CHAPTER 4

FUELS AND FUEL SYSTEMS

GENERAL

Fuel is a substance that, when combined with oxygen, will burn and produce heat. Fuels may be classified according to their physical state as solid, gaseous, or liquid.

Solid Fuels

Solid fuels are used extensively for external-combustion engines, such as a steam engine, where the burning takes place under boilers or in furnaces. They include such fuels as wood and coal. Solid fuels are not used in reciprocating engines, where the burning takes place inside the cylinder, because of their slow rate of burning, low heat value, and numerous other disadvantages.

Gaseous Fuels

Gaseous fuels are used to some extent for internal-combustion engines, where a large supply of combustible gas is readily available. Natural gas and liquefied petroleum gas are two of the more common types. Gaseous fuels can be disregarded for use in aircraft engines. The large space they occupy limits the supply of fuel that can be carried.

Liquid Fuels

Liquid fuels, in many respects, are the ideal fuel for use in internal-combustion engines. Liquid fuels are classified as either nonvolatile or volatile. The nonvolatile fuels are the heavy oils used in diesel engines. The volatile class includes those fuels that are commonly used with a fuel metering device and are carried into the engine cylinder or combustion chamber in a vaporized or partially vaporized condition. Among these are alcohol, benzol, kerosene, and gasoline.

Aviation fuel is a liquid containing chemical energy that, through combustion, is released as heat energy and then converted to mechanical energy by the engine. This mechanical energy is used to produce thrust, which propels the aircraft. Gasoline and kerosene are the two most widely used aviation fuels.

CHARACTERISTICS AND PROPERTIES OF AVIATION GASOLINE

Aviation gasoline consists almost entirely of hydrocarbons, namely, compounds consisting of hydrogen and carbon. Some impurities in the form of sulphur and dissolved water will be present. The water cannot be avoided, since the gasoline is exposed to moisture in the atmosphere. A small amount of sulphur, always present in crude petroleum, is left in the process of manufacture.

Tetraethyl lead (TEL) is added to the gasoline to improve its performance in the engine. Organic bromides and chlorides are mixed with TEL so that during combustion volatile lead halides will be formed. These then are exhausted with the combustion products. TEL, if added alone, would burn to a solid lead oxide and remain in the engine cylinder. Inhibitors are added to gasoline to suppress the formation of substances that would be left as solids when the gasoline evaporates.

Certain properties of the fuel affect engine performance. These properties are volatility, the manner in which the fuel burns during the combustion process, and the heating value of the fuel. Also important is the corrosiveness of the gasoline as well as its tendency to form deposits in the engine during use. These latter two factors are important because of their effect on general cleanliness, which has a bearing on the time between engine overhauls.

Volatility

Volatility is a measure of the tendency of a liquid substance to vaporize under given conditions. Gasoline is a complex blend of volatile

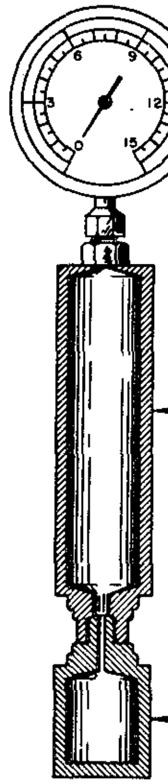


FIGURE 4–1. Vapor pressure test apparatus.

hydrocarbon compounds that have a wide range of boiling points and vapor pressures. It is blended in such a way that a straight chain of boiling points is obtained. This is necessary to obtain the required starting, acceleration, power, and fuel mixture characteristics for the engine.

If the gasoline vaporizes too readily, fuel lines may become filled with vapor and cause decreased fuel flow. If the fuel does not vaporize readily enough, it can result in hard starting, slow warm-up, poor acceleration, uneven fuel distribution to cylinders, and excessive crankcase dilution.

The lower grades of automobile fuel are not held within the tolerances required for aviation gasoline and usually contain a considerable amount of cracked gasoline, which may form excessive gum deposits. For these reasons, automobile fuels should not be used in aircraft engines, especially air-cooled engines operating at high cylinder temperatures.

Vapor Lock

Vaporization of gasoline in fuel lines results in a reduced supply of gasoline to the engine. In severe cases, it may result in engine stoppage. This phenomenon is referred to as vapor locking. A measure of a gasoline's tendency to vapor lock is obtained from the Reid vapor pressure test. In this test a sample of the fuel is sealed in a "bomb" equipped with a pressure gage. The apparatus (see figure 4–1) is then immersed in a constant-temperature bath and the indicated pressure is noted. The higher the corrected vapor pressure of the sample under test, the more susceptible it is to vapor locking. Aviation gasolines are limited to a maximum of 7 p.s.i. because of their increased tendency to vapor lock at high altitudes.

Carburetor Icing

Carburetor icing is also related to volatility. When the fuel changes from a liquid to a vapor state, it extracts heat from its surroundings to make this change. The more volatile the fuel, the more rapid the heat extraction will be. As the gasoline leaving the carburetor discharge nozzle vaporizes, it can freeze water vapor contained in the incoming air. The moisture freezes on the walls of the induction system, the venturi throat, and the throttle valves. This type of ice formation restricts the fuel and air passages of the carburetor. It causes loss of power and, if not eliminated, eventual engine stoppage. Extreme icing conditions can make operation of the throttle controls impossible. This icing condition is most severe in the temperature range of 30° to 40° F. outside air temperature.

Aromatic Fuels

Some fuels may contain considerable quantities of aromatic hydrocarbons, which are added to increase the rich mixture performance rating of the fuel. Such fuels, known as aromatic fuels, have a strong solvent and swelling action on some types of hose and other rubber parts of the fuel system. For this reason, aromatic-resistant hose and rubber parts have been developed for use with aromatic fuels.

Detonation

In an engine that is operating in a normal manner, the flame front traverses the charge at a steady velocity of about 100 feet per second until the charge is consumed. When detonation occurs, the first portion of the charge burns in a normal manner but the last portion burns almost instantaneously, creating an excessive momentary pressure unbalance in the combustion chamber. This abnormal type of combustion is called detonation. This tremendous increase in the speed of burning causes the cylinder head temperature to rise. In severe cases, the increase in burning speed will decrease engine efficiency and may cause structural damage to the cylinder head or piston.

During normal combustion, the expansion of the burning gases presses the head of the piston down firmly and smoothly without excessive shock. The increased pressure of detonation exerted in a short period of time produces a heavy shock load to the walls of the combustion chamber and the piston head. It is this shock to the combustion chamber that is heard as an audible knock in an automobile engine. If other sounds could be filtered out, the knock would be equally audible in an aircraft engine. Generally, it is necessary to depend upon instruments to detect detonation in an aircraft engine.

Surface Ignition

Ignition of the fuel/air mixture by hot spots or surfaces in the combustion chamber is called surface ignition. If this occurs before the normal ignition event, the phenomenon is referred to as preignition. When it is prevalent, the result is power loss and engine roughness. Preignition is generally attributed to overheating of such parts as spark plug electrodes, exhaust valves, carbon deposits, etc. Where preignition is present, an engine may continue to operate even though the ignition has been turned off.

Present information indicates that gasoline high in aromatic hydrocarbon content is much more likely to cause surface ignition than fuels with a low content.

Octane and Performance Number Rating

Octane and performance numbers designate the antiknock value of the fuel mixture in an engine cylinder. Aircraft engines of high power output have been made possible principally as a result of blending to produce fuels of high octane ratings. The use of such fuels has permitted increases in compression ratio and manifold pressure, resulting in improved engine power and efficiency. However, even the high-octane fuels will detonate under severe operating conditions and when certain engine controls are improperly operated.

Antiknock qualities of aviation fuel are designated by grades. The higher the grade, the more compression the fuel can stand without detonating. For fuels that have two numbers, the first number indicates the lean-mixture rating and the second the rich-mixture rating. Thus, grade 100/130 fuel has a lean-mixture rating of 100 and a rich-mixture rating of 130. Two different scales are used to designate fuel grade. For fuels below grade 100, octane numbers are used to designate grade. The octane number system is based on a comparison of any fuel with mixtures of iso-octane and normal heptane. The octane number of a fuel is the percentage of iso-octane in the mixture that duplicates the knock characteristics of the particular fuel being rated. Thus, grade 91 fuel has the same knock characteristics as a blend of 91 percent iso-octane and 9 percent normal heptane.

With the advent of fuels having antiknock characteristics superior to iso-octane, another scale was adopted to designate the grade of fuels above the 100-octane number. This scale represents the performance rating of the fuel—its knock-free power available as compared with that available with pure iso-octane. It is arbitrarily assumed that 100 percent power is obtained from iso-octane alone. An engine that has a knock-limited horsepower of 1,000 with 100-octane fuel will have a knock-limited horsepower of 1.3 times as much (1,300 horsepower) with 130 performance number fuel.

The grade of an aviation gasoline is no indication of its fire hazard. Grade 91/96 gasoline is as easy to ignite as grade 115/145 and explodes with as much force. The grade indicates only the gasoline's performance in the aircraft's engine.

A convenient means of improving the antiknock characteristics of a fuel is to add a knock inhibitor. Such a fluid must have a minimum of corrosive or other undesirable qualities, and probably the best available inhibitor in general use at present is TEL (tetraethyl lead). The few difficulties encountered because of the corrosion tendencies of ethylized gasoline are insignificant when compared with the results obtained from the high antiknock value of the fuel. For most aviation fuels the addition of more than 6 ml. per gallon is not permitted. Amounts in excess of this have little effect on the antiknock value, but increase corrosion and spark plug trouble.

There are two distinct types of corrosion caused by the use of ethyl gasoline. The first is caused by the reaction of the lead bromide with hot metallic surfaces, and occurs when the engine is in operation; the second is caused by the condensed products of combustion, chiefly hydrobromic acid, when the engine is not running.

Purity

Aviation fuels must be free of impurities that would interfere with the operation of the engine or the units in the fuel and induction system.

Even though all precautions are observed in storing and handling gasoline, it is not uncommon to find a small amount of water and sediment in an aircraft fuel system. A small amount of such contamination is usually retained in the strainers in the fuel system. Generally, this is not considered a source of great danger, provided the strainers are drained and cleaned at frequent intervals. However, the water can present a serious problem because it settles to the bottom of the fuel tank and can then be circulated through the fuel system. A small quantity of water will flow with the gasoline through the carburetor metering jets and will not be especially harmful. An excessive amount of water will displace the fuel passing through the jets and restrict the flow of fuel; it will cause loss of power and can result in engine stoppage.

Under certain conditions of temperature and humidity, condensation of moisture (from the air) occurs on the inner surfaces of the fuel tanks. Since this condensation occurs on the portion of the tank above the fuel level, it is obvious that the practice of servicing an airplane immediately after flight will do much to minimize this hazard.

Fuel Identification

Gasolines containing TEL must be colored to conform with the law. In addition, gasoline may be colored for purposes of identification. For example, grade 100 low lead aviation gasoline is *blue*, grade 100 is *green* and grade 80 is *red*. See figure 4–2.

100/130 gasoline is manufactured (1975) in two grades—high-lead, up to 4.6 milliliters of lead per gallon and low-lead, not over 2.0 milliliters per gallon. The purpose being to eliminate two grades of lower octane fuel (80/87) and 91/96). The high-lead will continue to be colored green whereas the low-lead will be blue.

The low-lead will replace the 80/87 and 91/96 octane fuels as they are phased out. Engine manufacturers have prepared instructions to be followed in making adjustments necessary for changeover to the 100 octane fuel.

A change in color of an aviation gasoline usually indicates contamination with another product or a loss of fuel quality. A color change can also be caused by a chemical reaction that has weakened the lighter dye component. This color change in itself may not affect the quality of the fuel.

A color change can also be caused by the preservative in a new hose. Grade 115/145 gasoline that has been trapped for a short period of time in new hose may appear green. Flushing a small amount of gasoline through the hose usually removes all traces of color change.

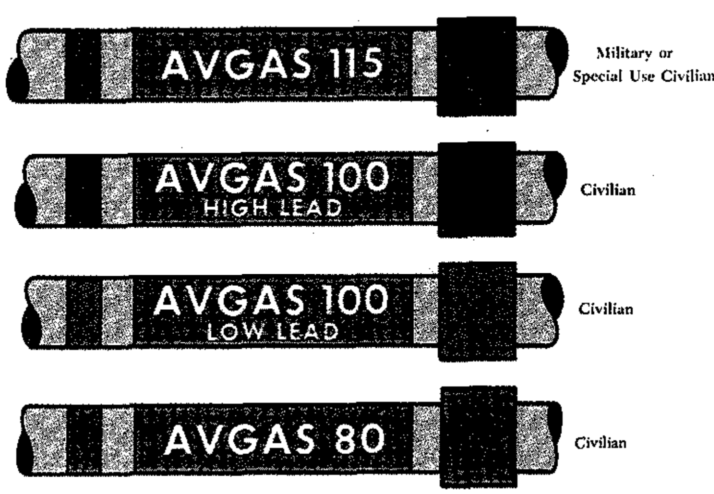


FIGURE 4–2. Identification of avgas.

