Chapter 2

Engine Fuel & Fuel Metering Systems

Fuel System Requirements

The engine fuel system must supply fuel to the engine's fuel metering device under all conditions of ground and air operation. It must function properly at constantly changing altitudes and in any climate. The most common fuels are AVGAS for reciprocating engines and Jet A for turbine engines. AVGAS is generally either 80 (red) or 100LL (blue) octane. The LL stands for low lead although it contains four times the lead of 80 octane AVGAS. Jet A is a kerosene-based fuel that is clear to straw in color.

Electronic engine controls have allowed great increases in controlling the metered fuel flow to the engine. Engine fuel systems have become very accurate at providing the correct mixture of fuel and air to the engines. Gas turbine fuel controls have also greatly improved the ability to schedule (meter) the fuel correctly during all flight regimes. Improvements in electronics and the use of digital computers have enabled the aircraft and engines to be electronically interfaced together. By the use of electronic sensors and computer logic built in to electronic controls, the engines can be controlled with much more accuracy. Fuel cost and availability have also become factors in providing engines with fuel systems that are efficient and very precise in scheduling fuel flow to the engine. Many engines use an interactive system that senses engine parameters and feeds the information to the onboard computer (electronic engine control). The computer determines the amount of fuel needed and then sends a signal to the metering device. This signal sent to the metering device determines the correct amount of fuel needed by the engine. Electronic controls have become quite common with gas turbines and have increased the capabilities of the fuel system, making it less complicated for the technician and decreasing maintenance problems.

Engine fuel systems can be fairly complicated, yet some are quite simple, such as on small aircraft with a simple gravity-feed fuel system. This system, consisting of a tank to supply fuel to the engine, is often installed in the overhead wing and feeds a small float-type carburetor. On multiengine aircraft, complex systems are necessary so that fuel can be pumped from any combination of tanks to any combination of engines through a crossfeed system. Provisions for transferring fuel from one tank to another may also be included on large aircraft.

Vapor Lock

All fuel systems should be designed so that vapor lock cannot take place. Older gravity-feed systems were more prone to vapor lock. The fuel system should be free of tendency to vapor lock, which can result from changes in ground and in-flight climatic conditions. Normally, the fuel remains in a liquid state until it is discharged into the air stream and then instantly changes to a vapor. Under certain conditions, the fuel may vaporize in the lines, pumps, or other units. The vapor pockets formed by this premature vaporization restrict the fuel flow through units which are designed to handle liquids rather than gases. The resulting partial or complete interruption of the fuel flow is called vapor lock. The three general causes of vapor lock are the lowering of the pressure on the fuel, high fuel temperatures, and excessive fuel turbulence.

At high altitudes, the pressure on the fuel in the tank is low. This lowers the boiling point of the fuel and causes vapor bubbles to form. This vapor trapped in the fuel may cause vapor lock in the fuel system.

Transfer of heat from the engine tends to cause boiling of the fuel in the lines and the pump. This tendency is increased if the fuel in the tank is warm. High fuel temperatures often combine with low pressure to increase vapor formation. This is most apt to occur during a rapid climb on a hot day. As the aircraft climbs, the outside temperature drops, but the fuel does not lose temperature rapidly. If the fuel is warm enough at takeoff, it retains enough heat to boil easily at high altitude. The chief causes of fuel turbulence are sloshing of the fuel in the tanks, the mechanical action of the engine-driven pump, and sharp bends or rises in the fuel lines. Sloshing in the tank tends to mix air with the fuel. As this mixture passes through the lines, the trapped air separates from the fuel and forms vapor pockets at any point where there are abrupt changes in direction or steep rises. Turbulence in the fuel pump often combines with the low pressure at the pump inlet to form a vapor lock at this point.

Vapor lock can become serious enough to block the fuel flow completely and stop the engine. Even small amounts of vapor in the inlet line restrict the flow to the engine-driven pump and reduce its output pressure. To reduce the possibility of vapor lock, fuel lines are kept away from sources of heat; also, sharp bends and steep rises are avoided. In addition, the volatility of the fuel is controlled in manufacture so that it does not vaporize too readily. The major improvement in reducing vapor lock, however, is the incorporation of booster pumps in the fuel system. These booster pumps, which are used widely in most modern aircraft, keep the fuel in the lines to the engine-driven pump under pressure. The pressure on the fuel reduces vapor formation and aids in moving a vapor pocket along. The boost pump also releases vapor from the fuel as it passes through the pump. The vapor moves upward through the fuel in the tank and out the tank vents. To prevent the small amount of vapor that remains in the fuel from upsetting its metering action, vapor eliminators are installed in some fuel systems ahead of the metering device or are built into this unit.

Basic Fuel System

The basic parts of a fuel system include tanks, boost pumps, lines, selector valves, strainers, engine-driven pumps, and pressure gauges. A review of fuel systems in the Aviation Maintenance Technician—General Handbook provides some information concerning these components.

Generally, there are several tanks, even in a simple system, to store the required amount of fuel. The location of these tanks depends on both the fuel system design and the structural design of the aircraft. From each tank, a line leads to the selector valve. This valve is set from the flight deck to select the tank from which fuel is to be delivered to the engine. The boost pump forces fuel through the selector valve to the main line strainer. This filtering unit, located in the lowest part of the system, removes water and dirt from the fuel. During starting, the boost pump forces fuel through a bypass in the engine-driven pump to the metering device. Once the engine-driven pump is rotating at sufficient speed, it takes over and delivers fuel to the metering device at the specified pressure.

The airframe fuel system begins with the fuel tank and ends at the engine fuel system. The engine fuel system usually includes the engine-driven pumps and the fuel metering systems. In aircraft powered with a reciprocating engine, the engine-driven fuel pump and metering system consists of the main components from the point at which the fuel enters the first control unit until the fuel is injected into the intake pipe or cylinder. For example, the engine fuel system of a typical engine has an engine-driven fuel pump, the air-fuel control unit (metering device), the fuel manifold valve, and the fuel discharge nozzles. The fuel metering system on current reciprocating engines meters the fuel at a predetermined ratio to airflow. The airflow to the engine is controlled by the carburetor or air-fuel control unit.

The fuel metering system of the typical gas turbine engine consists of an engine-driven pump, fuel flow transmitter, fuel control with an electronic engine control, a distribution system or manifold, flow divider, and fuel discharge nozzles. On some turboprop engines, a fuel heater and a start control is a part of the engine fuel system. The rate of fuel delivery can be a function of air mass flow, compressor inlet temperature, compressor discharge pressure, compressor revolutions per minute (rpm), exhaust gas temperature, and combustion chamber pressure.

Fuel Metering Devices for Reciprocating Engines

Basic principles of operation are discussed here with no attempt being made to give detailed maintenance instructions. For the specific information needed to inspect or maintain a particular installation or unit, consult the manufacturer's instructions.

The basic requirement of a reciprocating fuel metering system is the same, regardless of the type of system used or the model engine on which the equipment is installed. It must meter fuel proportionately to air to establish the proper air-fuel mixture ratio for the engine at all speeds and altitudes at which the engine may be operated. In the air-fuel mixture curves shown in *Figure 2-1,* note that the basic best power and best economy air-fuel mixture requirements for reciprocating engines are approximately the same. The fuel metering system must atomize and distribute the fuel from the carburetor into the mass airflow. This must be accomplished so that the air-fuel charges going to all cylinders holds equal amounts of fuel. Each one of the engine's cylinders should receive the same quantity of air-fuel mixture and at the same air-fuel ratio.

Due to the drop in atmospheric pressure as altitude is increased, the density of the air also decreases. A normally-aspirated engine has a fixed amount or volume of air that it can draw in during the intake stroke, therefore less air is drawn into the engine as altitude increases. Less air tends to make carburetors run richer at altitude than at ground level, because of the decreased density of the airflow through the carburetor throat for a given volume of air. Thus, it is necessary that a mixture control be provided to lean the mixture and compensate for this natural enrichment. Some aircraft use carburetors in which the mixture control is operated manually. Other aircraft employ carburetors which automatically lean the carburetor mixture at altitude to maintain the proper air-fuel mixture.

The rich mixture requirements for an aircraft engine are established by running a power curve to determine the air-fuel mixture for obtaining maximum usable power. This curve is plotted at 100 rpm intervals from idle speed to

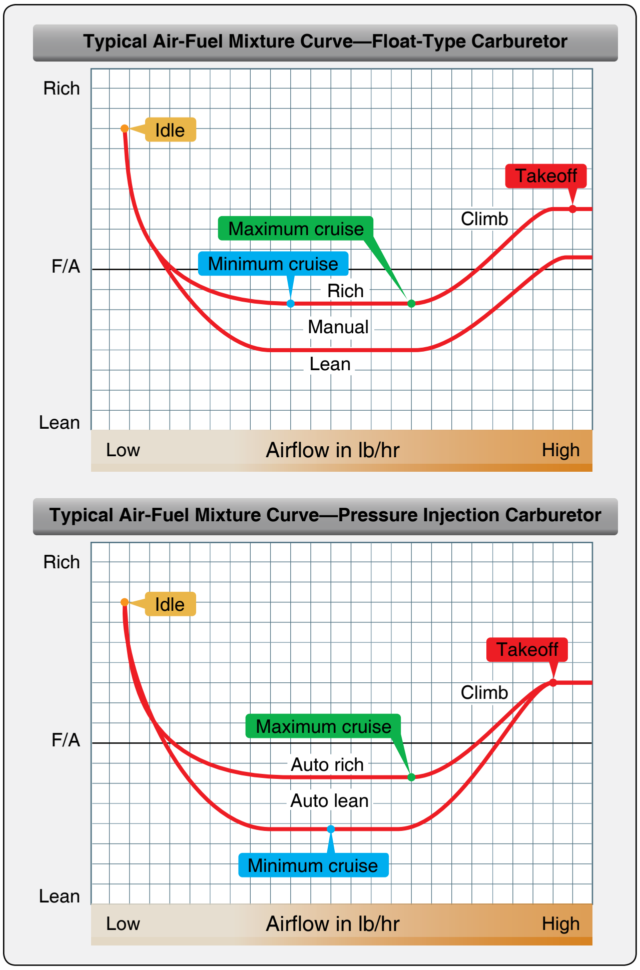


Figure 2-1. *Air-fuel mixture curves.*

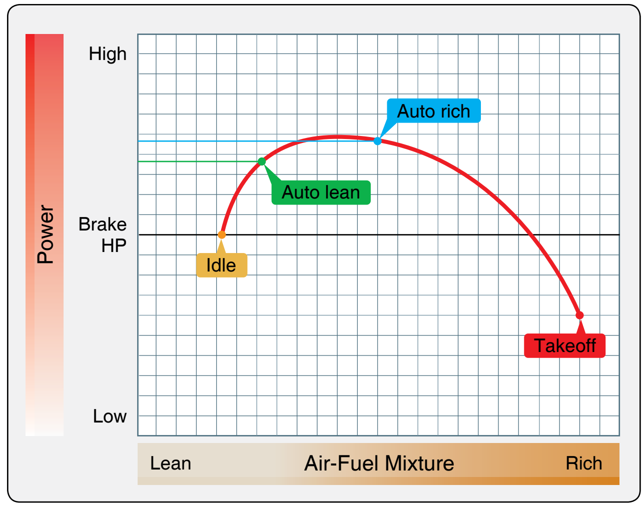


Figure 2-2. *Power versus air-fuel mixture curve.*

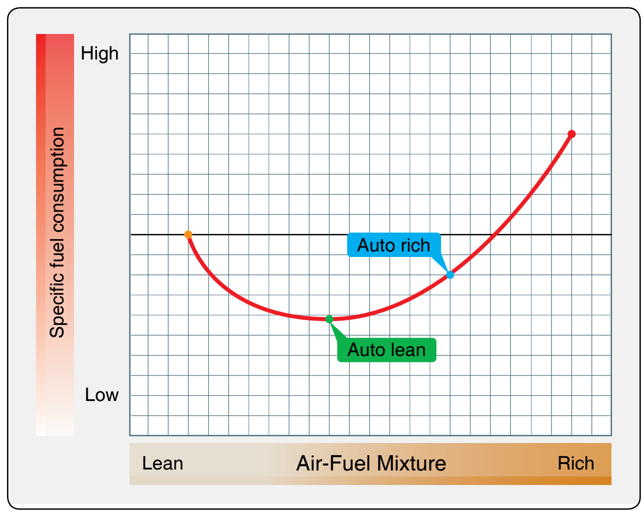


Figure 2-3. *Specific fuel consumption curve.*

takeoff speed. *[Figure 2-2]* Since it is necessary in the power range to add fuel to the basic air-fuel mixture requirements to keep cylinder-head temperatures in a safe range, the fuel mixture must become gradually richer as powers above cruise are used. *[Figure 2-1]* In the power range, the engine runs on a much leaner mixture, as indicated in the curves. However, on the leaner mixture, cylinder-head temperature would exceed the maximum permissible temperatures and detonation would occur.

The best economy setting is established by running a series of curves through the cruise range, as shown in the graph in *Figure 2-3,* the low point (auto-lean) in the curve being the air-fuel mixture where the minimum fuel per horsepower is used. In this range the engine operates normally on slightly leaner mixtures and obviously operates on richer mixtures than the low-point mixture. If a mixture leaner than that specified for the engine is used, the leanest cylinder of the engine is apt to backfire because the slower burning rate of the lean mixture results in a continued burning in the cylinder when the next intake stroke starts.

Air-Fuel Mixtures

Gasoline and other liquid fuels do not burn at all unless they are mixed with air. If the mixture is to burn properly within the engine cylinder, the ratio of air to fuel must be kept within a certain range. It would be more accurate to state that the fuel is burned with the oxygen in the air. Seventy-eight percent of air by volume is nitrogen, which is inert and does not participate in the combustion process, and 21 percent is oxygen. Heat is generated by burning the mixture of gasoline and oxygen. Nitrogen and gaseous byproducts of combustion absorb this heat energy and turn it into power by expansion. The mixture proportion of fuel and air by weight is of extreme importance to engine performance. The characteristics of a given mixture can be measured in terms of flame speed and combustion temperature.

The composition of the air-fuel mixture is described by the mixture ratio. For example, a mixture with a ratio of 12 to 1

(12:1) is made up of 12 pounds of air and 1 pound of fuel. The ratio is expressed in weight because the volume of air varies greatly with temperature and pressure. The mixture ratio can also be expressed as a decimal. Thus, an air-fuel ratio of 12:1 and an air-fuel ratio of 0.083 describe the same mixture ratio. Mixtures of air and gasoline as rich as 8:1 and as lean as 16:1 will burn in an engine cylinder, but beyond these mixtures, either lean or rich blow out could occur. The engine develops maximum power with a mixture of approximately 12 parts of air and 1 part of gasoline by weight.

From a chemist's point of view, the perfect mixture for combustion of fuel and air would be 0.067 pounds of fuel to 1 pound of air (mixture ratio of 15:1). The scientist calls this chemically correct combination a stoichiometric mixture (pronounced stoy-key-o-metric). With this mixture (given sufficient time and turbulence), all the fuel and all the oxygen in the air is completely used in the combustion process. The stoichiometric mixture produces the highest combustion temperatures because the proportion of heat released to a mass of charge (fuel and air) is the greatest. If more fuel is added to the same quantity of air charge than the amount giving a chemically perfect mixture, changes of power and temperature occur. The combustion gas temperature is lowered as the mixture is enriched, and the power increases until the air-fuel ratio is approximately 0.0725. For mixtures from 0.0725 air-fuel ratio to 0.080 air-fuel ratio, the power remains essentially constant even though the combustion temperature continues downward. Mixtures from 0.0725 air-fuel ratio to 0.080 air-fuel ratio are called best power mixtures, since their use results in the greatest power for a given airflow or manifold pressure. In this air-fuel ratio range, there is no increase in the total heat released, but the weight of nitrogen and combustion products is augmented by the vapor formed with the excess fuel. Thus, the working mass of the charge is increased. In addition, the extra fuel in the charge (over the stoichiometric mixture) speeds up the combustion process, which provides a favorable time factor in converting fuel energy into power.

If the air-fuel ratio is enriched above 0.080, there is loss of power and a reduction in temperature. The cooling effects of excess fuel overtake the favorable factor of increased mass. This reduced temperature and slower rate of burning lead to an increasing loss of combustion efficiency. If, with constant airflow, the mixture is leaned below 0.067, air-fuel ratio power and temperature decrease together. This time, the loss of power is not a liability but an asset. The purpose in leaning is to save fuel. Air is free and available in limitless quantities. The object is to obtain the required power with the least fuel flow. A measure of the economical use of fuel is called specific fuel consumption (SFC), which is the fuel weight in pounds per hour per horsepower.

$$\boxed{SFC = \frac{\text{pounds fuel/hour}}{\text{horsepower}}}$$

By using this ratio, the engine's use of fuel at various power settings can be compared. When leaning below 0.067 air-fuel ratio with constant airflow, even though the power diminishes, the cost in fuel to support each horsepower hour (SFC) also is lowered. While the mixture charge is becoming weaker, this loss of strength occurs at a rate lower than that of the reduction of fuel flow. This favorable tendency continues until a mixture strength known as best economy is reached. With this air-fuel ratio, the required hp is developed with the least fuel flow or, to put it another way, the greatest power produced by a given fuel flow. The best economy air-fuel ratio varies somewhat with rpm and other conditions, but for cruise powers on most reciprocating engines, it is sufficiently accurate to define this range of operation as being from 0.060 to 0.065 air-fuel ratios on aircraft where manual leaning is practiced.

Below the best economical mixture strength, power and temperature continue to fall with constant airflow while the SFC increases. As the air-fuel ratio is reduced further, combustion becomes so cool and slow that power for a given manifold pressure gets so low as to be uneconomical. The cooling effect of rich or lean mixtures results from the excess fuel or air over that needed for combustion. Internal cylinder cooling is obtained from unused fuel when air-fuel ratios above 0.067 are used. The same function is performed by excess air when air-fuel ratios below 0.067 are used.

Varying the mixture strength of the charge produces changes in the engine operating condition affecting power, temperature, and spark-timing requirements. The best power air-fuel ratio is desirable when the greatest power from a given airflow is required. The best economy mixture results from obtaining the given power output with the least fuel flow. The air-fuel ratio which gives most efficient operation varies with engine speed and power output.

In the graph showing this variation in air-fuel ratio, note that the mixture is rich at both idling and high-speed operation and is lean through the cruising range. *[Figure 2-1]* At idling speed, some air or exhaust gas is drawn into the cylinder through the exhaust port during valve overlap. The mixture that enters the cylinder through the intake port must be rich enough to compensate for this gas or additional air. At cruising power, lean mixtures save fuel and increase the range of the airplane. An engine running near full power requires a rich mixture to prevent overheating and detonation. Since the engine is operated at full power for only short periods, the

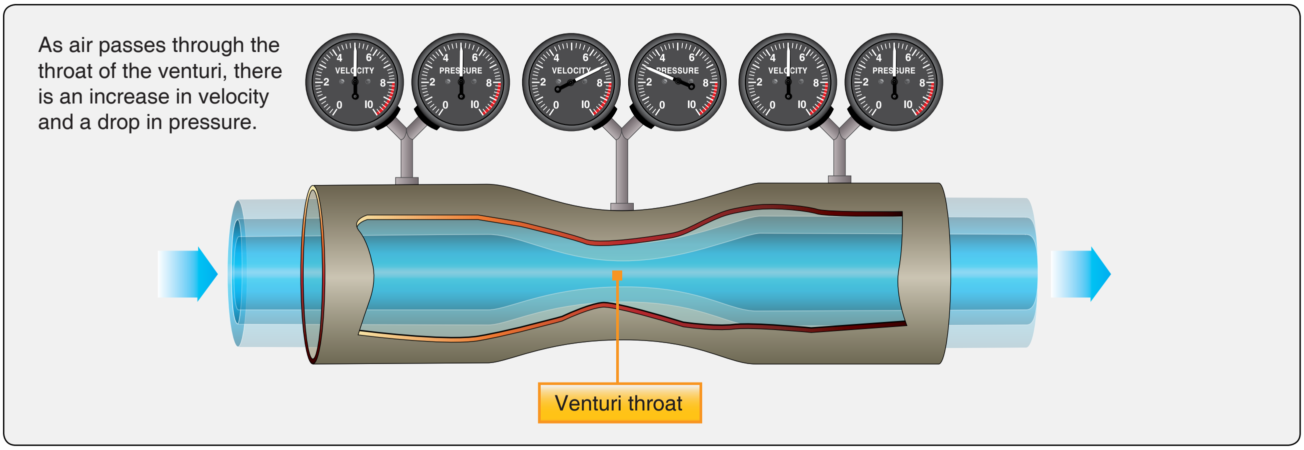


Figure 2-4. *Simple venturi.*

high fuel consumption is not a serious matter. If an engine is operating on a mixture that is too lean, and adjustments are made to increase the amount of fuel, the power output of the engine increases rapidly at first, then gradually until maximum power is reached. With a further increase in the amount of fuel, the power output drops gradually at first, then more rapidly as the mixture is further enriched.

There are specific instructions concerning mixture ratios for each type of engine under various operating conditions. Failure to follow these instructions results in poor performance and often in damage to the engine. Excessively rich mixtures result in loss of power and waste of fuel. With the engine operating near its maximum output, very lean mixtures cause a loss of power and, under certain conditions, serious overheating. When the engine is operated on a lean mixture, the cylinder head temperature gauge should be watched closely. If the mixture is excessively lean, the engine may backfire through the induction system or stop completely. Backfire results from slow burning of the lean mixture. If the charge is still burning when the intake valve opens, it ignites the fresh mixture and the flame travels back through the combustible mixture in the induction system.

Carburetion Principles

Venturi Principles

The carburetor must measure the airflow through the induction system and use this measurement to regulate the amount of fuel discharged into the airstream. The air measuring unit is the venturi, which makes use of a basic law of physics: as the velocity of a gas or liquid increases, the pressure decreases. As shown in *Figure 2-4,* simple venturi is a passageway or tube in which there is a narrow portion called the throat. As the velocity of the air increases to get through the narrow portion, its pressure drops. Note that the pressure in the throat is lower than that in any other part of the venturi. This pressure drop is proportional to the velocity and is, therefore, a measure of the airflow. The basic operating principle of most carburetors depends on the differential pressure between the inlet and the venturi throat.

Application of Venturi Principle to Carburetor

The carburetor is mounted on the engine so that air to the cylinders passes through the barrel, the part of the carburetor which contains the venturi. The size and shape of the venturi depends on the requirements of the engine for which the carburetor is designed. A carburetor for a high-powered engine may have one large venturi or several small ones. The air may flow either up or down the venturi, depending on the design of the engine and the carburetor. Those in which the air passes downward are known as downdraft carburetors, and those in which the air passes upward are called updraft carburetors. Some carburetors are made to use a side draft or horizontal air entry into the engine induction system, as shown in *Figure 2-5*.

Air flows through the induction system covered in Chapter 3. When a piston moves toward the crankshaft (down) on the intake stroke, the pressure in the cylinder is lowered.

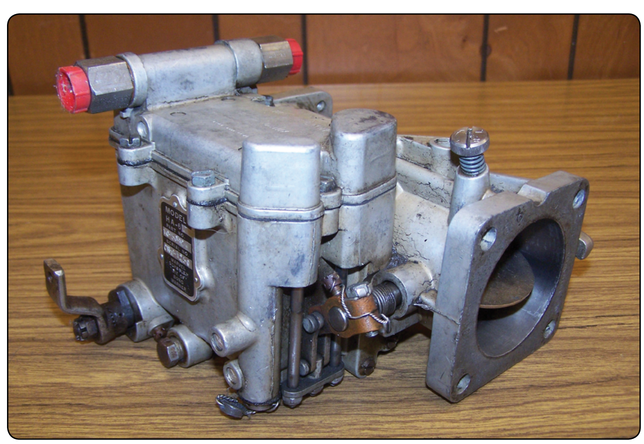


Figure 2-5. *Side draft horizontal flow carburetor.*

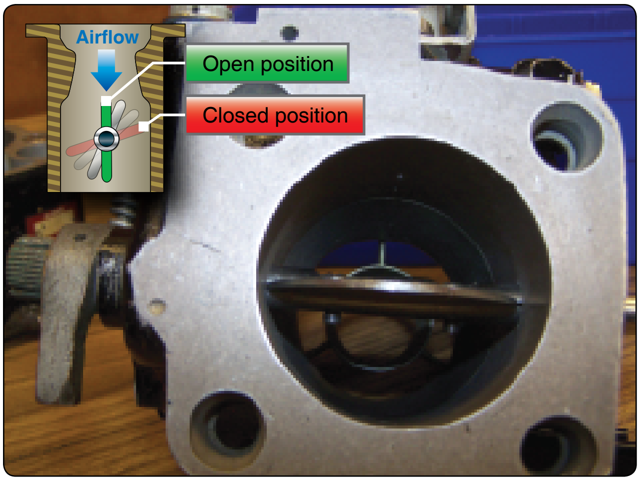


Figure 2-6. *Wide open throttle position.*

Air rushes through the carburetor and intake manifold to the cylinder to replace the air displaced by the piston as it moved down on the intake stroke. Due to this low pressure area caused by the piston moving down, the higher pressure air in the atmosphere flows in to fill the low pressure area. As it does, the airflow must pass through the carburetor venturi. The throttle valve is located between the venturi and the engine. Mechanical linkage connects this valve with the throttle lever in the flight deck. By means of the throttle, airflow to the cylinders is regulated and controls the power output of the engine. Actually, more air is admitted to the engine, and the carburetor automatically supplies enough additional gasoline to maintain the correct air-fuel ratio. This is because as the volume of airflow increases, the velocity in the venturi increases, lowering the pressure and allowing more fuel to be forced into the airstream. The throttle valve obstructs the passage of air very little when it is parallel with the flow, in the wide open throttle position. Throttle action is illustrated in *Figure 2-6*. Note how it restricts the airflow more and more as it rotates toward the closed position.

Metering & Discharge of Fuel

In *Figure 2-7,* showing the discharge of fuel into the airstream, locate the inlet through which fuel enters the carburetor from the engine-driven pump. The float-operated needle valve regulates the flow through the inlet, which maintains the correct level in the fuel float chamber. *[Figures 2-8* and *2-9]* This level must be slightly below the outlet of the discharge nozzle to prevent overflow when the engine is not running.

The discharge nozzle is located in the throat of the venturi at the point where the lowest drop in pressure occurs as air passes through the carburetor to the engine cylinders. There are two different pressures acting on the fuel in the carburetor—a low pressure at the discharge nozzle and a higher (atmospheric) pressure in the float chamber. The higher pressure in the float chamber forces the fuel through

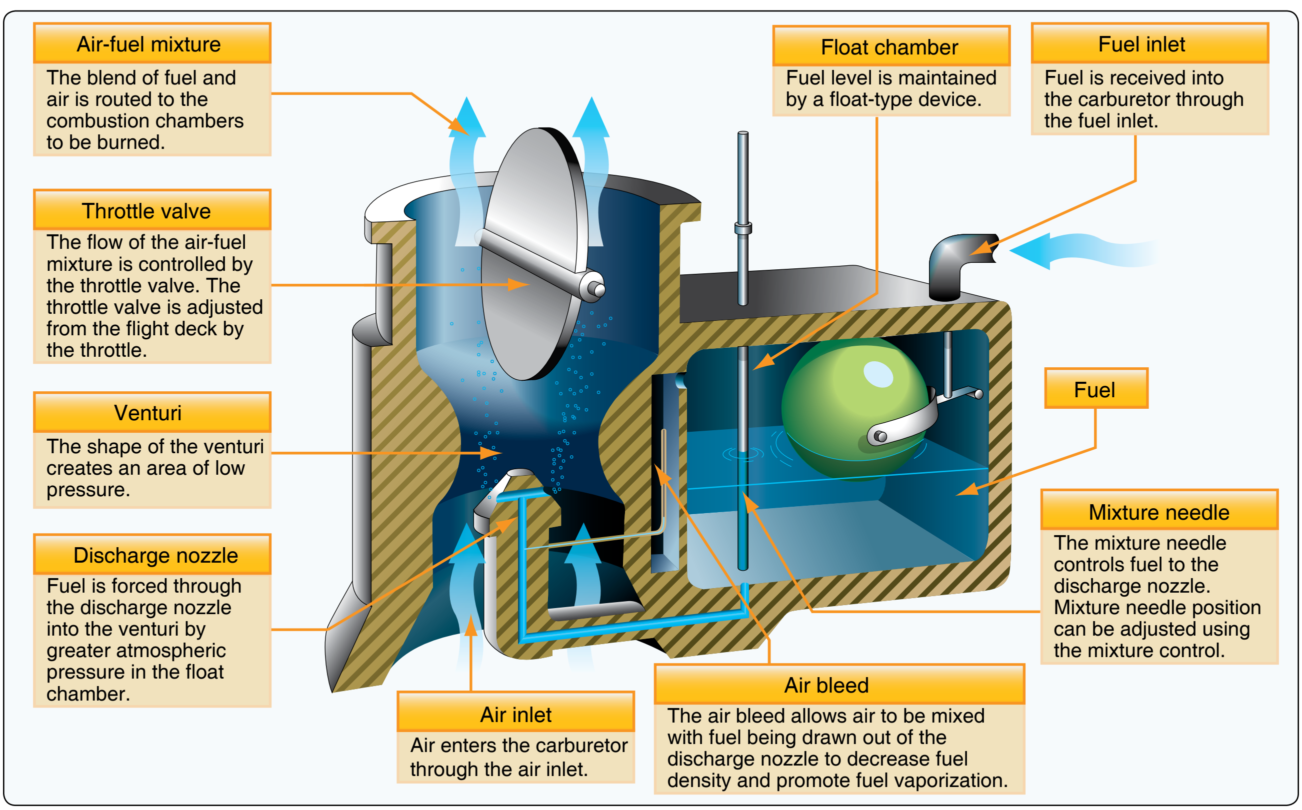


Figure 2-7. *Fuel discharge.*

Figure 2-8. *Needle valve and seat.*

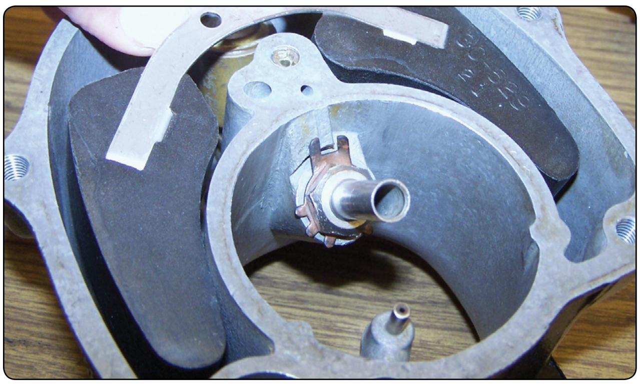


Figure 2-9. *Float chamber discharge nozzle and float.*

the discharge nozzle into the airstream. If the throttle is opened wider to increase the airflow to the engine, there is a greater drop in pressure at the venturi throat. Because of the higher differential pressure, the fuel discharge increases in proportion to the increase in airflow. If the throttle is moved toward the "closed" position, the airflow and fuel flow decrease.

