *An electronic display of fuel parameters, including fuel pressure.*

Pressure Warning Signal

On aircraft of any size, visual and audible warning devices are used in conjunction with gauge indications to draw the pilot's attention to certain conditions. Fuel pressure is an important parameter that merits the use of a warning signal when it falls outside of the normal operating range. Low fuel pressure warning lights can be illuminated through the use of simple pressure sensing switches. *[Figure 14-87]* The contacts of the switch will close when fuel pressure against the diaphragm is insufficient to hold them open. This allows current to flow to the annunciator or warning light in the cockpit.

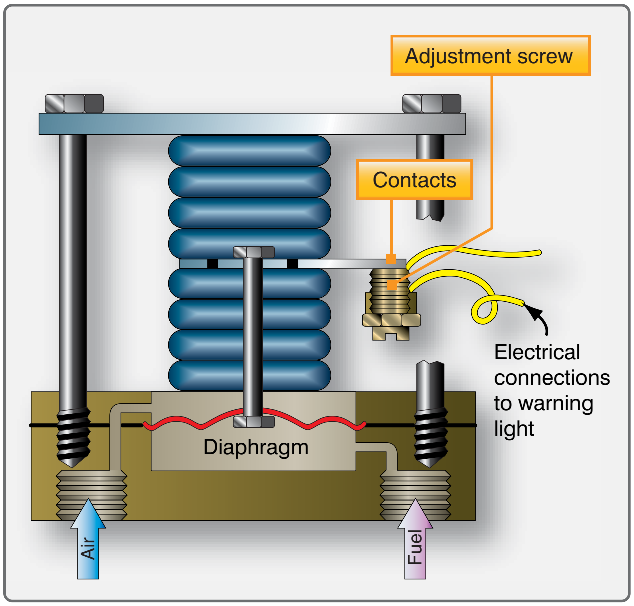


Figure 14-87. *A fuel pressure warning signal is controlled by a switch that closes when fuel pressure is low.*

Most turbine-powered aircraft utilize a low pressure warning switch at the outlet of each fuel boost pump. The annunciator for each is typically positioned adjacent to the boost pump ON/OFF switch on the fuel panel in the cockpit. *[Figure 14-88]*

Valve-In-Transit Indicator Lights

Aircraft with multiple fuel tanks use valves and pumps to move fuel and to have it flow to desired locations, such as the engines, a certain tank, or overboard during fuel jettison. The functioning of the valves in the fuel system is critical. Some aircraft indicate to the crew when the valve is opening or closing with the use of valve-in-transit lights. Contacts

Figure 14-88. *A transport category aircraft fuel panel with low pressure warning lights for each fuel boost pump.*

in the valve control the lights that go out when the valve is fully open or when it is fully closed. Alternately, annunciator lights that show the valve position as OPEN or CLOSED are also used. Valve-in-transit and valve position indicators, or lights, are located on the fuel panel in the cockpit adjacent to the valve ON/OFF switches. *[Figure 14-89]* Sometimes the switch mechanism has the annunciator light built into it. Digital display systems graphically depict valve positions on screen.

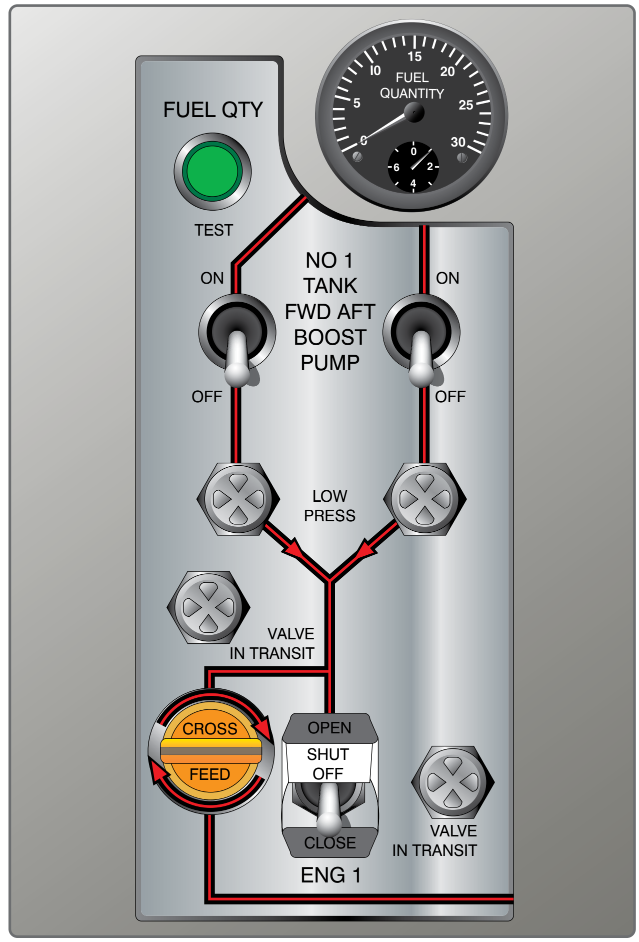


Figure 14-89. *Valve-in-transit lights are used on this section of a transport category aircraft fuel panel. Low boost pump pressure lights that look the same are also on the panel.*

Fuel System Repair

The integrity of an aircraft fuel system is critical and should not be compromised. Any evidence of malfunction or leak should be addressed before the aircraft is released for flight. The danger of fire, explosion, or fuel starvation in flight makes it imperative that fuel system irregularities be given top priority. Each manufacturer's maintenance and operation instructions must be used to guide the technician in maintaining the fuel system in airworthy condition. Follow the manufacturer's instructions at all times. Component manufacturers and STC holder instructions should be used when applicable. Some general instructions for fuel system maintenance and repair are given in the following sections.

Troubleshooting the Fuel System

Knowledge of the fuel system and how it operates is essential when troubleshooting. Manufacturers produce diagrams and descriptions in their maintenance manuals to aid the technician. Study these for insight. Many manuals have troubleshooting charts or flow diagrams that can be followed. As with all troubleshooting, a logical sequence of steps to narrow the problem to a specific component or location should be followed. Defects within the system can often be located by tracing the fuel flow from the tank through the system to the engine. Each component must be functioning as designed and the cause of the defect symptom must be ruled out sequentially.