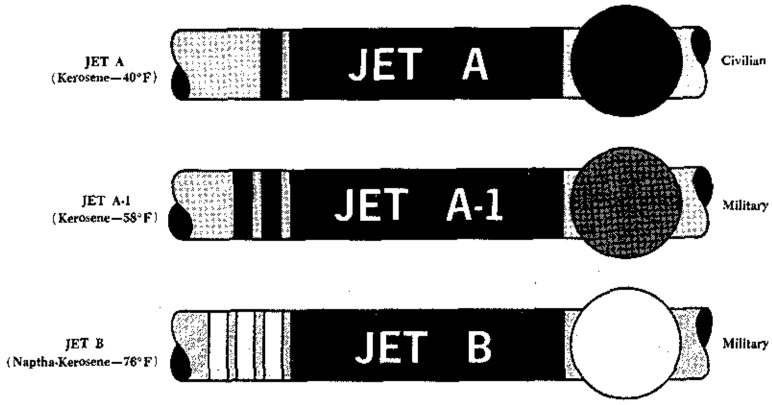


FIGURE 4–3. Identification of jet fuels.

Fuel Identification Markings

The most positive method of identifying the type and grade of fuel includes the following:

1. *Marking of Hose.* A color band not less than one foot wide painted adjacent to the fitting on each end of hose used to dispense fuel. The bands completely encircle the hose, and the name and grade of the product is stenciled longitudinally in one-inch letters of a contrasting color over the color band.

2. *Marking of Fuel Carriers, Pits and Fill Stands.* Tags identifying the name and grade of the product permanently affixed to each discharge meter and fill pipe. Porcelain tags (4″×6″) carrying the same information permanently bolted to the outside of the rear compartment of fuel servicing equipment. The delivery pipes of truck fill stands are banded with colors corresponding to that used on the dispensing hose.

TURBINE ENGINE FUELS

The aircraft gas turbine is designed to operate on a distillate fuel, commonly called jet fuel. Jet fuels are also composed of hydrocarbons with a little more carbon and usually a higher sulphur content than gasoline. Inhibitors may be added to reduce corrosion and oxidation. Anti-icing additives are also being blended to prevent fuel icing.

Two types of jet fuel in common use today are: (1) Kerosene grade turbine fuel, now named Jet A; and (2) a blend of gasoline and kerosene fractions, designated Jet B. There is a third type, called Jet A–1, which is made for operation at extremely low temperatures. See figure 4–3.

There is very little physical difference between Jet A (JP-5) fuel and commercial kerosene. Jet A was developed as a heavy kerosene having a higher flash point and lower freezing point than most kerosenes. It has a very low vapor pressure, so there is little loss of fuel from evaporation or boil-off at higher altitudes. It contains more heat energy per gallon than does Jet B (JP-4).

Jet B is similar to Jet A. It is a blend of gasoline and kerosene fractions. Most commercial turbine engines will operate on either Jet A or Jet B fuel. However, the difference in the specific gravity of the fuels may require fuel control adjustments. Therefore, the fuels cannot always be considered interchangeable.

Both Jet A and Jet B fuels are blends of heavy distillates and tend to absorb water. The specific gravity of jet fuels, especially kerosene, is closer to water than is aviation gasoline; thus, any water introduced into the fuel, either through refueling or condensation, will take an appreciable time to settle out. At high altitudes, where low temperatures are encountered, water droplets combine with the fuel to form a frozen substance referred to as "gel." The mass of "gel" or "icing" that may be generated from moisture held in suspension in jet fuel can be much greater than in gasoline.

Volatility

One of the most important characteristics of a jet fuel is its volatility. It must, of necessity, be a compromise between several opposing factors. A highly volatile fuel is desirable to aid in starting in cold weather and to make aerial restarts easier and surer. Low volatility is desirable to reduce

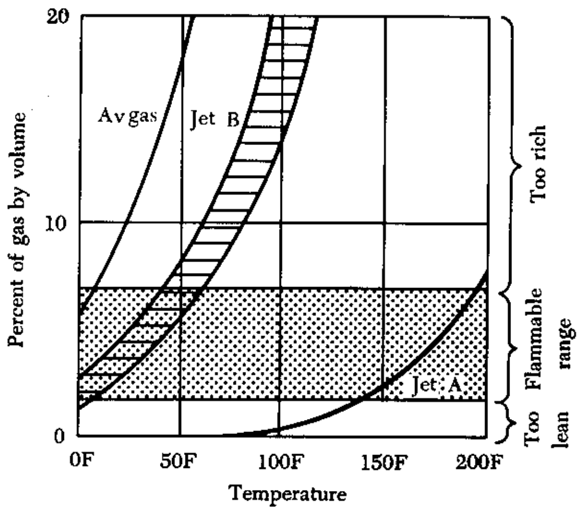


FIGURE 4–4. Vaporization of aviation fuels at atmospheric pressure.

the possibility of vapor lock and to reduce fuel losses by evaporation.

At normal temperatures, gasoline in a closed container or tank can give off so much vapor that the fuel/air mixture may be too rich to burn. Under the same conditions, the vapor given off by Jet B fuel can be in the flammable or explosive range. Jet A fuel has such a low volatility that at normal temperatures it gives off very little vapor and does not form flammable or explosive fuel/air mixtures. Figure 4–4 shows the vaporization of aviation fuels at atmospheric pressure.

Identification

Because jet fuels are not dyed, there is no on-sight identification for them. They range in color from a colorless liquid to a straw-colored (amber) liquid, depending on age or the crude petroleum source.

Jet fuel numbers are type numbers and have no relation to the fuel's performance in the aircraft engine.

FUEL SYSTEM CONTAMINATION

There are several forms of contamination in aviation fuel. The higher the viscosity of the fuel, the greater is its ability to hold contaminants in suspension. For this reason, jet fuels having a high viscosity are more susceptible to contamination than aviation gasoline. The principal contaminants that reduce the quality of both gasoline and turbine fuels are other petroleum products, water, rust or scale, and dirt.

Water

Water can be present in the fuel in two forms: (1) Dissolved in the fuel or (2) entrained or suspended in the fuel. Entrained water can be detected with the naked eye. The finely divided droplets reflect light and in high concentrations give the fuel a dull, hazy, or cloudy appearance. Particles of entrained water may unite to form droplets of free water.

Fuel can be cloudy for a number of reasons. If the fuel is cloudy and the cloud disappears at the bottom, air is present. If the cloud disappears at the top, water is present. A cloud usually indicates a water-in-fuel suspension. Free water can cause icing of the aircraft fuel system, usually in the aircraft boost-pump screens and low-pressure filters. Fuel gage readings may become erratic because the water short-circuits the aircrafts electrical fuel cell quantity probe. Large amounts of water can cause engine stoppage. If the free water is saline, it can cause corrosion of the fuel system components.

Foreign Particles

Most foreign particles are found as sediment in the fuel. They are composed of almost any material with which the fuel comes into contact. The most common types are rust, sand, aluminum and magnesium compounds, brass shavings, and rubber.

Rust is found in two forms: (1) Red rust, which is nonmagnetic and (2) black rust, which is magnetic. They appear in the fuel as red or black powder (which may resemble a dye), rouge, or grains. Sand or dust appears in the fuel in a crystalline, granular, or glasslike form.

Aluminum or magnesium compounds appear in the fuel as a form of white or gray powder or paste. This powder or paste becomes very sticky or gelatinous when water is present. Brass is found in the fuel as bright gold-colored chips or dust. Rubber appears in the fuel as fairly large irregular bits. All of these forms of contamination can cause sticking or malfunctions of fuel metering devices, flow dividers, pumps, and nozzles.

Contamination with Other Types or Grades of Fuel

The unintentional mixing of petroleum products can result in fuels that give unacceptable performance in the aircraft. An aircraft engine is designed to operate most efficiently on fuel of definite specifications. The use of fuels that differ from these specifications reduces operating efficiency and can lead to complete engine failure.

Operators of turbine-powered aircraft are sometimes forced by circumstances to mix fuels. Such mixing, however, has very definite disadvantages. When aviation gasoline is mixed with jet fuel, the TEL in the gasoline forms deposits on the turbine blades and vanes. Continuous use of mixed fuels may cause a loss in engine efficiency. However, on a limited usage basis, they will have no detrimental effects on the engine.

Aviation gasoline containing by volume more than 0.5 percent of jet fuel may be reduced below the allowable limits in knock rating. Gasoline contaminated with turbine fuel is unsafe for use in reciprocating engines.

Microbial Growth

Microbial growth is produced by various forms of micro-organisms that live and multiply in the water interfaces of jet fuels. These organisms may form a slime similar in appearance to the deposits found in stagnent water. The color of this slime growth may be red, brown, gray, or black. If not properly controlled by frequent removal of free water, the growth of these organisms can become extensive. The organisms feed on the hydrocarbons that are found in fuels, but they need free water in order to multiply.

Micro-organisms have a tendency to mat, generally appearing as a brown blanket which acts as a blotter to absorb more moisture. This mixture or mat accelerates the growth of micro-organisms. The buildup of micro-organisms not only can interfere with fuel flow and quantity indication, but, more important, it can start electrolytic corrosive action.

Sediment

Sediment appears as dust, powder, fibrous material, grains, flakes, or stain. Specks or granules of sediment indicate particles in the visible size range, i.e., approximately 40 microns or larger in size. (See figure 4–5.) The presence of any appreciable number of such particles indicates either a malfunction of the filter/separators or a source of contamination downstream of the filter/separator, or else an improperly cleaned sample container. Even with the most efficient filter/separators and careful fuel handling, an occasional

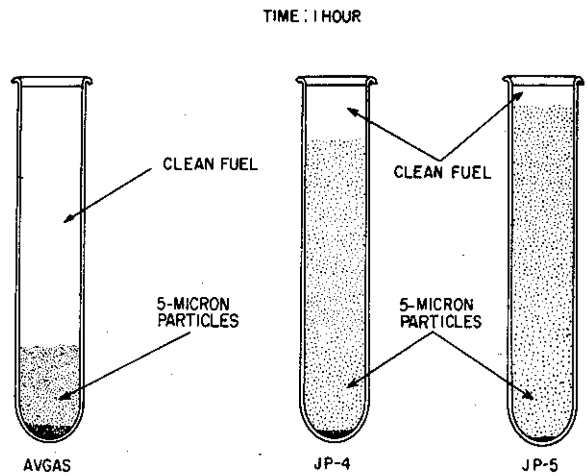


FIGURE 4–5. Comparison of particle's rate of settling in three types of fuel.

visible particle will be encountered. These strays are usually due to particle migration through the filter media and may represent no particular problem to the engine or fuel control. The sediment ordinarily encountered is an extremely fine powder, rouge, or silt. The two principle components of this fine sediment are normally sand and rust.

Sediment includes both organic and inorganic matter. The presence of appreciable quantities of fibrous materials (close to naked eye visibility) is usually indicative of filter element breakdown, either because of a ruptured element or mechanical disintegration of a component in the system. Usually, high metal content of relatively large particles suggest a mechanical failure somewhere in the system which is necessarily not limited to a metallic filter failure.

In a clean sample of fuel, sediment should not be visible except upon the most meticulous inspection. Persistent presence of sediment is suspect and requires that appropriate surveillance tests and corrective measures be applied to the fuel handling system.

Sediment or solid contamination can be separated into two categories: (1) coarse sediment and (2) fine sediment.

Course Sediment

Sediment that can be seen and that easily settles out of fuel or can be removed by adequate filtration is coarse sediment. Ordinarily, particles 10 microns in size and larger are regarded as coarse sediment. (See figure 4–6.)

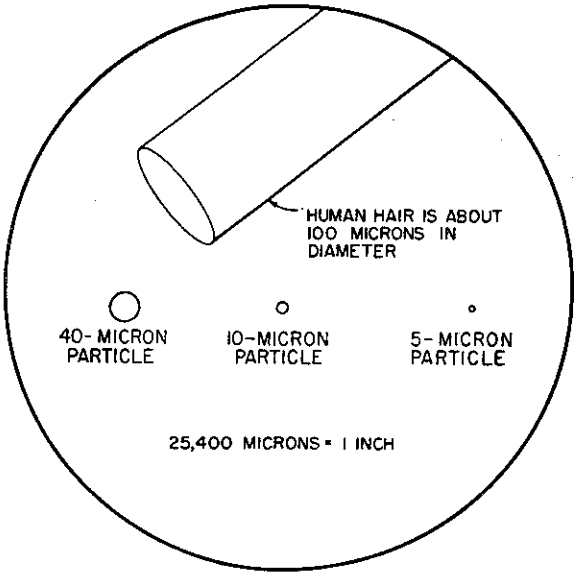


FIGURE 4–6. Enlargement of small particles and comparison to human hair.