The fuel must pass through the metering jet to reach the discharge nozzle. *[Figure 2-7]* A metering jet is really a certain size hole that the fuel passes through. The size of this jet determines the rate of fuel discharge at each differential pressure. If the jet is replaced with a larger one, the fuel flow increases, resulting in a richer mixture. If a smaller jet is installed, there is a decrease in fuel flow and a leaner mixture.

Carburetor Systems

To provide for engine operation under various loads and at different engine speeds, each carburetor has six systems:

1. Main metering,
2. Idling,
3. Accelerating,
4. Mixture control,
5. Idle cutoff, and
6. Power enrichment or economizer.

Each of these systems has a definite function. It may act alone or with one or more of the others.

The main metering system supplies fuel to the engine at all speeds above idling. The fuel discharged by this system is determined by the drop in pressure in the venturi throat.

A separate system is necessary for idling because the main metering system can be erratic at very low engine speeds. At low speeds the throttle is nearly closed. As a result, the velocity of the air through the venturi is low and there is little drop in pressure. Consequently, the differential pressure is not sufficient to operate the main metering system, and no fuel is discharged from this system. Therefore, most carburetors have an idling system to supply fuel to the engine at low engine speeds.

The accelerating system supplies extra fuel during sudden increases in engine power. When the throttle is opened, the airflow through the carburetor increases to obtain more power from the engine. The main metering system then increases the fuel discharge. During sudden acceleration, however, the increase in airflow is so rapid that there is a slight time lag before the increase in fuel discharge is sufficient to provide the correct mixture ratio with the new airflow. By supplying extra fuel during this period, the accelerating system prevents a temporary leaning out of the mixture and gives smooth acceleration.

The mixture control system determines the ratio of fuel to air in the mixture. By means of a flight deck control, the manual mixture control can select the mixture ratio to suit operating conditions. In addition to these manual controls, many carburetors have automatic mixture controls so that the air-fuel ratio, once it is selected, does not change with variations in air density. This is necessary because as the airplane climbs and the atmospheric pressure decreases, there is a corresponding decrease in the weight of air passing through the induction system. The volume, however, remains constant. Since it is the volume of airflow that determines the pressure drop at the throat of the venturi, the carburetor tends to meter the same amount of fuel to this thin air as to the dense air at sea level. Thus, the natural tendency is for the mixture to become richer as the airplane gains altitude. The automatic mixture control prevents this by decreasing the rate of fuel discharge to compensate for the decrease in air density.

The carburetor has an idle cutoff system so that the fuel can be shut off to stop the engine. This system, incorporated in the manual mixture control, stops the fuel discharge from the carburetor completely when the mixture control lever is set to the "idle cutoff" position. An aircraft engine is stopped by shutting off the fuel rather than by turning off the ignition. If the ignition is turned off with the carburetor still supplying fuel, fresh air-fuel mixture continues to pass through the induction system to the cylinders. As the engine is coasting to a stop and if it is excessively hot, this combustible mixture may be ignited by local hot spots within the combustion chambers. This can cause the engine to continue running or kick backward. Also, the mixture may pass through the cylinders unburned, but be ignited in the hot exhaust manifold. Or, the engine comes to an apparently normal stop, but a combustible mixture remains in the induction passages, the cylinders, and the exhaust system. This is an unsafe condition since the engine may kick over after it has been stopped and seriously injure anyone near the propeller. When the engine is shut down by means of the idle cutoff system, the spark plugs continue to ignite the air-fuel mixture until the fuel discharge from the carburetor ceases. This alone should prevent the engine from coming to a stop with a combustible mixture in the cylinders. Some engine manufacturers suggest that just before the propeller stops turning, the throttle be opened wide so that the pistons can pump fresh air through the induction system, the cylinders, and the exhaust system as an added precaution against accidental kick-over. After the engine has come to a complete stop, the ignition switch is turned to the "off" position.

The power enrichment system automatically increases the richness of the mixture during high power operation. It makes possible the variation in air-fuel ratio necessary to fit different operating conditions. Remember that at cruising speeds, a lean mixture is desirable for economy reasons, while at high power output, the mixture must be rich to obtain maximum power and to aid in cooling the engine cylinders. The power enrichment system automatically brings about the necessary change in the air-fuel ratio. Essentially, it is a valve that is closed at cruising speeds and opened to supply extra fuel to the mixture during high power operation. Although it increases the fuel flow at high power, the power enrichment system is actually a fuel saving device. Without this system, it would be necessary to operate the engine on a rich mixture over the complete power range. The mixture would then be richer than necessary at cruising speed to ensure safe operation at maximum power. The power enrichment system is sometimes called an economizer or a power compensator.

Although the various systems have been discussed separately, the carburetor functions as a unit. The fact that one system is in operation does not necessarily prevent another from functioning. At the same time that the main metering system is discharging fuel in proportion to the airflow, the mixture control system determines whether the resultant mixture is rich or lean. If the throttle is suddenly opened wide, the accelerating and power enrichment systems act to add fuel to that already being discharged by the main metering system.

Carburetor Types

There are two types of carburetor used on aircraft with reciprocating engines—the float-type and the pressure-type. The float-type carburetor, the most common of the two, has several distinct disadvantages. The effect that abrupt maneuvers have on the float action and the fact that its fuel must be discharged at low pressure leads to incomplete vaporization and difficulty in discharging fuel into some types of supercharged systems. The chief disadvantage of the float carburetor, however, is its icing tendency. Since the float carburetor must discharge fuel at a point of low pressure, the discharge nozzle must be located at the venturi throat, and the throttle valve must be on the engine side of the discharge nozzle. This means that the drop in temperature due to fuel vaporization takes place within the venturi. As a result, ice readily forms in the venturi and on the throttle valve.

A pressure-type carburetor discharges fuel into the airstream at a pressure well above atmospheric. This results in better vaporization and permits the discharge of fuel into the airstream on the engine side of the throttle valve. With the discharge nozzle located at this point, the drop in temperature due to fuel vaporization takes place after the air has passed the throttle valve and at a point where engine heat tends to offset it. Thus, the danger of fuel vaporization icing is practically eliminated. The effects of rapid maneuvers and rough air on the pressure-type carburetors are negligible since its fuel chambers remain filled under all operating conditions. Pressure carburetors have been replaced mostly by fuel injection systems and have limited use on modern aircraft engines.

Carburetor Icing

There are three general classifications of carburetor icing:

1. Fuel evaporation ice,
2. Throttle ice, and
3. Impact ice.

Fuel evaporation ice or refrigeration ice is formed because of the decrease in air temperature resulting from the evaporation of fuel after it is introduced into the airstream. As the fuel evaporates, the temperature is lowered in the area where the evaporation takes place. Any moisture in the incoming air can form ice in this area. It frequently occurs in those systems in which fuel is injected into the air upstream from the carburetor throttle, as in the case of float-type carburetors. It occurs less frequently in systems in which the fuel is injected into the air downstream from the carburetor. Refrigeration ice can be formed at carburetor air temperatures as high as 100 °F over a wide range of atmospheric humidity conditions, even at relative humidity well below 100 percent. Generally, fuel evaporation ice tends to accumulate on the fuel distribution nozzle in the carburetor. This type of ice can lower manifold pressure, interfere with fuel flow, and affect mixture distribution.

Throttle ice is formed on the rear side of the throttle, usually when the throttle is in a partially "closed" position. The rush of air across and around the throttle valve causes a low pressure on the rear side; this sets up a pressure differential across the throttle, which has a cooling effect on the air-fuel charge. Moisture freezes in this low pressure area and collects as ice on the low pressure side. Throttle ice tends to accumulate in a restricted passage. The occurrence of a small amount of ice may cause a relatively large reduction in airflow and manifold pressure. A large accumulation of ice may jam the throttles and cause them to become inoperable. Throttle ice seldom occurs at temperatures above 38 °F.

Impact ice is formed either from water present in the atmosphere as snow, sleet, or from liquid water which impinges on surfaces that are at temperatures below 32 °F. Because of inertia effects, impact ice collects on or near a surface that changes the direction of the airflow. This type of ice may build up on the carburetor elbow, as well as the carburetor screen and metering elements. The most dangerous impact ice is that which collects on the carburetor screen and causes a very rapid reduction of airflow and power. In general, danger from impact ice normally exists only when ice forms on the leading edges of the aircraft structure. Under some conditions, ice may enter the carburetor in a comparatively dry state and will not adhere to the inlet screen or walls or affect engine airflow or manifold pressure. This ice may enter the carburetor and gradually build up internally in the carburetor air metering passages and affect carburetor metering characteristics.

Float-Type Carburetors

A float-type carburetor consists essentially of six subsystems that control the quantity of fuel discharged in relation to the flow of air delivered to the engine cylinders. These systems work together to provide the engine with the correct fuel flow during all engine operating ranges.

The essential subsystems of a float-type carburetor are illustrated in *Figure 2-10*. These systems are:

1. Float chamber mechanism system,
2. Main metering system,
3. Idling system,
4. Mixture control system,

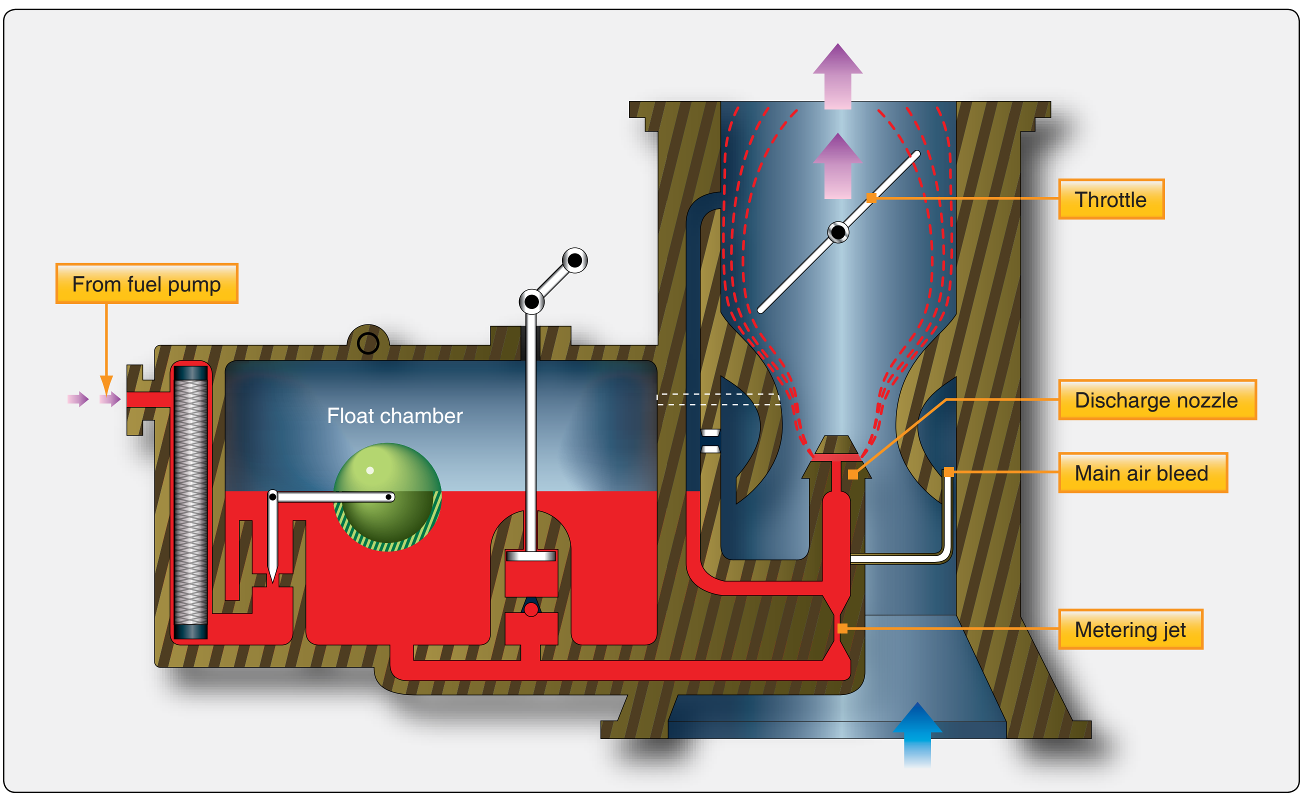


Figure 2-10. *A float-type carburetor.*

5. Accelerating system, and
6. Economizer system.

Float Chamber Mechanism System

A float chamber is provided between the fuel supply and the main metering system of the carburetor. The float chamber, or bowl, serves as a reservoir for fuel in the carburetor. *[Figure 2-11]* This chamber provides a nearly constant level of fuel to the main discharge nozzle which is usually about ⅛" below the holes in the main discharge nozzle. The fuel level must be maintained slightly below the discharge nozzle outlet holes to provide the correct amount of fuel flow and to prevent fuel leakage from the nozzle when the engine is not operating.

The level of fuel in the float chamber is kept nearly constant by means of a float-operated needle valve and a seat. The needle seat is usually made of bronze. The needle valve is constructed of hardened steel, or it may have a synthetic rubber section which fits the seat. With no fuel in the float chamber, the float drops toward the bottom of the chamber and allows the needle valve to open wide. As fuel is admitted from the supply line, the float rises (floats in the fuel) and closes the needle valve when the fuel reaches a predetermined level. When the engine is running, and fuel is being drawn out of the float chamber, the valve assumes an intermediate position so that the valve opening is just sufficient to supply the required amount of fuel and keep the level constant. *[Figure 2-10]* If fuel is found leaking from the discharge nozzle of the carburetor when the engine is not running, the most likely cause is that the float needle valve and seat is leaking and needs to be replaced.

With the fuel at the correct level (float chamber), the discharge rate is controlled accurately by the air velocity through the carburetor venturi where a pressure drop at the discharge nozzle causes fuel to flow into the intake airstream. Atmospheric pressure on top of the fuel in the float chamber forces the fuel out the discharge nozzle. A vent or small opening in the top of the float chamber allows air to enter or leave the chamber as the level of fuel rises or falls.

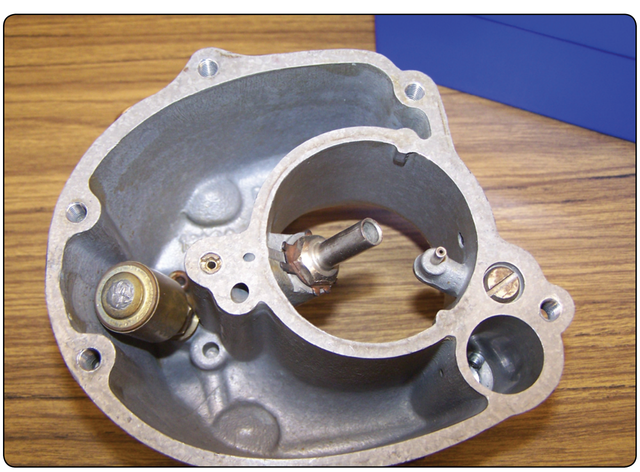


Figure 2-11. *Float chamber (bowl) with float removed.*

Main Metering System

The main metering system supplies fuel to the engine at all speeds above idling and consists of:

1. Venturi,
2. Main metering jet,
3. Main discharge nozzle,
4. Passage leading to the idling system, and
5. Throttle valve.

Since the throttle valve controls the mass airflow through the carburetor venturi, it must be considered a major unit in the main metering system as well as in other carburetor systems. A typical main metering system is illustrated in *Figure 2-12*. The venturi performs three functions:

1. Proportions the air-fuel mixture,
2. Decreases the pressure at the discharge nozzle, and
3. Limits the airflow at full throttle.

The fuel discharge nozzle is located in the carburetor barrel so that its open end is in the throat or narrowest part of the

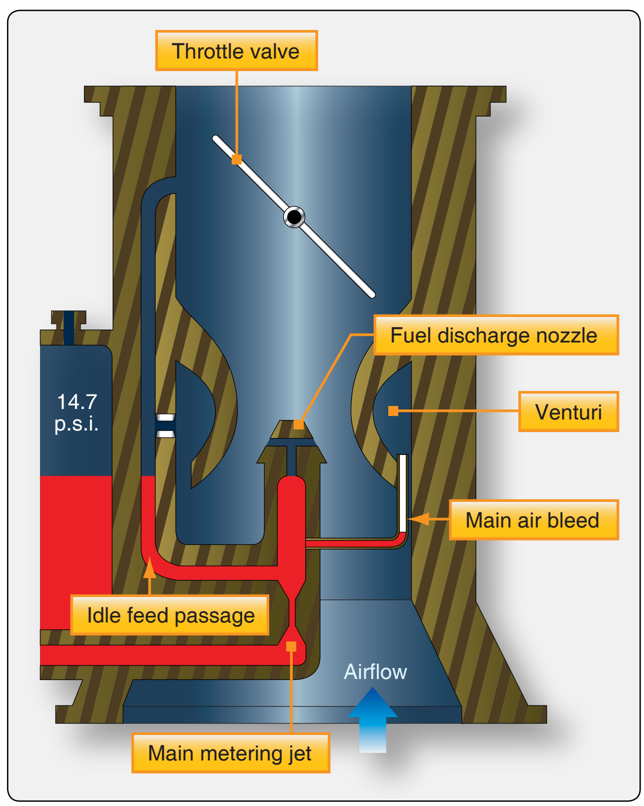


Figure 2-12. *Main metering system.*

venturi. A main metering orifice, or jet, is placed in the fuel passage between the float chamber and the discharge nozzle to limit the fuel flow when the throttle valve is wide open.

When the engine crankshaft is revolved with the carburetor throttle open, the low pressure created in the intake manifold acts on the air passing through the carburetor barrel. Due to the difference in pressure between the atmosphere and the intake manifold, air flows from the air intake through the carburetor barrel into the intake manifold. The volume of airflow depends upon the degree of throttle opening. As the air flows through the venturi, its velocity increases. This velocity increase creates a low pressure area in the venturi throat. The fuel discharge nozzle is exposed to this low pressure. Since the float chamber is vented to atmospheric pressure, a pressure drop across the discharge nozzle is created. It is this pressure difference, or metering force, that causes fuel to flow from the discharge nozzle. The fuel comes out of the nozzle in a fine spray, and the tiny particles of fuel in the spray quickly vaporize in the air.

The metering force (pressure differential) in most carburetors increases as the throttle opening is increased. The fuel must be raised in the discharge nozzle to a level at which it discharges into the airstream. To accomplish this, a pressure differential of 0.5 "Hg is required. When the metering force is considerably reduced at low engine speeds, the fuel delivery from the discharge nozzle decreases if an air bleed (air metering jet) is not incorporated in the carburetor. The decrease in fuel flow in relation to airflow is due to two factors:

1. The fuel tends to adhere to the walls of the discharge nozzle and break off intermittently in large drops instead of forming a fine spray.
2. A part of the metering force is required to raise the fuel level from the float chamber level to the discharge nozzle outlet.

The basic principle of the air bleed can be explained by simple diagrams, as shown in *Figure 2-13*. In each case, the same degree of suction is applied to a vertical tube placed in the container of liquid. As shown in A, the suction applied on the upper end of the tube is sufficient to lift the liquid a distance of about 1 inch above the surface. If a small hole is made in the side of the tube above the surface of the liquid, as in B, and suction is applied, bubbles of air enter the tube and the liquid is drawn up in a continuous series of small slugs or drops. Thus, air "bleeds" into the tube and partially reduces the forces tending to retard the flow of liquid through the tube. However, the large opening at the bottom of the tube effectively prevents any great amount of suction from being exerted on the air bleed hole or vent. Similarly, an air bleed hole that is too large in proportion to the size of the tube would reduce the suction available to lift the liquid. If the system is modified by placing a metering orifice in the bottom of the tube and air is taken in below the fuel level by means of an air bleed tube, a finely divided mixture of air and liquid is formed in the tube, as shown in C.

In a carburetor, a small air bleed is bled into the fuel nozzle slightly below the fuel level. The open end of the air bleed is in the space behind the venturi wall where the air is relatively motionless and at approximately atmospheric pressure. The low pressure at the tip of the nozzle not only draws fuel from the float chamber but also draws air from behind the venturi. Air bled into the main metering fuel system decreases the fuel density and destroys surface tension. This results in better vaporization and control of fuel discharge, especially at lower engine speeds. The throttle, or butterfly valve, is located in the carburetor barrel near one end of the venturi. It provides a means of controlling engine speed or power output by regulating the airflow to the engine. This valve is

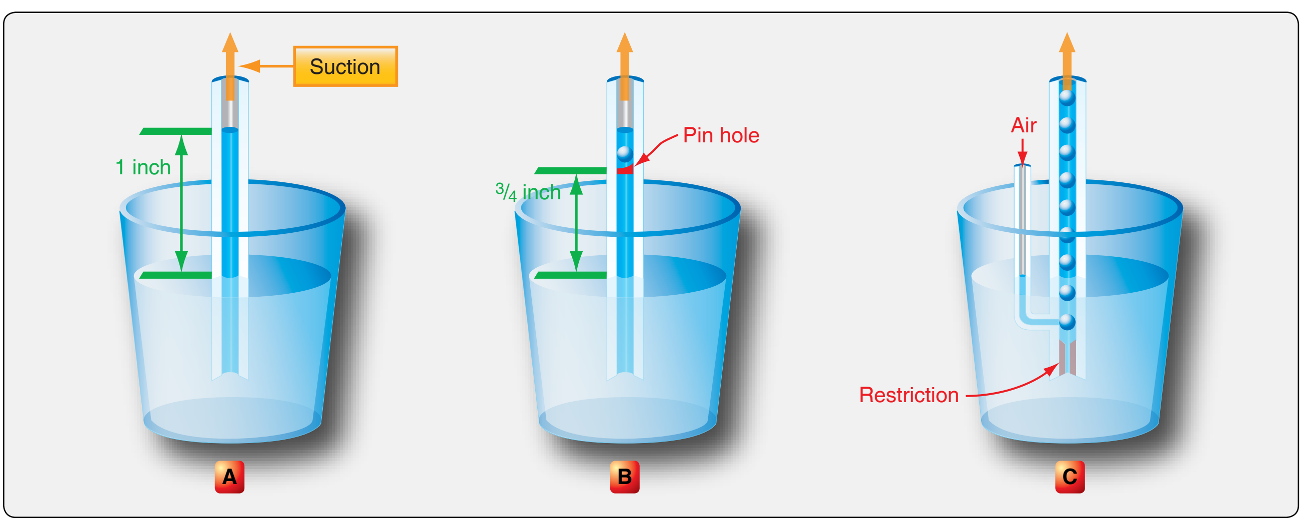


Figure 2-13. *Air bleed principle.*

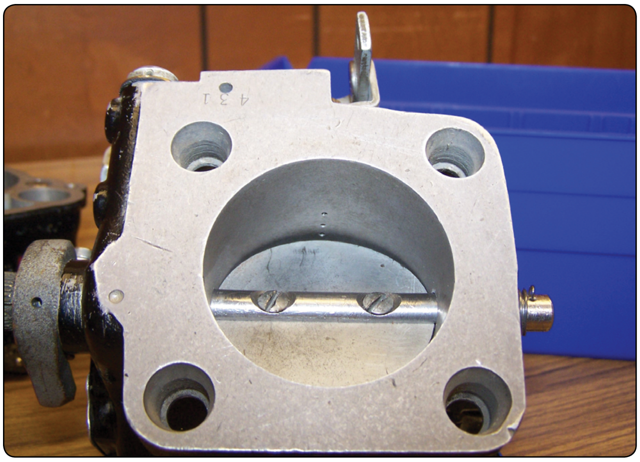


Figure 2-14. *Throttle action in idle position.*

a disc that can rotate on an axis, so that it can be turned to open or close the carburetor air passage.

Idling System

With the throttle valve closed at idling speeds, air velocity through the venturi is so low that it cannot draw enough fuel from the main discharge nozzle; in fact, the spray of fuel may stop altogether. However, low pressure (piston suction) exists on the engine side of the throttle valve. In order to allow the engine to idle, a fuel passageway is incorporated to discharge fuel from an opening in the low pressure area near the edge of the throttle valve. *[Figure 2-14]* This opening is called the idling jet. With the throttle open enough so that the main discharge nozzle is operating, fuel does not flow out of the idling jet. As soon as the throttle is closed far enough to stop the spray from the main discharge nozzle, fuel flows out the idling jet. A separate air bleed, known as the idle air bleed, is included as part of the idling system. It functions in the same manner as the main air bleed. An idle mixture adjusting device is also incorporated. A typical idling system is illustrated in *Figure 2-15*.

Mixture Control System

As altitude increases, the air becomes less dense. At an altitude of 18,000 feet, the air is only half as dense as it is at sea level. This means that a cubic foot of space contains only half as much air at 18,000 feet as at sea level. An engine cylinder full of air at 18,000 feet contains only half as much oxygen as a cylinder full of air at sea level.

The low pressure area created by the venturi is dependent upon air velocity rather than air density. The action of the venturi draws the same volume of fuel through the discharge nozzle at a high altitude as it does at a low altitude. Therefore, the fuel mixture becomes richer as altitude increases. This can be overcome either by a manual or an automatic mixture control.

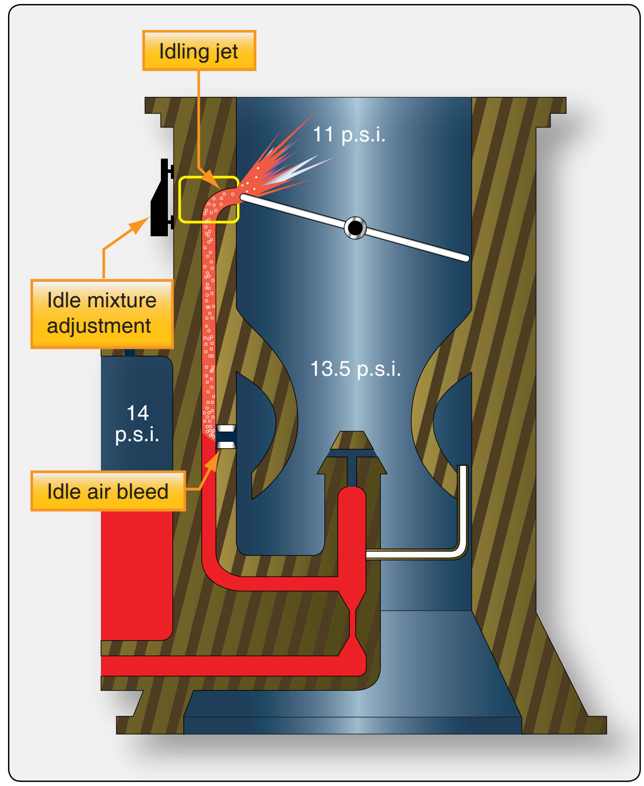


Figure 2-15. *Idling system.*

On float-type carburetors, two types of purely manual or flight deck controllable devices are in general use for controlling air-fuel mixtures, the needle type and the back-suction type. *[Figures 2-16 and 2-17]*

With the needle-type system, manual control is provided by a

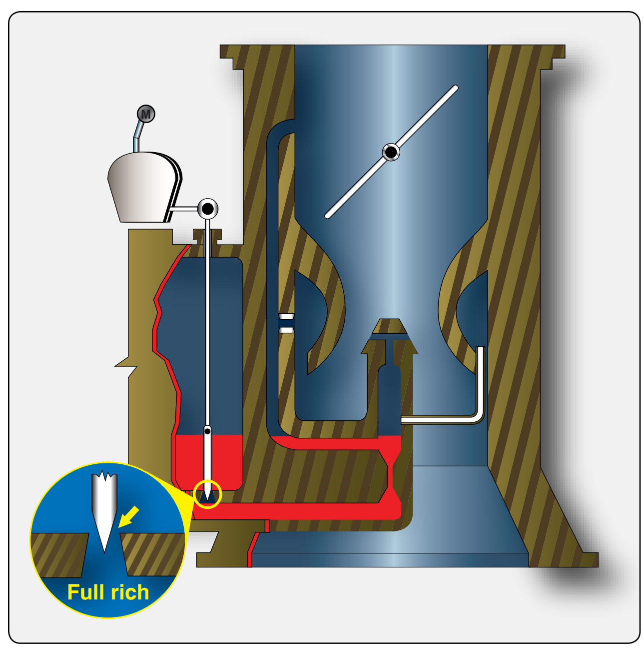


Figure 2-16. *Needle-type mixture control system.*

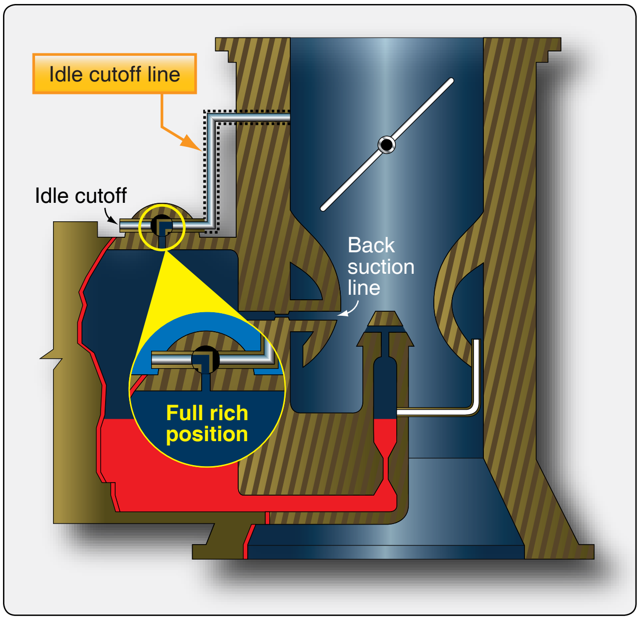


Figure 2-17. *Back-suction-type mixture control system.*

needle valve in the base of the float chamber. *[Figure 2-16]* This can be raised or lowered by adjusting a control in the flight deck. Moving the control to "rich," opens the needle valve wide, which permits the fuel to flow unrestricted to the nozzle. Moving the control to "lean," partially closes the valve and restricts the flow of fuel to the nozzle.