Location of Leaks and Defects

Close visual inspection is required whenever a leak or defect is suspected in a fuel system. Leaks can often be traced to the connection point of two fuel lines or a fuel line and a component. Occasionally, the component itself may have an internal leak. Fuel leaks also occur in fuel tanks and are discussed below. Leaking fuel produces a mark where it travels. It can also cause a stronger than normal odor. Gasoline may collect enough of its dye for it to be visible or an area clean of dirt may form. Jet fuel is difficult to detect at first, but it has a slow evaporation rate. Dirt and dust eventually settle into it, which makes it more visible.

When fuel leaks into an area where the vapors can collect, the leak must be repaired before flight due to the potential for fire or explosion. Repair could be deferred for external leaks that are not in danger of being ignited. However, the source of the leak should be determined and monitored to ensure it does not become worse. Follow the aircraft manufacturer's instructions on the repair of fuel leaks and the requirements that need to be met for airworthiness. Detailed visual inspection can often reveal a defect.

Fuel Leak Classification

Four basic classifications are used to describe aircraft fuel leaks: stain, seep, heavy seep, and running leak. *[Figure 14-90]* In 30 minutes, the surface area of the collected fuel from a leak is a certain size. This is used as the classification standard. When the area is less than ¾ inch in diameter, the leak is said to be a stain. From ¾ to 1½ inches in diameter, the leak is classified as a seep. Heavy seeps form an area from 1½ inches to 4 inches in diameter. Running leaks pool and actually drip from the aircraft. They may follow the contour of the aircraft for a long distance.

Replacement of Gaskets, Seals, and Packings

A leak can often be repaired by replacing a gasket or seal. When this occurs or a component is replaced or reassembled after a maintenance operation, a new gasket, seal, or packing must be installed. Do not use the old one(s). Always be sure to use the correct replacement as identified by part number. Also, most gaskets, seals, and packings have a limited shelf life. They should be used only if they are within the service life stamped on the package.

Remove the entire old gasket completely, and clean all mating surfaces. Clean surfaces and grooves allow a tight seal. Inspect new gaskets and seals for any flaws. Follow the manufacturer's instructions for replacement, including cleaning procedures and any sealing compound that you may need to apply during replacement. Torque assembly bolts evenly so as to provide even pressure and prevent pinching.

Fuel Tank Repair

Whether rigid removable, bladder-type, or integral, all fuel tanks have the potential to develop leaks. Repair a tank according to the manufacturer's instructions. Some general notes for repair of each tank type follow. Note that at the time a tank is repaired, a thorough inspection should be made. Corrosion, such as that caused by water and microbes, should be identified and treated at this time, even if it is not the cause of the leak.

Rigid removable fuel tanks can be riveted, welded, or soldered together. A leak can develop at any of these types of seams or can be elsewhere on the tank. Generally, the repair must match the construction in technique.

Some metal fuel tanks experiencing minor seepage can be repaired with a sloshing procedure. An approved sloshing compound is poured into the tank, and the tank is moved so that the compound coats the entire inner surface area of the tank. Any excess compound is then poured out and the compound in the tank is allowed to cure for a specified amount

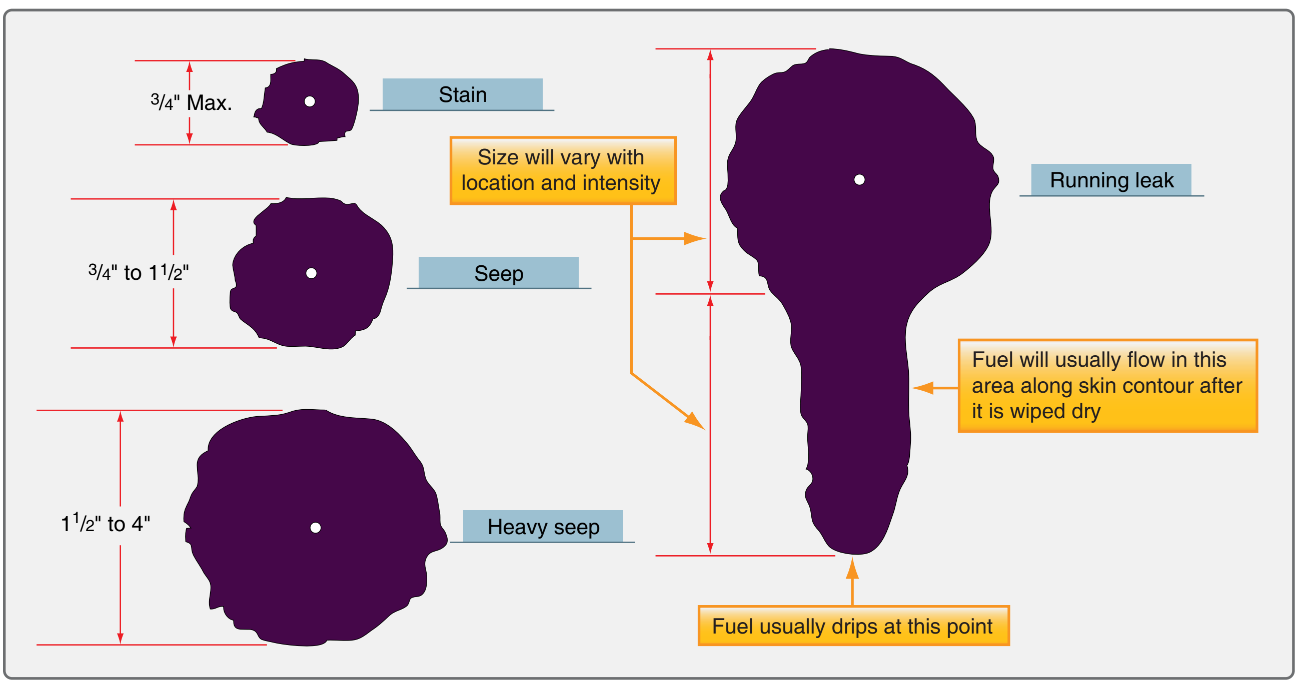


Figure 14-90. *The surface area of collected fuel from a leak is used to classify the leak into the categories shown.*

of time. Minor gaps in the seams of the tank and repairs are filled in this manner. The compound is fuel resistant once dry. Check with the aircraft manufacturer to ensure that sloshing is an airworthy repair for the aircraft fuel tank in question.