Coarse particles clog orifices and wedge in sliding valve clearances and shoulders, causing malfunctions and excessive wear of fuel controls and metering equipment. They are also effective in clogging nozzle screens and other fine screens throughout the aircraft fuel system.

Fine Sediment

Particles smaller than 10 microns may be defined as fine sediment. (See figure 4–6.) Ninety eight percent of the fine sediment in fuel can be removed by proper settling, filtration, and centrifuging. Particles in this range accumulate throughout fuel controls, appearing as a dark shellac-like surface on sliding valves, and may also be centrifuged out in rotating chambers as sludge-like matter, causing sluggish operation of fuel metering equipment. Fine particles are not visible to the naked eye as distinct or separate particles; they will, however, scatter light and may appear as point flashes of light or a slight haze in fuel.

Maximum possible settling time should be allowed in fuel tanks after filling to allow reasonable settlement of water and sediment.

Contamination Detection

Coarse contamination can be detected visually. The major criterion for contamination detection is that the fuel be clean, bright, and contain no perceptible free water. Clean means the absence of any readily visible sediment or entrained water. Bright refers to the shiny appearance of clean, dry fuels. Free water is indicated by a cloud, haze, or a water slug. A cloud may or may not be present when the fuel is saturated with water. Perfectly clear fuel can contain as much as three times the volume of water considered to tolerable.

Several field methods for checking water content have been devised. One is the adding of a food color that is soluble in water, but not in fuel. Colorless fuel samples acquire a definite tint if water is present. Another method uses a gray chemical powder that changes color to pink through purple, if 30 or more p.p.m. (parts per million) of water are present in a fuel sample. In a third method a hypodermic needle is used to draw a fuel sample through a chemically treated filter. If the sample changes the color of the filter from yellow to blue, the fuel contains at least 30 p.p.m. of water.

Since fuel drained from tank sumps may have been cold-soaked, it should be realized that no method of water detection can be accurate while the fuel entrained water is frozen into ice crystals.

There is a good chance that water will not be drained or detected if the sumps are drained while the fuel is below 32° F. after being cooled in flight. The reason for this is that the sump drains may not be at the lowest point in the fuel tank while the airplane is in a flight attitude, and water may accumulate and freeze on other areas of the tank where it will remain undetected until it thaws.

Draining will be more effective if it is done after the fuel has been undisturbed for a period of time during which the free water can precipitate and settle to the drain point. The benefits of a settling period will be lost, however, unless the accumulated water is removed from the drains before the fuel is disturbed by internal pumps.

Contamination Control

The aircraft fuel system can be considered as being divided into three parts when discussing clean fuel. The manufacturer produces clean fuel. Contamination can occur at any time after the fuel is produced. The first part of the fuel system is the delivery and storage system between the refinery and the airport fuel service truck. Although this system is not physically a part of the aircraft, it is of equal importance in controlling contamination.

Anytime fuel is transferred it is susceptible to contamination. Therefore, all aviation maintenance personnel should be familiar with the following means of contamination control.

Fundamental in the control of contamination of turbine fuels are the methods followed by the industry in receiving and storing any bulk shipment of a petroleum product. These methods have long been established as sound, and they are too well known to need repetition here. The refueling facilities used by operators of turbine powered aircraft should incorporate the following features:

1. Fuel being pumped into airport storage should pass through a filter-separator. The filter should meet the requirements of U.S. Government Specification MIL–F–8508A.

2. Turbine fuels should be allowed to settle for a period of one hour per foot of depth of the fuel before being withdrawn for use. This means that ordinarily more than one storage tank must be provided for each grade of product.

3. Storage tanks should be checked with litmus paper after each new load of fuel is received and the fuel has settled. The litmus paper should remain submerged for a minimum of 15 seconds. During periods of heavy rain underground tanks should be checked with litmus paper more frequently.

4. Suction lines should be a minimum of 6 inches from the bottom of the tank. *Kerosene storage tanks* should be equipped with floating type suction lines. Floating suction does not remove the bottom product, which may not have settled sufficiently. It also prevents reintroduction into the fuel of any contamination at the bottom of the tank. Floating suction is the only logical way to take full advantage of gravity in removing water and particulate matter contamination. Its importance must not be minimized.

5. Fuel being withdrawn from storage should be passed through a filter-separator meeting the specification MIL–F–8508A.

6. Great care should be exercised in loading mobile fuelers to exclude airborne dust and dirt, rain or other foreign material.

7. To lessen the likelihood of rust and scale the tanks of mobile fuelers should be constructed of either stainless steel, nonferrous material or steel coated with a reliable, inert material.

8. As turbine fuel is being dispensed into the aircraft from truck or hydrant it should be filtered to a degree of 5 microns for solid particles and contain no more than 0.0015 per cent of free and entrained water. Bypass valves around the filter should not be permitted.

9. All the quality control procedures usually followed in handling aviation gasoline should be employed. These include regular and frequent check of filter-separators; frequent quality check such as the "clear and bright" test; and continual emphasis on cleanliness. Examples: "Don't let the hose nozzle drag on the apron." "Keep the dust cap on the nozzle at all times when nozzle is not in use."

FUEL SYSTEM

The aircraft fuel system stores fuel and delivers the proper amount of clean fuel at the right pressure to meet the demands of the engine. A well-designed fuel system ensures positive and reliable fuel flow throughout all phases of flight, which include changes in altitude, violent maneuvers and sudden acceleration and deceleration. Furthermore, the system must be reasonably free from tendency to vapor lock, which can result from changes in ground and in-flight climatic conditions. Such indicators as fuel pressure gages, warning signals, and tank quantity gages are provided to give continuous indications of how the system is functioning.

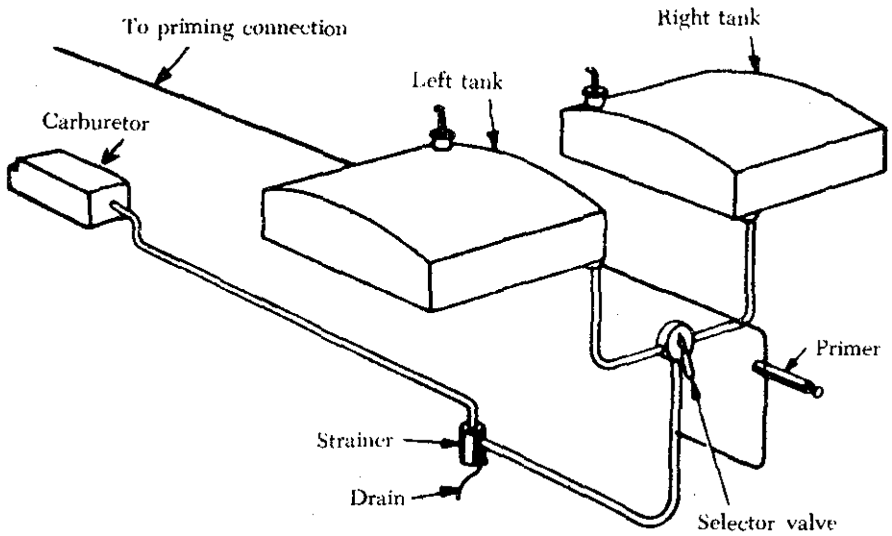


FIGURE 4–7. Gravity feed fuel system.

The simplest type of fuel system is the gravity feed, which is still in use on many low-powered airplanes. A gravity feed system is shown in figure 4–7. The fuel tanks are mounted above the carburetor, with gravity causing the fuel to flow from the tanks to the carburetor. A selector valve is provided to stop the fuel flow or to select a particular tank in the system from which to draw fuel. A strainer filters the fuel before it reaches the carburetor. A drain is provided for removing water and sediment trapped at the strainer. A primer furnishes the additional fuel required for engine starting.

Airplanes equipped with a high-output engine require a fuel system that supplies fuel to the carburetor at a positive pressure. The basic source for this pressure is an engine-driven fuel pump, but auxiliary fuel pumps or booster pumps are required in every pressure feed system to: (1) supply fuel pressure for starting the engine; (2) supply fuel to the primer system; and (3) to serve as an emergency pump in case the engine-driven pump fails.

FUEL SYSTEM COMPONENTS

The basic components of a fuel system include tanks, lines, valves, pumps, filtering units, gages, warning signal, and primer. Some systems will include central refueling provisions, fuel dump valves, and a means for transferring fuel. In order to clarify the operating principles of complex aircraft fuel systems, the various units are discussed in the following paragraphs.

Fuel Tanks

The location, size, shape, and construction of fuel tanks vary with the type and intended use of the aircraft. In some aircraft, the fuel tanks are integral with the wing or other structural portions of the aircraft.

Fuel tanks are made of materials that will not react chemically with any aviation fuel. Aluminum alloy is widely used, and synthetic rubber bladder-type fuel cells are used in some installations.

Usually a sump and a drain are provided at the lowest point in the tank as shown in figure 4–8. When a sump or low point is provided in the tank, the main fuel supply is not drawn from the bottom of the sump, but from a higher point in the tank.

The top of each tank is vented to the outside air in order to maintain atmospheric pressure within the tank. Air vents are designed to minimize the possibility of their stoppage by dirt and ice formation. In order to permit rapid changes in internal air pressure, the size of the vent is proportional to the size of the tank, thus preventing the collapse of the tank in a steep dive or glide. All except the very smallest of tanks are fitted with internal baffles to resist fuel surging caused by changes in the attitude of the aircraft. Usually an expansion space is provided in fuel tanks to allow for an increase in fuel volume due to expansion.

The filler neck and cap are usually located in a recessed well, equipped with a scupper and

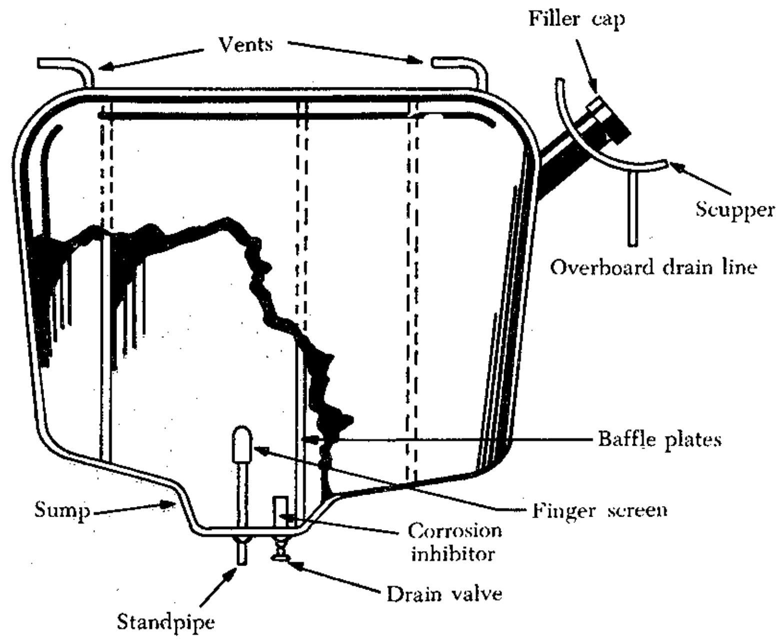


FIGURE 4–8. A typical metal fuel tank.

drain. The scupper is designed to prevent overflowing fuel from entering the wing or fuselage structure. Fuel caps have provisions for locking devices to prevent accidental loss during flight. Filler openings are clearly marked with the word "FUEL", the tank capacity, and the type of fuel to be used. Information concerning the capacity of each tank is usually posted near the fuel selector valves, as well as on the tank filler caps.

Some fuel tanks are equipped with dump valves that make it possible to jettison fuel during flight in order to reduce the weight of the aircraft to its specified maximum landing weight. In aircraft equipped with dump valves, the operating control is located within reach of the pilot, copilot, or flight engineer. Dump valves are designed and installed to afford safe, rapid discharge of fuel.

Fuel Cells

Present day aircraft may be equipped with one or more of the following types of fuel cells: the bladder-type fuel cell and the integral fuel cell.