The back-suction-type mixture control system is the most widely used. *[Figure 2-17]* In this system, a certain amount of venturi low pressure acts upon the fuel in the float chamber so that it opposes the low pressure existing at the main discharge nozzle. An atmospheric line, incorporating an adjustable valve, opens into the float chamber. When the valve is completely closed, pressures on the fuel in the float chamber and at the discharge nozzle are almost equal, and fuel flow is reduced to maximum lean. With the valve wide open, pressure on the fuel in the float chamber is greatest and fuel mixture is richest. Adjusting the valve to positions between these two extremes controls the mixture. The quadrant in the flight deck is usually marked "lean" near the back end and "rich" at the forward end. The extreme back position is marked "idle cutoff" and is used when stopping the engine.

On float carburetors equipped with needle-type mixture control, placing the mixture control in idle cutoff seats the needle valve, thus shutting off fuel flow completely. On carburetors equipped with back-suction mixture controls, a separate idle cutoff line, leading to the extreme low pressure on the engine side of the throttle valve, is incorporated. (See the dotted line in *Figure 2-17*.) The mixture control is so linked that when it is placed in the "idle cutoff" position, it opens another passage that leads to piston suction. When placed in other positions, the valve opens a passage leading to the atmosphere. To stop the engine with such a system, close the throttle and place the mixture in the "idle cutoff" position. Leave the throttle in the closed position until the engine has stopped running and then open the throttle completely.

Accelerating System

When the throttle valve is opened quickly, a large volume of air rushes through the air passage of the carburetor; the amount of fuel that is mixed with the air is less than normal due to the slow response rate of the main metering system. As a result, after a quick opening of the throttle, the air-fuel mixture leans out momentarily. This can cause the engine to accelerate slowly or stumble as it tries to accelerate.

To overcome this tendency, the carburetor is equipped with a small fuel pump called an accelerating pump. A common type of accelerating system used in float carburetors is illustrated in *Figure 2-18*. It consists of a simple piston pump operated through linkage by the throttle control and a passageway opening into the main metering system or the carburetor barrel near the venturi. When the throttle is closed, the piston moves back, and fuel fills the cylinder. If the piston is pushed forward slowly, the fuel seeps past it back into the float chamber; if pushed rapidly, it sprays fuel in the venturi and enriches the mixture. An example of a cutaway accelerator pump is shown in *Figure 2-19*.

Economizer System

For an engine to develop maximum power at full throttle, the fuel mixture must be richer than for cruise. The additional fuel is used for cooling the engine combustion chambers to prevent detonation. An economizer is essentially a valve that is closed at throttle settings below approximately 60–70

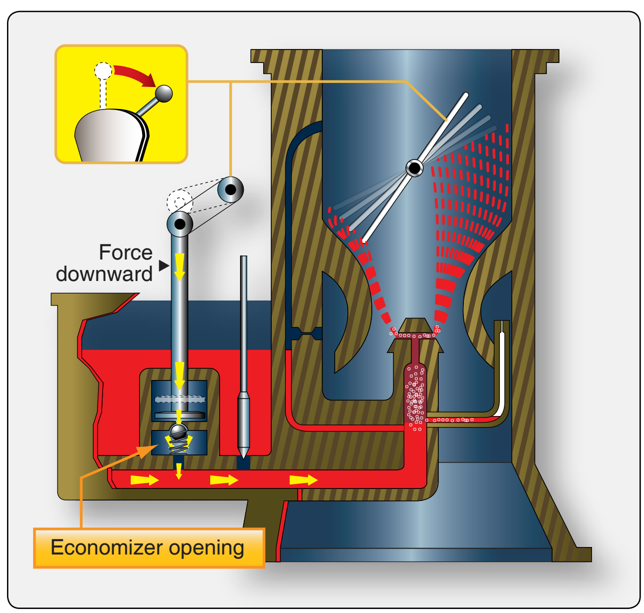


Figure 2-18. *Accelerating system.*

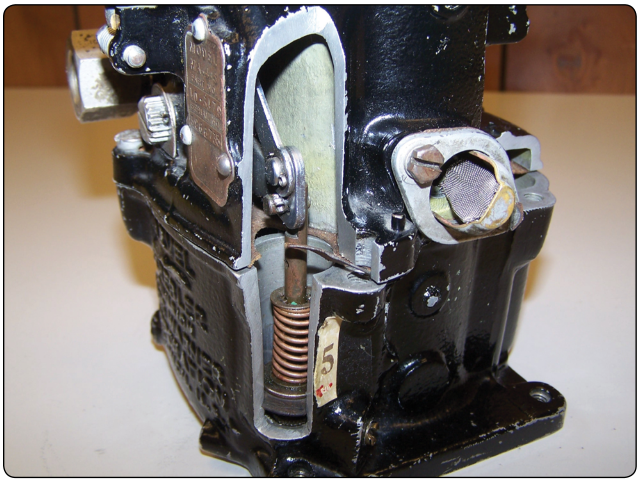


Figure 2-19. *Accelerating pump shown in cutaway.*

percent of rated power. This system, like the accelerating system, is operated by the throttle control.

A typical economizer system consists of a needle valve which begins to open when the throttle valve reaches a predetermined point near the wide-open position. *[Figure 2-20]* As the throttle continues to open, the needle valve is opened further and additional fuel flows through it. This additional fuel supplements the flow from the main metering jet direct to the main discharge nozzle.

A pressure-operated economizer system is shown in *Figure 2-21*. This type has a sealed bellows located in an enclosed compartment. The compartment is vented to engine manifold pressure. When the manifold pressure reaches a certain value, the bellows is compressed and opens a valve in a carburetor fuel passage, supplementing the normal quantity of fuel being discharged through the main nozzle.

Another type of economizer is the back-suction system. *[Figure 2-22]* Fuel economy in cruising is provided by reducing the effective pressure acting on the fuel level in the float compartment. With the throttle valve in cruising position, suction is applied to the float chamber through an economizer hole and back-suction economizer channel and jet. The suction applied to the float chamber opposes the nozzle suction applied by the venturi. Fuel flow is reduced, leaning the mixture for cruising economy.

Another type of mixture control system uses a metering valve that is free to rotate in a stationary metering sleeve. Fuel enters the main and idling systems through a slot cut in the mixture sleeve. Fuel metering is accomplished by the relative position between one edge of the slot in the hollow metering valve and one edge of the slot in the metering sleeve. Moving the mixture control to reduce the size of the slot provides a leaner mixture for altitude compensation.

Pressure Injection Carburetors

Pressure injection carburetors are distinctly different from float-type carburetors as they do not incorporate a vented float chamber or suction pickup from a discharge nozzle located in the venturi tube. Instead, they provide a pressurized fuel system that is closed from the engine fuel pump to the discharge nozzle. The venturi serves only to create pressure differentials for controlling the quantity of fuel to the metering jet in proportion to airflow to the engine.

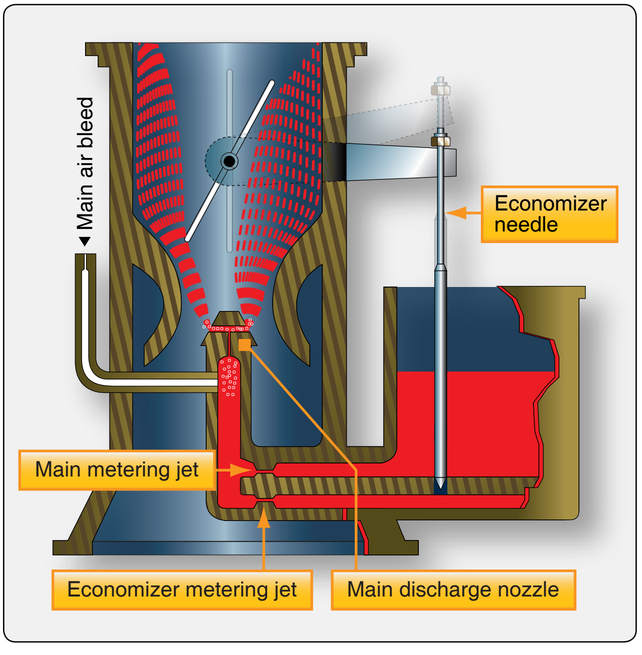


Figure 2-20. *A needle-valve type economizer system.*

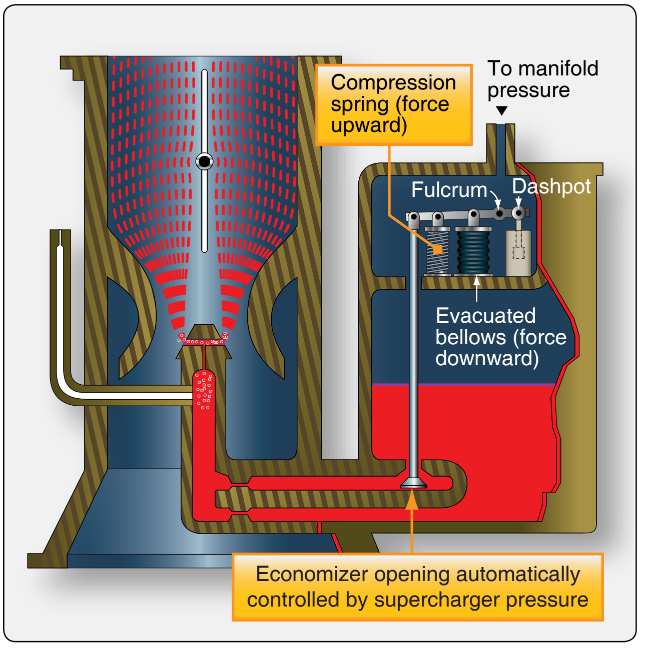


Figure 2-21. *A pressure operated economizer system.*

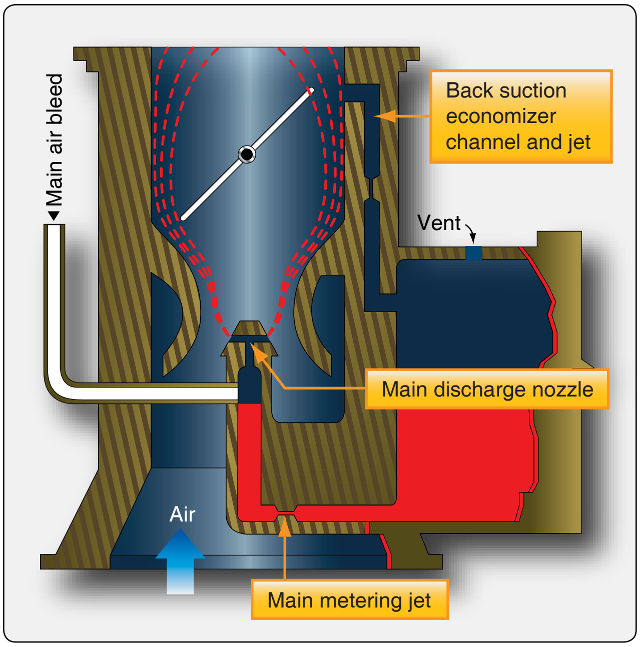


Figure 2-22. *Float-type carburetor.*

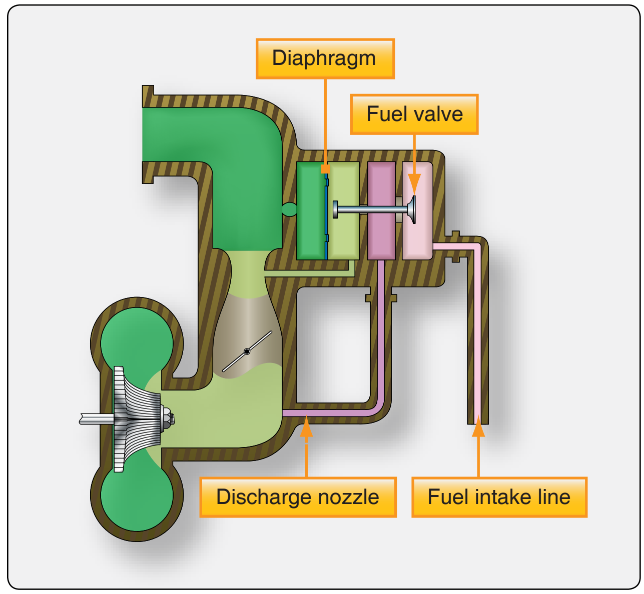


Figure 2-23. *Pressure-type carburetor.*

Typical Injection Carburetor

The injection carburetor is a hydromechanical device employing a closed feed system from the fuel pump to the discharge nozzle. It meters fuel through fixed jets according to the mass airflow through the throttle body and discharges it under a positive pressure.

The illustration in *Figure 2-23* represents a pressure-type carburetor simplified so that only the basic parts are shown. Note the two small passages, one leading from the carburetor air inlet to the left side of the flexible diaphragm and the other from the venturi throat to the right side of the diaphragm.

When air passes through the carburetor to the engine, the pressure on the right of the diaphragm is lowered because of the drop in pressure at the venturi throat. As a result, the diaphragm moves to the right, opening the fuel valve. Pressure from the engine-driven pump then forces fuel through the open valve to the discharge nozzle, where it sprays into the airstream. The distance the fuel valve opens is determined by the difference between the two pressures acting on the diaphragm. This difference in pressure is proportional to the airflow through the carburetor. Thus, the volume of airflow determines the rate of fuel discharge.

The pressure injection carburetor is an assembly of the following units:

1. Throttle body,
2. Automatic mixture control,
3. Regulator unit, and
4. Fuel control unit (some are equipped with an adapter).

Throttle Body

The throttle body contains the throttle valves, main venturi, boost venturi, and the impact tubes. All air entering the cylinders must flow through the throttle body; therefore, it is the air control and measuring device. The airflow is measured by volume and by weight so that the proper amount of fuel can be added to meet the engine demands under all conditions. As air flows through the venturi, its velocity is increased, and its pressure is decreased (Bernoulli's principle). This low pressure is vented to the low pressure side of the air diaphragm *[Figure 2-24 chamber B]* in the regulator assembly. The impact tubes sense carburetor inlet air pressure and direct it to the automatic mixture control, which measures the air density. From the automatic mixture control, the air is directed to the high pressure side of the air diaphragm (chamber A). The pressure differential of the two chambers acting upon the air diaphragm is known as the air metering force which opens the fuel poppet valve.

The throttle body controls the airflow with the throttle valves. The throttle valves may be either rectangular or disc shaped, depending on the design of the carburetor. The valves are mounted on a shaft, which is connected by linkage to the idle valve and to the throttle control in the flight deck. A throttle stop limits the travel of the throttle valve and has an adjustment which sets engine idle speed.

Regulator Unit

The regulator is a diaphragm-controlled unit divided into five chambers and contains two regulating diaphragms and a poppet valve assembly. *[Figure 2-24]* Chamber A is

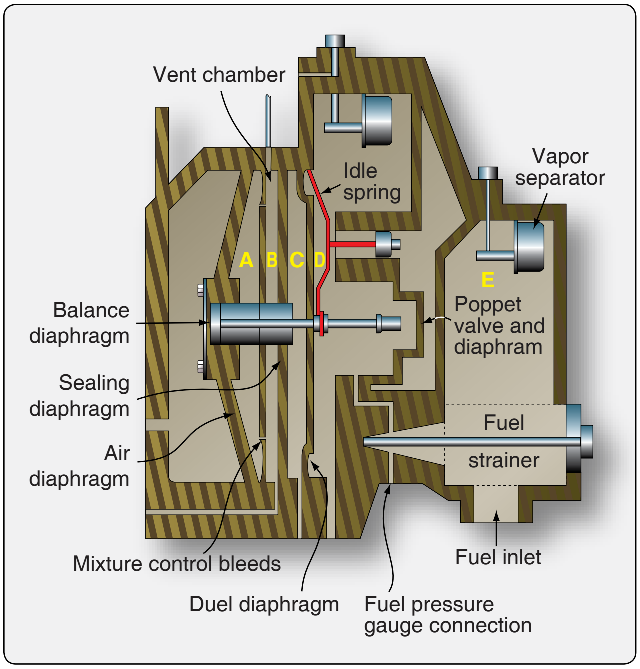


Figure 2-24. *Regulator unit.*

regulated air-inlet pressure from the air intake. Chamber B is boost venturi pressure. Chamber C contains metered fuel pressure controlled by the discharge nozzle or fuel feed valve. Chamber D contains unmetered fuel pressure controlled by the opening of the poppet valve. Chamber E is fuel pump pressure controlled by the fuel pump pressure relief valve. The poppet valve assembly is connected by a stem to the two main control diaphragms. The purpose of the regulator unit is to regulate the fuel pressure to the inlet side of the metering jets in the fuel control unit. This pressure is automatically regulated according to the mass airflow to the engine.

The carburetor fuel strainer (also called the gascolator), located in the inlet to chamber E, is a fine mesh screen through which all the fuel must pass as it enters chamber D. The strainer must be removed and cleaned at scheduled intervals.

Referring to *Figure 2-24*, assume that for a given airflow in lb/hr through the throttle body and venturi, a negative pressure of ¼ psi is established in chamber B. This tends to move the diaphragm assembly and the poppet valve in a direction to open the poppet valve permitting more fuel to enter chamber D. The pressure in chamber C is held constant at 5 psi (10 psi on some installations) by the discharge nozzle or impeller fuel feed valve. Therefore, the diaphragm assembly and poppet valve moves in the open direction until the pressure in chamber D is 5¼ psi. Under these pressures, there is a balanced condition of the diaphragm assembly with a pressure drop of ¼ psi across the jets in the fuel control unit (auto-rich or auto-lean).

If nozzle pressure (chamber C pressure) rises to 5½ psi, the diaphragm assembly balance is upset, and the diaphragm assembly moves to open the poppet valve to establish the necessary 5¾ psi pressure in chamber D. Thus, the ¼ psi differential between chamber C and chamber D is re-established, and the pressure drop across the metering jets remains the same.

If the fuel inlet pressure is increased or decreased, the fuel flow into chamber D tends to increase or decrease with the pressure change causing the chamber D pressure to do likewise. This upsets the balanced condition previously established, and the poppet valve and diaphragm assembly respond by moving to increase or decrease the flow to re-establish the pressure at the ¼ psi differential.

The fuel flow changes when the mixture control plates are moved from auto-lean to auto-rich, thereby selecting a different set of jets or cutting one or two in or out of the system. When the mixture position is altered, the diaphragm and poppet valve assembly repositions to maintain the established pressure differential of ¼ psi between chambers C and D, maintaining the established differential across the jets. Under low power settings (low airflows), the difference in pressure created by the boost venturi is not sufficient to accomplish consistent regulation of the fuel. Therefore, an idle spring, shown in *Figure 2-24*, is incorporated in the regulator. As the poppet valve moves toward the closed position, it contacts the idle spring. The spring holds the poppet valve off its seat far enough to provide more fuel than is needed for idling. This potentially overrich mixture is regulated by the idle valve. At idling speed, the idle valve restricts the fuel flow to the proper amount. At higher speeds, it is withdrawn from the fuel passage and has no metering effect.

Vapor vent systems are provided in these carburetors to eliminate fuel vapor created by the fuel pump, heat in the engine compartment, and the pressure drop across the poppet valve. The vapor vent is located in the fuel inlet (chamber E) or, on some models of carburetors, in both chambers D and E.

The vapor vent system operates in the following way. When air enters the chamber in which the vapor vent is installed, the air rises to the top of the chamber, displacing the fuel and lowering its level. When the fuel level has reached a predetermined position, the float (which floats in the fuel) pulls the vapor vent valve off its seat, permitting the vapor in the chamber to escape through the vapor vent seat, its connecting line, and back to the fuel tank.

If the vapor vent valve sticks in a closed position or the vent line from the vapor vent to the fuel tank becomes clogged, the vapor-eliminating action is stopped. This causes the vapor to build up within the carburetor to the extent that vapor passes through the metering jets with the fuel. With a given size carburetor metering jet, the metering of vapor reduces the quantity of fuel metered. This causes the air-fuel mixture to lean out, usually intermittently.

If the vapor vent valve sticks open or the vapor vent float becomes filled with fuel and sinks, a continuous flow of fuel and vapor occurs through the vent line. It is important to detect this condition, as the fuel flow from the carburetor to the fuel supply tank may cause an overflowing tank with resultant increased fuel consumption.

To check the vent system, disconnect the vapor vent line where it attaches to the carburetor, and turn the fuel booster pump on while observing the vapor vent connection at the carburetor. Move the carburetor mixture control to auto-rich; then return it to idle cutoff. When the fuel booster pump is turned on, there should be an initial ejection of fuel and air followed by a cutoff with not more than a steady drip from the vent connection. Installations with a fixed bleed from the D chamber connected to the vapor vent in the fuel inlet by a short external line should show an initial ejection of fuel and air followed by a continuing small stream of fuel. If there is no flow, the valve is sticking closed; if there is a steady flow, it is sticking open.

Fuel Control Unit

The fuel control unit is attached to the regulator assembly and contains all metering jets and valves. *[Figure 2-25]* The idle and power enrichment valves, together with the mixture control plates, select the jet combinations for the various settings (i.e., auto-rich, auto-lean, and idle cutoff).

The purpose of the fuel control unit is to meter and control the fuel flow to the discharge nozzle. The basic unit consists of three jets and four valves arranged in series, parallel, and series-parallel hookups. *[Figure 2-25]* These jets and valves receive fuel under pressure from the regulator unit and then meter the fuel as it flows to the discharge nozzle. The manual mixture control valve controls the fuel flow. By using proper size jets and regulating the pressure differential across the jets, the right amount of fuel is delivered to the discharge nozzle, giving the desired air-fuel ratio in the various power settings. It should be remembered that the inlet pressure to the jets is regulated by the regulator unit and the outlet pressure is controlled by the discharge nozzle.

The jets in the basic fuel control unit are the auto-lean jet, the auto-rich jet, and power enrichment jet. The basic fuel flow is the fuel required to run the engine with a lean mixture and is metered by the auto-lean jet. The auto-rich jet adds enough fuel to the basic flow to give a slightly richer mixture than

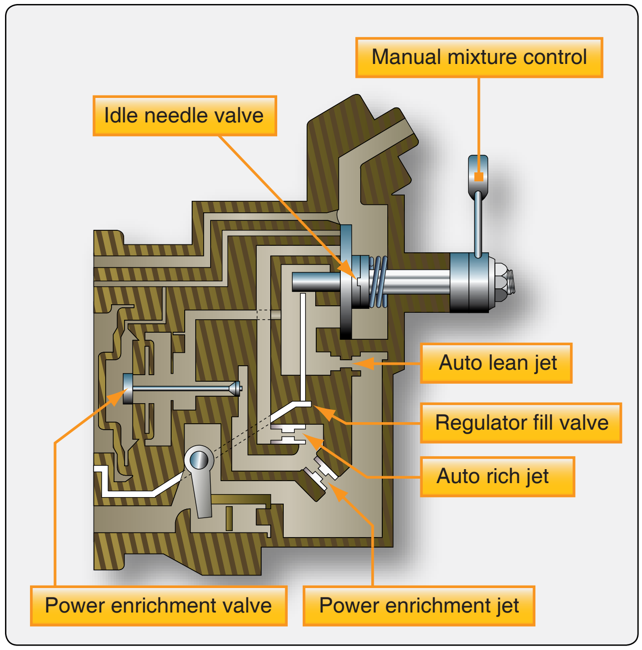


Figure 2-25. *Fuel control unit.*

best power mixture when the manual mixture control is in the auto-rich position.

The four valves in the basic fuel control unit are:

1. Idle needle valve,
2. Power enrichment valve,
3. Regulator fill valve, and
4. Manual mixture control.

The functions of these valves are:

1. The idle needle valve meters the fuel in the idle range only. It is a round, contoured needle valve, or a cylinder valve placed in series with all other metering devices of the basic fuel control unit. The idle needle valve is connected by linkage to the throttle shaft so that it restricts the fuel flowing at low power settings (idle range).
2. The manual mixture control is a rotary disc valve consisting of a round stationary disc with ports leading from the auto-lean jet, the auto-rich jet, and two smaller ventholes. Another rotating part, resembling a cloverleaf, is held against the stationary disc by spring tension and rotated over the ports in that disc by the manual mixture control lever. All ports and vents are closed in the idle cutoff position. In the auto-lean position, the ports from the auto-lean jet and the two ventholes are open. The port from the auto-rich jet remains closed in this position. In the auto-rich position, all ports are open. The valve plate positions

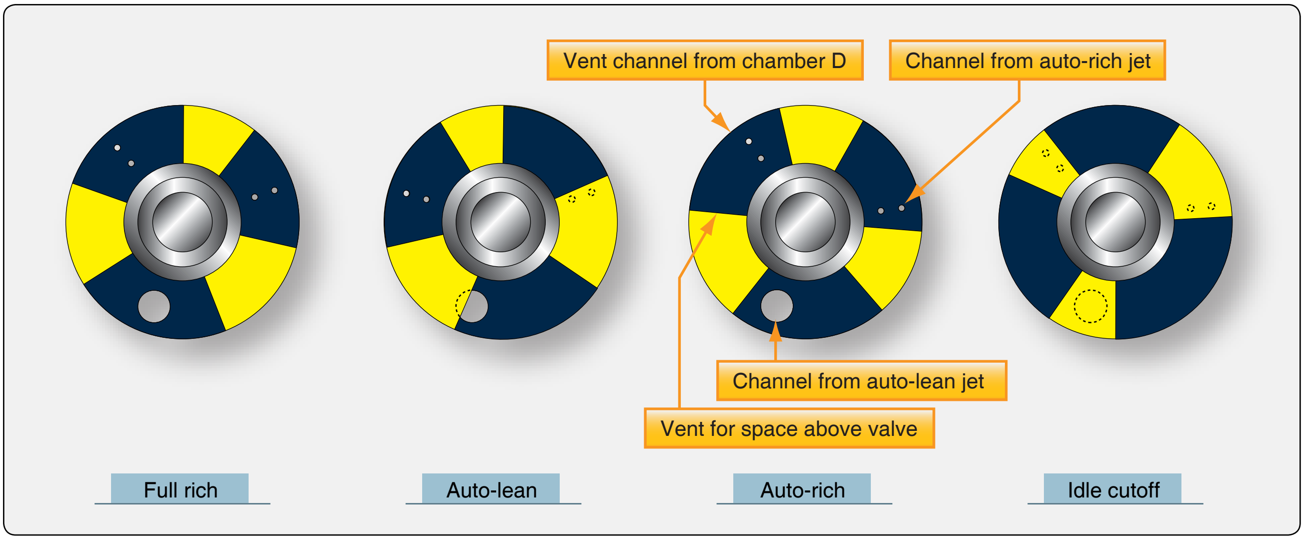


Figure 2-26. *Manual mixture control valve plate positions.*

are illustrated in *Figure 2-26*. The three positions of the manual mixture control lever make it possible to select a lean mixture a rich mixture, or to stop fuel flow entirely. The idle cutoff position is used for starting or stopping the engine. During starting, fuel is supplied by the primer.

3. The regulator fill valve is a small poppet-type valve located in a fuel passage which supplies chamber C of the regulator unit with metered fuel pressure. In idle cutoff, the flat portion of the cam lines up with the valve stem, and a spring closes the valve. This provides a means of shutting off the fuel flow to chamber C and thus provides for a positive idle cutoff.
4. The power enrichment valve is another poppet-type valve. It is in parallel with the auto-lean and auto-rich jets, but it is in series with the power enrichment jet. This valve starts to open at the beginning of the power range. It is opened by the unmetered fuel pressure overcoming metered fuel pressure and spring tension. The power enrichment valve continues to open wider during the power range until the combined flow through the valve and the auto-rich jet exceeds that of the power enrichment jet. At this point the power enrichment jet takes over the metering and meters fuel throughout the power range.
5. Carburetors equipped for water injection are modified by the addition of a derichment valve and a derichment jet. The derichment valve and derichment jet are in series with each other and parallel with the power enrichment jet.

The carburetor controls fuel flow by varying two basic factors. The fuel control unit, acting as a pressure-reducing valve, determines the metering pressure in response to the metering forces. The regulator unit, in effect, varies the size of the orifice through which the metering pressure forces the fuel. It is a basic law of hydraulics that the amount of fluid that passes through an orifice varies with the size of the orifice and the pressure drop across it. The internal automatic devices and mixture control act together to determine the effective size of the metering passage through which the fuel passes. The internal devices, fixed jets, and variable power enrichment valve are not subject to direct external control.