Welded Tanks

Welded tank repairs are usually done by welding. These tanks can be constructed from steel or weldable aluminum, such as 3003S or 5052SO. The tank is removed from the aircraft for the repair. It must be treated to remove any fuel vapors that remain in the tank before it is welded. This is critical to avoid serious injury from explosion should the fuel vapor ignite. The manufacturer usually gives a procedure for doing this. Some common methods for purging the tank include steam cleaning, hot water purging, and inert gas purging. Most procedures involve running the steam, water, or gas through the tank for a stated period of time. Adapters may need to be fashioned or purchased for the fill port to enable proper cleaning. Follow the manufacturer's procedure for the proper time to keep the cleaning medium in the tank and for prepping the tank for welding in general.

After a seam or a damaged area is welded, you must clean the tank of any flux or debris that may have fallen into the tank. Water rinsing and acid solutions are commonly used. A leak check to ensure the repair is sound follows a welded repair. This can be done by pressurizing the tank with a specified amount of air pressure and using a soapy solution on all seams and the repaired area. Bubbles form should air escape. The amount of air pressure used for a leak check is very low. One half to 3.5 psi is common. Use an accurate regulator and pressure gauge to prevent overpressurization that could deform or otherwise damage the tank. Tanks ordinarily supported by aircraft structure when installed should be similarly supported or reinstalled in the airframe before pressurization. *Figure 14-91* shows an aircraft fuel tank being welded and the repaired tank installed in the frame of an antique aircraft.

Riveted Tanks

Riveted tanks are often repaired by riveting. The seams and rivets are coated with a fuel resistant compound when assembled to create a leak-free container. This practice is followed during a patch repair, or when repairing a seam, which may require replacing the rivets in the seam. Some minor leak repairs may only require the application of addition compound. Follow manufacturer's instructions. The compound used may be heat sensitive and require inert gas purging to prevent degradation from hot water or steam purging. Again, follow all manufacturer guidance to insure a safe airworthy repair.

Soldered Tanks

Terneplate aircraft fuel tanks that are assembled by soldering are also repaired by soldering. All patches have a minimum amount that must overlap the damaged area. Flux used in soldering must be removed from the tank after the repair with techniques similar to that used on a welded tank. Follow manufacturer's instructions.

Bladder Tanks

Bladder fuel tanks that develop leaks can also be repaired. Most commonly, they are patched using patch material, adhesive, and methods approved by the manufacturer. As with soldered tanks, the patch has a required overlap of the damaged area. Damage that penetrates completely through the bladder is repaired with an external, as well as internal, patch.

Figure 14-91. *A rigid removable fuel tank with welded seams is repaired by welding.*

Synthetic bladder tanks have a limited service life. At some point, they seep fuel beyond acceptable limits and need to be replaced. Bladder tanks are usually required to remain wetted with fuel at all times to prevent drying and cracking of the bladder material. Storage of bladder tanks without fuel can be accomplished by coating the tanks with a substance to prevent drying, such as clean engine oil that can be flushed from the tank when ready to return to service. Follow all manufacturer's instructions for the care and repair of these common tanks. It is important to ensure that bladder tanks are correctly secured in place with the proper fasteners when reinstalling them in the aircraft after a repair.

Integral Tanks

Occasionally, an integral tank develops a leak at an access panel. This can often be repaired by transferring fuel to another tank so the panel can be removed and the seal replaced. Use of the proper sealing compound and bolt torque are required.

Other integral fuel tank leaks can be more challenging and time consuming to repair. They occur when the sealant used to seal the tank seams loses its integrity. To repair, fuel needs to be transferred or defueled out of the tank. You must enter large tanks on transport category aircraft. Preparing the tank for safe entry requires a series of steps outlined by the aircraft manufacturer. These include drying the tank and venting it of dangerous vapors. The tank is then tested with a combustible-gas indicator to be certain it can be entered safely. Clothing that does not cause static electricity and a respirator is worn. An observer is stationed outside of the tank to assist the technician in the tank. *[Figure 14-92]* A continuous flow of ventilating air is made to flow through the tank. A checklist for fuel tank preparation for entry taken from a transport category maintenance manual is shown in *Figure 14-93.* The details of the procedures are also given in the manual.

Once the location of the leak is determined, the tank sealant is removed and new sealant is applied. Remove old sealant with a nonmetallic scraper. Aluminum wool can be used to remove the final traces of the sealant. After cleaning the area with the recommended solvent, apply new sealant as instructed by the manufacturer. Observe cure time and leak checks as recommended before refilling the tank.

Fire Safety

Fuel vapor, air, and a source of ignition are the requirements for a fuel fire. Whenever working with fuel or a fuel system component, the technician must be vigilant to prevent these elements from coming together to cause a fire or explosion. A source of ignition is often the most controllable. In addition to removing all sources of ignition from the work area, care must be exercised to guard against static electricity. Static electricity can easily ignite fuel vapor, and its potential for igniting fuel vapor may not be as obvious as a flame or an operating electrical device. The action of fuel flowing through a fuel line can cause a static buildup as can many other situations in which one object moves past another. Always assess the work area and take steps to remove any potential static electricity ignition sources.