Bladder-Type Fuel Cells

The bladder-type fuel cell is a nonself-sealing cell that is used to reduce weight. It depends entirely upon the structure of the cavity in which it sits to support the weight of the fuel within it. For this reason, the cell is made slightly larger than the cavity. The bladder cells in use are made either of rubber or of nylon.

Integral Fuel Cells

Since integral fuel cells are usually built into the wings of the aircraft structure, they are not removable. An integral cell is a part of the aircraft structure, which has been so built that after the seams, structural fasteners, and access doors have been properly sealed, the cell will hold fuel without leaking. This type of construction is usually referred to as a "wet wing."

Fuel Lines and Fittings

In an aircraft fuel system, the various tanks and other components are usually joined together by fuel lines made of metal tubing connected, where flexibility is necessary, by lengths of flexible hose. The metal tubing usually is made of aluminum alloy, and the flexible hose is made of synthetic rubber or Teflon. The diameter of the tubing is governed by the fuel flow requirements of the engine.

Each fuel line is identified by a color-coded band near each end. Except for short lines between flexible connections, tubing should be properly supported by clamping to structural members of the aircraft.

A special heat-resistant hose is used where the

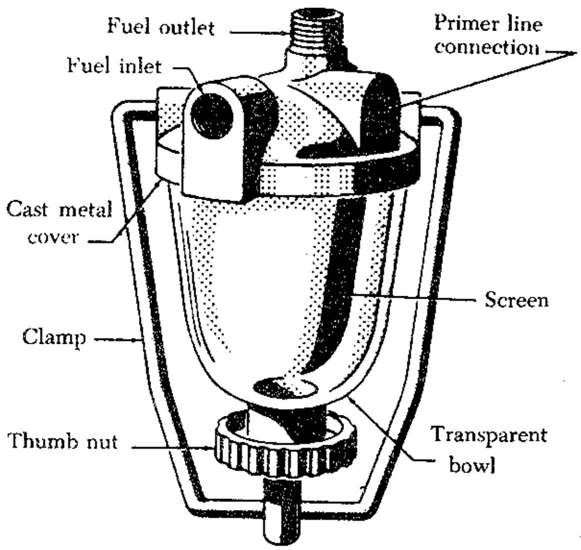


FIGURE 4–9. Main fuel strainer for light aircraft.

flexible lines will be subjected to intense heat. For all flexible fuel lines located forward of the firewall, fire-resistant hose is used.

In many installations, the fuel lines are designed to be located within the tanks. Therefore, minor leaks occurring within the tank are classified as internal leaks and will not cause fire hazards.

Fuel Strainers

Strainers are installed in the tank outlets and frequently in the tank filler necks. These are of fairly coarse mesh and prevent only the larger particles from entering the fuel system. Other, fine-mesh, strainers are provided in the carburetor fuel inlets and in the fuel lines.

The function of the main strainer is important: it not only prevents foreign matter from entering the carburetor, but also, because of its location at the low point of the fuel system, traps any small amount of water that may be present in the system. In multiengine aircraft, one main strainer is usually installed in each engine nacelle.

A main fuel strainer for a light airplane is shown in figure 4–9. It consists of a cast metal top, a screen, and a glass bowl. The bowl is attached to the cover by a clamp and thumb nut. Fuel enters the unit through the inlet port, filters through the screen, and exits through the outlet port. At regular intervals the glass bowl is drained, and the screen is removed for inspection and cleaning.

The main fuel strainer shown in figure 4–10 is so installed that the fuel flows through it before reaching the engine-driven pump. It is located at the lowest point in the fuel system. The shape and construction of the fine-mesh screen provides

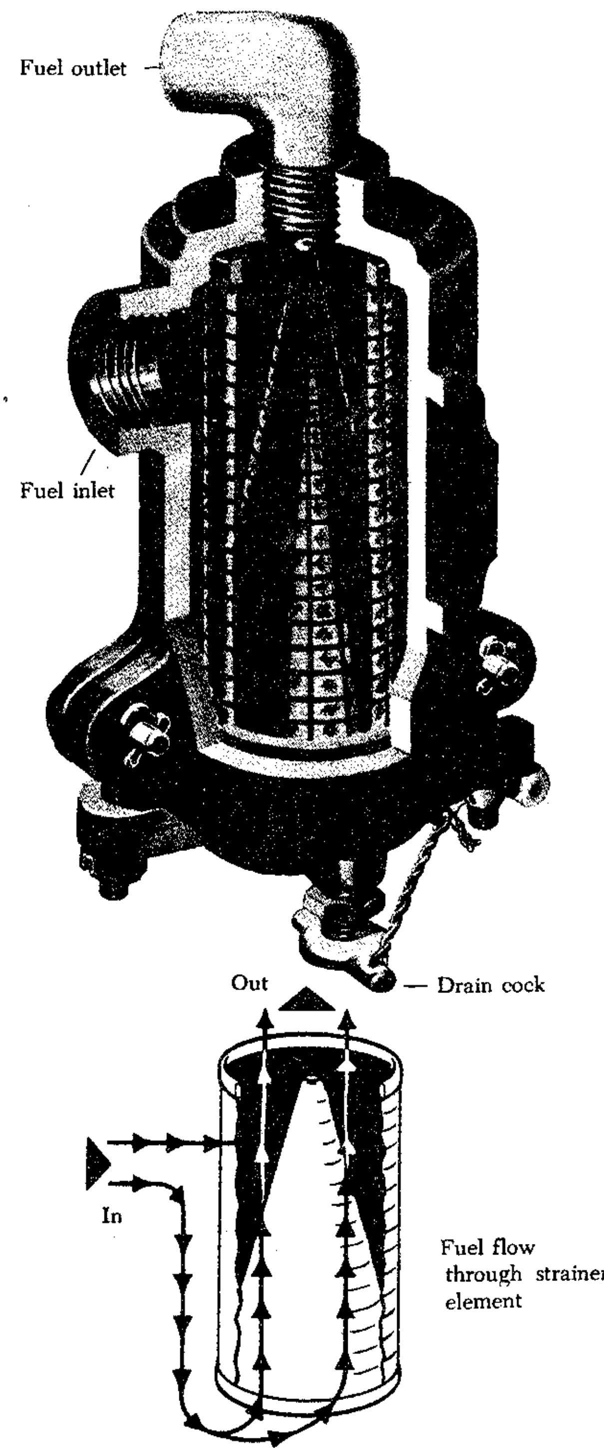


FIGURE 4–10. Main fuel strainer.

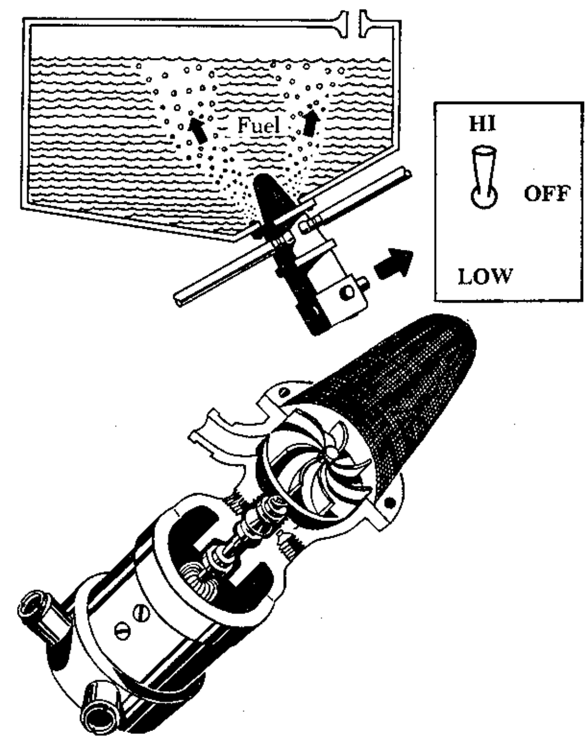


FIGURE 4–11. Centrifugal fuel booster pump.

a large screening surface encased in a compact housing. Reinforcing the screen is a coarse, heavy-wire mesh.

Auxiliary Fuel Pumps

The electrically driven centrifugal booster pump, shown in figure 4–11, supplies fuel under pressure to the inlet of the engine-driven fuel pump. This type of pump is an essential part of the fuel system, particularly at high altitudes, to keep the pressure on the suction side of the engine-driven pump from becoming low enough to permit the fuel to boil. This booster pump is also used to transfer fuel from one tank to another, to supply fuel under pressure for priming when starting the engine, and, as an emergency unit, to supply fuel to the carburetor in case the engine-driven pump fails. To increase the capacity of the pump under emergency conditions, many pumps are equipped with a two-speed or variable-speed control so that the recommended fuel inlet pressure to the carburetor can be maintained. As a precautionary measure, the booster pump is always turned on during takeoffs and landings to ensure a positive supply of fuel.

The booster pump is mounted at the tank outlet within a detachable sump or is submerged in fuel at the bottom of the fuel tank. The seals between the impeller and the power section of the pump prevent leakage of fuel or fumes into the motor. If any liquid or vapor should leak past the seal, it is vented overboard through a drain. As an added precaution in nonsubmerged-type pumps, air is allowed to circulate around the motor to remove dangerous fuel vapor.

As fuel enters the pump from the tank, a high-speed impeller throws the fuel outward in all directions at high velocity. The high rotational speed swirls the fuel and produces a centrifuge action that separates air and vapor from the fuel before it enters the fuel line to the carburetor. This results in practically vapor-free fuel delivery to the carburetor and permits the separated vapors to rise through the fuel tank and escape through the tank vents. Since a centrifugal-type pump is not a positive-displacement pump, no relief valve is necessary.

Although the centrifugal type is the most common type of booster pump, there are still a few sliding-vane-type booster pumps in service. This type, too, is driven by an electric motor. Unlike the centrifugal type, it does not have the advantage of the centrifuge action to separate the vapor from the fuel. Since it is a positive-displacement-type pump, it must have a relief valve to prevent excessive pressure. Its construction and operation are identical to the engine-driven pump.

Hand Pump

The hand, or wobble, pump is frequently used on light aircraft. It is generally located near other fuel system components and operated from the cockpit by suitable controls. A diagram of a wobble pump is shown in figure 4–12. When the handle attached to the central blade is operated, the low pressure created on the chamber below the upward moving blade, permits the incoming fuel pressure to lift the lower flapper and allows fuel to flow into this chamber. At the same time fuel flows through a drilled passageway to fill the chamber above the downward moving blade. As the blade moves downward, the lower flapper closes, preventing fuel from escaping back into the inlet line. The fuel below the downward moving blade flows through a passageway into another chamber and is discharged through an outlet flapper valve to the carburetor. The cycle is re-

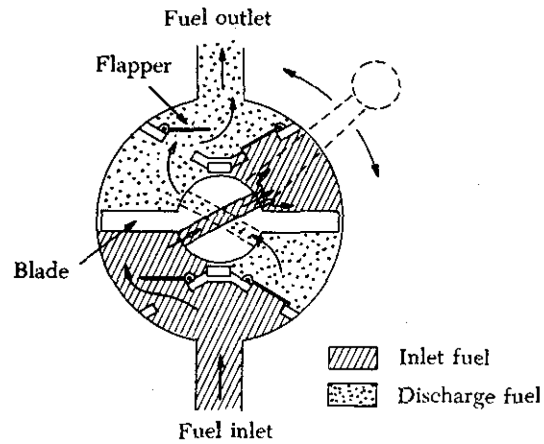


FIGURE 4–12. Schematic diagram of a wobble pump.

peated each time the handle is moved in either direction.

Engine-Driven Fuel Pump

The purpose of the engine-driven fuel pump is to deliver a continuous supply of fuel at the proper pressure at all times during engine operation. The pump widely used at the present time is the positive-displacement, rotary-vane-type pump.

A schematic diagram of a typical engine-driven pump (vane-type) is shown in figure 4–13. Regardless of variations in design, the operating principle of all vane-type fuel pumps is the same.

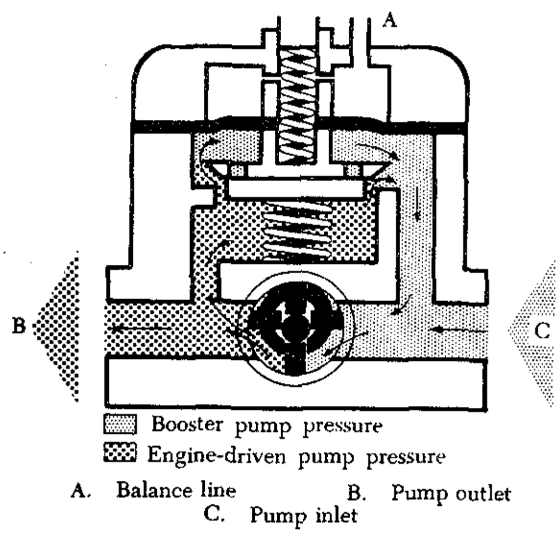


FIGURE 4–13. Engine-driven fuel pump (pressure delivery).