Automatic Mixture Control (AMC)

The automatic mixture control unit consists of a bellows assembly, calibrated needle, and seat. *[Figure 2-27]* The purpose of the automatic mixture control is to compensate for changes in air density due to temperature and altitude changes.

The automatic mixture control contains a metallic bellows, which is sealed at 28 "Hg absolute pressure. The bellows responds to changes in pressure and temperature. In the illustration, the automatic mixture control is located at the carburetor air inlet. As the density of the air changes, the expansion and contraction of the bellows moves the tapered needle in the atmospheric line. At sea level, the bellows is contracted, and the needle is not in the atmospheric passage. As the aircraft climbs and the atmospheric pressure decreases, the bellows expands, inserting the tapered needle farther and farther into the atmospheric passage and restricting the flow of air to chamber A of the regulator unit. *[Figure 2-24]* At the same time, air leaks slowly from chamber A to chamber B through the small bleed (often referred to as the back-suction bleed or mixture control bleed). The rate at which air leaks through this bleed is about the same at high altitude as it is at sea level. As the tapered needle restricts the flow of air into chamber A, the pressure on the left side of the air diaphragm decreases. As

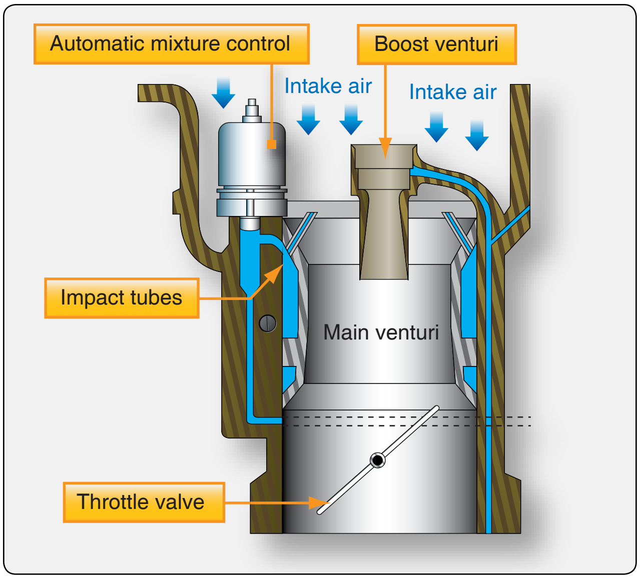


Figure 2-27. *Automatic mixture control and throttle body.*

a result, the poppet valve moves toward its seat, reducing the fuel flow to compensate for the decrease in air density.

The automatic mixture control can be removed and cleaned if the lead seal at the point of adjustment is not disturbed.

Stromberg PS Carburetor

The PS series carburetor is a low-pressure, single-barrel, injection-type carburetor. The carburetor consists basically of the air section, the fuel section, and the discharge nozzle mounted together to form a complete fuel metering system. This carburetor is similar to the pressure-injection carburetor; therefore, its operating principles are the same.

In this type carburetor, metering is accomplished on a mass airflow basis. *[Figure 2-28]* Air flowing through the main venturi creates suction at the throat of the venturi, which is transmitted to the B chamber in the main regulating part of the carburetor and to the vent side of the fuel discharge nozzle diaphragm. The incoming air pressure is transmitted to a chamber A of the regulating part of the carburetor and to the main discharge bleed in the main fuel discharge jet. The discharge nozzle consists of a spring-loaded diaphragm connected to the discharge nozzle valve, which controls the

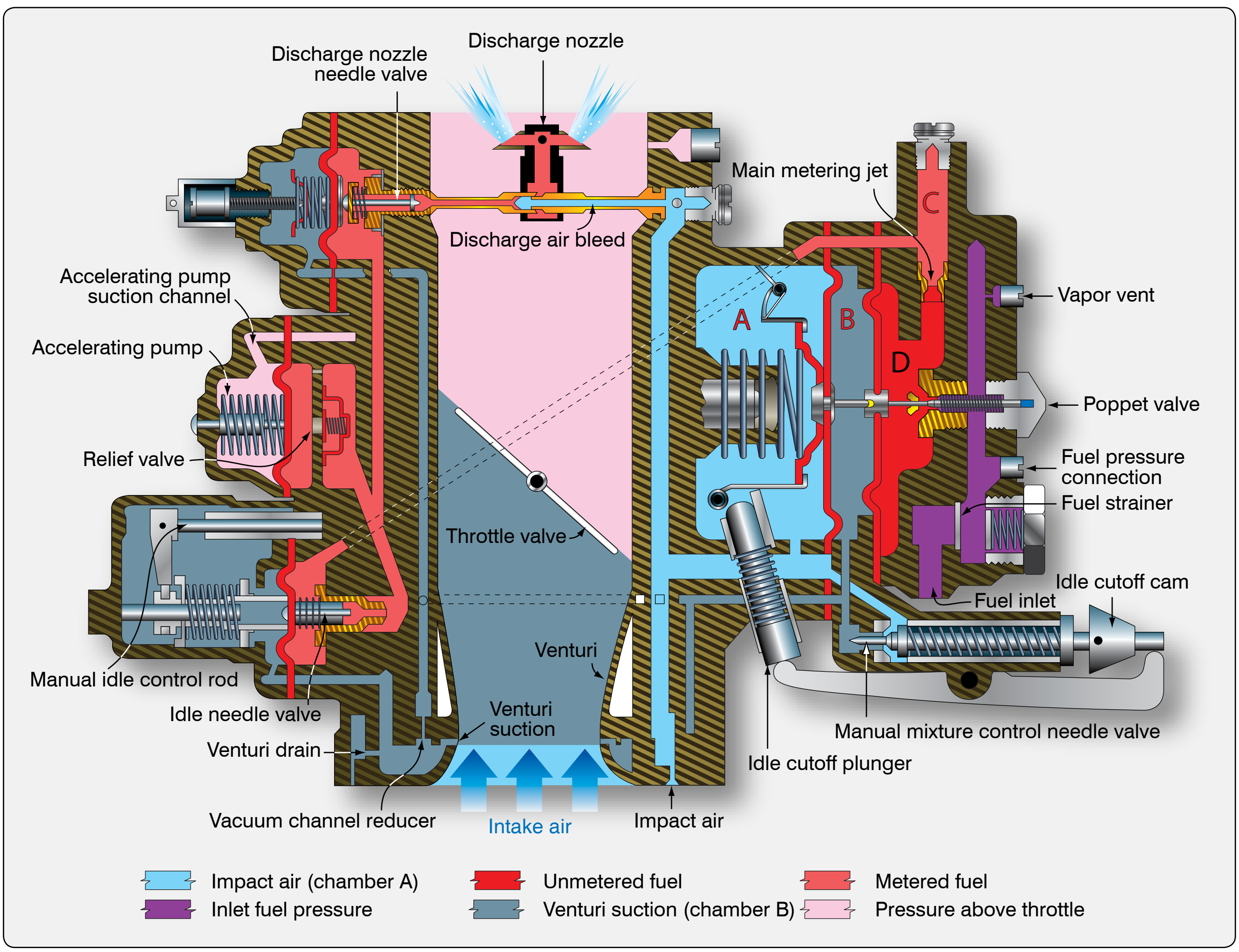


Figure 2-28. *Schematic of the PS series carburetor.*

flow of fuel injected into the main discharge jet. Here, it is mixed with air to accomplish distribution and atomization into the airstream entering the engine.

In the PS series carburetor, as in the pressure-injection carburetor, the regulator spring has a fixed tension, which tends to hold the poppet valve open during idling speeds or until the D chamber pressure equals approximately 4 psi. The discharge nozzle spring has a variable adjustment which, when tailored to maintain 4 psi, results in a balanced pressure condition of 4 psi in chamber C of the discharge nozzle assembly and 4 psi in chamber D. This produces a zero drop across the main jets at zero fuel flow.

At a given airflow, if the suction created by the venturi is equivalent to ¼ pound, the pressure decrease is transmitted to chamber B and to the vent side of the discharge nozzle. Since the area of the air diaphragm between chambers A and B is twice as great as that between chambers B and D, the ¼ pound decrease in pressure in chamber B moves the diaphragm assembly to the right to open the poppet valve. Meanwhile, the decreased pressure on the vent side of the discharge nozzle assembly causes a lowering of the total pressure from 4 pounds to 3¾ pounds. The greater pressure of the metered fuel (4¼ pounds) results in a differential across the metering head of ¼ pound (for the ¼ pound pressure differential created by the venturi).

The same ratio of pressure drop across the jet to venturi suction applies throughout the range. Any increase or decrease in fuel inlet pressure tends to upset the balance in the various chambers in the manner already described. When this occurs, the main fuel regulator diaphragm assembly repositions to restore the balance.

The mixture control, whether operated manually or automatically, compensates for enrichment at altitude by bleeding impact air pressure into chamber B, thereby increasing the pressure (decreasing the suction) in chamber B. Increasing the pressure in chamber B tends to move the diaphragm and poppet valve more toward the closed position, restricting fuel flow to correspond proportionately to the decrease in air density at altitude.

The idle valve and economizer jet can be combined in one assembly. The unit is controlled manually by the movement of the valve assembly. At low airflow positions, the tapered section of the valve becomes the predominant jet in the system, controlling the fuel flow for the idle range. As the valve moves to the cruise position, a straight section on the valve establishes a fixed orifice effect which controls the cruise mixture. When the valve is pulled full-open by the throttle valve, the jet is pulled completely out of the seat, and the seat side becomes the controlling jet. This jet is calibrated for takeoff power mixtures.

An airflow-controlled power enrichment valve can also be used with this carburetor. It consists of a spring-loaded, diaphragm-operated metering valve. Refer to *Figure 2-29* for a schematic view of an airflow power enrichment valve. One side of the diaphragm is exposed to unmetered fuel pressure and the other side to venturi suction plus spring tension. When the pressure differential across the diaphragm establishes a force strong enough to compress the spring, the valve opens and supplies an additional amount of fuel to the metered fuel circuit in addition to the fuel supplied by the main metering jet.

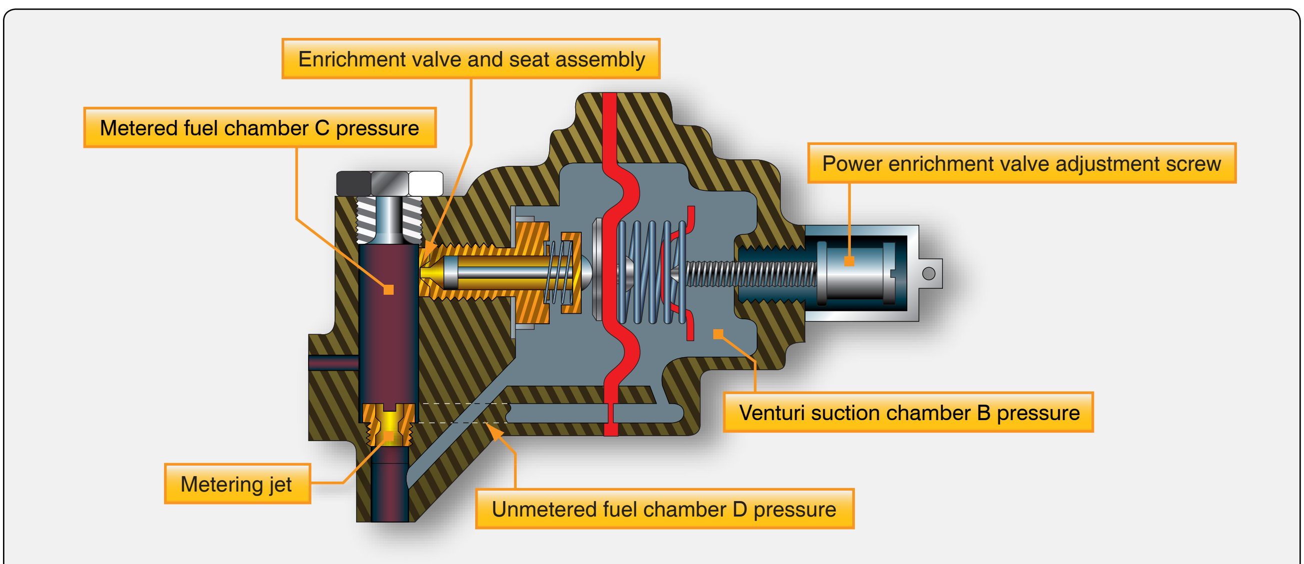


Figure 2-29. *Airflow power enrichment valve.*

Accelerating Pump

The accelerating pump of the Stromberg PS carburetor is a spring-loaded diaphragm assembly located in the metered fuel channel with the opposite side of the diaphragm vented to the engine side of the throttle valve. With this arrangement, opening the throttle results in a rapid decrease in suction. This decrease in suction permits the spring to extend and move the accelerating pump diaphragm. The diaphragm and spring action displace the fuel in the accelerating pump and force it out the discharge nozzle.

Vapor is eliminated from the top of the main fuel chamber D through a bleed hole, then through a vent line back to the main fuel tank in the aircraft.

Manual Mixture Control

A manual mixture control provides a means of correcting for enrichment at altitude. It consists of a needle valve and seat that form an adjustable bleed between chamber A and chamber B. The valve can be adjusted to bleed off the venturi suction to maintain the correct air-fuel ratio as the aircraft gains altitude.

When the mixture control lever is moved to the idle cutoff position, a cam on the linkage actuates a rocker arm which moves the idle cutoff plunger inward against the release lever in chamber A. The lever compresses the regulator diaphragm spring to relieve all tension on the diaphragm between chambers A and B. This permits fuel pressure plus poppet valve spring force to close the poppet valve, stopping the fuel flow. Placing the mixture control lever in idle cutoff also positions the mixture control needle valve off its seat and allows metering suction within the carburetor to bleed off.

Fuel-Injection Systems

The fuel-injection system has many advantages over a conventional carburetor system. There is less danger of induction system icing, since the drop in temperature due to fuel vaporization takes place in or near the cylinder. Acceleration is also improved because of the positive action of the injection system. In addition, fuel injection improves fuel distribution. This reduces the overheating of individual cylinders often caused by variation in mixture due to uneven distribution. The fuel-injection system also gives better fuel economy than a system in which the mixture to most cylinders must be richer than necessary so that the cylinder with the leanest mixture operates properly.

Fuel-injection systems vary in their details of construction, arrangement, and operation. The Bendix and Continental fuel-injection systems are discussed in this section. They are described to provide an understanding of the operating principles involved. For the specific details of any one system, consult the manufacturer's instructions for the equipment involved.

Bendix/Precision Fuel-Injection System

The Bendix inline stem-type regulator injection system (RSA) series consists of an injector, flow divider, and fuel discharge nozzle. It is a continuous-flow system which measures engine air consumption and uses airflow forces to control fuel flow to the engine. The fuel distribution system to the individual cylinders is obtained by the use of a fuel flow divider and air bleed nozzles.

Fuel Injector

The fuel injector assembly consists of:

1. An airflow section,
2. A regulator section, and
3. A fuel metering section. Some fuel injectors are equipped with an automatic mixture control unit.

Airflow Section

The airflow consumption of the engine is measured by sensing impact pressure and venturi throat pressure in the throttle body. These pressures are vented to the two sides of an air diaphragm. A cutaway view of the airflow measuring section is shown in *Figure 2-30*. Movement of the throttle valve causes a change in engine air consumption. This results in a change in the air velocity in the venturi. When airflow through the engine increases, the pressure on the left of the diaphragm is lowered due to the drop in pressure at the venturi throat. *[Figure 2-31]* As a result, the diaphragm moves to the left, opening the ball valve. Contributing to this force is the impact pressure that is picked up by the impact tubes. *[Figure 2-32]* This pressure differential is referred to as the "air metering force." This force is accomplished by channeling the impact and venturi suction pressures to opposite sides of a diaphragm. The difference between these

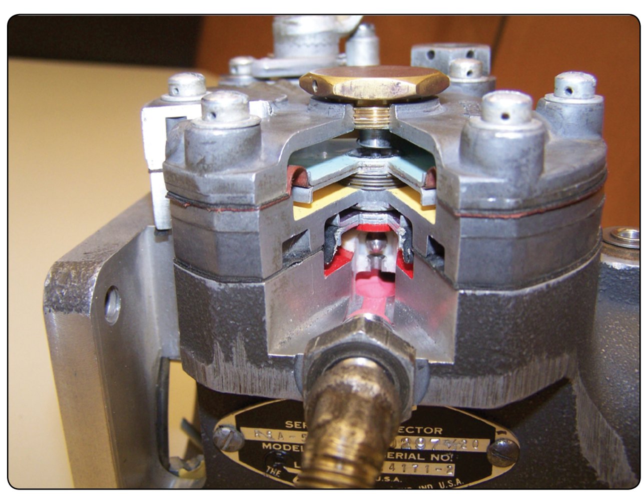


Figure 2-30. *Cutaway view of airflow measuring section.*

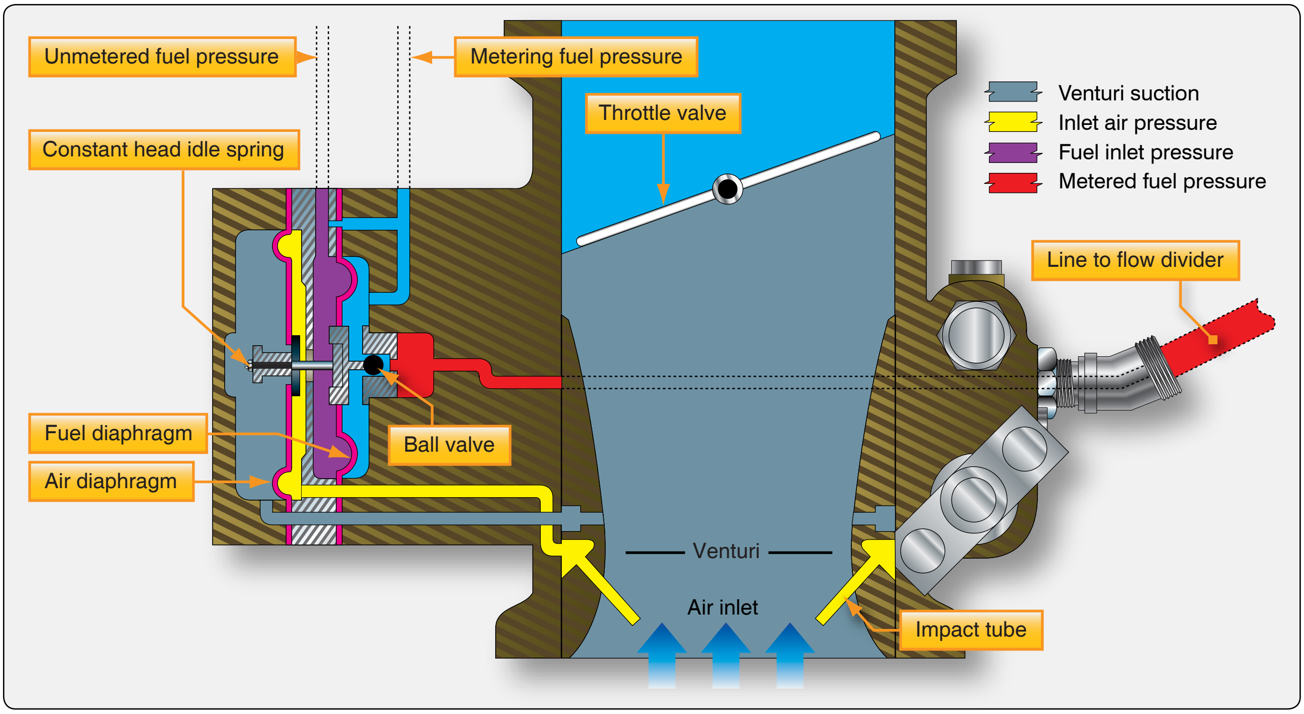


Figure 2-31. *Airflow section of a fuel injector.*

two pressures becomes a usable force that is equal to the area of the diaphragm times the pressure difference.

Regulator Section

The regulator section consists of a fuel diaphragm that opposes the air metering force. Fuel inlet pressure is applied to one side of the fuel diaphragm and metered fuel pressure is applied to the other side. The differential pressure across the fuel diaphragm is called the fuel metering force. The fuel pressure shown on the ball side of the fuel diaphragm is the pressure after the fuel has passed through the fuel strainer and the manual mixture control rotary plate and is referred to as metered fuel pressure. Fuel inlet pressure is applied to the opposite side of the fuel diaphragm. The ball valve attached to the fuel diaphragm controls the orifice opening and fuel flow through the forces placed on it. *[Figure 2-33]*

The distance the ball valve opens is determined by the difference between the pressures acting on the diaphragms. This difference in pressure is proportional to the airflow through the injector. Thus, the volume of airflow determines the rate of fuel flow.

Under low power settings, the difference in pressure created by the venturi is insufficient to accomplish consistent regulation of the fuel. A constant-head idle spring is

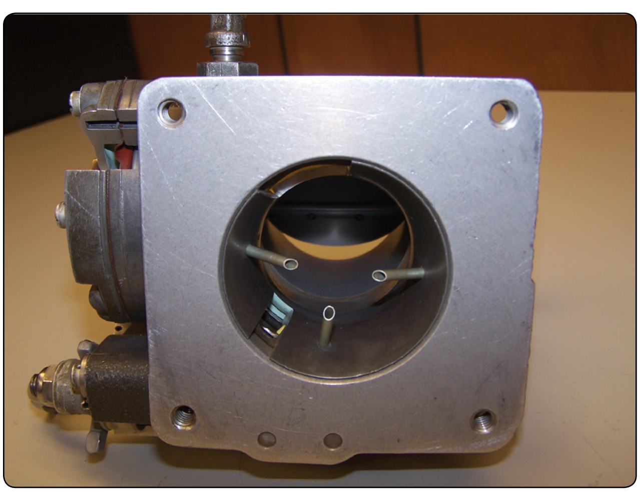


Figure 2-32. *Impact tubes for inlet air pressure.*

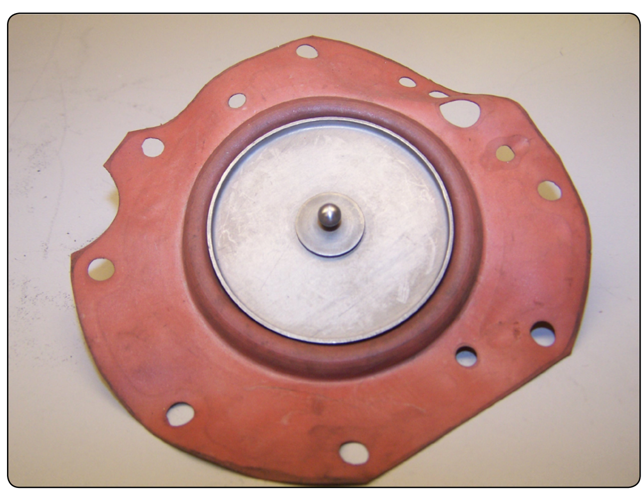


Figure 2-33. *Fuel diaphragm with ball valve attached.*

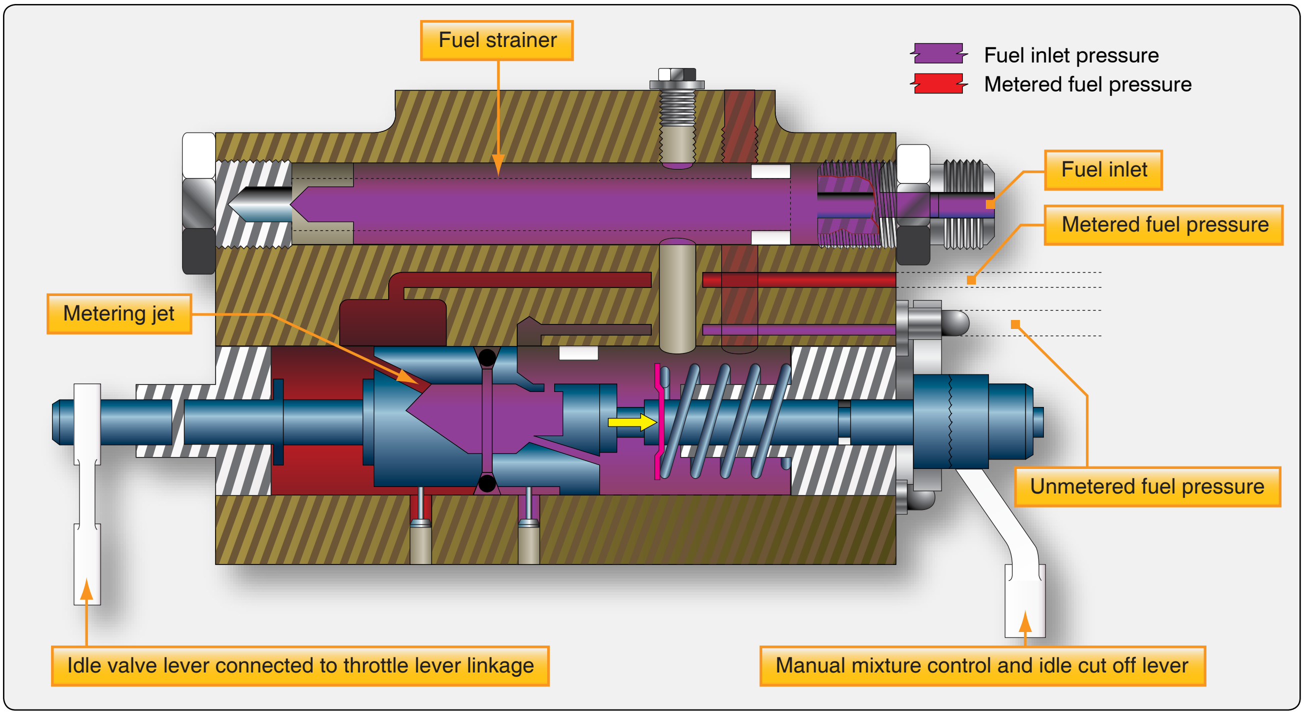


Figure 2-34. *Fuel metering section of the injector.*

incorporated to provide a constant fuel differential pressure. This allows an adequate final flow in the idle range.

Fuel Metering Section

The fuel metering section is attached to the air metering section and contains an inlet fuel strainer, a manual mixture control valve, an idle valve, and the main metering jet. *[Figure 2-34]* The idle valve is connected to the throttle valve by means of an external adjustable link. In some injector models, a power enrichment jet is also located in this section. The purpose of the fuel metering section is to meter and control the fuel flow to the flow divider. *[Figure 2-35]* The manual mixture control valve produces full rich condition when the lever is against the rich stop, and a progressively leaner mixture as the lever is moved toward idle cutoff. Both idle speed and idle mixture may be adjusted externally to meet individual engine requirements.

Flow Divider

The metered fuel is delivered from the fuel control unit to a pressurized flow divider. This unit keeps metered fuel under pressure, divides fuel to the various cylinders at all engine speeds, and shuts off the individual nozzle lines when the control is placed in idle cutoff.

Referring to the diagram in *Figure 2-36*, metered fuel pressure enters the flow divider through a channel that permits fuel to pass through the inside diameter of the flow divider needle. At idle speed, the fuel pressure from the regulator must build up to overcome the spring force applied to the diaphragm and valve assembly. This moves the valve upward until fuel can pass out through the annulus of the valve to the fuel nozzle. *[Figure 2-37]* Since the regulator meters and delivers a fixed amount of fuel to the flow divider, the valve opens only as far as necessary to pass this amount to the nozzles. At idle, the opening required is very small; the fuel for the individual cylinders is divided at idle by the flow divider.

As fuel flow through the regulator is increased above idle requirements, fuel pressure builds up in the nozzle lines. This pressure fully opens the flow divider valve, and fuel distribution to the engine becomes a function of the discharge nozzles.