AVGAS is especially volatile. It vaporizes quickly due to its high vapor pressure and can be ignited very easily. Turbine engine fuel is less volatile but still possesses enormous capacity to ignite. This is especially true if atomized, such as when escaping out of a pressurized fuel hose or in a hot engine compartment on a warm day. Treat all fuels as potential fire

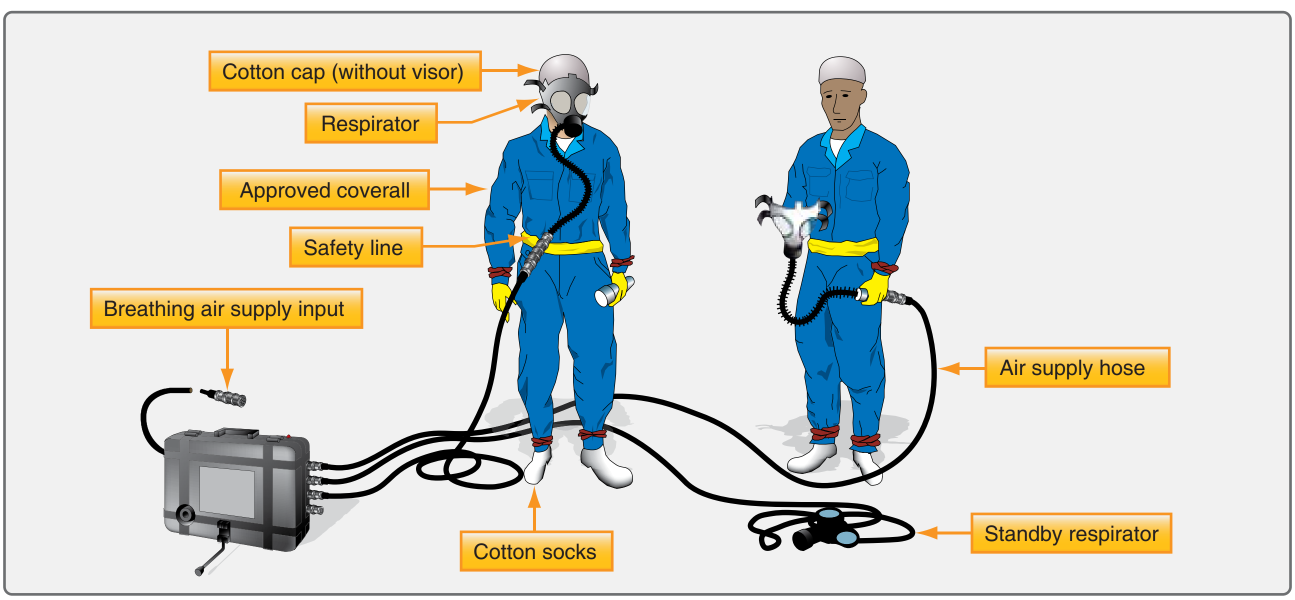


Figure 14-92. *Wear a nonstatic protective suit and respirator when entering an integral fuel tank for inspection or repair.*

This checklist must be completed prior to start of wet fuel cell entry and/or at shift change PRIOR to work assignment for the continuation of tank work started by a previous shift.

Wet fuel cell entry location

Area or building: ______________ Stall: ______________ Airplane: ______________ Tank: ______________

Shift: ______________ Date: ______________ Supervisor: ______________

- ◯ 1. Airplane and adjacent equipment properly grounded.
- ◯ 2. Area secured and warning signs positioned.
- ◯ 3. Boost pump switches off and circuit breakers pulled and placarded.
- ◯ 4. No power on airplane: battery disconnected, external power cord disconnected from airplane, and external power recepacle placarded.
- ◯ 5. Radio and radar equipment off (see separation distance requirements).
- ◯ 6. Only approved explosion-proof equipment and tools will be used for fuel cell entry (lights, blowers, pressure and test equipment, etc.).
- ◯ 7. Ensure requirements listed on aircraft confined space entry permit are complied with, including appropriate personal protective equipment: OSH class 110 respirator at a minimum, approved coveralls, cotton cap and foot coverings, and eye protection.
- ◯ 8. Trained attendant and confined space logsheet required for all wet fuel cell entries.
- ◯ 9. Aerators checked for cleanliness prior to use.
- ◯ 10. Sponges available for residual fuel mop out.
- ◯ 11. All plugs in use have streamers attached.
- ◯ 12. Mechanical ventilation (venturis or blowers) installed to ventilate all open fuel cells.

  Note: Ventilation system must remain in operation at all times while fuel cells are open. If ventilation system fails or any ill effects, such as dizziness, irriation, or excessive odors, are noted, all work shall stop and fuel cells must be evacuated.
- ◯ 13. Shop personnel entering cells and standby observers have current "fuel cell entry" certification cards. Certification requires the following training:
  - Aircraft confined space entry safety
  - Respirator use and maintenance
  - Wet fuel cell entry
- ◯ 14. Fire department notified.

Meter Reading

- ◯ 15. Oxygen reading (%): ______________ By: ______________
- ◯ 16. Fuel vapor level reading (ppm): ______________ By: ______________
- ◯ 17. Combustible gas meter (LEL) reading: ______________ By (FD): ______________

I confirm that all entry requirements were met prior to any entry.

______________________________ ______________

Signature of supervisor or designee Date

Figure 14-93. *Fuel tank checklist entry.*

hazards in all situations. As was discussed, empty fuel tanks have an extreme potential for ignition or explosion. Although the liquid fuel has been removed, ignitable fuel vapor can remain for a long period of time. Purging the vapor out of any empty fuel tank is an absolute necessity before any repair is initiated.

A fire extinguisher should be on hand during fuel system maintenance or whenever fuel is being handled. A fuel fire can be put out with a typical carbon dioxide (CO_2) fire extinguisher. Aim the extinguisher nozzle at the base of the flame and spray in a sweeping motion to have the agent fall over the flames to displace the oxygen and smother the fire. Dry chemical fire extinguishers rated for fuel can also be used. These leave behind a residue that requires cleanup that can be extensive and expensive. Do not use a water-type extinguisher. Fuel is lighter than water and could be spread without being extinguished. Additional precautions used to prevent fire are discussed below in the fueling–defueling section of this chapter.

Fuel System Servicing

Maintaining aircraft fuel systems in acceptable condition to deliver clean fuel to the engine(s) is a major safety factor in aviation. Personnel handling fuel or maintaining fuel systems should be properly trained and use best practices to ensure that the fuel, or fuel system, are not the cause of an incident or accident.

Checking for Fuel System Contaminants

Continuous vigilance is required when checking aircraft fuel systems for contaminants. Daily draining of strainers and sumps is combined with periodic filter changes and inspections to ensure fuel is contaminant free. Turbine powered engines have highly refined fuel control systems through which flow hundreds of pounds of fuel per hour of operation. Sumping alone is not sufficient. Particles are suspended longer in jet fuel due to its viscosity. Engineers design a series of filters into the fuel system to trap foreign matter. Technicians must supplement these with cautious procedures and thorough visual inspections to accomplish the overall goal of delivering clean fuel to the engines.