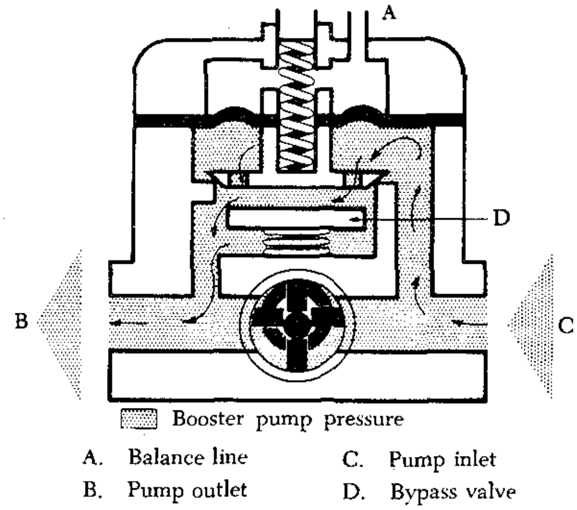


FIGURE 4–14. Engine-driven fuel pump (bypass flow).

The engine-driven pump is usually mounted on the accessory section of the engine. The rotor, with its sliding vanes, is driven by the crankshaft through the accessory gearing. Note how the vanes carry fuel from the inlet to the outlet as the rotor turns in the direction indicated. A seal prevents leakage at the point where the drive shaft enters the pump body, and a drain carries away any fuel that leaks past the seal. Since the fuel provides enough lubrication for the pump, no special lubrication is necessary.

Since the engine-driven fuel pump normally discharges more fuel than the engine requires, there must be some way of relieving excess fuel to prevent excessive fuel pressures at the fuel inlet of the carburetor. This is accomplished through the use of a spring-loaded relief valve that can be adjusted to deliver fuel at the recommended pressure for a particular carburetor. Figure 4–13, shows the pressure relief valve in operation, bypassing excess fuel back to the inlet side of the pump. Adjustment is made by increasing or decreasing the tension of the spring.

The relief valve of the engine-driven pump is designed to open at the set pressure regardless of the pressure of the fuel entering the pump. To maintain the proper relation between fuel pressure and carburetor inlet air pressure, the chamber above the fuel pump relief valve is vented either to the atmosphere or through a balance line to carburetor air inlet pressure. The combined pressures of spring tension and either atmospheric or carburetor inlet air pressure determine the absolute pressure at which the relief valve opens. This balanced-type relief valve has certain objectionable features that must be investigated when encountering fuel system troubles. A sylphon or diaphragm failure will allow air to enter the fuel on the inlet side of the pump if the pump inlet pressure is less than atmospheric. Conversely, if the pump inlet pressure is above atmospheric pressure, fuel will be discharged from the vent. For proper altitude compensation the vent must be open. If it should become clogged by ice or foreign matter while at altitude, the fuel pressure will decrease during descent. If the vent becomes clogged during ascent, the fuel pressure will increase as the altitude is increased.

In addition to the relief valve, the fuel pump has a bypass valve that permits fuel to flow around the pump rotor whenever the pump is inoperative. This valve, shown in figure 4–14, consists of a disk that is lightly spring-loaded against a series of ports in the relief valve head. When fuel is needed for starting the engine, or in the event of engine-driven pump failure, fuel at booster-pump pressure is delivered to the fuel pump inlet. When the pressure is great enough to move the bypass disk from its seat, fuel is allowed to enter the carburetor for priming or metering. When the engine-driven pump is in operation, the pressure built up on the outlet side of the pump, together with the pressure of the bypass spring, holds the disk on its seat and prevents fuel flow through the ports.

Valves

Selector valves are installed in the fuel system to provide a means for shutting off the fuel flow, for tank and engine selection, for crossfeed, and for fuel transfer. The size and number of ports (openings) vary with the type of installation. For example, a single-engine aircraft with two fuel tanks and a reserve fuel supply requires a valve with four ports—three inlets from the tanks and a common outlet. The valve must accommodate the full flow capacity of the fuel line, must not leak, and must operate freely with a definite "feel" or "click" when it is in the correct position. Selector valves may be operated either manually or electrically. A tube, rod, or cable is attached to a manually operated valve so that it can be operated from the cockpit. Electrically operated valves have an actuator, or motor. The three main types of selector valves are the poppet, cone, and disk.

The poppet-type selector valve has an individual poppet valve at each inlet port. A cam and yoke on the same shaft act to open the selected poppet valve as the yoke is turned. Figure 4–15 shows how the cam lifts the upper poppet valve from its seat when the control handle is set to the "number 2" tank. This opens the passage from the "number 2" tank to the engine. At the same time, a raised portion of the index plate drops into a notch in the side of the cam. (See the detail of the index mechanism.) This produces the "feel" that indicates the valve is in the wide open position. The control handle should always be set by "feel" rather than by the marking on the indicator dial. The index mechanism also keeps the valve in the desired position and prevents creeping caused by vibration. Some valves have more than one raised portion on the cam to allow two or more ports to be opened at the same time.

The cone-type selector valve has either an all-metal or a cork-faced aluminum housing. The cone, which fits into the housing, is rotated by means of a cockpit control. To supply fuel from the desired tank, the cockpit control is turned until the passages in the cone align with the correct ports in the housing. An indexing mechanism aids in obtaining the desired setting and also holds the cone in the selected position. Some cone-type valves have a friction release mechanism that reduces the amount of turning torque required to make a tank selection and that can be adjusted to prevent leakage.

The rotor of the disk-type selector valve fits into a cylindrical hole in the valve body. A disk-type valve is shown in figure 4–16. Note that the rotor has one open port and several sealing disks—one for each port in the housing. To select a tank, the rotor is turned until the open port aligns with the port from which fuel flow is desired. At this time, all other ports are closed by the sealing disks. In this position, fuel will flow from the desired tank to the selector valve and out through the engine-feed port at the bottom of the valve. To ensure positive port alignment for full fuel flow, the indexing mechanism (shown in the center of figure 4–16 forces a spring-loaded ball into a ratchet ring. When the selector valve is placed in the closed position, the open port in the rotor is opposite a blank in the valve body, while each sealing disk covers a tank port.

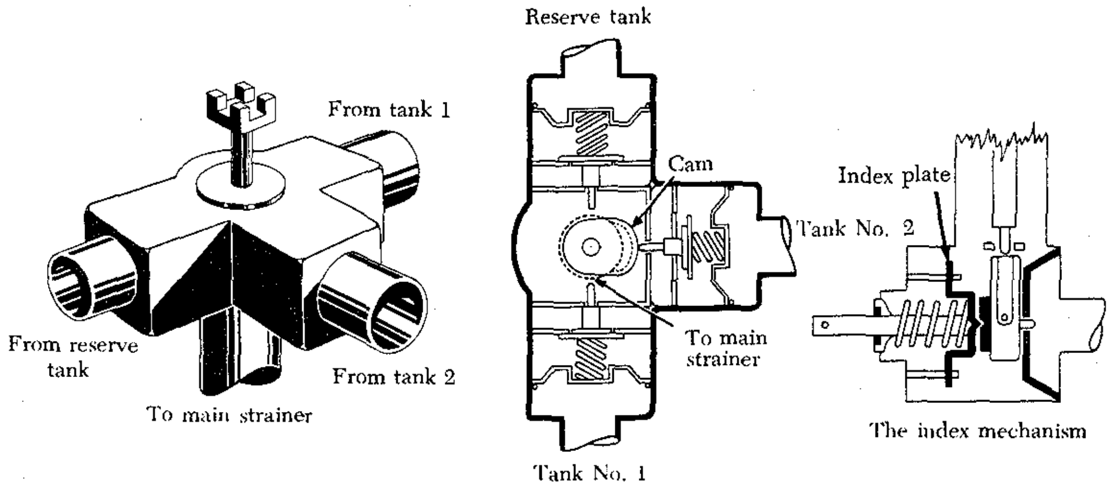


FIGURE 4–15. Poppet-type selector valve.

Fuel tank shutoff valves have two positions, open and closed. They are installed in the system to prevent fuel loss when a fuel system component is being removed or when a part of the system is damaged. In some installations they are used to control the fuel flow during fuel transfer. They are operated either manually or electrically. An electrically operated fuel shutoff valve includes a reversible electric motor linked to a sliding-valve assembly. The motor moves the valve gate in and out of the passage through which the fuel flows, thus, shutting off or turning on the fuel flow.

FUEL SYSTEM INDICATORS

Fuel Quantity Gages

Fuel quantity gages are necessary so that the operator may know the quantity of fuel remaining in the tanks during operation of the aircraft. The four general types of fuel gages are: (1) Sight glass, (2) mechanical, (3) electrical, and (4) electronic. The type of fuel gage installation depends on the size of the aircraft and the number and location of the fuel tanks. Since the sight glass and mechanical fuel gages are not suitable for aircraft where tanks are located an appreciable distance from the cockpit, larger aircraft use either electrical or electronic fuel quantity gages. On some aircraft, one fuel gage, called a totalizer, indicates the total amount of fuel remaining in all the fuel tanks.

The sight glass is the simplest form of fuel quantity gage. The indicator is a glass or plastic tube placed on the same level as the tank. It operates on the principle that a liquid seeks its

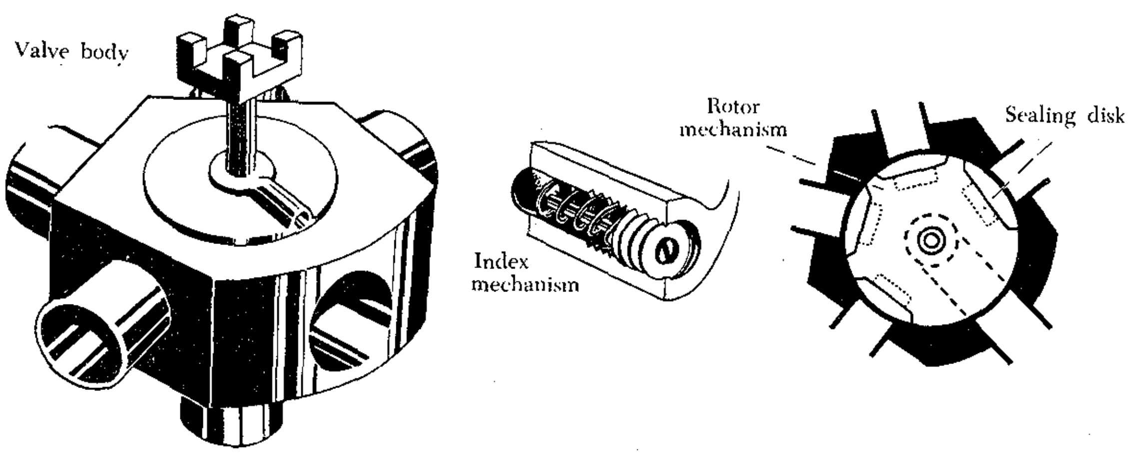


FIGURE 4–16. Disk-type selector valve.

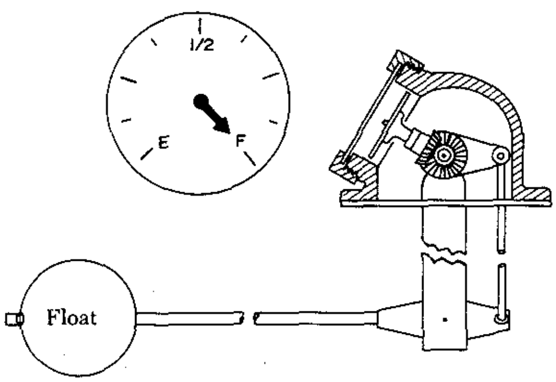


FIGURE 4–17. Float-and-lever type fuel level gage.

own level. The tube is calibrated in gallons or has a metal scale near it. The sight glass may have a shutoff valve so that the fuel can be shut off for cleaning and for preventing loss of fuel if the tube is broken.

The mechanical-type fuel quantity gage is usually located in the tank and is known as a direct reading gage. It has an indicator connected to a float resting on the surface of the fuel. As the fuel level changes, the float mechanically operates the indicator, thus showing the level of fuel in the tank. One type of mechanical fuel gage is illustrated in figure 4–17.

The electrical-type quantity gage consists of an indicator in the cockpit and a float-operated transmitter installed in the tank. As the fuel level changes, the transmitter sends an electric signal to the indicator, which shows the changing fuel level. Two important advantages of this fuel quantity gage (and the electronic type discussed in the next paragraph) are that the indicator can be located any distance from the tank and the fuel levels of several tanks can be read on one indicator.