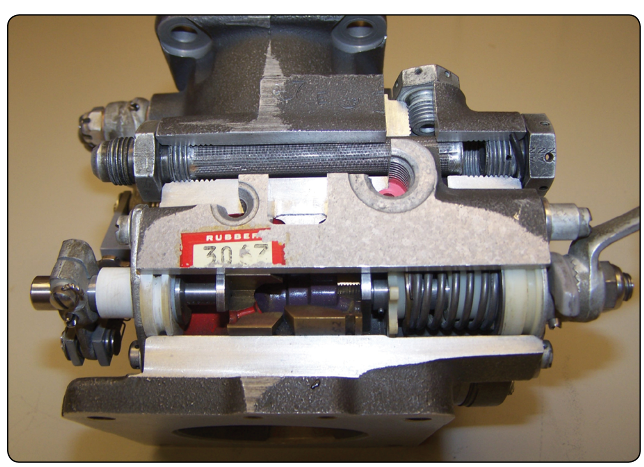


Figure 2-35. *Fuel inlet and metering.*

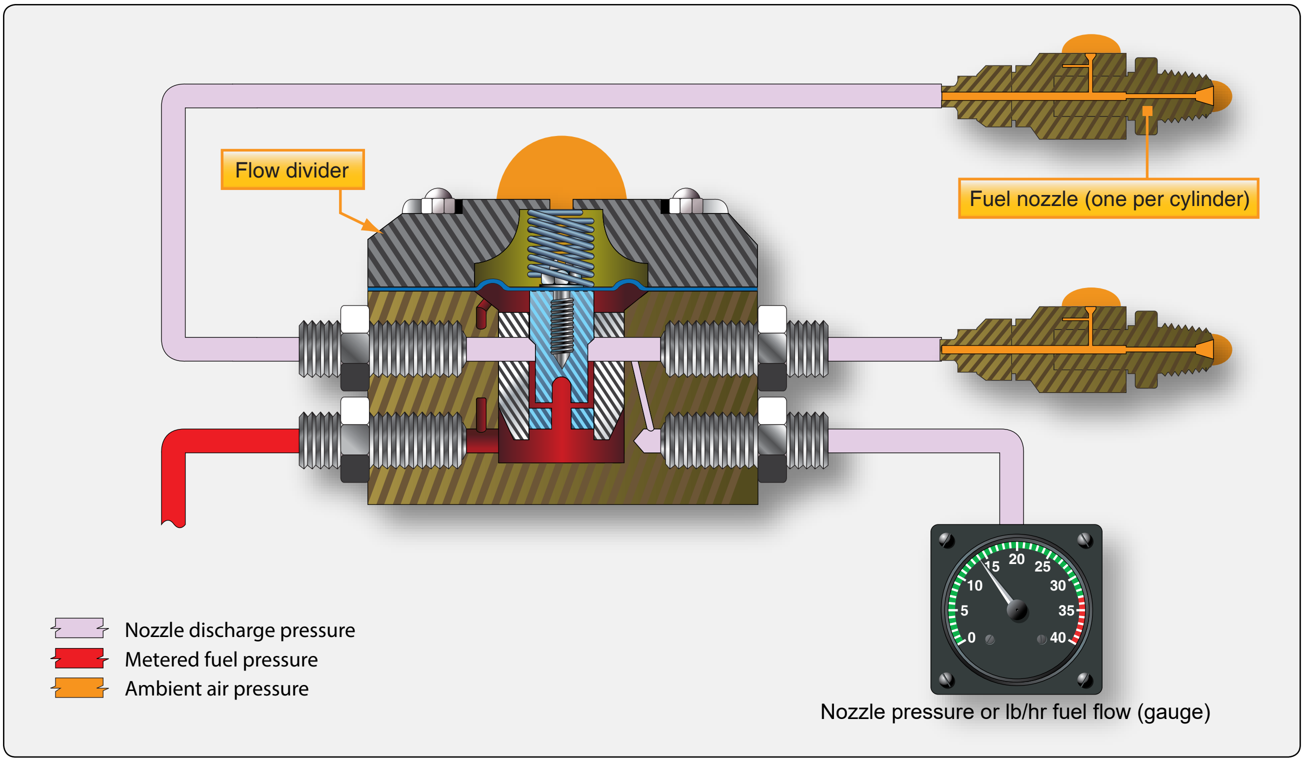


Figure 2-36. *Flow divider.*

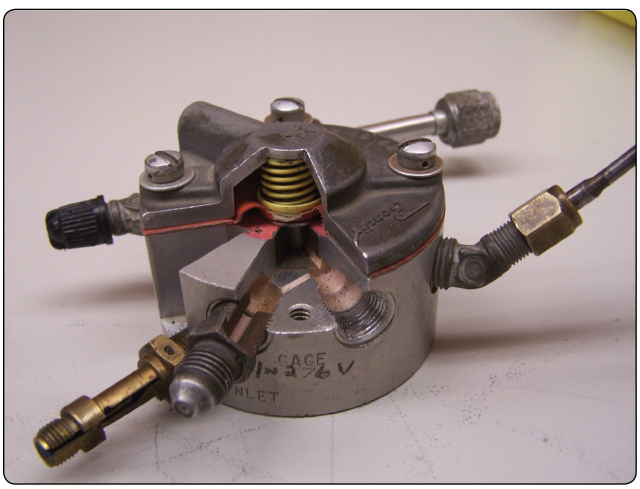


Figure 2-37. *Flow divider cutaway.*

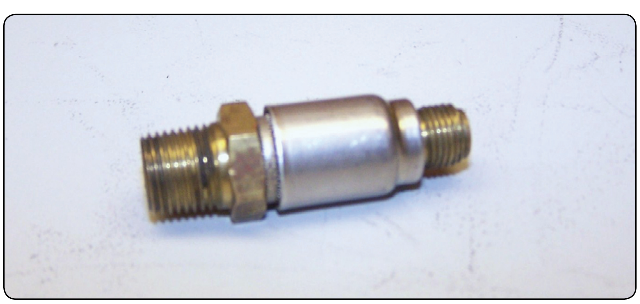


Figure 2-38. *Fuel nozzle assembly.*

A fuel pressure gauge, calibrated in pounds per hour fuel flow, can be used as a fuel flow meter with the Bendix RSA injection system. This gauge is connected to the flow divider and senses the pressure being applied to the discharge nozzle. This pressure is in direct proportion to the fuel flow and indicates the engine power output and fuel consumption.

Fuel Discharge Nozzles

The fuel discharge nozzles are of the air bleed configuration. There is one nozzle for each cylinder located in the cylinder head. *[Figure 2-38]* The nozzle outlet is directed into the intake port. Each nozzle incorporates a calibrated jet. The jet size is determined by the available fuel inlet pressure and the maximum fuel flow required by the engine. The fuel is discharged through this jet into an ambient air pressure chamber within the nozzle assembly. Before entering the individual intake valve chambers, the fuel is mixed with air to aid in atomizing the fuel. Fuel pressure, before the individual nozzles, is in direct proportion to fuel flow; therefore, a simple pressure gauge can be calibrated in fuel flow in gallons per hour and be employed as a flow meter. Engines modified with turbosuperchargers must use shrouded nozzles. By the use of an air manifold, these nozzles are vented to the injector air inlet pressure.

Continental/TCM Fuel-Injection System

The Continental fuel-injection system injects fuel into the intake valve port in each cylinder head. *[Figure 2-39]* The system consists of a fuel injector pump, a control unit, a fuel manifold, and a fuel discharge nozzle. It is a continuous-flow type, which controls fuel flow to match engine airflow. The continuous-flow system permits the use of a rotary vane pump which does not require timing to the engine.

Fuel-Injection Pump

The fuel pump is a positive-displacement, rotary-vane type with a splined shaft for connection to the accessory drive system of the engine. *[Figure 2-40]* A spring-loaded, diaphragm-type relief valve is provided. The relief valve diaphragm chamber is vented to atmospheric pressure. A sectional view of a fuel-injection pump is shown in *Figure 2-41*.

Fuel enters at the swirl well of the vapor separator. Here, vapor is separated by a swirling motion so that only liquid fuel is delivered to the pump. The vapor is drawn from the top center of the swirl well by a small pressure jet of fuel and is directed into the vapor return line. This line carries the vapor back to the fuel tank.

Ignoring the effect of altitude or ambient air conditions, the use of a positive-displacement, engine-driven pump means that changes in engine speed affect total pump flow proportionally. Since the pump provides greater capacity than is required by the engine, a recirculation path is required. By arranging a calibrated orifice and relief valve in this path, the pump delivery pressure is also maintained in proportion to engine speed. These provisions assure proper pump pressure and fuel delivery for all engine operating speeds.

A check valve is provided so that boost pump pressure to the system can bypass the engine-driven pump for starting. This feature also suppresses vapor formation under high ambient temperatures of the fuel and permits use of the auxiliary pump as a source of fuel pressure in the event of engine-driven pump failure.

Air-Fuel Control Unit

The function of the air-fuel control assembly is to control engine air intake and to set the metered fuel pressure for proper air-fuel ratio. The air throttle is mounted at the manifold inlet and its butterfly valve, positioned by the throttle control in the aircraft, controls the flow of air to the engine. *[Figure 2-42]*

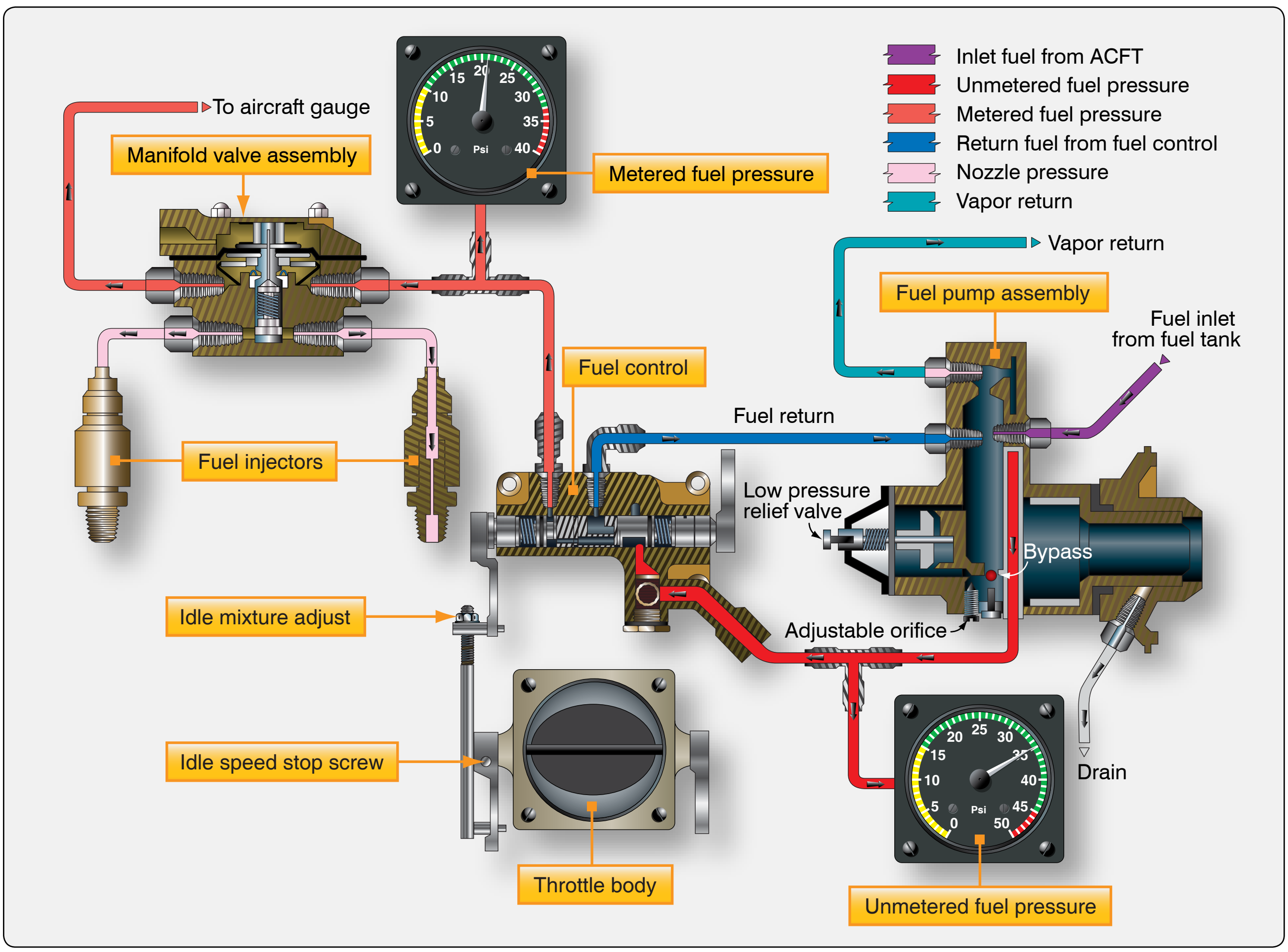


Figure 2-39. *Continental/TCM Fuel-Injection System.*

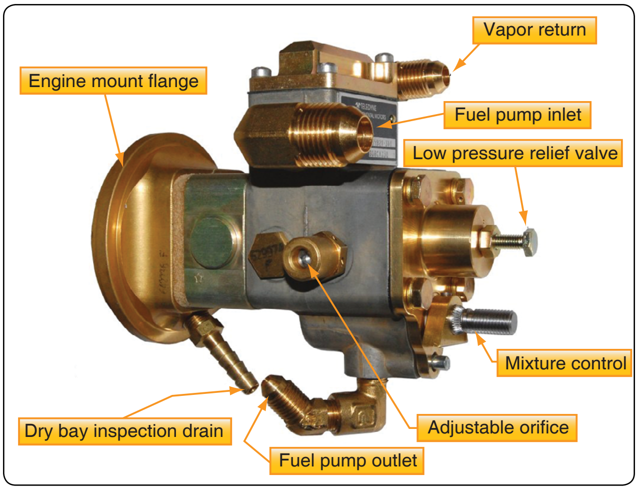


Figure 2-40. *Fuel pump.*

The air throttle assembly is an aluminum casting which contains the shaft and butterfly-valve assembly. The casting bore size is tailored to the engine size, and no venturi or other restriction is used.

Fuel Control Assembly

The fuel control body is made of bronze for best bearing action with the stainless steel valves. Its central bore contains a metering valve at one end and a mixture control valve at the other end. Each stainless steel rotary valve includes a groove which forms a fuel chamber.

Fuel enters the control unit through a strainer and passes to the metering valve. *[Figure 2-43]* This rotary valve has a cam-shaped edge on the outer part of the end face. The position of the cam at the fuel delivery port controls the fuel passed to the manifold valve and the nozzles. The fuel return port connects to the return passage of the center metering plug. The alignment of the mixture control valve with this passage determines the amount of fuel returned to the fuel pump.

By connecting the metering valve to the air throttle, the fuel flow is properly proportioned to airflow for the correct air-fuel ratio. A control level is mounted on the mixture control valve shaft and connected to the flight deck mixture control.

Fuel Manifold Valve

The fuel manifold valve contains a fuel inlet, a diaphragm chamber, and outlet ports for the lines to the individual nozzles. *[Figure 2-44]* The spring-loaded diaphragm operates a valve in the central bore of the body. Fuel pressure provides the force for moving the diaphragm. The diaphragm is enclosed by a cover that retains the diaphragm loading spring. When the valve is down against the lapped seat in the body, the fuel lines to the cylinders are closed off. The valve is drilled for passage of fuel from the diaphragm chamber to its base, and a ball valve is installed within the valve. All incoming fuel must pass through a fine screen installed in the diaphragm chamber.

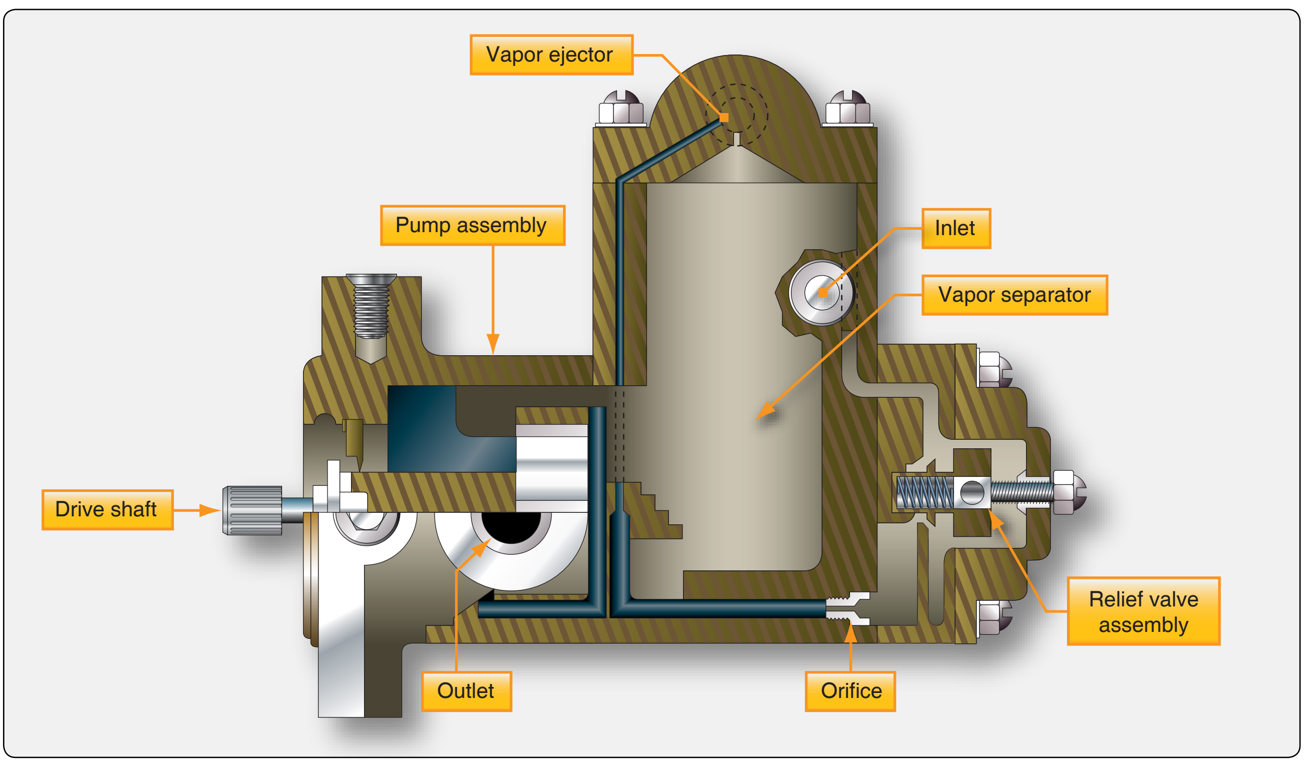


Figure 2-41. *Fuel injection pump.*

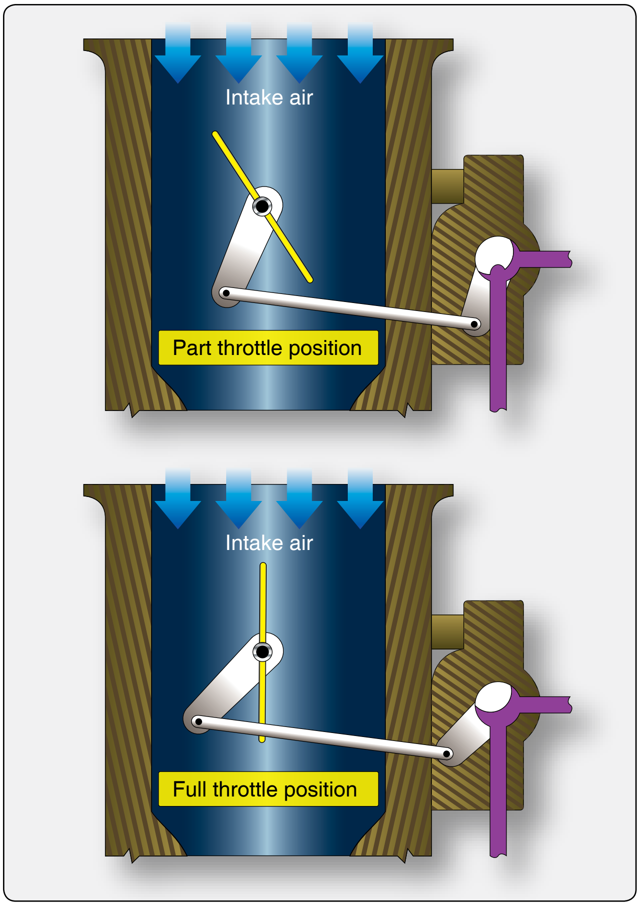


Figure 2-42. *Fuel air control unit.*

From the fuel-injection control valve, fuel is delivered to the fuel manifold valve, which provides a central point for dividing fuel flow to the individual cylinders. In the fuel manifold valve, a diaphragm raises or lowers a plunger valve to open or close the individual cylinder fuel supply ports simultaneously.

Fuel Discharge Nozzle

The fuel discharge nozzle is located in the cylinder head with its outlet directed into the intake port. The nozzle body contains a drilled central passage with a counterbore at each end. *[Figure 2-45]* The lower end is used as a chamber for air-fuel mixing before the spray leaves the nozzle. The upper bore contains a removable orifice for calibrating the nozzles. Nozzles are calibrated in several ranges, and all nozzles furnished for one engine are of the same range and are identified by a letter stamped on the hex of the nozzle body.

Drilled radial holes connect the upper counterbore with the outside of the nozzle body. These holes enter the counterbore above the orifice and draw air through a cylindrical screen fitted over the nozzle body. A shield is press-fitted on the nozzle body and extends over the greater part of the filter screen, leaving an opening near the bottom. This provides both mechanical protection and an abrupt change in the direction of airflow which keeps dirt and foreign material out of the nozzle interior.

Carburetor Maintenance

Carburetor Removal

The removal procedures vary with both the type of carburetor concerned and the type of engine on which it is used. Always refer to the applicable manufacturer's technical instructions for a particular installation. Generally, the procedures are much the same, regardless of the type of carburetor concerned.

Before removing a carburetor, make sure the fuel shutoff (or selector) valve is closed. Disconnect the throttle and mixture control linkages, and lockwire the throttle valve in the closed position. Disconnect the fuel inlet line and all vapor return, gauge, and primer lines. If the same carburetor is to be re-installed, do not alter the rigging of the throttle and mixture controls. Remove the airscoop or airscoop adapter. Remove

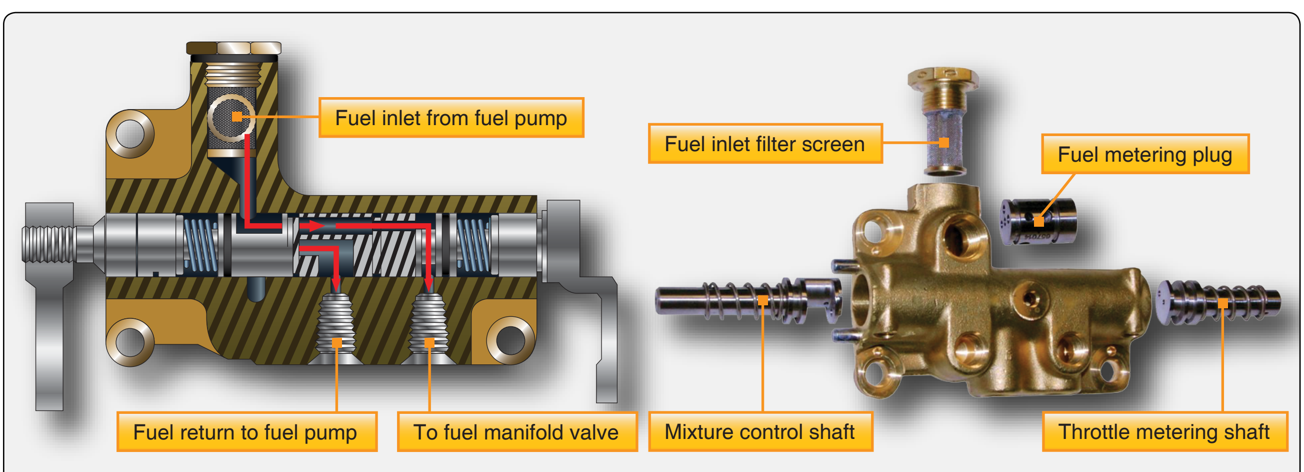


Figure 2-43. *Dual fuel control assembly.*

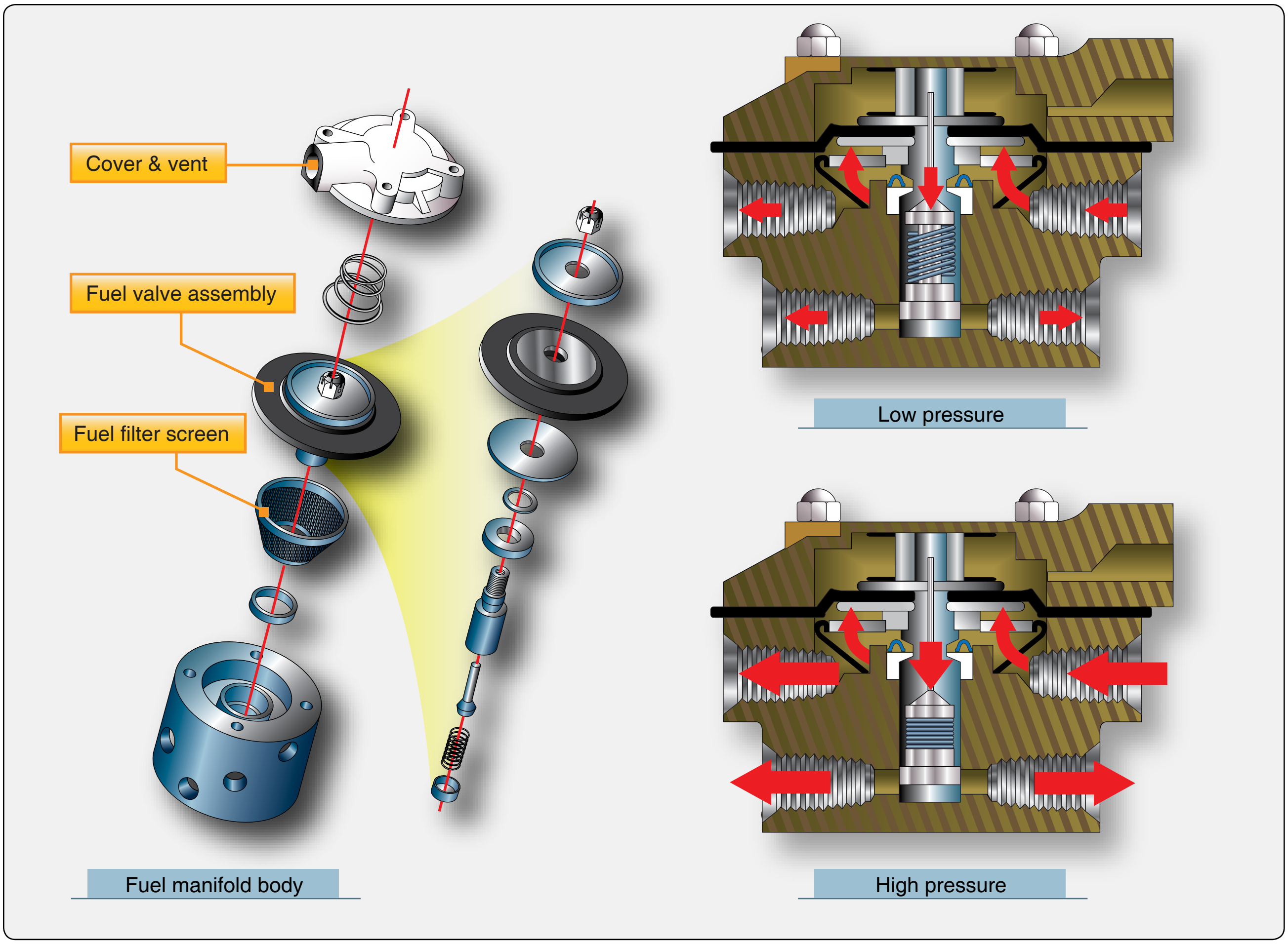


Figure 2-44. *Fuel manifold valve assembly.*

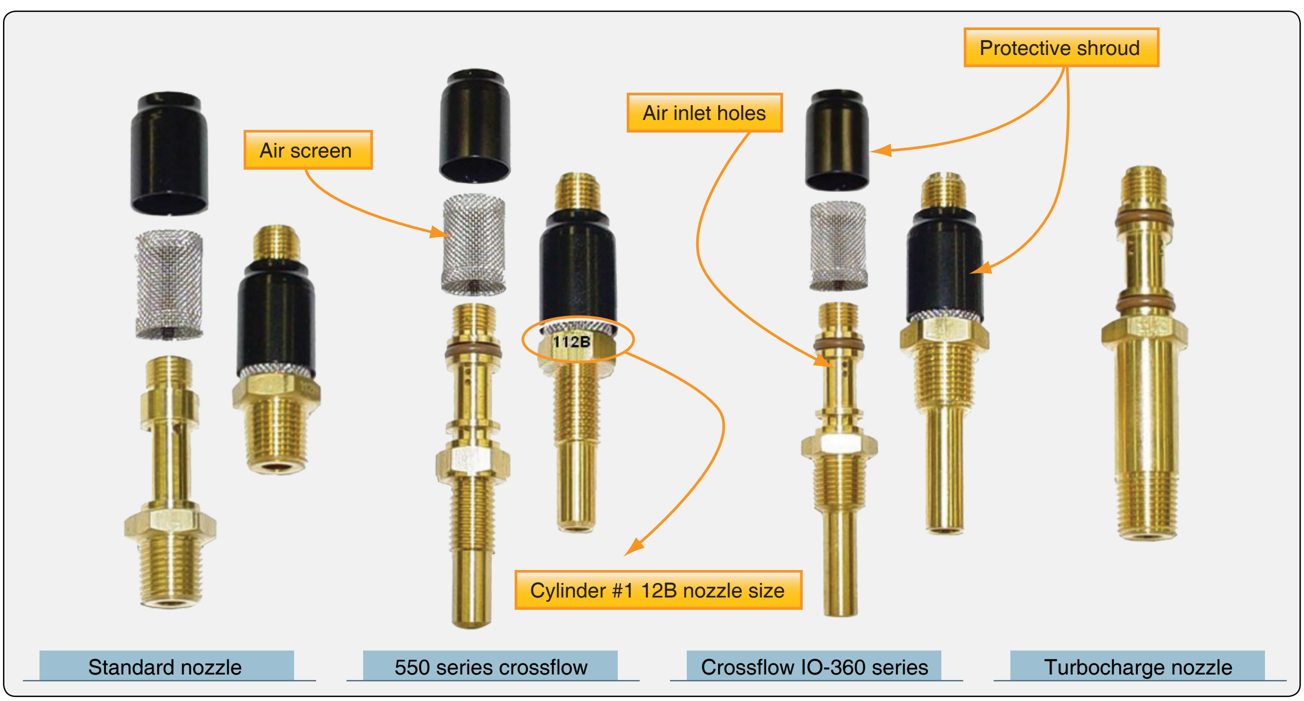


Figure 2-45. *Fuel discharge nozzles.*

the air screens and gaskets from the carburetor. Remove the nuts and washers securing the carburetor to the engine. When removing a downdraft carburetor, use extreme care to ensure that nothing is dropped into the engine. Remove the carburetor. Immediately install a protective cover on the carburetor mounting flange of the engine to prevent small parts or foreign material from falling into the engine. When there is danger of foreign material entering open fuel lines during removal or installation of the carburetor, plug them using the proper cover fittings.