Keeping a fuel system clean begins with an awareness of the common types of contamination. Water is the most common. Solid particles, surfactants, and microorganisms are also common. However, contamination of fuel with another fuel not intended for use on a particular aircraft is possibly the worst type of contamination.

Water

Water can be dissolved into fuel or entrained. Entrained water can be detected by a cloudy appearance to the fuel. Close examination is required. Air in the fuel tends to cause a similar cloudy condition but is near the top of the tank. The cloudiness caused by water in the fuel tends to be more towards the bottom of the tank as the water slowly settles out.

As previously discussed, water can enter a fuel system via condensation. The water vapor in the vapor space above the liquid fuel in a fuel tank condenses when the temperature changes. It normally sinks to the bottom of the fuel tank into the sump where it can be drained off before flight. *[Figure 14-94]* However, time is required for this to happen.

On some aircraft, a large amount of fuel needs to be drained before settled water reaches the drain valve. Awareness of this type of sump idiosyncrasy for a particular aircraft is important. The condition of the fuel and recent fueling practices need to be considered and are equally important. If the aircraft has been flown often and filled immediately after flight, there is little reason to suspect water contamination beyond what would be exposed during a routine sumping.

Figure 14-94. *A sump drain tool used to open and collect fuel and contaminants from the fuel system sumps. Daily sump draining is part of the procedures needed to remove water from fuel that is to be delivered to the engine(s).*

An aircraft that has sat for a long period of time with partially full fuel tanks is a cause of concern.

It is possible that water is introduced into the aircraft fuel load during refueling with fuel that already contains water. Any suspected contamination from refueling or the general handling of the aircraft should be investigated. A change in fuel supplier may be required if water continues to be an issue despite efforts are made to keep the aircraft fuel tanks full and sumps drained on a regular basis. Note that fuel below freezing temperature may contain entrained water in ice form that may not settle into the sump until melted. Use of an anti-icing solution in turbine fuel tanks helps prevent filter blockage from water that condenses out of the fuel as ice during flight.

Note that the fuel anti-ice additive level should be monitored so that recommended quantity for the tank capacity is maintained. After repeated fueling, the level can be obscured. A field hand-held test unit can be used to check the amount of anti-ice additive already in a fuel load. *[Figure 14-95]*

Figure 14-95. *A hand-held refractometer with digital display measures the amount of fuel anti-ice additive contained in a fuel load.*

Strainers and filters are designed with upward flow exits to have water collect at the bottom of the fuel bowl to be drained off. This should not be overlooked. Entrained water in small quantities that makes it to the engine usually poses no problem. Large amounts of water can disrupt engine operation. Settled water in tanks can cause corrosion. This can be magnified by microorganisms that live in the fuel/water interface. High quantities of water in the fuel can also cause discrepancies in fuel quantity probe indications.

Solid Particle Contaminants

Solid particles that do not dissolve in the fuel are common contaminants. Dirt, rust, dust, metal particles, and just about anything that can find its way into an open fuel tank is of concern. Filter elements are designed to trap these contaminants and some fall into the sump to be drained off. Pieces of debris from the inside of the fuel system may also accumulate, such as broken-off sealant, or pieces of filter elements, corrosion, etc.

Preventing solid contaminant introduction into the fuel is critical. Whenever the fuel system is open, care must be taken to keep out foreign matter. Lines should be capped immediately. Fuel tank caps should not be left open for any longer than required to refuel the tanks. Clean the area adjacent to wherever the system is opened before it is opened.

Coarse sediments are those visible to the naked eye. Should they pass beyond system filters, they can clog in fuel metering device orifices, sliding valves, and fuel nozzles. Fine sediments cannot actually be seen as individual particles. They may be detected as a haze in the fuel or they may refract light when examining the fuel. Their presence in fuel controls and metering devices is indicated by dark shellac-like marks on sliding surfaces.

The maximum amount of solid particle contamination allowable is much less in turbine engine fuel systems than in reciprocating-engine fuel systems. It is particularly important to regularly replace filter elements and investigate any unusual solid particles that collect therein. The discovery of significant metal particles in a filter could be a sign of a failing component upstream of the filter. A laboratory analysis is possible to determine the nature and possible source of solid contaminants.

Surfactants

Surfactants are liquid chemical contaminants that naturally occur in fuels. They can also be introduced during the refining or handling processes. These surface active agents usually appear as tan to dark brown liquid when they are present in large quantities. They may even have a soapy consistency. Surfactants in small quantities are unavoidable and pose little threat to fuel system functioning. Larger quantities of surfactants do pose problems. In particular, they reduce the surface tension between water and the fuel and tend to cause water and even small particles in the fuel to remain suspended rather than settling into the sumps. Surfactants also tend to collect in filter elements making them less effective.

Surfactants are usually in the fuel when it is introduced into the aircraft. Discovery of either excessive quantities of dirt and water making their way through the system or a sudsy residue in filters and sumps may indicate their presence. The source of fuel should be investigated and avoided if found to contain a high level of these chemicals. As mentioned, slow settling rates of solids and water into sumps is a key indicator that surfactant levels are high in the fuel. Most quality fuel providers have clay filter elements on their fuel dispensing trucks and in their fixed storage and dispensing systems. These filters, if renewed at the proper intervals, remove most surfactants through adhesion. Surfactants discovered in the aircraft systems should be traced to the fuel supply source and the use and condition of these filters. *[Figure 14-96]*

Figure 14-96. *Clay filter elements remove surfactants. They are used in the fuel dispensing system before fuel enters the aircraft.*

Microorganisms

The presence of microorganisms in turbine engine fuels is a critical problem. There are hundreds of varieties of these life forms that live in free water at the junction of the water and fuel in a fuel tank. They form a visible slime that is dark brown, grey, red, or black in color. This microbial growth can multiply rapidly and can cause interference with the proper functioning of filter elements and fuel quantity indicators. Moreover, the slimy water/microbe layer in contact with the fuel tank surface provides a medium for electrolytic corrosion of the tank. *[Figure 14-97]*

Since the microbes live in free water and feed on fuel, the most powerful remedy for their presence is to keep water from accumulating in the fuel. Fuel 100 percent free of water is not practicable. By following best practices for sump draining and filter changes, combined with care of fuel stock tanks used to refuel aircraft, much of the potential for water to accumulate in the aircraft fuel tanks can be mitigated. The addition of biocides to the fuel when refueling also helps by killing organisms that are present.