The electronic-type (capacitance) fuel quantity gage differs from the other types in that it has no movable devices in the fuel tank. Instead of floats and their attendant mechanical units, the dielectric qualities of fuel and air furnish a measurement of fuel quantity. Essentially, the tank transmitter is a simple electric condenser. The dielectric (or nonconducting material) of the condenser is fuel and air (vapor) above the fuel. The capacitance of the tank unit at any one time will depend on the existing proportion of fuel and vapors in the tank. The capacitance of the transmitter is compared to a reference capacitor in a rebalance-type bridge circuit. The unbalanced signal is amplified by the voltage amplifiers that drive a phase discriminating power stage. The output stage supplies power to one phase of a two-phase a.c. motor that mechanically drives a rebalancing potentiometer and indicator pointer. The electronic type system of measuring fuel quantity is more accurate in measuring fuel level, as it measures the fuel by weight instead of in gallons. Fuel volume will vary with temperature (a gallon of gasoline weighs more when it is cold than when it is hot); thus, if it is measured in pounds instead of gallons, the measurement will be more accurate.

In addition to the cockpit fuel quantity indicating system, some aircraft are provided with a means to determine the fuel quantity in each tank when the aircraft is on the ground. This is accomplished in several different ways. Some manufacturers use float-operated, direct-reading fuel gages mounted in the lower surface of the wing. Another means is to use under-wing bayonet gages. There are two types in use, the drip gage and the sight gage.

When using the drip gage it is necessary to proceed slowly, using the trial-and-error method to find the exact fuel level. In large area tanks a proportionately large amount of fuel is represented by a fraction of an inch variation in fuel level. The long, hollow drip tubes require some time to drain once they are filled with fuel, and a substantial error in reading will be made if the diminishing drainage drip is mistaken for the steady drip that signifies that the tube is properly positioned.

When the cap and hollow drip tube are drawn out from the lower wing surface, the fuel enters the open top of the tube when it reaches the level of the fuel. As stated previously steady drip from a drip hole signifies that the tube is properly positioned with a tiny head of fuel above the opening. The drip gage tube may be calibrated in pounds or inches. When calibrated in inches, the reading is compared with a special chart to give a reading of fuel quantity in gallons.

The sight gage is somewhat simpler in construction than the drip gage, and offers unmistakable visual evidence when it is properly positioned for reading. As shown in figure 4–18, the sight gage is basically a long lucite rod, protected by a calibrated tube, which terminates at the top in an exposed quartz tip. When the tip is above the fuel it acts as a reflector. Light rays traveling up the lucite rod are deflected at right angles by

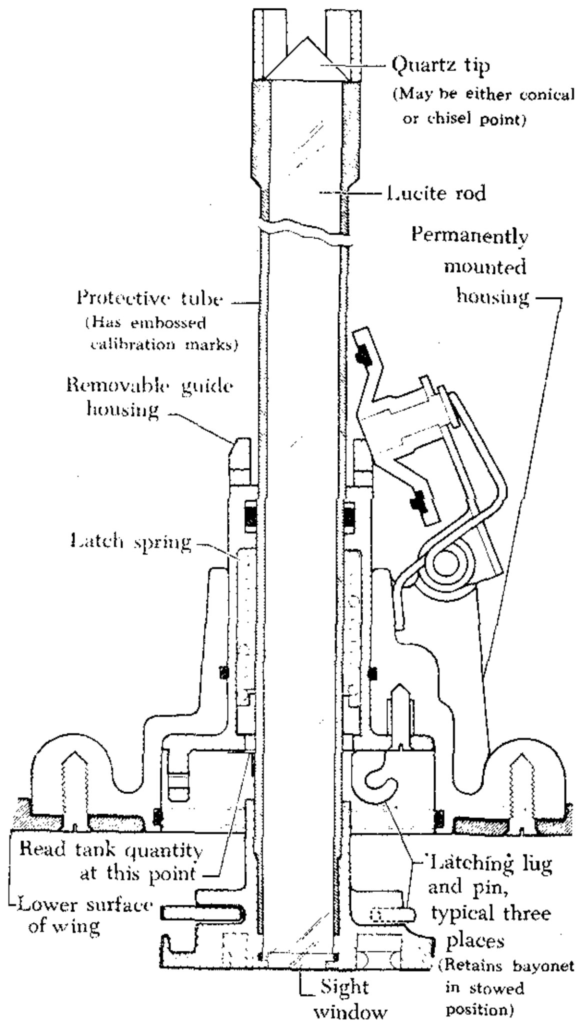


FIGURE 4–18. Under-wing sight gage.

the 45° surface at one side of the tip and deflected 90° again by the 45° surface at the opposite side and returned down the lucite rod.

Any portion of the tip submerged in fuel will not act as a reflector. Consequently, when the fuel level is part way up the taper, a light pattern is created that is visible at the lower end of the lucite rod and that has the dimension and shape described by the intersection of the tip and the fuel. When the reflected light is reduced to the smallest perceptible point in the case of cone-tipped gages, or hairline in the case of chisel-tipped gages, the rod is properly positioned. The fuel tank quantity can be read on the tube where it emerges from the recessed guide housing. Drip gage readings are taken at this location also.

Fuel Flowmeter

The fuel flowmeter is normally used only in multiengine aircraft. The system consists of a transmitter and an indicator. The transmitter is installed in the fuel inlet line to the engine, where it measures the rate of fuel flow. The transmitter is electrically connected to the indicator located in the cockpit. This gage shows the rate of fuel consumption in pounds per hour.

The transmitter signal may be developed by a movable vane mounted in the fuel flow path. The impact of fuel causes the vane to swing and move against the restraining force of a calibrated spring. The final position assumed by the vane represents a measure of the rate at which fuel is passing through the flowmeter and the corresponding signal to be sent to the indicator. A vane-type fuel flowmeter system is illustrated in figure 4–19.

The transmitter used with turbine engines is the mass-flow type having a range of 500 to 2,500 pounds per hour. It consists of two cylinders placed in the fuel stream so that the direction of fuel flow is parallel to the axes of the cylinders. (See figure 4–20.) The cylinders have small vanes in the outer periphery. The upstream cylinder, called the impeller, is driven at a constant angular velocity by the power supply. This velocity imparts an angular momentum to the fuel. The fuel then transmits this angular velocity to the turbine (the downstream cylinder), causing the turbine to rotate until a restraining spring force balances the force due to the angular momentum of the fuel. The deflection of the turbine positions a magnet in the second harmonic transmitter to a position corresponding to the fuel flow. The turbine position is transmitted to the flight station indicator by means of a selsyn system.

Fuel Pressure Gage

The fuel pressure gage indicates the pressure of the fuel entering the carburetor. This gage may be included with the oil pressure gage and the oil temperature gage in one casing, called the engine gage unit. Most aircraft today have separate gages for these functions. An engine gage unit is shown in figure 4–21.

The fuel pressure gage is a differential pressure indicator with two connections on the back of the indicator housing. The air connection (see figure 4–22) is vented to the carburetor air inlet, and the fuel connection is attached to the fuel

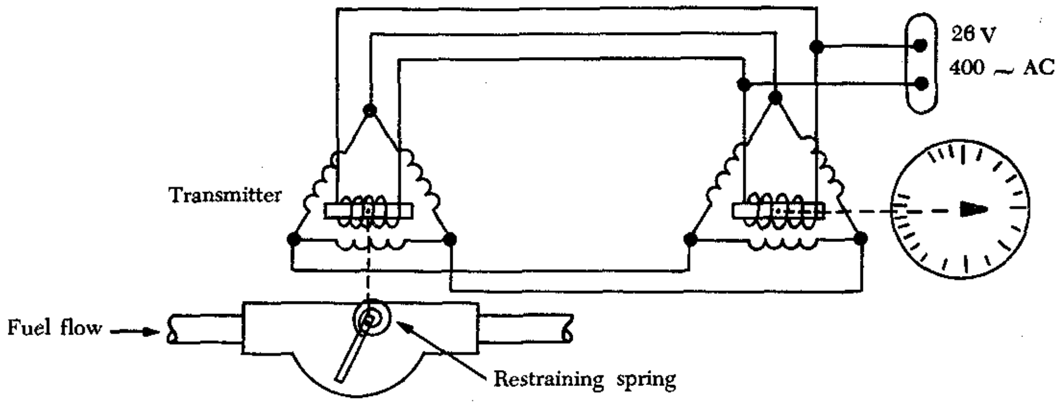


FIGURE 4–19. Vane-type fuel flowmeter system.

inlet chamber of the carburetor. In this way the gage indicates the difference between the fuel pressure entering the carburetor and the air pressure at the carburetor air inlet. In some installations, the air fitting on the gage is left open to the air pressure of the cockpit, which is generally the same as the pressure of the atmosphere. When this venting arrangement is used, the relief valve of the engine-driven fuel pump is also vented to the atmosphere, and the gage indicates the fuel pressure resulting from the adjusted spring pressure only. In order to dampen pressure pulsations that cause pointer fluctuation, a restrictor fitting (A) is installed at the carburetor end of the fuel gage line. (See the Y connection shown in figure 4–22.) The second restrictor (B) meters fuel to the oil system during oil dilution. The arrangement of these restrictors provides an indicated drop in fuel pressure when the oil dilution system is used. The oil-dilution system will be discussed

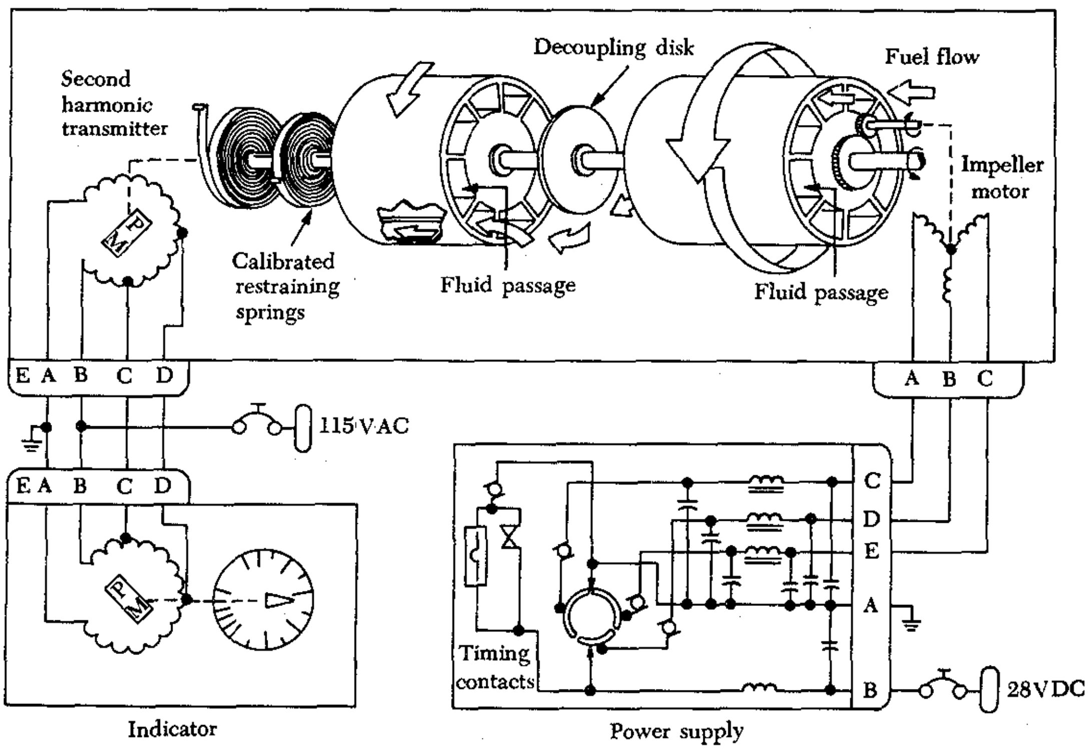


FIGURE 4–20. Schematic of a turbine engine fuel flow indicating system.