Installation of Carburetor

Check the carburetor for proper lockwiring before installation on an engine. Be sure that all shipping plugs have been removed from the carburetor openings.

Remove the protective cover from the carburetor mounting flange on the engine. Place the carburetor mounting flange gasket in position. On some engines, bleed passages are incorporated in the mounting pad. The gasket must be installed so that the bleed hole in the gasket is aligned with the passage in the mounting flange.

Inspect the induction passages for the presence of any foreign material before installing the carburetor. As soon as the carburetor is placed in position on the engine, close and lockwire the throttle valves in the closed position until the remainder of the installation is completed. Place the carburetor deck screen, when feasible, in position to further eliminate the possibility of foreign objects entering the induction system.

When installing a carburetor that uses diaphragms for controlling fuel flow, connect the fuel lines and fill the carburetor with fuel. To do this, turn on the fuel boost pump and move the mixture control from the idle cutoff position to rich position. Continue the flow until oil-free fuel flows from the drain valve. This indicates that the preservative oil has been flushed from the carburetor. Turn off the fuel flow, plug the fuel inlet and vapor vent outlet, and then allow the carburetor, filled with fuel, to stand for a minimum of 8 hours. This is necessary in order to soak the diaphragms and render them pliable to the same degree as when the unit was originally calibrated. Tighten the carburetor mounting bolts to the value specified in the table of torque limits in the applicable maintenance manual. Tighten and safety any other nuts and bolts incidental to the installation of the carburetor before connecting the throttle and mixture-control levers. After the carburetor has been bolted to the engine, check the throttle and mixture-control lever on the unit for freedom of movement before connecting the control cables or linkage. Check the vapor vent lines or return lines from the carburetor to the aircraft fuel tank for restriction.

Rigging Carburetor Controls

Connect and adjust carburetor or fuel metering equipment throttle controls so that full movement of the throttle is obtained from corresponding full movement of the control in the flight deck. In addition, check and adjust the throttle control linkages so that springback on the throttle quadrant in the aircraft is equal in both the full-open and full-closed positions. Correct any excess play or looseness of control linkage or cables. Controls should be checked so that they go stop-to-stop on the carburetor. Check for complete and full travel of each control.

When installing carburetors or fuel metering equipment incorporating manual-type mixture controls that do not have marked positions, adjust the mixture control mechanism to provide an equal amount of springback at both the rich and lean ends of the control quadrant in the flight deck when the mixture control on the carburetor or fuel metering equipment is moved through the full range. Where mixture controls with detents are used, rig the control mechanism so that the designated positions on the control quadrant in the aircraft agree with the corresponding positions on the carburetor or fuel metering equipment. Controls should move freely and smoothly without binding throughout their total travel. In all cases, check the controls for proper positioning in both the advance and retard positions. Correct excess play or looseness of control linkage or cables. Safety all controls properly to eliminate the possibility of loosening from vibration during operation.

Adjusting Idle Mixtures

Excessively rich or lean idle mixtures result in incomplete combustion within the engine cylinder, with resultant formation of carbon deposits on the spark plugs and subsequent spark plug fouling. In addition, excessively rich or lean idle mixtures make it necessary to taxi at high idle speeds with resultant fast taxi speeds and excessive brake wear. Each engine must have the carburetor idle mixture tailored for the particular engine and installation if best operation is to be obtained.

Engines that are properly adjusted, insofar as valve operation, cylinder compression, ignition, and carburetor idle mixture are concerned, idle at the prescribed rpm for indefinite periods without loading up, overheating, or spark plug fouling. If an engine does not respond to idle mixture adjustment with the resultant stable idling characteristics previously outlined, some other phase of engine operation is not correct. In such cases, determine and correct the cause of the difficulty. A general guide to check and adjust the idle mixture and speed on many types of reciprocating engine is discussed in the following paragraphs. Always refer to the appropriate manual for specific information.

Before checking the idle mixture on any engine, warm up the engine until oil and cylinder head temperatures are normal. Keep the propeller control in the increase rpm setting throughout the entire process of warming up the engine. Always make idle mixture adjustments with cylinder head temperatures at normal values. The idle mixture adjustment is made on the idle mixture fuel control valve. *[Figure 2-46]* It should not be confused with the adjustment of the idle speed stop. The importance of idle mixture adjustment cannot be overstressed. Optimum engine operation at low speeds can be obtained only when proper air-fuel mixtures are delivered to every cylinder of the engine. Excessively rich idle mixtures and the resultant incomplete combustion are responsible for more spark plug fouling than any other single cause. Excessively lean idle mixtures result in faulty acceleration. Furthermore, the idle mixture adjustment affects the air-fuel mixture and engine operation well up into the cruise range.

On an engine with a conventional carburetor, the idle mixture is checked by manually leaning the mixture with the flight deck mixture control. Move the carburetor mixture control slowly and smoothly toward the idle cutoff position. On installations that do not use a manifold pressure gauge, it is necessary to observe the tachometer for an indication of a rpm change. With most installations, the idle mixture should be adjusted to provide an rpm rise prior to decreasing as the engine ceases to fire. This rpm increase varies from 10 to 50 rpm, depending on the installation. Following the momentary increase in rpm, the engine speed starts to drop. Immediately move the mixture control back to rich to prevent the engine from stopping completely.

On RSA fuel-injection engines, the optimum idle setting is one that is rich enough to provide a satisfactory acceleration under all conditions and lean enough to prevent spark plug fouling or rough operation. A rise of 25–50 rpm as the mixture control is moved to the idle cutoff position usually satisfies both of these conditions. The actual idle mixture adjustment is made by the lengthening or shortening of the linkage between the throttle lever and the idle lever. *[Figure 2-47]*

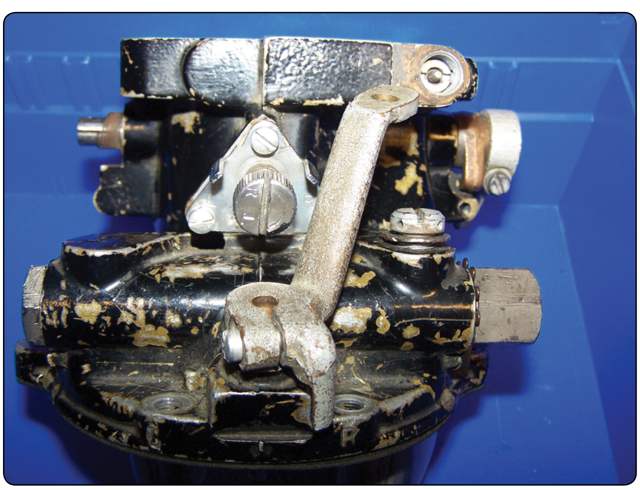


Figure 2-46. *Idle mixture adjustment for carburetor.*

If the check of the idle mixture reveals it to be too lean or too rich, increase or decrease the idle fuel flow as required. Then, repeat the check. Continue checking and adjusting the idle mixture until it checks out properly. During this process, it may be desirable to move the idle speed stop completely out of the way and to hold the engine speed at the desired rpm by means of the throttle. This eliminates the need for frequent readjustments of the idle stop as the idle mixture is improved and the idle speed picks up. After each adjustment, clear the engine by briefly running it at higher rpm. This prevents fouling of the plugs which might otherwise be caused by incorrect idle mixture. After adjusting the idle mixture, recheck it several times to determine definitively that the mixture is correct and remains constant on repeated changes from high power back to idle. Correct any inconsistency in engine idling before releasing the aircraft for service.

Setting the idle mixture on the continental TCM fuel injection system consists of a conventional spring loaded screw located in the air throttle lever. *[Figure 2-48]* The fuel pump pressure is part of the basic calibration and requires servicing to make sure the pump pressure are set correctly before making idle adjustments. The idle mixture adjustment is the locknut at the metering valve end of the linkage between the metering valve and the air throttle levers. Tightening the nut to shorten the linkage provides a richer mixture. A leaner mixture is obtained by backing off the nut to lengthen the linkage. Adjust to obtain a slight and momentary gain in idle speed as the mixture control is slowly moved toward idle cut off. If the idle mixture is set too lean, the idle speed drops with no gain in speed.

Idle Speed Adjustment

After adjusting the idle mixture, reset the idle stop to the idle rpm specified in the aircraft maintenance manual. The engine must be warmed up thoroughly and checked for ignition system malfunctioning. Throughout any carburetor adjustment procedure, periodically run the engine up to approximately half of normal rated speed to clear the engine.

Some carburetors are equipped with an eccentric screw to adjust idle rpm. Others use a spring-loaded screw to limit the throttle valve closing. In either case, adjust the screw as required to increase or decrease rpm with the throttle retarded against the stop. Open the throttle to clear the engine; close the throttle and allow the rpm to stabilize. Repeat this operation until the desired idling speed is obtained.

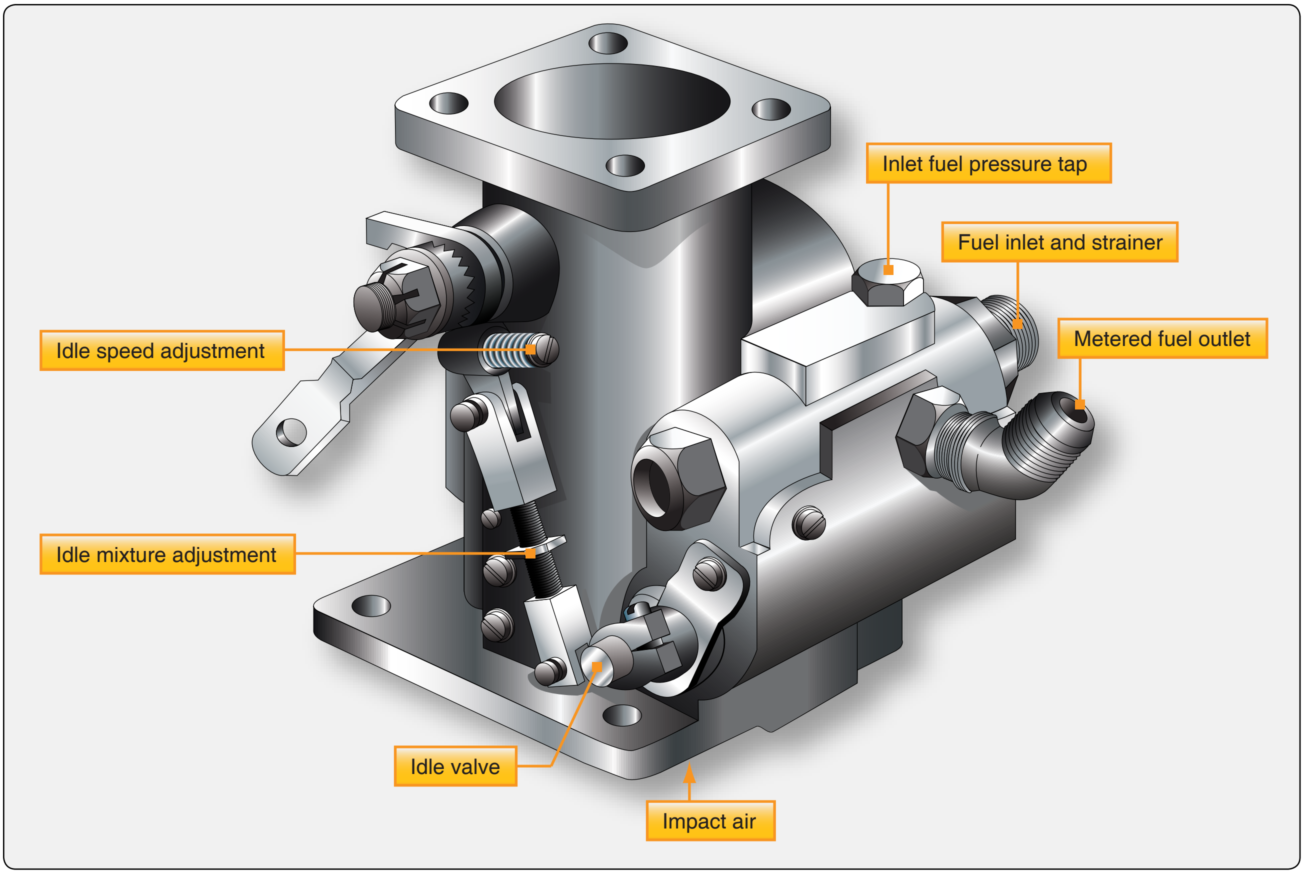


Figure 2-47. *Bendix adjustment of idle mixture linkage.*

Fuel System Inspection & Maintenance

The inspection of a fuel system installation consists basically of an examination of the system for conformity to design requirements together with functional tests to prove correct operation. Since there are considerable variations in the fuel systems used on different aircraft, no attempt has been made to describe any particular system in detail. It is important that the manufacturer's instructions for the aircraft concerned be followed when performing inspection or maintenance functions.

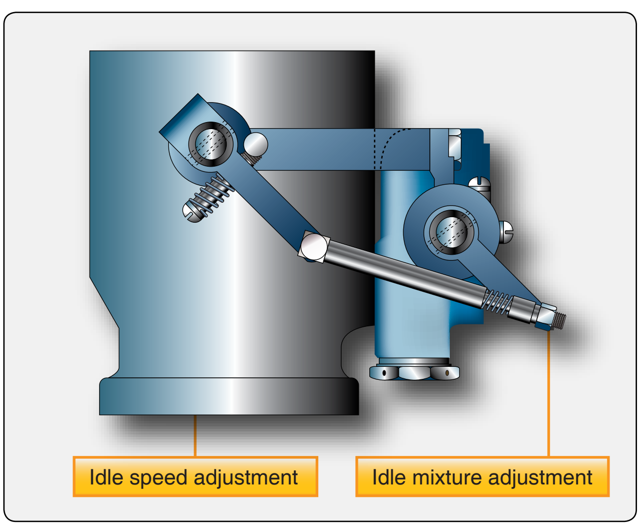


Figure 2-48. *TCM adjustment points.*

Complete System

Inspect the entire system for wear, damage, or leaks. Make sure that all units are securely attached and properly safetied. The drain plugs or valves in the fuel system should be opened to check for the presence of sediment or water. The filter and sump should also be checked for sediment, water, or slime. The filters or screens, including those provided for flow meters and auxiliary pumps, must be clean and free from corrosion. The controls should be checked for freedom of movement, security of locking, and freedom from damage due to chafing. The fuel vents should be checked for correct positioning and freedom from obstruction; otherwise, fuel flow or pressure fueling may be affected. Filler neck drains should be checked for freedom from obstruction.

If booster pumps are installed, the system should be checked for leaks by operating the pumps. During this check, the ammeter or load meter should be read and the readings of all the pumps, where applicable, should be approximately the same.

Fuel Tanks

All applicable panels in the aircraft skin or structure should be removed and the tanks inspected for corrosion on the external surfaces, for security of attachment, and for correct adjustment of straps and slings. Check the fittings and connections for leaks or failures.

Some fuel tanks manufactured of light alloy materials are provided with inhibitor cartridges to reduce the corrosive effects of combined leaded fuel and water. Where applicable, the cartridge should be inspected and renewed at the specified periods.

Lines & Fittings

Be sure that the lines are properly supported and that the nuts and clamps are securely tightened. To tighten hose clamps to the proper torque, use a hose-clamp torque wrench. If this wrench is not available, tighten the clamp finger-tight plus the number of turns specified for the hose and clamp. If the clamps do not seal at the specified torque, replace the clamps, the hose, or both. After installing a new hose, check the clamps daily and tighten if necessary. When this daily check indicates that cold flow has ceased, inspect the clamps at less frequent intervals.

Replace the hose if the plys have separated, if there is excessive cold flow, or if the hose is hard and inflexible. Permanent impressions from the clamp and cracks in the tube or cover stock indicate excessive cold flow. Replace any hose that has collapsed at the bends or as a result of misaligned fittings or lines. Some hoses tend to flare at the ends beyond the clamps. This is not an unsatisfactory condition unless leakage is present.

Blisters may form on the outer synthetic rubber cover of the hose. These blisters do not necessarily affect the serviceability of the hose. When a blister is discovered on a hose, remove the hose from the aircraft and puncture the blister with a pin. The blister should then collapse. If fluid (oil, fuel, or hydraulic) emerges from the pinhole in the blister, reject the hose. If only air emerges, then test the hose pressure at 1½ times the working pressure. If no fluid leakage occurs, the hose can be regarded as serviceable.

Puncturing the outer cover of the hose may permit the entry of corrosive elements, such as water, which could attack the wire braiding and ultimately result in failure. For this reason, puncturing the outer covering of hoses exposed to the elements should be avoided.

The external surface of hose may develop fine cracks, usually short in length, which are caused by surface aging. The hose assembly may be regarded as serviceable, provided these cracks do not penetrate to the first braid.

Selector Valves

Rotate selector valves and check for free operation, excessive backlash, and accurate pointer indication. If the backlash is excessive, check the entire operating mechanism for worn joints, loose pins, and broken drive lugs. Replace any defective parts. Inspect cable control systems for worn or frayed cables, damaged pulleys, or worn pulley bearings.

Pumps

During an inspection of booster pumps, check for the following conditions:

1. Proper operation;
2. Leaks and condition of fuel and electrical connections; and
3. Wear of motor brushes.

Be sure the drain lines are free of traps, bends, or restrictions. Check the engine-driven pump for leaks and security of mounting. Check the vent and drain lines for obstructions.

Main Line Strainers

Drain water and sediment from the main line strainer at each preflight inspection. Remove and clean the screen at the periods specified in the airplane maintenance manual. Examine the sediment removed from the housing. Particles of rubber are often early warnings of hose deterioration. Check for leaks and damaged gaskets.

Fuel Quantity Gauges

If a sight gauge is used, be sure that the glass is clear and that there are no leaks at the connections. Check the lines leading to it for leaks and security of attachment. Check the mechanical gauges for free movement of the float arm and for proper synchronization of the pointer with the position of the float.

On the electrical and electronic gauges, be sure that both the indicator and the tank units are securely mounted and that their electrical connections are tight.

Fuel Pressure Gauge

Check the pointer for zero tolerance and excessive oscillation. Check the cover glass for looseness and for proper range markings. Check the lines and connections for leaks. Be sure that there is no obstruction in the vent. Replace the instrument if it is defective.

Pressure Warning Signal

Inspect the entire installation for security of mounting and condition of the electrical, fuel, and air connections.

Check the lamp by pressing the test switch to see that it lights. Check the operation by turning the battery switch on, building up pressure with the booster pump, and observing the pressure at which the light goes out. If necessary, adjust the contact mechanism.

Water Injection Systems for Reciprocating Engines

These systems have very limited use in modern aircraft engines. Water injection was used mostly on large radial engines. The water injection system enabled more power to be obtained from the engine at takeoff than is possible without water injection. The carburetor (operating at high power settings) delivers more fuel to the engine than it actually needs. A leaner mixture would produce more power; however, the additional fuel is necessary to prevent overheating and detonation. With the injection of the antidetonant fluid, the mixture can be leaned out to that which produces maximum power, and the vaporization of the water-alcohol mixture then provides the cooling formerly supplied by the excess fuel.

Turbine Engine Fuel System—General Requirements

The fuel system is one of the more complex aspects of the gas turbine engine. It must be possible to increase or decrease the power at will to obtain the thrust required for any operating condition. In turbine-powered aircraft, this control is provided by varying the flow of fuel to the combustion chambers. However, some turboprop aircraft also use variable-pitch propellers; thus, the selection of thrust is shared by two controllable variables, fuel flow and propeller blade angle.

The quantity of fuel supplied must be adjusted automatically to correct for changes in ambient temperature or pressure. If the quantity of fuel becomes excessive in relation to mass airflow through the engine, the limiting temperature of the turbine blades can be exceeded, or it will produce compressor stall and a condition referred to as rich blowout. Rich blowout occurs when the amount of oxygen in the air supply is insufficient to support combustion and when the mixture is cooled below the combustion temperature by the excess fuel. The other extreme, lean flameout, occurs if the fuel quantity is reduced proportionally below the air quantity. The engine must operate through acceleration and deceleration without any fuel-control-related problems.

The fuel system must deliver fuel to the combustion chambers not only in the right quantity, but also in the right condition for satisfactory combustion. The fuel nozzles form part of the fuel system and atomize or vaporize the fuel so that it ignites and burns efficiently. The fuel system must also supply fuel so that the engine can be easily started on the ground and in the air. This means that the fuel must be injected into the combustion chambers in a combustible condition during engine starting, and that combustion must be sustained while the engine is accelerating to its normal idling speed. Another critical condition to which the fuel system must respond occurs during a rapid acceleration. When the engine is accelerated, energy must be furnished to the turbine in excess of that necessary to maintain a constant rpm. However, if the fuel flow increases too rapidly, an over rich mixture can be produced, with the possibility of a rich blowout or compressor stall.

Turbofan, turbojet, turboshaft, and turboprop engines are equipped with a fuel control unit which automatically satisfies the requirements of the engine. Although the basic requirements apply generally to all gas turbine engines, the way in which individual fuel controls meet these needs cannot be conveniently generalized.

Turbine Fuel Controls

Gas turbine engine fuel controls can be divided into three basic groups:

1. Hydromechanical,
2. Hydromechanical/electronic, and
3. Full Authority Digital Engine (or Electronics) Control (FADEC).

The hydromechanical/electronic fuel control is a hybrid of the two types of fuel control but can function solely as a hydromechanical control. In the dual mode, inputs and outputs are electronic, and fuel flow is set by servo motors. The third type, FADEC, uses electronic sensors for its inputs and controls fuel flow with electronic outputs. The FADEC-type control gives the electronic controller (computer) complete control. The computing section of the FADEC system depends completely on sensor inputs to the electronic engine control (EEC) to meter the fuel flow. The fuel metering device meters the fuel using only outputs from the EEC. Most turbine fuel controls are quickly going to the FADEC type of control. This electronically controlled fuel control is very accurate in scheduling fuel by sensing many of the engine parameters.

Regardless of the type, all fuel controls accomplish essentially the same function. That function is to schedule the fuel flow to match the power required by the pilot. Some sense more engine variables than others. The fuel control can sense many different inputs, such as power lever position, engine rpm for each spool, compressor inlet pressure and temperature, burner pressure, compressor discharge pressure, and many more parameters as needed by the specific engine. These variables affect the amount of thrust that an engine produces for a given fuel flow. By sensing these parameters, the fuel control has a clear picture of what is happening in the engine and can adjust fuel flow as needed. Each type of turbine engine has its own specific needs for fuel delivery and control.

Hydromechanical Fuel Control

Hydromechanical fuel controls were used and are still used on many engines, but their use is becoming limited giving way to electronic based controls. Fuel controls have two sections, computing and metering, to provide the correct fuel flow for the engine. A pure hydromechanical fuel control has no electronic interface assisting in computing or metering the fuel flow. It also is generally driven by the gas generator gear train of the engine to sense engine speed. Other mechanical engine parameters that are sensed are compressor discharge pressure, burner pressure, exhaust temperature, and inlet air temperature and pressure. Once the computing section determines the correct amount of fuel flow, the metering section through cams and servo valves delivers the fuel to the engine fuel system. Actual operating procedures for a hydromechanical fuel control is very complicated and still the fuel metering is not as accurate as with an electronic type of interface or control. Electronic controls can receive more inputs with greater accuracy than hydromechanical controls. Early electronic controls used a hydromechanical control with an electronic system added on the system to fine tune the metering of the fuel. This arrangement also used the hydromechanical system as a backup if the electronic system failed. *[Figure 2-49]*

Hydromechanical/Electronic Fuel Control

The addition of the electronic control to the basic hydromechanical fuel control was the next step in the development of turbine engine fuel controls. Generally, this type of system used a remotely located EEC to adjust the fuel flow. A description of a typical system is explained in the following information. The basic function of the engine fuel system is to pressurize the fuel, meter fuel flow, and deliver atomized fuel to the combustion section of the engine. Fuel flow is controlled by a hydromechanical fuel control assembly, which contains a fuel shutoff section and a fuel metering section.

This fuel control unit is sometimes mounted on the vane fuel pump assembly. It provides the power lever connection and the fuel shutoff function. The unit provides mechanical overspeed protection for the gas generator spool during normal (automatic mode) engine operation. In automatic mode, the EEC is in control of metering the fuel. In manual mode, the hydromechanical control takes over.

During normal engine operation, a remotely mounted electronic fuel control unit (EFCU) (same as an EEC) performs the functions of thrust setting, speed governing and acceleration, and deceleration limiting through EFCU outputs to the fuel control assembly in response to power lever inputs. In the event of electrical or EFCU failure, or at the option of the pilot, the fuel control assembly functions in manual mode to allow engine operation at reduced power under control of the hydromechanical portion of the controller only.

The total engine fuel and control system consists of the following components and provides the functions as indicated:

1. The vane fuel pump assembly is a fixed displacement fuel pump that provides high pressure fuel to the engine fuel control system. *[Figure 2-50]*

2. The filter bypass valve in the fuel pump allows fuel to bypass the fuel filter when the pressure drop across the fuel filter is excessive. An integral differential pressure indicator visually flags an excessive differential pressure condition before bypassing occurs, by extending a pin from the fuel filter bowl. Fuel pump discharge flow in excess of that required by the fuel control assembly is returned from the control to the pump interstage.

3. The hydromechanical fuel control assembly provides the fuel metering function of the EFCU.

   Fuel is supplied to the fuel control through a 200-micron inlet filter screen and is metered to the engine by the servo-operated metering valve. It is a fuel flow/compressor discharge pressure (Wf/P3) ratio device that positions the metering valve in response to engine compressor discharge pressure (P3). Fuel pressure differential across the servo valve is maintained by the servo-operated bypass valve in response to commands from the EFCU. *[Figure 2-49]* The manual mode solenoid valve is energized in the automatic mode. The automatic mode restricts operation of the mechanical speed governor. It is restricted to a single overspeed governor setting above the speed range controlled electronically. Deenergizing the manual mode valve enables the mechanical speed governor to function as an all speed governor in response to power lever angle (PLA). The fuel control system includes a low power sensitive torque motor which may be activated to increase or decrease fuel flow in the automatic mode (EFCU mode). The torque motor provides an interface to an electronic control unit that senses various engine and ambient parameters and activates the torque motor to meter fuel flow accordingly. This torque motor provides electromechanical conversion of an electrical signal from the EFCU. The torque motor current is zero in the manual mode, which establishes a fixed Wf/P3 ratio.

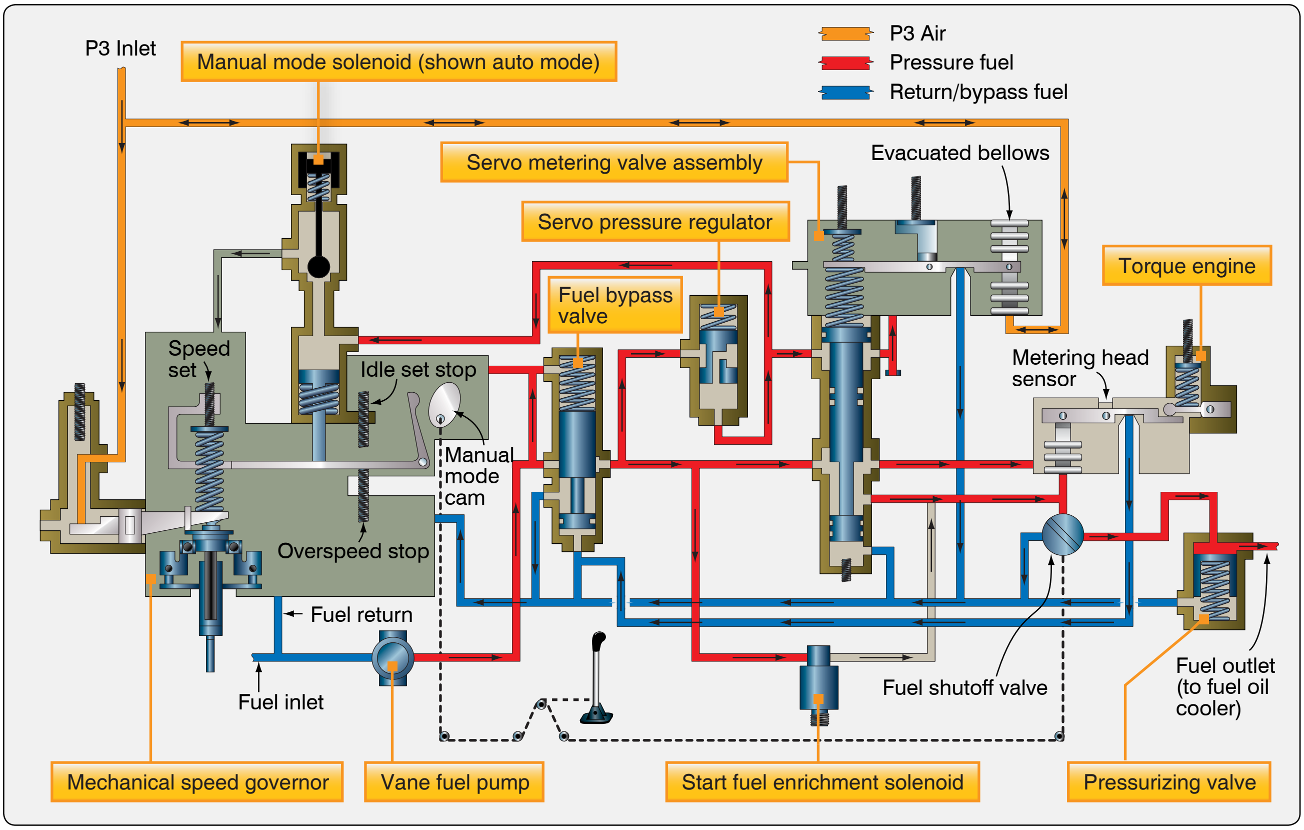


Figure 2-49. *Fuel control assembly schematic hydromechanical/electronic.*

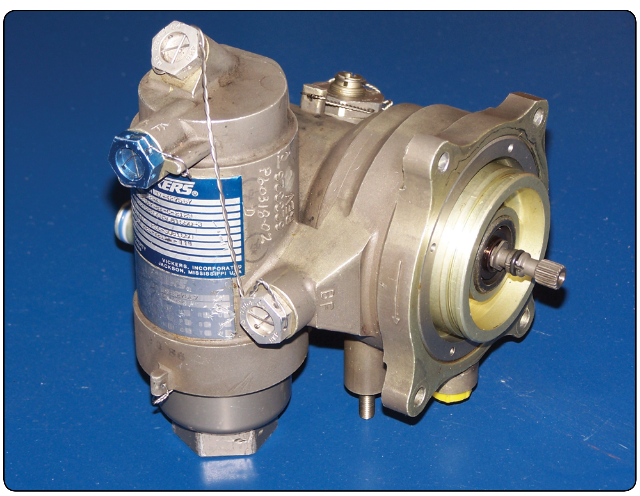


Figure 2-50. *Fuel pump and filter.*

This fixed Wf/P3 ratio is such that the engine operates surge free and is capable of producing a minimum of 90 percent thrust up to 30,000 feet for this example system. All speed governing of the high-pressure spool (gas generator) is achieved by the flyweight governor. The flyweight governor modulates a pneumatic servo, consistent with the speed set point as determined by the power lever angle (PLA) setting. The pneumatic servo accomplishes Wf/P3 ratio modulation to govern the gas generator speed by bleeding down the P3 acting on the metering valve servo. The P3 limiter valve bleeds down the P3 pressure acting in the metering valve servo when engine structural limits are encountered in either control mode. The start fuel enrichment solenoid valve provides additional fuel flow in parallel with the metering valve when required for engine cold starting or altitude restarts. The valve is energized by the EFCU when enrichment is required. It is always deenergized in the manual mode to prevent high altitude sub-idle operation. Located downstream of the metering valve are the manual shutoff and pressurizing valves. The shutoff valve is a rotary unit connected to the power lever. It allows the pilot to direct fuel to the engine manually. The pressurizing valve acts as a discharge restrictor to the hydromechanical control. It functions to maintain minimum operating pressures throughout the control. The pressurizing valve also provides a positive leak-tight fuel shutoff to the engine fuel nozzles when the manual valve is closed.