Foreign Fuel Contamination

Aircraft engines operate effectively only with the proper fuel. Contamination of an aircraft's fuel with fuel not intended for use in that particular aircraft can have disastrous consequences. It is the responsibility of all aviators to put forth effort continuously to ensure that only the fuel designed for the operation of the aircraft's engine(s) is put into the fuel tanks. Each fuel tank receptacle or fuel cap area is clearly marked to indicate which fuel is required. *[Figure 14-98]*

If the wrong fuel is put into an aircraft, the situation must be rectified before flight. If discovered before the fuel pump is operated and an engine is started, drain all improperly filled tanks. Flush out the tanks and fuel lines with the correct fuel and then refill the tanks with the proper fuel. However, if discovered after an engine has been started or attempted to be started, the procedure is more in depth. The entire fuel system, including all fuel lines, components, metering device(s) and tanks, must be drained and flushed. If the engines have been operated, a compression test should be accomplished and the combustion chamber and pistons should be borescope inspected. Engine oil should be drained and all screens and filters examined for any evidence of damage. Once reassembled and the tanks have been filled with the correct fuel, a full engine run-up check should be performed before releasing the aircraft for flight.

Contaminated fuel caused by the introduction of small quantities of the wrong type of fuel into an aircraft may not look any different when visually inspected, making a dangerous situation more dangerous. Any person recognizing that this error has occurred must ground the aircraft. The lives of the aircraft occupants are at stake.

Detection of Contaminants

Visual inspection of fuel should always reveal a clean, bright looking liquid. Fuel should not be opaque, which could be a sign of contamination and demands further investigation. As mentioned, the technician must always be aware of the fuel's appearance, as well as when and from what sources refueling has taken place. Any suspicion of contamination must be investigated.

In addition to the detection methods mentioned for each type of contamination above, various field and laboratory tests can be performed on aircraft fuel to expose contamination. A common field test for water contamination is performed by adding a dye that dissolves in water but not fuel to a test sample drawn from the fuel tank. The more water present in the fuel, the greater the dye disperses and colors the sample.

Another common test kit commercially available contains a grey chemical powder that changes color to pink or purple when the contents of a fuel sample contains more than 30 parts per million (ppm) of water. A 15 ppm test is available for turbine engine fuel. *[Figure 14-99]* These levels of water are considered generally unacceptable and not safe for operation of the aircraft. If levels are discovered above these amounts, time for the water to settle out of the fuel should be given or the aircraft should be defueled and refueled with acceptable fuel.

Figure 14-97. *This fuel-water sample has microbial growth at the interface of the two liquids.*

Figure 14-98. *All entry points of fuel into the aircraft are marked with the type of fuel to be used. Never introduce any other fuel into the aircraft other than that which is specified.*

Figure 14-99. *This kit allows periodic testing for water in fuel.*

The presence and level of microorganisms in a fuel tank can also be measured with a field device. The test detects the metabolic activity of bacteria, yeast, and molds, including sulfate reducing bacteria, and other anaerobe microorganisms. This could be used to determine the amount of anti-microbial agent to be added to the fuel. The testing unit is shown in *Figure 14-100.*

Figure 14-100. *A capture solution is put into a 1 liter sample of fuel and shaken. The solution is then put into the analyzer shown to determine the level of microorganisms in the fuel.*

Bug test kits test fuel specifically for bacteria and fungus. While other types of microorganisms may exist, this semi-quantitative test is quick and easy to perform. Treat a fuel sample with the product and match the color of the sample to the chart for an indication of the level of bacteria and fungus present. These are some of the most common types of microorganisms that grow in fuel; if growth levels of fungus and bacteria are acceptable, the fuel could be usable. *[Figure 14-101]*

Figure 14-101. *Fuel bug test kits identify the level of bacteria and fungus present in a fuel load by comparing the color of a treated sample with a color chart.*

Fuel trucks and fuel farms may make use of laser contaminant identification technology. All fuel exiting the storage tank going into the servicing hose is passed through the analyzer unit. Laser sensing technology determines the difference between water and solid particle contaminants. When an excessive level of either is detected, the unit automatically shuts off flow to the fueling nozzle. Thus, aircraft are fueled only with clean dry fuel. When surfactant filters are combined with contaminant identification technology and microorganism detection, chances of delivering clean fuel to the aircraft engines are good. *[Figure 14-102]*

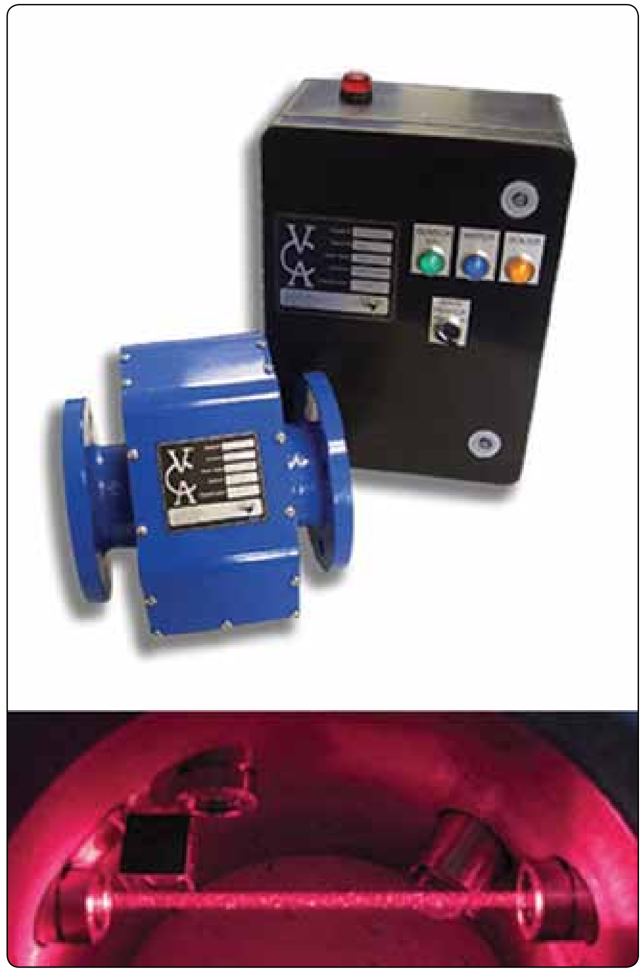


Figure 14-102. *This contaminant analyzer is used on fuel supply source outflow, such as that on a refueling truck. Water and solid contaminant levels are detected using laser identification technology. The valve to the fill hose is automatically closed when levels of either are elevated beyond acceptable limits.*