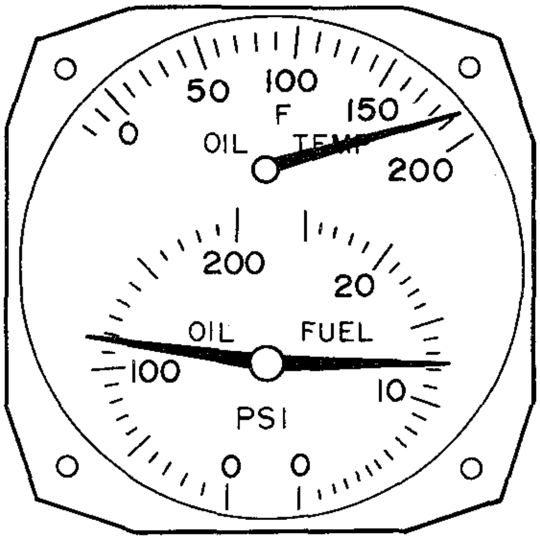


FIGURE 4–21. Engine gage unit.

thoroughly in the Powerplant Handbook, and is mentioned at this time only because the fuel pressure indicator provides a means for a check on the operation of other fuel system units.

In small aircraft the fuel pressure gage may be actuated by a Bourdon tube (an instrument that converts changes in pressure to mechanical motion), or an aneroid and bellows type, installed with a pressure line leading directly from the carburetor to the indicator. On larger aircraft, where the fuel pressure gage is located some distance from the carburetor, a transmitter is usually installed. The pressure transmitter may be a simple cast metal cell that is divided into two chambers by a flexible diaphragm. Pressure applied by the fuel source to the transmitter inlet pushes against the diaphragm and builds up an equal pressure to a thin fluid (highly refined kerosene), which transfers the pressure to the indicator mechanism. Some installations, however, use electrical transmitters to register fuel pressure on the gage. In this electrical arrangement, the pressure-indicating unit is contained in the transmitter. Fuel pressure, acting upon the aneroid and bellows portion of the unit, causes motion of one part of an electrical unit (the synchro transmitter). As the unit turns, it causes a similar movement of a corresponding unit (the synchro motor). This receiving unit actuates the indicator on the instrument panel. These pressure and electrical arrangements make it unnecessary for combustible fuel to enter the cockpit or flight deck, thereby reducing fire risk.

A fuel pressure gage often used with fuel injection systems on light aircraft engines is illustrated in figure 4–23. A gage of this type registers metered fuel pressure at the fuel injection unit distributor valve and is a direct indication of engine power output when installed in a fuel injection system for light aircraft engines. The dial of the gage is marked to indicate percent of power. The gage does not indicate either the engine-driven pump or the boost pump pressure.

Pressure Warning Signal

In an aircraft with several tanks, there is always the possible danger of allowing the fuel supply in one tank to become exhausted before the selector valve is switched to another. To prevent this, pressure-warning signals are installed in some aircraft. The complete installation, shown in figure 4–22, consists of a pressure-sensitive mechanism and a warning light. The warning mechanism has both a fuel and an air connection.

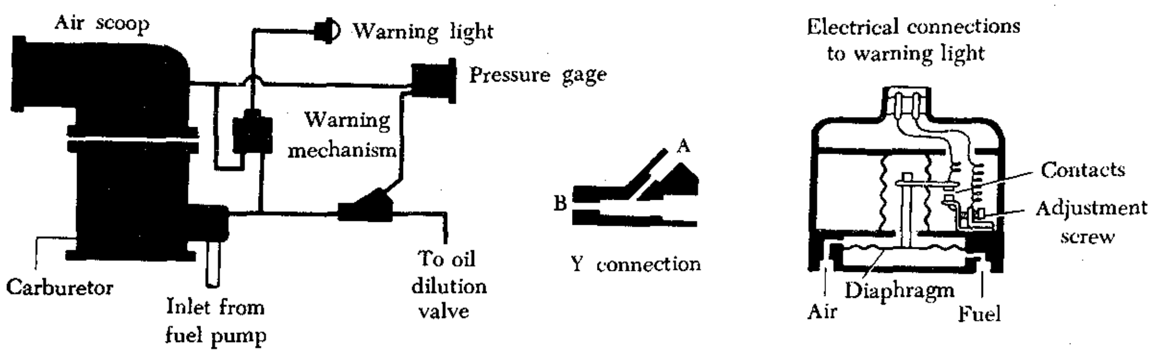
The connection marked "fuel" is connected to the fuel pressure line of the carburetor. The air connection is vented to either atmospheric or carburetor air inlet pressure. This arrangement prevents the warning mechanism from acting in response to changes in the absolute pressure of the fuel. If, for example, the absolute pressure of the fuel decreases because of a change in atmospheric or carburetor air inlet pressure, the change is also reflected at the warning mechanism, which then cancels the effects of the change. Normal fuel pressure against the power surface of the diaphragm holds the electrical contacts apart. When the fuel pressure drops below specified limits, the contacts close and the warning light is turned on. This alerts the operator to take whatever action is necessary to boost the fuel pressure.

Valve-In-Transit Indicator Lights

On large multiengine aircraft, each of the fuel crossfeed and line valves may be provided with a valve-in-transit indicator light. This light is on only during the time the valve is in motion and is off when movement is complete.

Fuel Temperature Indicator

A means for checking the temperature of the fuel in the tanks and at the engine is provided on some turbine-powered aircraft. During extreme cold, especially at altitude, the gage can



Location of units in the system

Pressure warning mechanism

FIGURE 4–22. Fuel pressure-indicating system.

be checked to determine when fuel temperatures are approaching those at which there may be danger of ice crystals forming in the fuel.

MULTIENGINE FUEL SYSTEMS

The design of the fuel system for an aircraft having two or more engines presents problems not normally encountered in single-engine fuel systems. A large number of tanks are often required to carry the necessary fuel. These tanks may be located in widely separated parts of the aircraft, such as the fuselage and the inboard and outboard sections of the wings. The individual engine fuel systems must be interconnected so that fuel can be fed from the various tanks to any engine. In case of engine failure, the fuel normally supplied to the inoperative engine must be made available to the others.

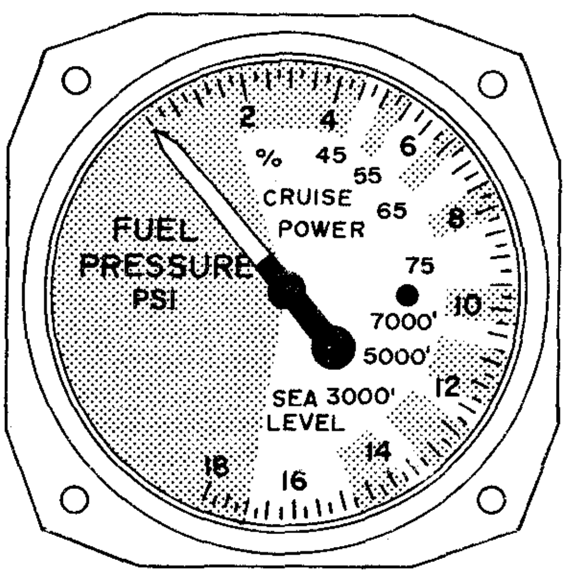


FIGURE 4–23. Fuel pressure gage for fuel-injection system.

Crossfeed System

The twin-engine fuel system illustrated in figure 4–24 is the simple crossfeed type. As shown, the tank selector valves are set to supply fuel from the main tanks to the engines. These valves can also be positioned to supply fuel from the auxiliary tanks. The crossfeed valve is shown in the off position. It can also be set to supply fuel from the fuselage tank to either or both engines and to crossfeed. A few of the numerous combinations in which the three valves can be set are also illustrated.

Manifold System

The main feature of the four-engine system shown in figure 4–25 is the fuel manifold. This fuel manifold system is actually a variation of the crossfeed. As shown, fuel is being supplied from the main tanks directly to the engines. The manifold valves can also be set so that all tanks feed into the manifold and each engine receives its fuel supply from this line. The auxiliary fuel supply can be delivered to the engines only through the manifold. The main advantage of this system is its flexibility. Should an engine fail, its fuel is immediately available to the other engines. If a tank is damaged, the corresponding engine can be supplied with fuel from the manifold.

Another advantage of this system is that all fuel tanks can be serviced at the same time through a single line manifold connection. This

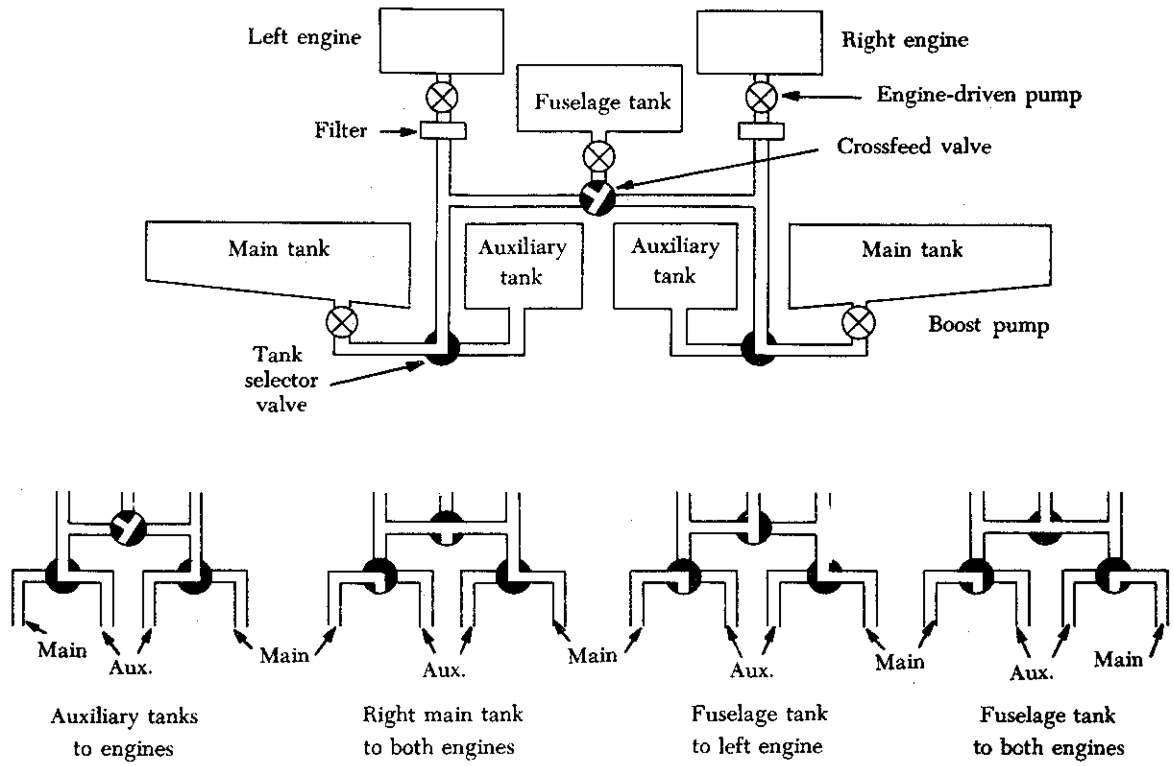


FIGURE 4-24. Twin-engine crossfeed system schematic.

method of fuel servicing has greatly reduced servicing time on large aircraft because fuel can be introduced into the fueling manifold under high pressure.

FUEL JETTISON SYSTEMS

A fuel jettison system is required for transport category and general aviation aircraft if the maximum take-off weight exceeds the maximum landing weight. The maximum take-off and landing weights are design specifications and may be found in the Aircraft Type Certificate data sheets.

A fuel jettison system must be able to jettison enough fuel within 10 minutes for general aviation, or 15 minutes for transport category aircraft, to meet the requirements of the specifications and Federal Air Regulations. It must be operable under the conditions encountered during all operations of the aircraft.

Design requirements are that fuel jettisoning must be stopped with a minimum of fuel for 45 minutes of cruise at maximum continuous power for reciprocating engines. Turbine powered aircraft require enough fuel for take-off and landing and 45 minutes cruising time.

The fuel jettisoning system is usually divided into two separate, independent systems, one for each wing, so that lateral stability can be maintained by jettisoning fuel from the "heavy" wing if it is necessary to do so. Normally, if an unbalanced fuel load exists, fuel will be used from the "heavy" wing by supplying fuel to engines on the opposite wing.

The system consists of lines, valves, dump chutes and chute-operating mechanisms. Each wing contains either a fixed or an extendable dump chute depending upon system design. In either case the fuel must discharge clear of the airplane.

TROUBLESHOOTING THE FUEL SYSTEM

In order to become proficient at the art of troubleshooting, one must be familiar with the complete system. To do this, one can become familiar with the schematics of various portions of the system, the nomenclature of the units, and their particular function within the system by studying aircraft and engine maintenance manuals.