4. The flow divider and drain valve assembly proportions fuel to the engine primary and secondary fuel nozzles. It drains the nozzles and manifolds at engine shutdown. It also incorporates an integral solenoid for

modifying the fuel flow for cold-starting conditions.

During an engine start, the flow divider directs all flow through the primary nozzles. After start, as the engine fuel demand increases, the flow divider valve opens to allow the secondary nozzles to function. During all steady-state engine operation, both primary and secondary nozzles are flowing fuel. A 74-micron, self-bypassing screen is located under the fuel inlet fitting and provides last chance filtration of the fuel prior to the fuel nozzles.

5. The fuel manifold assembly is a matched set consisting of both primary and secondary manifolds and the fuel nozzle assemblies.

Twelve fuel nozzles direct primary and secondary fuel through the nozzles causing the fuel to swirl and form a finely atomized spray. The manifold assembly provides fuel routing and atomizing to ensure proper combustion.

The EEC system consists of the hydromechanical fuel control, EFCU, and aircraft mounted power lever angle potentiometer. Aircraft-generated control signals include inlet pressure, airstream differential pressure, and inlet temperature plus pilot selection of either manual or auto mode for the EFCU operation. Engine-generated control signals include fan spool speed, gas generator spool speed, inner turbine temperature, fan discharge temperature, and compressor discharge pressure. Aircraft- and engine-generated control signals are directed to the EFCU where these signals are interpreted. The PLA potentiometer is mounted in the throttle quadrant. The PLA potentiometer transmits an electrical signal to the EFCU, which represents engine thrust demand in relation to throttle position. If the EFCU determines a power change is required, it commands the torque motor to modulate differential pressure at the head sensor. This change in differential pressure causes the metering valve to move, varying fuel flow to the engine as required. The EFCU receives electrical signals which represent engine operating variables. It also receives a pilot-initiated signal (by power-lever position) representing engine thrust demand. The EFCU computes electrical output signals for use by the engine fuel control for scheduling engine operation within predetermined limits. The EFCU is programmed to recognize predetermined engine operating limits and to compute output signals such that these operating limits are not exceeded. The EFCU is remotely located and airframe mounted. An interface between the EFCU and aircraft/engine is provided through the branched wiring harness assembly. *[Figure 2-51]*

FADEC Fuel Control Systems

A full authority digital electronic control (FADEC) has been developed to control fuel flow on most new turbine engine models. A true FADEC system has no hydromechanical fuel control backup system. The system uses electronic sensors that feed engine parameter information into the EEC. The EEC gathers the needed information to determine the amount of fuel flow and transmits it to a fuel metering valve. The fuel metering valve simply reacts to the commands from the EEC. The EEC is a computer that is the computing section of the fuel delivery system and the metering valve meters the fuel flow. FADEC systems are used on many types of turbine engines from APUs to the largest propulsion engines.

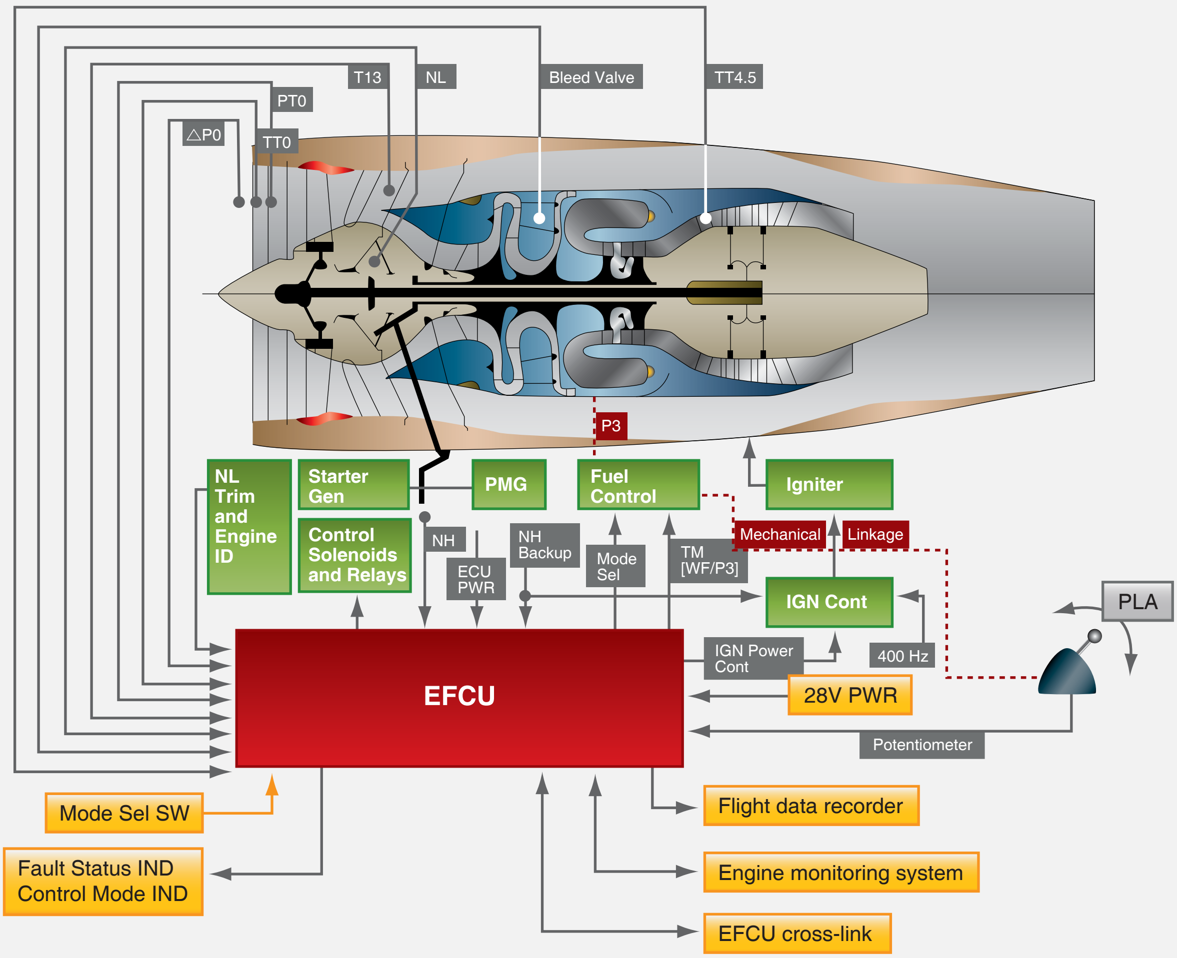
FADEC for an Auxiliary Power Unit

An APU engine uses the aircraft fuel system to supply fuel to the fuel control. An electric boost pump may be used to supply fuel under pressure to the control. The fuel usually passes through an aircraft shutoff valve that is tied to the fire detecting/extinguishing system. An aircraft furnished inline fuel filter may also be used. Fuel entering the fuel control unit first passes through a 10-micron filter. If the filter becomes contaminated, the resulting pressure drop opens the filter bypass valve and unfiltered fuel then is supplied to the APU. Shown in *Figure 2-52* is a pump with an inlet pressure access plug so that a fuel pressure gauge might be installed for troubleshooting purposes. Fuel then enters a positive displacement, gear-type pump. Upon discharge from the pump, the fuel passes through a 70-micron screen. The screen is installed at this point to filter any wear debris that might be discharged from the pump element. From the screen, fuel branches to the metering valve, differential pressure valve, and the ultimate relief valve. Also shown at this point is a pump discharge pressure access plug, another point where a pressure gauge might be installed.

The differential pressure valve maintains a constant pressure drop across the metering valve by bypassing fuel to the pump inlet so that metered flow is proportional to metering valve area. The metering valve area is modulated by the torque motor, which receives variable current from the engine control unit (ECU). The ultimate relief valve opens to bypass excess fuel back to the pump inlet whenever system pressure exceeds a predetermined pressure. This occurs during each shutdown since all flow is stopped by the shutoff valve and the differential pressure valve, is unable to bypass full pump capacity. Fuel flows from the metering valve out of the fuel control unit (FCU), through the solenoid shutoff valve and on to the atomizer. Initial flow is through the primary nozzle tip only. The flow divider opens at higher pressure and adds flow through the secondary path.

FADEC Fuel Control Propulsion Engine

Many large high-bypass turbofan engines use the FADEC type of fuel control system. The EEC is the primary component of the FADEC engine fuel control system. The



SYMBOLS	
NH	Core spool speed
NL	Fan spool speed
PT0	Free stream total pressure
PLA	Power lever angle
TT0	Total temperature
T4.5	Interturbine temperature
T13	Fan exit air temperature
△P	Indicated airspeed

Engine Control System

Figure 2-51. *Engine control system.*

EEC is a computer that controls the operation of the engine. The EEC housing contains two electronic channels (two separate computers) that are physically separated internally and is naturally cooled by convection. The EEC is generally placed in an area of the engine nacelle that is cool during engine operation. It attaches to the lower-left fan case with shock mounts. *[Figure 2-53]*

The EEC computer uses data it receives from many engine sensors and airplane systems to control the engine operation. It receives electronic signals from the flight deck to set engine power or thrust. The throttle lever angle resolver supplies the

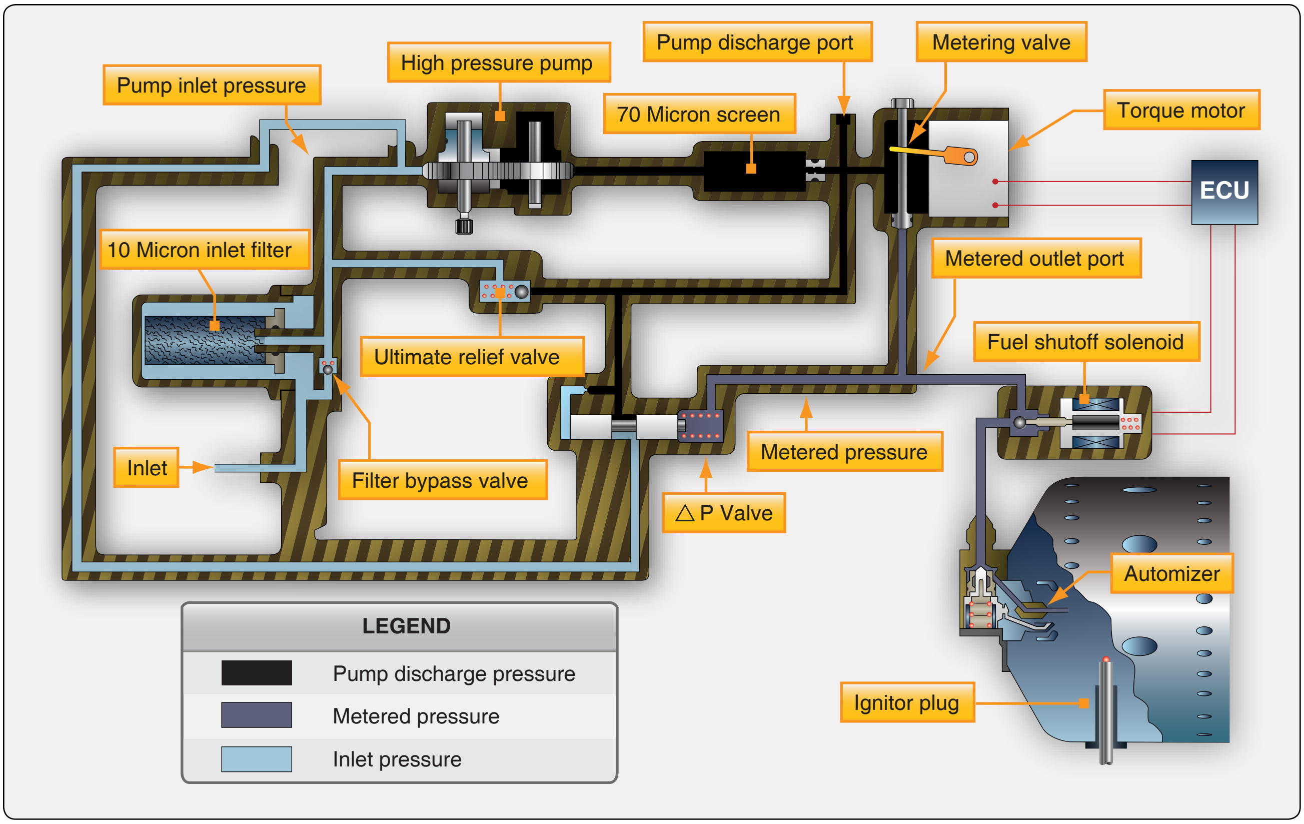


Figure 2-52. *APU fuel system schematic.*

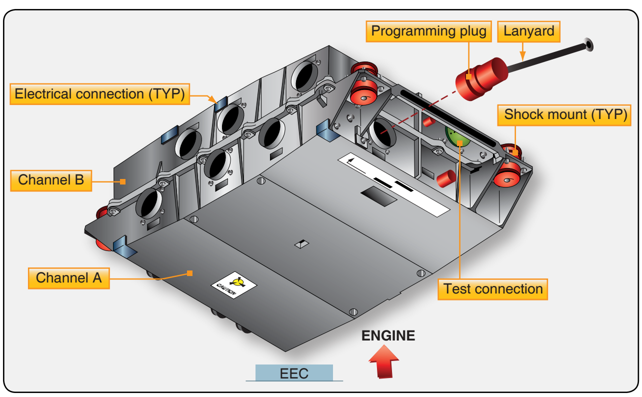


Figure 2-53. *EEC and programming plug.*

EEC with a signal in proportion to the thrust lever position. The EEC controls most engine components and receives feedback from them. Many components supply the EEC with data for engine operation.

Power for the EEC comes from the aircraft electrical system or the permanent magnet alternator (PMA). When the engine is running, the PMA supplies power to the EEC directly. The EEC is a two channel computer that controls every aspect of engine operation. Each channel, which is an independent computer, can completely control the operation of the engine. The processor does all of the control calculations and supplies all the data for the control signals for the torque motors and solenoids. The cross-talk logic compares data from channels A and B and uses the cross-talk logic to find which EEC channel is the best to control the output driver for a torque motor or solenoid bank. The primary channel controls all of the output drivers. If the cross-talk logic finds that the other channel is better for control of a specific bank, the EEC changes control of that one bank to the other channel. The EEC has output driver banks that supply the control signals to engine components. Each channel of the EEC supplies the driver banks with control signals. The EEC has both volatile and nonvolatile memory to store performance and maintenance data.

The EEC can control the engine thrust in two modes, which can be selected by use of a mode selection switch. In the normal mode, engine thrust is set with engine pressure ratio (EPR); in the alternate mode, thrust is set by N1. When the fuel control switch is moved from run to cutoff, the EEC resets. During this reset, all fault data is recorded in the nonvolatile memory. The EEC controls the metering valve in the fuel metering unit to supply fuel flow for combustion. *[Figure 2-54]* The fuel metering unit is mounted on the front face of the gearbox and is attached to the front of the fuel pump. *[Figure 2-55]* The EEC also sends a signal to the minimum pressure and shutoff valve in the fuel metering unit to start or stop fuel flow. The EEC receives position feedback for several engine components by using

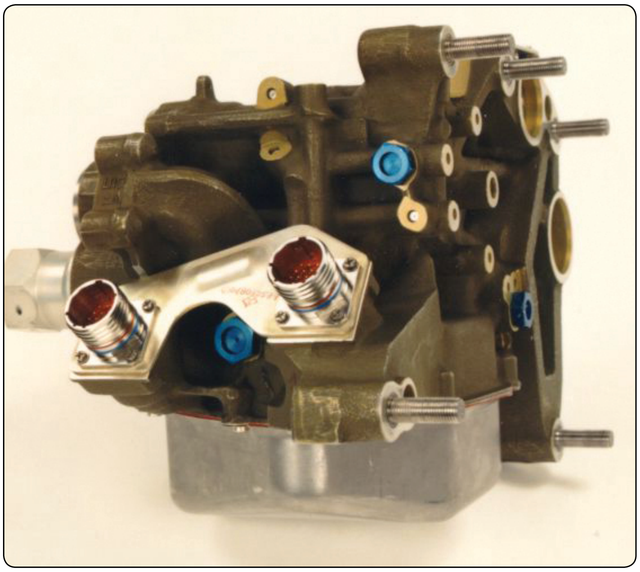


Figure 2-54. *Fuel metering unit.*

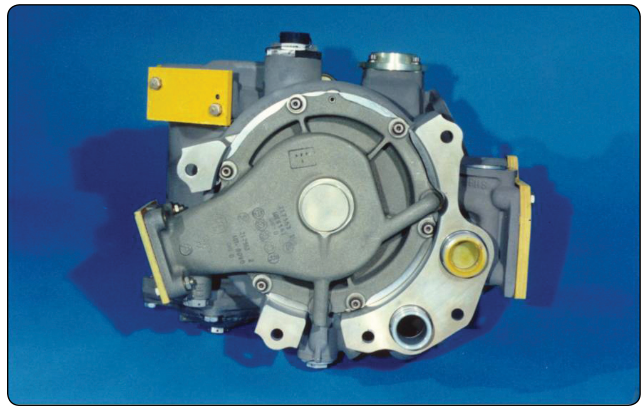


Figure 2-55. *Fuel pump.*

rotary differential transformer, linear variable differential transformer, and thermocouples. These sensors feed engine parameter information from several systems back to the EEC. The fuel control run cutoff switch controls the high pressure fuel shut off valve that allows or cuts off fuel flow. The fuel temperature sensor thermocouple attaches to the fuel outlet line on the rear of the fuel/oil cooler and sends this information to the EEC. The EEC uses a torque motor driver to control the position of the metering valve in the fuel metering unit. The EEC uses solenoid drivers to control the other functions of the fuel metering unit (FMU). The EEC also controls several other subsystems of the engine, as shown in *Figure 2-56*, through torque motors and solenoids, such as fuel and air oil coolers, bleed valves, variable stator vanes, turbine cooling air valves, and the turbine case cooling system.

Each channel of the EEC has seven electrical connections, three on each side and one on the bottom. Both channels share the inputs of the two connections on the top of the EEC. These are the programming plug and test connector. The programming plug selects the proper software in the EEC for the thrust rating of the engine. The plug attaches to the engine fan case with a lanyard. When removing the EEC, the plug remains with the engine. Each channel of the EEC has three pneumatic connections on the bottom of the EEC. Transducers inside the EEC supply the related and opposite EEC channel with a signal in proportion to the pressure. The pressures that are read by the EEC are ambient pressure, burner pressure, low pressure compressor (LPC) exit pressure, and fan inlet pressure. Each channel has its own wire color that connects the EEC to its sensors. Channel A wiring is blue and channel B sensor signals are green. The non-EEC circuit wire is gray while the thermocouple signals are yellow. This color coding helps simplify which sensors are used with each channel.

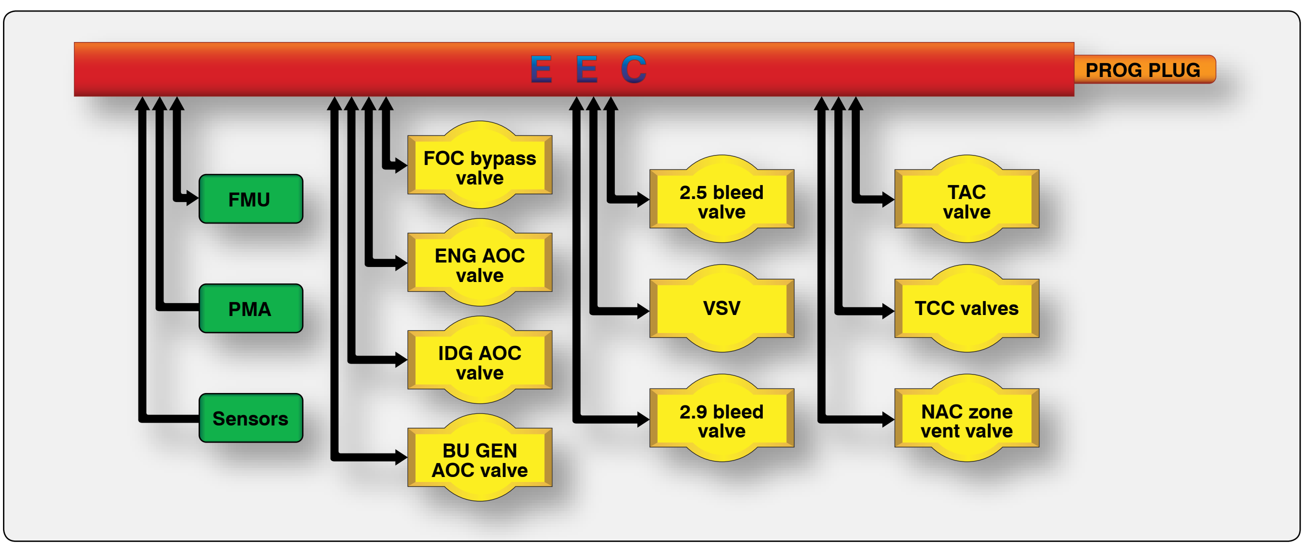


Figure 2-56. *Systems controlled by EEC.*

Fuel System Operation

The fuel pump receives fuel from the airplane fuel system. The low pressure boost stage of the pump pressurizes the fuel and sends it to the fuel/oil cooler (FOC). The fuel flows from the FOC, through the fuel pump filter element, and then to the high pressure main stage of the pump. The high pressure main stage increases the fuel pressure and sends it to the fuel metering unit (FMU). It also supplies servo fuel to the servo fuel heater and engine components. Fuel for combustion (metered fuel) goes through the fuel flow transmitter to the distribution valve. *[Figure 2-57]* The fuel distribution valve supplies metered fuel to the fuel supply manifolds. *[Figure 2-58]* The fuel injectors get the metered fuel from the fuel supply manifolds and spray the fuel into the engine for combustion. *[Figure 2-59]* The fuel pump housing contains a disposable fuel filter element. The fuel filter differential pressure switch supplies a signal to the EEC that indicates an almost clogged filter condition. Unfiltered fuel can then bypass the filter element if the element becomes clogged.

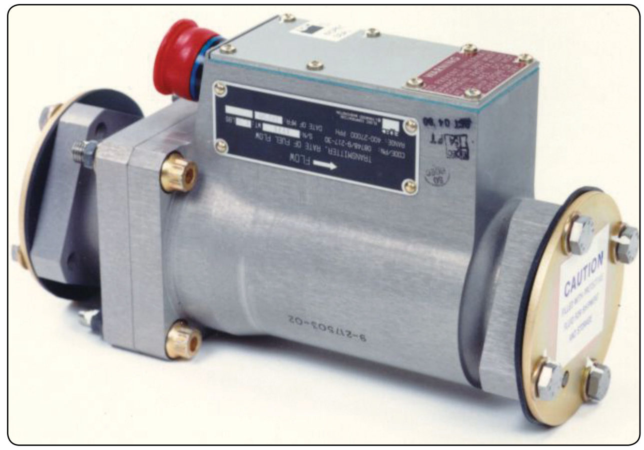


Figure 2-57. *Fuel flow transmitter.*

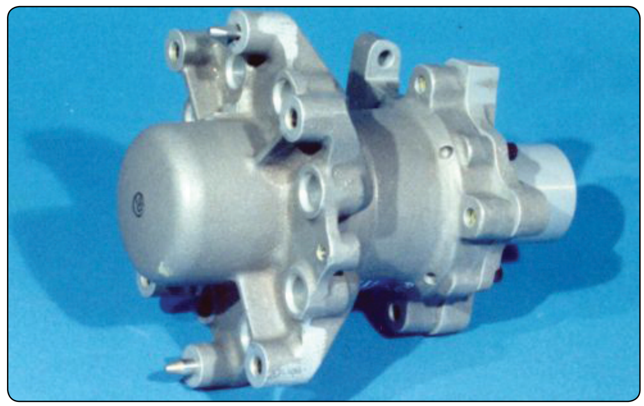


Figure 2-58. *Fuel distribution valve.*

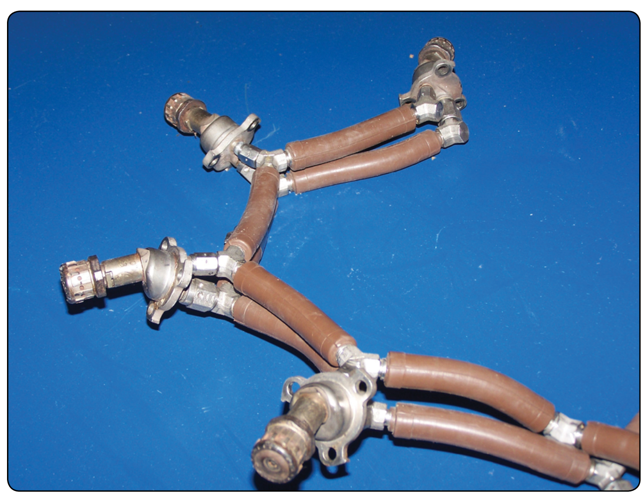


Figure 2-59. *Fuel manifolds.*

Water Injection System

On warm days, thrust is reduced because of the decrease in air density. This can be compensated for by injecting water at the compressor inlet or diffuser case. This lowers the air temperature and increases air density. A microswitch in the fuel control is actuated by the control shaft when the power lever is moved toward the maximum power position.

A water injection speed reset servo resets the speed adjustment to a higher value during water injection. Without this adjustment, the fuel control would decrease rpm so that no additional thrust would be realized during water injection. The servo is a shuttle valve that is acted upon by water pressure during water injection. Movement of the servo displaces a lever on the cam-operated lever linkage to the speed governor speeder spring, increasing the force of the speeder spring and increasing the set speed. Because the resulting rpm is usually higher while water is flowing, increased thrust during water injection is ensured. If the water injection system is not armed in the flight deck or if there is no water available, nothing happens when the water injection switch in the fuel control unit is actuated. When water is available, a portion of it is directed to the water injection speed re-set servo. Water injection systems are not normally used on high-bypass turbofan engines.

Fuel Control Maintenance

The field repair of the turbine engine fuel control is very limited. The only repairs permitted in the field are the replacement of the control and adjustments afterwards. These adjustments are limited to the idle rpm and the maximum speed adjustment, commonly called trimming the engine. Both adjustments are made in the normal range of operation.

During engine trimming, the fuel control is checked for idle rpm, maximum rpm, acceleration, and deceleration. The procedures used to check the fuel control vary depending on the aircraft and engine installation.

The engine is trimmed in accordance with the procedures in the maintenance or overhaul manual for a particular engine. In general, the procedure consists of obtaining the ambient air temperature and the field barometric pressure (not sea level) immediately preceding the trimming of the engine. Care must be taken to obtain a true temperature reading comparable to that of the air that enters the engine. Using these readings, the desired turbine discharge pressure or EPR (engine pressure ratio) reading is computed from charts published in the maintenance manual.

The engine is operated at full throttle (or at the part power control trim stop) for a sufficient period of time to ensure that it has completely stabilized. Five minutes is the usual recommended stabilization period. A check should be made to ensure that the compressor air-bleed valves have fully closed and that all accessory drive air bleed for which the trim curve has not been corrected (such as a cabin air-conditioning unit) has been turned off. When the engine has stabilized, a comparison is made of the observed and the computed turbine discharge pressure Pt7 (or EPR) to determine the approximate amount of trimming required. If a trim is necessary, the engine fuel control is then adjusted to obtain the target turbine discharge pressure Pt7 or EPR on the gauge. Immediately following the fuel control adjustment, the tachometer reading is observed and recorded. Fuel flow and exhaust gas temperature readings should also be taken.