Before various test kits were developed for use in the field by nonscientific personnel, laboratories provided complete fuel composition analysis to aviators. These services are still available. A sample is sent in a sterilized container to the lab. It can be tested for numerous factors including water, microbial growth, flash point, specific gravity, cetane index (a measure of combustibility and burning characteristics), and more. Tests for microbes involve growing cultures of whatever organisms are present in the fuel. *[Figure 15-103]*

Fuel Contamination Control

A continuous effort must be put forth by all those in the aviation industry to ensure that each aircraft is fueled only with clean fuel of the correct type. Many contaminants, both

Figure 14-103. *Laboratory tests of fuel samples are available.*

soluble and insoluble, can contaminate an aircraft's fuel supply. They can be introduced with the fuel during fueling or the contamination may occur after the fuel is onboard.

Contamination control begins long before the fuel gets pumped into an aircraft fuel tank. Many standard petroleum industry safeguards are in place. Fuel farm and delivery truck fuel handling practices are designed to control contamination. Various filters, testing, and treatments effectively keep fuel contaminant free or remove various contaminants once discovered. However, the correct clean fuel for an aircraft should never be taken for granted. The condition of all storage tanks and fuel trucks should be monitored. All filter changes and treatments should occur regularly and on time. The fuel supplier should take pride in delivering clean, contaminant-free fuel to its customers.

Onboard aircraft fuel systems must be maintained and serviced according to manufacturer's specifications. Samples from all drains should be taken and inspected on a regular basis. Filters should be changed at the specified intervals. The fuel load should be visually inspected and tested from time to time or when there is a potential contamination issue. Particles discovered in filters should be indentified and investigated if needed. Inspection of the fuel system during periodic inspections should be treated with highest concern.

Most importantly, the choice of the correct fuel for an aircraft should never be in question. No one should ever put a fuel into an aircraft fuel tank unless absolutely certain it is the correct fuel for that aircraft and its engine(s). Personnel involved in fuel handling should be properly trained. All potential contamination situations should be investigated and remedied.

Fueling and Defueling Procedures

Maintenance technicians are often asked to fuel or defuel aircraft. Fueling procedure can vary from aircraft to aircraft. Tanks may need to be fueled in a prescribed sequence to prevent structural damage to the airframe. The proper procedure should be confirmed before fueling an unfamiliar aircraft.

Fueling

Always fuel aircraft outside, not in a hangar where fuel vapors may accumulate and increase the risk and severity of an accident. Generally, there are two types of fueling process: over-the-wing refueling and pressure refueling. Over-the-wing refueling is accomplished by opening the fuel tank cap on the upper surface of the wing or fuselage, if equipped with fuselage tanks. The fueling nozzle is carefully inserted into the fill opening and fuel is pumped into the tank. This process is similar to the process used to refuel an automobile gas tank. When finished, the cap is secured and subsequent tanks are opened and refilled until the aircraft has the desired fuel load onboard. Pressure refueling occurs at the bottom, front, or rear of the fuel tank. A pressure refueling nozzle locks onto the fueling port at the aircraft fueling station. Fuel is pumped into the aircraft through this secured and sealed connection. Gauges are monitored to ascertain when the tanks are properly loaded. An automatic shutoff system may be part of the aircraft system. It closes the fueling valve when the tanks are full. *[Figure 14-104]*

Figure 14-104. *A float switch installed in a fuel tank can close the refueling valve when the tanks are full during pressure fueling of an aircraft. Other more sophisticated automatic shutoff systems exist.*

Precautions should be used with either type of fueling. First and foremost, it is absolutely essential that the correct fuel be put in the aircraft. The type of fuel to be used is placarded near the fill port on over-the-wing systems and at the fueling station on pressure refueled aircraft. If there is any question about which fuel to use, the pilot in command, other knowledgeable personnel, or the manufacturer's maintenance/operations manual should be consulted before proceeding. Note that an over-the-wing refueling nozzle for turbine engine fuel should be too large to fit into the fill opening on an aircraft utilizing gasoline.

Clean the area adjacent to the fill port when refueling over the wing. Ensure the fuel nozzle is also clean. Aviation fuel nozzles are equipped with static bonding wires that must be attached to the aircraft before the fuel cap is opened.

[Figure 14-105] Open the cap only when ready to dispense the fuel. Insert the nozzle into the opening with care. The aircraft structure is much more delicate than the fuel nozzle, which could easily damage the aircraft. Do not insert the neck of the nozzle deeply enough to hit bottom. This could dent the tank, or the aircraft skin, if it is an integral tank. Exercise caution to avoid damage to the surface of the airframe by the heavy fuel hose. Lay the hose over your shoulder or use a refueling mat to protect the paint. *[Figure 14-106]*