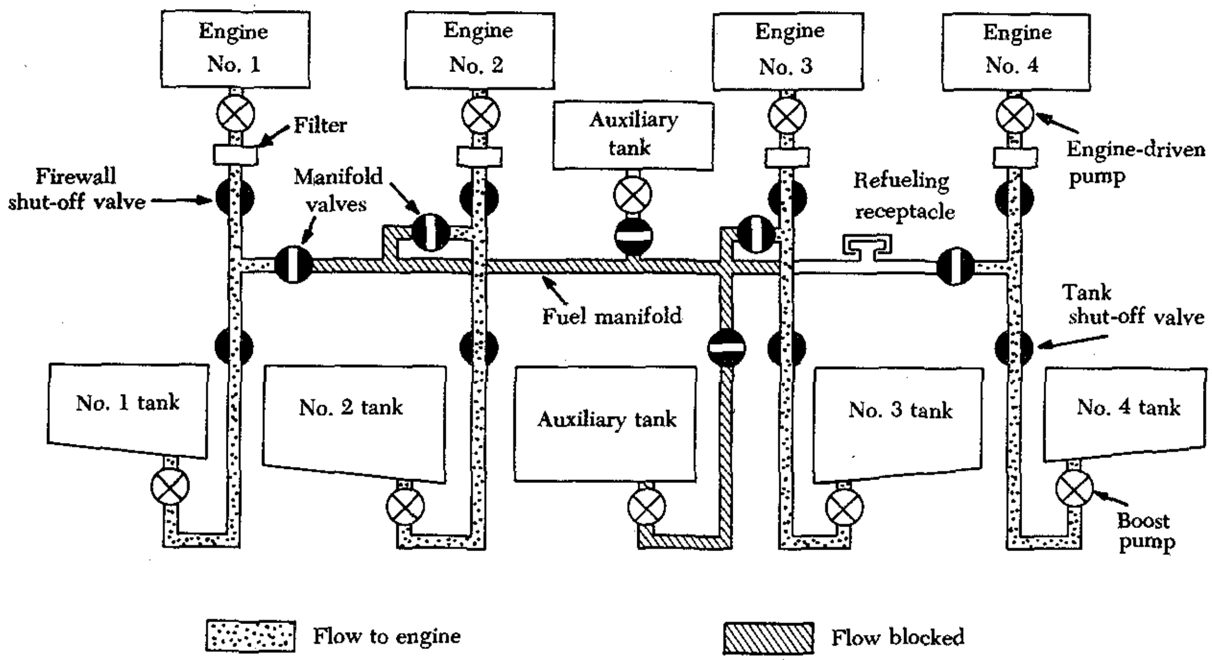


FIGURE 4–25. A typical manifold crossfeed system.

Location of Leaks and Defects

The location of leaks and defects within the internal portions of the fuel system is usually a matter of observation of the pressure gage and operation of the selector valves to determine where the trouble lies. Troubleshooting of the internal fuel system can be aided by visualizing the path of flow of the fuel from the fuel tank to the fuel-metering device, noting the location of the pump(s), selector valves, emergency shutoff valves, etc.

The location of leaks or defects in the external portions of the fuel system involves very little time in comparison to locating leaks within the internal system. Usually, fuel leaks are evidenced by stains or wet spots, if they are newly developed, and by the presence of fuel odor. The plumbing, clamps, gaskets, supports, etc., are to be examined carefully at each inspection period. Any defect or leak in the internal or external fuel system is a potential hazard.

Replacement of Gaskets, Seals, and Packings

In order to prevent leakage of fuel, it is of utmost importance that all gaskets, seals, and packings be properly installed. Listed below are some of the general precautions that should always be observed.

When replacing units of the fuel system, it is necessary to check each part for cleanliness, ensure that all of the old gasket material is removed, and ensure that none of the old seal remains in the groove seat. Always replace old gaskets and seals with new ones, check the new gaskets and seals for cleanliness and integrity, and ensure that it is the right part for the job. Mating surfaces should be perfectly flat so that the gasket can do the job for which it is designed. Screws, nuts, and bolts that hold units together should be evenly tightened or torqued to prevent leakage past the gasket or seal.

FUEL TANK REPAIRS

There are three basic type fuel cells used in aircraft. Welded sheet metal integral and fuel cell. No fuel system is airworthy if it will not contain fuel. Inspection of the fuel tank bays or aircraft structure for evidence of fuel leaks is a very important part of the preflight inspection.

Welded Steel Tanks

Welded tanks are most common in the smaller single and twin engine aircraft. If the access plates to the fuel tank compartment are discolored the tank should be inspected for leaks. When leaks are found, the tank must be drained and inerted. Fuel will be drained in accordance with local instructions and the manufacturer's recommendations. Inerting the tank may be accomplished by slowly discharging a CO_2 fire extinguisher (5 lb. minimum size) into the tank. Dry nitrogen may be used if it is available. If the tank is to be welded, removal is necessary.

Before welding, the tank must be steamed for a minimum of 8 hours. This is to remove all traces of fuel. Air pressure not over ½ psi may be used to detect the leaking area. Liquid soap or bubble solution brushed in the suspected area may identify the leak. Aluminum tanks are fabricated from weldable alloys. After riveting patches in place, the rivets may be welded to insure no leaks from that area. Pressure checks should be performed after repairs are completed to assure that all leaks were corrected.

Fuel Cells

Fuel cell leaks will usually appear on the lower skin of the aircraft. A fuel stain in any area should be investigated immediately. Fuel cells suspected of leaking should be drained, removed from the aircraft and pressure checked. When performing a pressure check, ¼ to ½ psi air presure is adequate. All fuel cell maintenance must be accomplished in accordance with the manufacturer's specifications.

Integral Fuel Tanks

The integral tank is a nonremovable part of the aircraft. Because of the nature of an integral tank, some leaks allow fuel to escape directly to the atmosphere. This makes it completely feasible to disregard certain minute leaks that do not represent a fire hazard or too great a loss of fuel. In order to standardize the procedures for integral tank fuel storage maintenance, the various rates of fuel leakage are classified.

Fuel Leak Classification

The size of the surface area that a fuel leak moistens in a 30-minute period is used as the classification standard. Wipe the leak area completely dry with clean cotton cloths. Compressed air may also be used to dry the leak areas that are difficult to wipe. Wear goggles when using compressed air to dry the leak area. Dust the leak area with dyed red talcum powder. The talcum powder turns red as the fuel wets it, making the wet area easier to see.

At the end of 30 minutes, each leak is classified into one of four classes of leaks: slow seep, seep, heavy seep, or running leak. The four classes of leaks are shown in figure 4–26. *A slow seep* is a leak in which the fuel wets an area around the

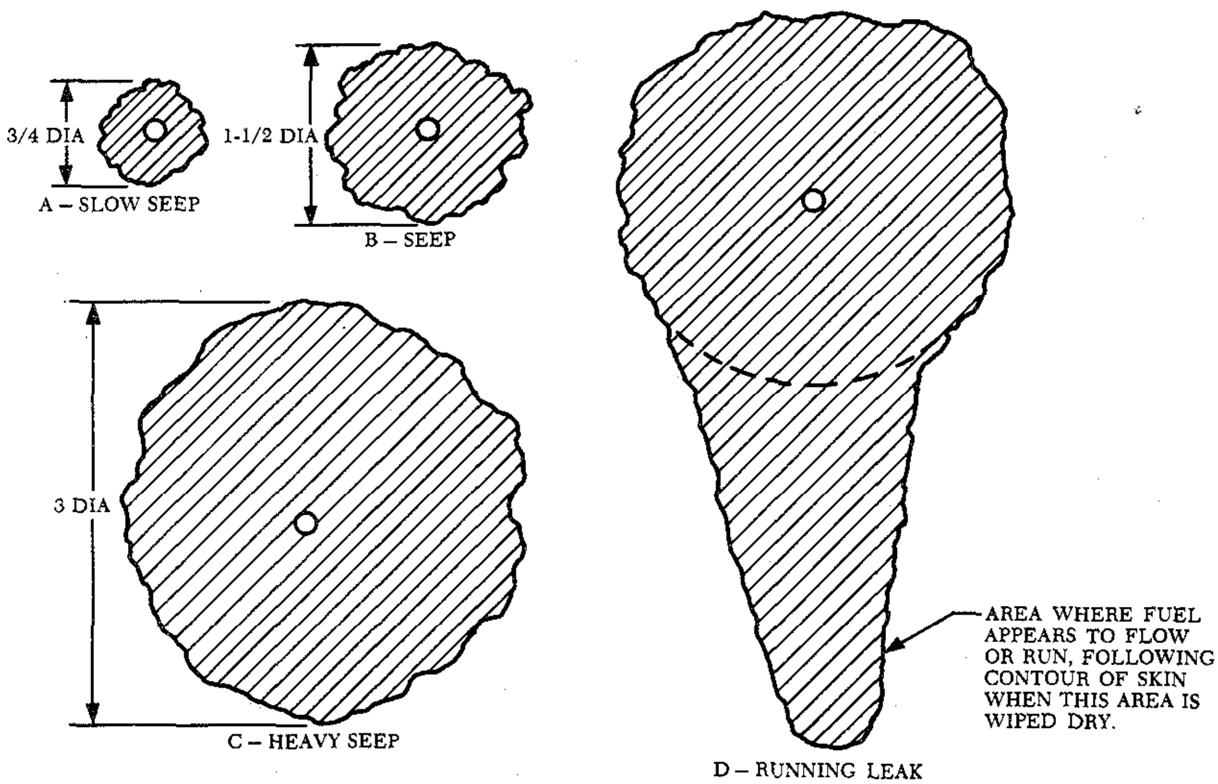


FIGURE 4–26. Fuel leak classification.

leak source not over $3/4$ of an inch in diameter. *A seep* is a leak that wets an area from $3/4$ inches to $1\frac{1}{2}$ inches in diameter. *A heavy seep* is a fuel leak that wets an area around the leak source from $1\frac{1}{2}$ inches to 3 inches in diameter. In none of these three leak classifications does the fuel run, flow, drip, or resemble any of these conditions at the end of the 30-minute time period.

The last classification, a *running leak,* is the most severe and the most dangerous. It may drip from the aircraft surface, it may run down vertical surfaces, or it may even run down your finger when you touch the wet area. The aircraft is unsafe for flight and must be grounded for repair. When possible, the fuel from the leaking tank should be removed after you mark the leak location. If it is impossible to defuel the tank immediately, the aircraft should be isolated in an approved area. Place appropriate warning signs around the aircraft until qualified personnel can defuel the leaking tank.

Grounding of the aircraft for slow seeps, seeps, and heavy seeps, is determined by the applicable aircraft handbook. This determination may depend on the location of the fuel leak. For example, can the leakage progress to a potential fire source? The number of fuel leaks in a given area is also a contributing factor. There is no rule of thumb for determining if the aircraft is to be grounded. Running leaks ground the aircraft regardless of location.

You may only have to make appropriate entries on the aircraft forms and periodically observe the progress of the fuel leak if it is determined that the aircraft is airworthy and no repair is required. When repair is required, you must find the cause of the fuel leak and make an *effective* repair.

Leak Repairs

Repair of leaks in integral fuel tanks must be accomplished in accordance with the aircraft manufacturer's specifications. No attempt will be made in this handbook to discuss integral tank repairs further.

Fire Safety

The first and most difficult step in the achievement of fire safety is to correct the misconceptions about the "safety" of turbine fuels. At the time these fuels were first introduced many people said, "fire problems in aircraft are over, turbine fuel is completely safe." This is obviously nonsense but it has been persistent nonsense.

Flight line personnel have agreed that aviation gasoline will burn, and therefore they have exercised reasonable care and caution in handling it. However, it has been difficult to convince them that under some circumstances turbine fuels are just as dangerous from the fire standpoint.

The characteristics of turbine fuel do vary from those of gasoline. Kerosene, for example, has a slow flame propagation and burning rate, which makes it less hazardous in the event of spill or a ground accident. However, it does ignite readily when vaporized or when misted, as when sprayed through a small leak in a service hose.

One disadvantage of the low volatility fuels is that they will not evaporate readily and completely if spilled on the ramp, so special treatment of the spill area is required. Small spills of kerosene should be removed with a commercial absorbent cleaning agent. On large spills it is better to apply an approved emulsifier and then flush away the resulting mixture with large volumes of water. This will prevent or appreciably lessen any oily residue.

Just as with gasoline, an electrostatic charge may be built up in pumping turbine fuel through a service hose. In fact, the amount of the charge is higher in kerosene because of the higher specific gravity and wider boiling range. Also, the amount of the charge increases with high linear rate of fuel flow, such as is required for servicing turbine powered aircraft.

In consequence, all of the fire safety precautions observed in the handling of gasoline must be followed with equal care in the handling of turbine fuels. These precautions are well known and have been detailed by the National Fire Protection Association in its bulletin No. 407. It is recommended that this bulletin be made required reading for all personnel handling turbine fuel.