On Pratt and Whitney engines, using a dual-spool compressor, the observed N2 tachometer reading is next corrected for speed bias by means of temperature/rpm curve. The observed tachometer reading is divided by the percent trim speed obtained from the curve. The result is the new engine trim speed in percent, corrected to standard day (59 °F or 15 °C) temperature. The new trim speed in rpm may be calculated when the rpm at which the tachometer reads 100 percent is known. This value may be obtained from the appropriate engine manual. If all these procedures have been performed satisfactorily, the engine has been properly trimmed.

Engine trimming should always be carried out under precisely controlled conditions with the aircraft headed into the wind. Precise control is necessary to ensure maintenance of a minimum thrust level upon which the aircraft performance is based. In addition, precise control of engine trimming contributes to better engine life in terms of both maximum time between overhaul and minimum out-of-commission time due to engine maintenance requirements. Engines should never be trimmed if icing conditions exist.

Most electronic control fuel control systems do not require trimming or mechanical adjustments. Changes to the EEC in the FADEC system is normally accomplished through software changes or changing the EEC.

Engine Fuel System Components

Main Fuel Pumps (Engine Driven)

Main fuel pumps deliver a continuous supply of fuel at the proper pressure and at all times during operation of the aircraft engine. The engine-driven fuel pump must be capable of delivering the maximum needed flow at appropriate pressure to obtain satisfactory nozzle spray and accurate fuel regulation.

These engine driven fuel pumps may be divided into two distinct system categories:

1. Nonconstant displacement and
2. Nonpositive displacement.

Their use depends on where in the engine fuel system they are used. A nonpositive-displacement pump produces a continuous flow. However, because it does not provide a positive internal seal against slippage, its output varies considerably as pressure varies. Centrifugal and propeller pumps are examples of nonpositive-displacement pumps. If the output port of a nonpositive-displacement pump was blocked off, the pressure would rise and output would decrease to zero. Although the pumping element would continue moving, flow would stop because of slippage inside the pump. In a positive displacement pump, slippage is negligible compared to the pump's volumetric output flow. If the output port were plugged, pressure would increase instantaneously to the point that the pump pressure relief valve opens. Generally, a nonpositive-displacement is used at the inlet of the engine-driven pump to provide positive flow to the second stage of the pump. The output of a centrifugal pump can be varied as needed and is sometimes referred to as a boost stage of the engine-driven pump.

The second or main stage of the engine-driven fuel pump for turbine engines is generally a positive displacement type of pump. The term "positive displacement" means that the gear supplies a fixed quantity of fuel to the engine for every revolution of the pump gears. Gear-type pumps have approximately straight line flow characteristics, whereas fuel requirements fluctuate with flight or ambient air conditions. Hence, a pump of adequate capacity at all engine operating conditions has excess capacity over most of the range of operation. This is the characteristic that requires the use of a pressure relief valve for bypassing excess fuel back to the inlet. A typical two-stage turbine engine driven pump is illustrated in *Figure 2-60*. The impeller, which is driven at a greater speed than the high pressure elements, increases the fuel pressure depending upon engine speed.

The fuel is discharged from the boost element (impeller) to the two high-pressure gear elements. A relief valve is

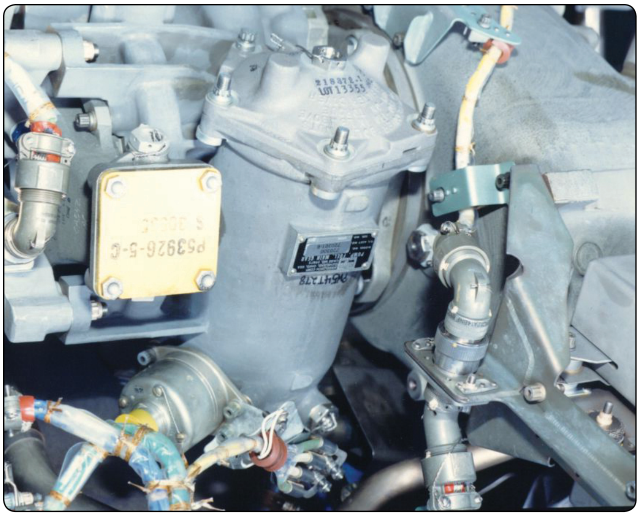


Figure 2-60. *Dual element fuel pump.*

incorporated in the discharge port of the pump. This valve opens at a predetermined pressure and is capable of bypassing the total fuel flow. This allows fuel in excess of that required for engine operation at the time to be recirculated. The bypass fuel is routed to the inlet side of the second stage pump. Fuel flows from the pump to the fuel metering unit or fuel control. The fuel control is often attached to the fuel pump. The fuel pump is also lubricated by the fuel passing through the pump, and it should never be turned without fuel flow supplied to the inlet of the pump. As the engine coasts down at shutdown, the fuel pump should be provided with fuel until it comes to a stop.

Fuel Heater

Gas turbine engine fuel systems are very susceptible to the formation of ice in the fuel filters. When the fuel in the aircraft fuel tanks cools to 32 °F or below, residual water in the fuel tends to freeze, forming ice crystals. When these ice crystals in the fuel become trapped in the filter, they block fuel flow to the engine, which causes a very serious problem. To prevent this problem, the fuel is kept at a temperature above freezing. Warmer fuel also can improve combustion, so some means of regulating the fuel temperature is needed.

The method of regulating fuel temperature is to use a fuel heater which operates as a heat exchanger to warm the fuel. The heater can use engine bleed air or engine lubricating oil as a source of heat. The bleed air type is called an air-to-liquid exchanger and the oil type is known as a liquid-to-liquid heat exchanger. The function of a fuel heater is to protect the engine fuel system from ice formation. However, should ice form in the filter, the heater can also be used to thaw ice on the fuel screen to allow fuel to flow freely again. On most installations, the fuel filter is fitted with a pressure-drop warning switch, which illuminates a warning light on the flight deck instrument panel. If ice begins to collect on the filter surface, the pressure across the filter slowly decreases. When the pressure reaches a predetermined value, the warning light alerts the flight deck personnel.

Fuel deicing systems are designed to be used intermittently. The control of the system may be manual, by a switch in the flight deck, or automatic, using a thermostatic sensing element in the fuel heater to open or close the air or oil shutoff valve. A fuel heater system is shown in *Figure 2-61*. In a FADEC system, the computer controls the fuel temperature by sensing the fuel temperature and heating it as needed.

Fuel Filters

A low-pressure filter is installed between the supply tanks and the engine fuel system to protect the engine-driven fuel pump and various control devices. An additional high-pressure fuel filter is installed between the fuel pump and the fuel control to protect the fuel control from contaminants that could come from the low pressure pump.

The three most common types of filters in use are the micron filter, the wafer screen filter, and the plain screen mesh filter. The individual use of each of these filters is dictated by the filtering treatment required at a particular location. The micron filter has the greatest filtering action of any present-day filter type and, as the name implies, is rated in microns. *[Figure 2-62]* (A micron is one thousandth of 1 millimeter.) The porous cellulose material frequently used in construction of the filter cartridges is capable of removing foreign matter measuring from 10–25 microns. The minute openings make this type of filter susceptible to clogging; therefore, a bypass valve is a necessary safety factor.

Since the micron filter does such a thorough job of removing foreign matter, it is especially valuable between the fuel tank and engine. The cellulose material also absorbs water, preventing it from passing through the pumps. If water does seep through the filter, which happens occasionally when filter elements become saturated with water, the water can and does quickly damage the working elements of the fuel pump and control units, since these elements depend solely on the fuel for their lubrication. To reduce water damage to pumps and control units, periodic servicing and replacement of filter elements is imperative. Daily draining of fuel tank sumps and low-pressure filters eliminates much filter trouble and undue maintenance of pumps and fuel control units.

The most widely used fuel filters are the 200-mesh and the 35-mesh micron filters. They are used in fuel pumps, fuel controls, and between the fuel pump and fuel control where removal of micronic particles is needed. These filters, usually made of fine-mesh steel wire, are a series of layers of wire.

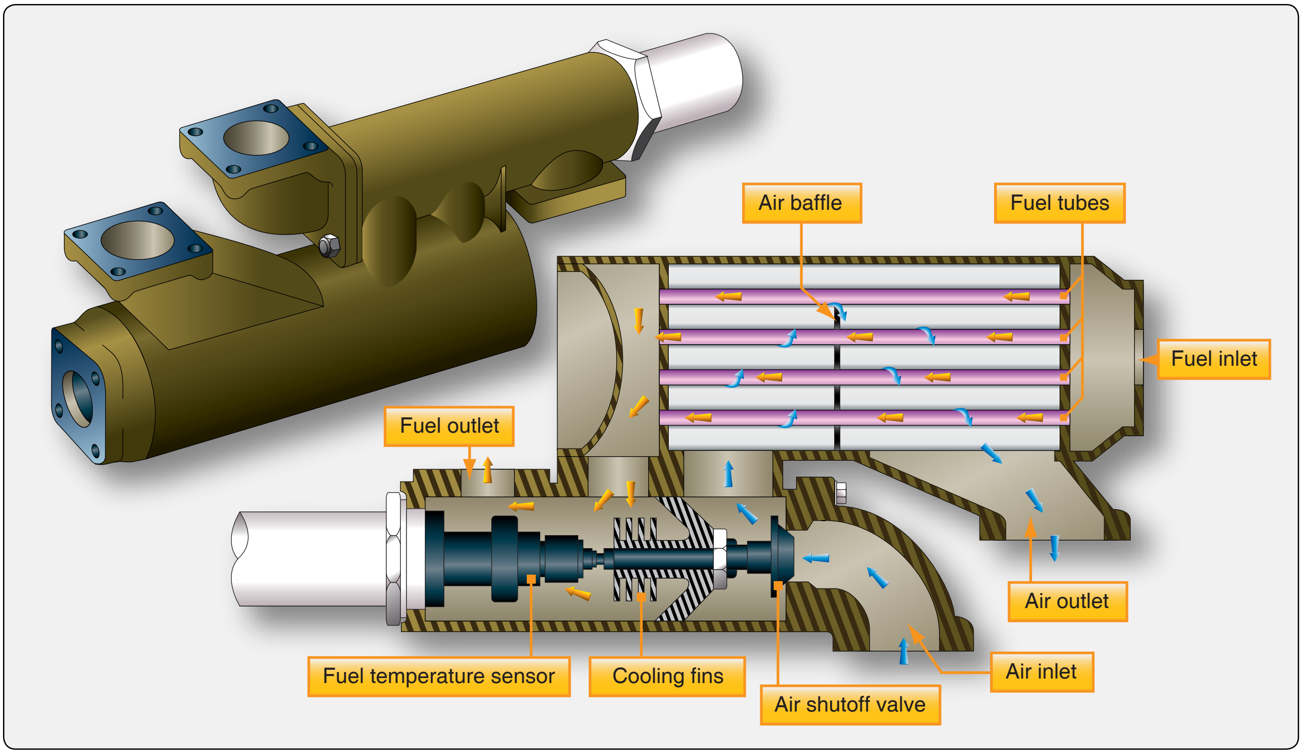


Figure 2-61. *Fuel heater.*

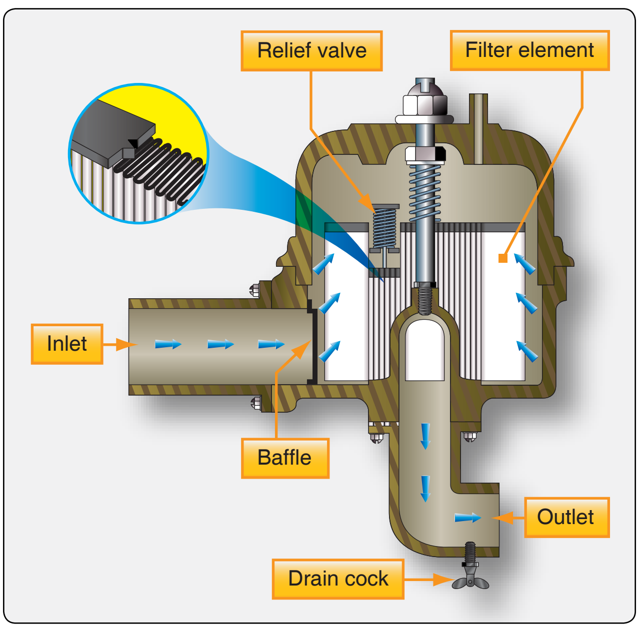


Figure 2-62. *Aircraft fuel filter.*

The wafer screen type of filter has a replaceable element, which is made of layers of screen discs of bronze, brass, steel, or similar material. *[Figure 2-63]* This type of filter is capable of removing micronic particles. It also has the strength to withstand high pressure.

Fuel Spray Nozzles & Fuel Manifolds

Although fuel spray nozzles are an integral part of the fuel system, their design is closely related to the type of combustion chamber in which they are installed. The fuel nozzles inject fuel into the combustion area in a highly atomized, precisely patterned spray so that burning is completed evenly, in the shortest possible time, and in the smallest possible space. It is very important that the fuel be evenly distributed and well centered in the flame area within the liners. This is to preclude the formation of any hot spots or hot streaking in the combustion chambers and to prevent the flame burning through the liner.

Fuel nozzle types vary considerably between engines, although for the most part fuel is sprayed into the combustion area under pressure through small orifices in the nozzles. The two types of fuel nozzles generally used are the simplex and the duplex configurations. The duplex nozzle usually requires a dual manifold and a pressurizing valve or flow divider for dividing primary and secondary (main) fuel flow, but the simplex nozzle requires only a single manifold for proper fuel delivery.

The fuel nozzles can be constructed to be installed in various ways. The two methods used quite frequently are:

1. External mounting wherein a mounting pad is provided for attachment of the nozzles to the case or the inlet air elbow, with the nozzle near the dome; or

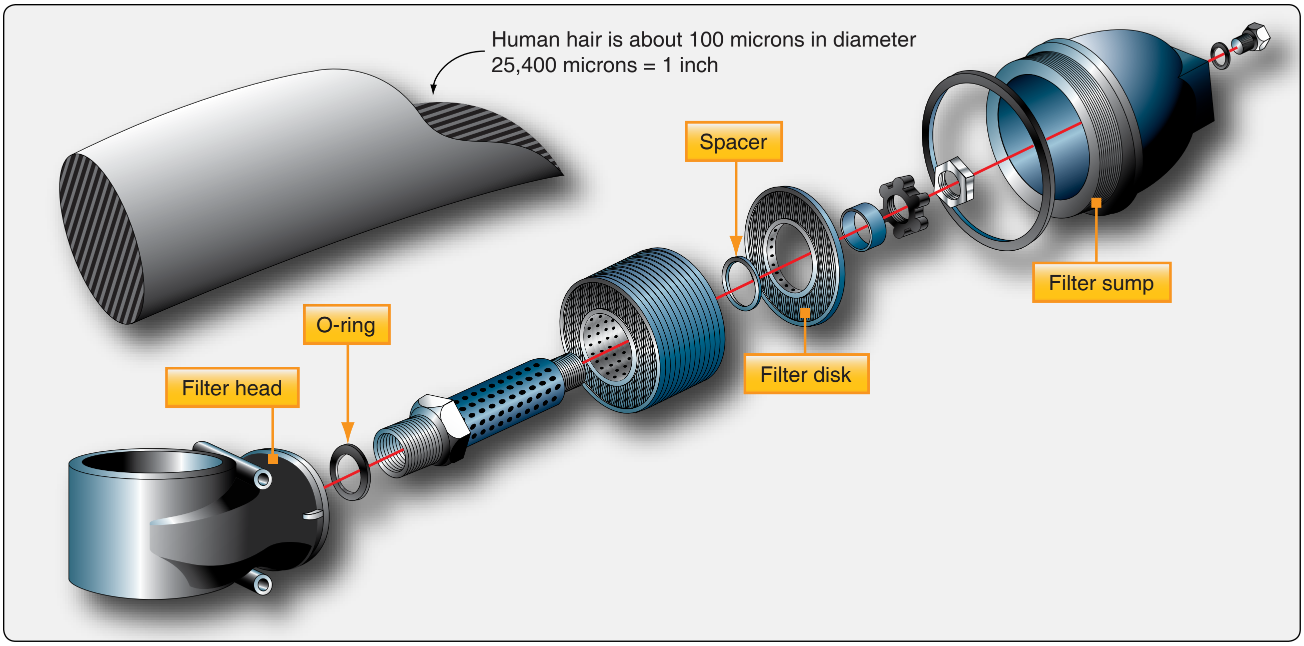


Figure 2-63. *Wafer screen filter.*

2. Internal mounting at the liner dome, in which the chamber cover must be removed for replacement or maintenance of the nozzle.

The nozzles used in a specific engine should be matched so that they flow equal amounts of fuel. Even fuel distribution is important to efficient combustion in the burner section. The fuel nozzle must present a fine spray with the correct pattern and optimum atomization.

Simplex Fuel Nozzle

The simplex fuel nozzle was the first nozzle type used in turbine engines and was replaced in most installations with the duplex nozzle, which gave better atomization at starting and idling speeds. The simplex nozzle is still being used in several installations. *[Figure 2-64]* Each of the simplex nozzles consists of a nozzle tip, an insert, and a strainer made up of fine-mesh screen and a support.

Duplex Fuel Nozzle

The duplex fuel nozzle is widely used in present day gas turbine engines and produces two different spray patterns. As mentioned previously, its use requires a flow divider, but at the same time it offers a desirable spray pattern for combustion over a wide range of operating pressures. *[Figure 2-65]* A nozzle typical of this type is illustrated in *Figure 2-66*.

Airblast Nozzles

Airblast nozzles are used to provide improved mixing of the fuel and airflow to provide an optimum spray for combustion. As can be seen in *Figure 2-64*, swirl vanes are used to mix the

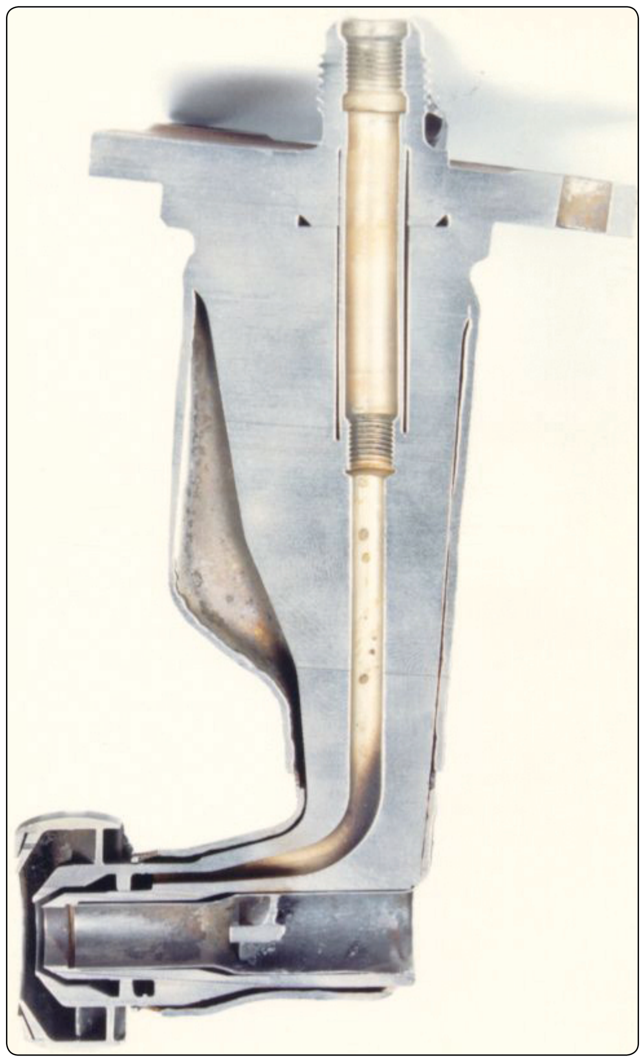


Figure 2-64. *Simplex airblast nozzle cutaway.*

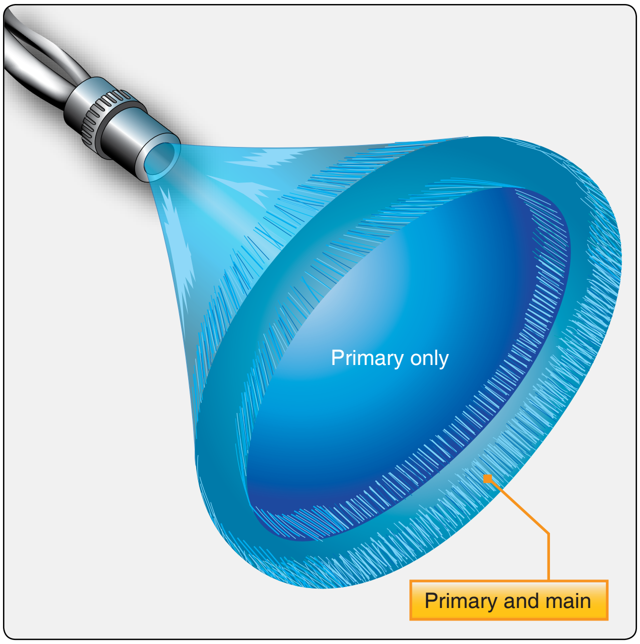


Figure 2-65. *Duplex nozzle spray pattern.*

air and fuel at the nozzle opening. By using a proportion of the primary combustion airflow in the fuel spray, locally rich fuel concentrations can be reduced. This type of fuel nozzle can be either simplex or duplex, depending upon the engine. This nozzle type can operate at lower working pressures than other nozzles which allows for lighter pumps. This airblast nozzle also helps in reducing the tendency of the nozzle to carbon up which can disturb the flow pattern.

Flow Divider

A flow divider creates primary and secondary fuel supplies that are discharged through separate manifolds, providing two separate fuel flows. *[Figure 2-67]* Metered fuel from the fuel control enters the inlet of the flow divider and passes through an orifice and then on to the primary nozzles. A passage in the flow divider directs fuel flow from both sides of the orifice to a chamber. This chamber contains a differential pressure bellows, a viscosity compensated restrictor (VCR), and a surge dampener. During engine start, fuel pressure is applied to the inlet port and across the VCR, surge dampener, and on to the primary side of the nozzles. Fuel is also applied under pressure to the outside of the flow divider bellows and through the surge dampener to the inside of the flow divider bellows. This unequal pressure causes the flow divider valve to remain closed. When fuel flow increases, the differential pressure on the bellows also increases. At a predetermined pressure, the bellows compresses, allowing the flow divider valve to open. This action starts fuel flow to the secondary manifold, which increases the fuel flow to the engine. This fuel flows out of the secondary opening in the nozzles.

Fuel Pressurizing & Dump Valves

The fuel pressurizing valve is usually required on engines incorporating duplex fuel nozzles to divide the flow into primary and secondary manifolds. As the fuel required for starting and altitude idling flows, it passes through the primary line. As the fuel flow increases, the valve begins to open the main line until at maximum flow the secondary line is passing approximately 90 percent of the fuel.

Fuel pressurizing valves usually trap fuel forward of the

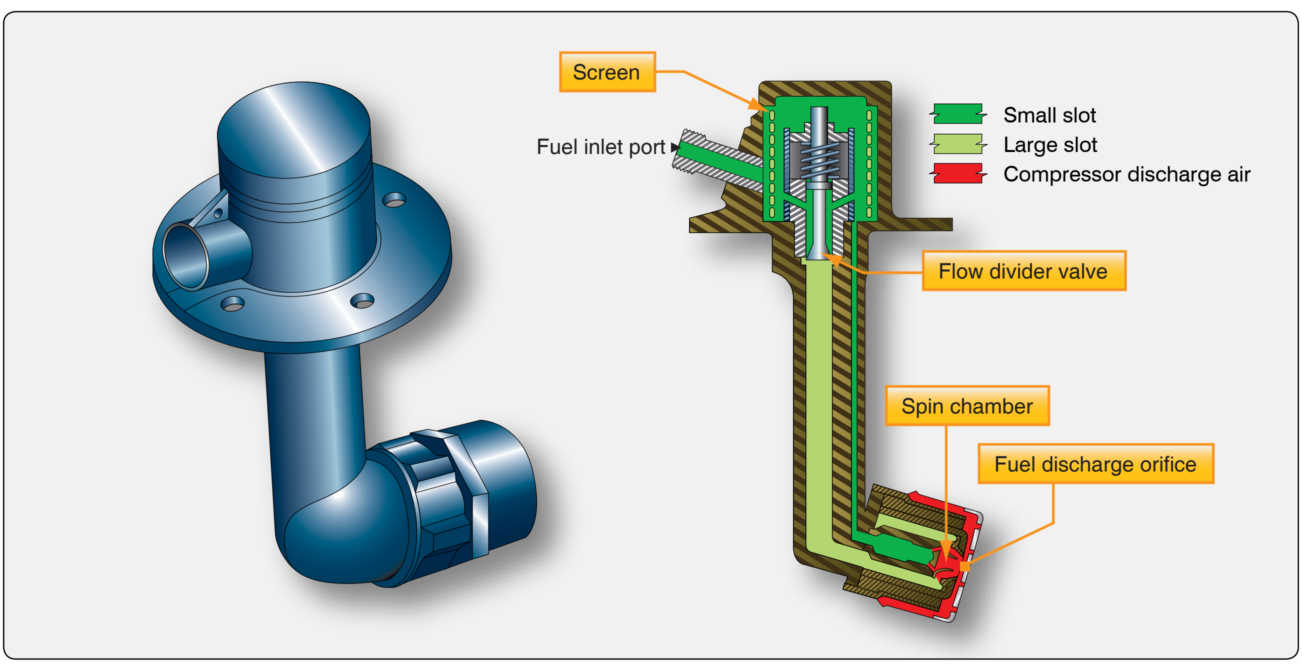


Figure 2-66. *Duplex fuel nozzle.*

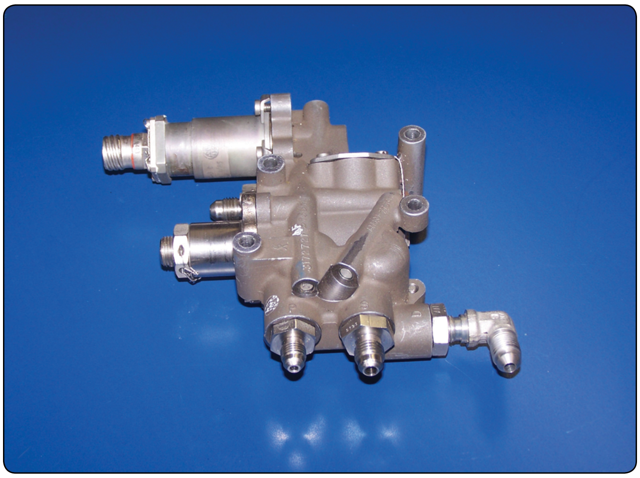


Figure 2-67. *Flow divider.*

manifold, giving a positive cutoff. This cutoff prevents fuel from dribbling into the manifold and through the fuel nozzles, limiting afterfires and carbonization of the fuel nozzles. Carbonization occurs because combustion chamber temperatures are lowered, and the fuel is not completely burned.

A flow divider performs essentially the same function as a pressurizing valve. It is used, as the name implies, to divide flow to the duplex fuel nozzles. It is not unusual for units performing identical functions to have different nomenclature between engine manufacturers.

Combustion Drain Valves

The drain valves are units used for draining fuel from the various components of the engine where accumulated fuel is most likely to present operating problems. The possibility of combustion chamber accumulation with the resultant fire hazard is one problem. A residual problem is leaving gum deposits, after evaporation, in such places as fuel manifolds and fuel nozzles.

In some instances, the fuel manifolds are drained by an individual unit known as a drip or dump valve. This type of valve may operate by pressure differential, or it may be solenoid operated.

The combustion chamber drain valve drains fuel that accumulates in the combustion chamber after each shutdown and fuel that may have accumulated during a false start. If the combustion chambers are the can type, fuel drains by gravity down through the flame tubes or interconnector tubes until it gathers in the lower chambers, which are fitted with drain lines to the drain valve. If the combustion chamber is of the basket or annular type, the fuel merely drains through the air holes in the liner and accumulates in a trap in the bottom of the chamber housing, which is connected to the drain line.

After the fuel accumulates in the bottom of the combustion chamber or drain lines, the drain valve allows the fuel to be drained whenever pressure within the manifold or the burner(s) has been reduced to near atmospheric pressure. A small spring holds the valve off its seat until pressure in the combustion chamber during operation overcomes the spring and closes the valve. The valve is closed during engine operation. It is imperative that this valve be in good working condition to drain accumulated fuel after each shutdown. Otherwise, a hot start during the next starting attempt or an afterfire after shutdown is likely to occur.

Fuel Quantity Indicating Units

Fuel quantity units vary from one installation to the next. A fuel counter or indicator, mounted on the instrument panel, is electrically connected to a flow meter installed in the fuel line to the engine.

The fuel counter, or totalizer, is used to keep record of fuel use. When the aircraft is serviced with fuel, the counter is manually set to the total number of pounds of fuel in all tanks. As fuel passes through the measuring element of the flow meter, it sends electrical impulses to the fuel counter. These impulses actuate the fuel counter mechanism so that the number of pounds passing to the engine is subtracted from the original reading. Thus, the fuel counter continually shows the total quantity of fuel, in pounds, remaining in the aircraft. However, there are certain conditions that cause the fuel counter indication to be inaccurate. Any jettisoned fuel is indicated on the fuel counter as fuel still available for use. Any fuel that leaks from a tank or a fuel line upstream of the flow meter is not counted.