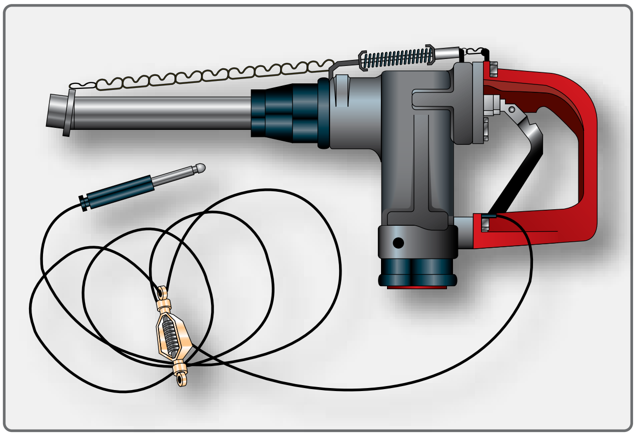


Figure 14-105. *An AVGAS fueling nozzle with static bonding grounding wire.*

Figure 14-106. *Over-the-wing refueling a Cessna.*

When pressure refueling, the aircraft receptacle is part of a fueling valve assembly. When the fueling nozzle is properly connected and locked, a plunger unlocks the aircraft valve so fuel can be pumped through it. Normally, all tanks can be fueled from a single point. Valves in the aircraft fuel system are controlled at the fueling station to direct the fuel into the proper tank. *[Figure 14-107]* Ensure that the pressure developed by the refueling pump is correct for the aircraft before pumping fuel. Note that, while similar, pressure fueling panels and their operation are different on different aircraft. Refueling personnel should be guided through the correct use of each panel. Do not guess at how the panel and associated valves operate.

Figure 14-107. *This panel at the pressure refueling station has valve position switches and quantity gauges to be used during refueling. Valve open position lights are adjacent to the switches for each tank.*

When fueling from a fuel truck, precautions should be taken. If the truck is not in continuous service, all sumps should be drained before moving the truck, and the fuel should be visually inspected to be sure it is bright and clean. Turbine fuel should be allowed to settle for a few hours if the fuel truck tank has recently been filled or the truck has been jostled, such as when driven over a bumpy service road at the airport. Properly maneuver the fuel truck into position for refueling. The aircraft should be approached slowly. The truck should be parked parallel to the wings and in front of the fuselage if possible. Avoid backing toward the aircraft. Set the parking brake and chock the wheels. Connect a static bonding cable from the truck to the aircraft. This cable is typically stored on a reel mounted on the truck.

There are other miscellaneous good practices that should be employed when refueling an aircraft. A ladder should be used if the refuel point is not accessible while standing on the ground. Climbing on an expensive aircraft to access the fueling ports is possible but does not give the stability of a ladder and may not be appreciated by the aircraft owner. If it is necessary to walk on the wings of the aircraft, do so only in designated areas, which are safe.

Filler nozzles should be treated as the important tools that they are. They should not be dropped or dragged across the apron. Most have attached dust caps that should be removed only for the actual fueling process and then immediately replaced. Nozzles should be clean to avoid contamination of the fuel. They should not leak and should be repaired at the earliest sign of leak or malfunction. Keep the fueling nozzle in constant contact with the filler neck spout when fueling. Never leave the nozzle in the fill spout unattended. When fueling is complete, always doublecheck the security of all fuel caps and ensure that bonding wires have been removed and stowed.

Defueling

Removing the fuel contained in aircraft fuel tanks is sometimes required. This can occur for maintenance, inspection, or due to contamination. Occasionally, a change in flight plan may require defueling. Safety procedures for defueling are the same as those for fueling. Always defuel outside. Fire extinguishers should be on hand. Bonding cables should be attached to guard against static electricity buildup. Defueling should be performed by experienced personnel, and inexperienced personnel must be checked out before doing so without assistance.

Remember that there may be a sequence in defueling an aircraft's fuel tanks just as there is when fueling to avoid structural damage. Consult the manufacturer's maintenance/operations manual(s) if in doubt.

Pressure fueled aircraft normally defuel through the pressure fueling port. The aircraft's in-tank boost pumps can be used to pump the fuel out. The pump on a fuel truck can also be used to draw fuel out. These tanks can also be drained through the tank sump drains, but the large size of the tanks usually makes this impractical. Aircraft fueled over the wing are normally drained through the tank sump drains. Follow the manufacturer's procedure for defueling the aircraft.

What to do with the fuel coming out of a tank depends on a few factors. First, if the tank is being drained due to fuel contamination or suspected contamination, it should not be mixed with any other fuel. It should be stored in a separate container from good fuel, treated if possible, or disposed of properly. Take measures to ensure that contaminated fuel is never placed onboard an aircraft or mixed with good fuel. Second, the manufacturer may have requirements for good fuel that has been defueled from an aircraft, specifying whether it can be reused and the type of storage container in which it must be stored. Above all, fuel removed from an aircraft must not be mixed with any other type of fuel.

Good fuel removed from an aircraft must be handled with all precautions used when handling any fuel. It must only be put into clean tanks and efforts must be made to keep it clean. It may be put back in the aircraft or another aircraft if the manufacturer allows. Large aircraft can often transfer fuel from a tank requiring maintenance to another tank to avoid the defueling process.

Fire Hazards When Fueling or Defueling

Due to the combustible nature of AVGAS and turbine engine fuel, the potential for fire while fueling and defueling aircraft must be addressed. Always fuel and defuel outside, not in a hangar that serves as an enclosed area for vapors to build up to a combustible level. Clothing worn by refueling personnel should not promote static electricity buildup. Synthetics, such as nylon, should be avoided. Cotton has proved to be safe for fuel handling attire.

As previously mentioned, the most controllable of the three ingredients required for fire is the source of ignition. It is absolutely necessary to prevent a source of ignition anywhere near the aircraft during fueling or refueling. Any open flame, such as a lit cigarette, must be extinguished. Operation of any electrical devices must be avoided. Radio and radar use is prohibited. It is important to note that fuel vapors proliferate well beyond the actual fuel tank opening and a simple spark, even one caused by static electricity, could be enough for ignition. Any potential for sparks must be nullified.

Spilled fuel poses an additional fire hazard. A thin layer of fuel vaporizes quickly. Small spills should be wiped up immediately. Larger spills can be flooded with water to dissipate the fuel and the potential for ignition. Do not sweep fuel that has spilled onto the ramp.

Class B fire extinguishers need to be charged and accessible nearby during the fueling and defueling processes. Fueling personnel must know exactly where they are and how to use them. In case of an emergency, the fuel truck, if used, may need to be quickly driven away from the area. For this reason alone, it should be positioned correctly on the ramp relative to the aircraft.