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Supersedes

WAR DEPARTMENT TECHNICAL MANUAL

AIRCRAFT INDUCTION, FUEL AND OIL SYSTEMS

WAR DEPARTMENT • 22 FEBRUARY 1944

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(For explanation of symbols see FM 21–6.)

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SECTION I

AIRCRAFT ENGINE FUELS AND LUBRICANTS

1. GENERAL. a. Combustion. When a fuel-air mixture is ignited, combustion or burning occurs. This means that oxygen from the air combines with one or more elements, usually hydrogen or carbon, to form new substances called oxides. Heat energy is stored in fuels and this is liberated during combustion. The walls of the chamber in which the combustion occurs become very hot by absorbing part of this released energy. The remainder of the energy heats the oxides to very high temperatures.

(1) The oxides formed during the burning of fuels in internal combustion engines used on airplanes are in the form of gases and vapors. If at the same temperature and free to expand, these gases and vapors would occupy much more space than the fuel and air from which they are produced. If confined to a limited space, they would exert much more pressure on the walls of the container.

(2) By absorbing the heat released during combustion, these gases and vapors further expand to occupy still more space, or they exert a still greater pressure.

(3) When the combustion occurs within an engine cylinder, the pressure pushes the piston out and the gas expands to fill the available space, thus converting part of the heat energy into work. The amount of energy required to perform work will depend upon the equipment which is operated by the piston as it is moved. The final temperature of the gases is less than it would be if the combustion had occurred in a container where no expansion could occur and no work could be done.

b. Oxygen, hydrogen, and carbon. Approximately 20 percent of the air is oxygen, an active gas which unites very readily with many other elements. Hydrogen is a light gas which burns with great rapidity when ignited in the presence of oxygen. Intense heat is produced and the oxide formed is water vapor. Soot or lampblack, graphite, and diamonds are familiar forms of pure carbon. The combustion of carbon in the presence of a plentiful supply of oxygen produces carbon dioxide (CO_2), an inactive and harmless gas. When the oxygen supply is scant, part of the product will be carbon monoxide (CO). This gas is colorless, odorless, and very poisonous. It may cause death when only four parts of it are present in 10,000 parts of air.

c. Fuel compounds. Pure carbon and hydrogen do not occur in sufficient quantities for use as fuels, but many compounds of the two gases with other substances are common. These include coal, petroleum, ethyl alcohol, and similar substances used for fuel.

d. Hydrocarbon compounds. Crude petroleum is abundant in many parts of the earth, and numerous hydrocarbon compounds suited to use as engine fuels may be extracted from it. Those commonly used in airplane engine fuels are the paraffins, the naphthenes, and some aromatic hydrocarbons. Gasolines are blends of some of these products. Different samples of gasoline will vary greatly in content and properties. For this reason, all gasoline purchased for use in airplane engines is carefully tested to see that it conforms to standard specifications.

e. Aromatics. The aromatic fuels include those which contain aromatic amines or benzol, a mixture of benzene, toluene, xylene, and other light hydrocarbons. The latter have freezing points only slightly below that of water, making them unsuited for use by themselves as airplane engine fuels. Aromatic compounds are frequently mixed with straight gasoline to produce fuels with certain desirable qualities. However, they cause excessive swelling and rapid deterioration of ordinary rubber and some synthetic rubbers. For this reason it is necessary that they be used only in fuel systems especially constructed for their use.

2. AVIATION FUELS. a. Properties. A good aviation fuel must be available in large quantities; it must vaporize readily enough at low temperatures to insure starting of the engine, but not so readily as to cause vapor lock; it must have a high energy content per unit weight and a sufficiently high octane rating to permit high compression without detonation.

(1) Gasoline and ethyl alcohol are available in quantities sufficient for use as aviation fuels. The aromatic hydrocarbons, though not so plentiful, are available in considerable quantity.

(2) Gasoline blends which vaporize readily enough for engine starting but do not produce excessive vapor lock are now available. Alcohol vaporizes readily without serious vapor lock qualities but, when mixed with gasoline, it tends to separate at low temperatures. Benzene crystals begin to form in benzol at temperatures just below freezing. Other aromatic hydrocarbons also tend to freeze at fairly common flying temperatures.

(3) Gasoline and benzol have high energy content per unit weight. The energy content per unit weight of alcohol is much less than any of the other fuels discussed.

(4) The power output of engines has increased steadily since improved metal alloys have made it possible to use higher compression ratios and higher manifold pressures. However, this improvement has been limited

by the fact that when any vaporized fuel in an engine cylinder is compressed to a critical pressure which is characteristic of that particular fuel, detonation will occur. By detonation is meant that, after ignition, the fuel-air mixture burns at a normal rate until approximately 75 or 80 percent of it is consumed, and then the remainder burns with explosive rapidity. This causes an unusual rise in pressure at the maximum, accompanied by a distinct metallic knock. The gases, engine valves, etc., are heated to excessive temperatures. This is followed immediately by a rapid decrease in pressure, resulting in low mean effective pressure and consequently in low engine efficiency. Detonation may stop the engine, cause mechanical damage to engine parts (cracked pistons, burned valves, etc.), or lead to pre-ignition. Pre-ignition occurs when metal parts within the combustion chamber are overheated from any cause and ignite the fuel-air mixture before the ignition spark jumps the gap. Since this advances ignition abnormally, the efficiency of the engine is further reduced. If the ignition switch of an overheated engine is opened, the engine may continue to run for some time because of this abnormal ignition of the fuel. Pre-ignition always occurs before the normal period of ignition; detonation always occurs after normal ignition.

(5) Experiments show that a number of factors contribute to the cause of detonation: the antiknock, or octane value of the fuel; cylinder temperature; the amount of induced charge; mixture temperature; mixture ratio; intake manifold pressure; shape of the combustion chamber; and positions of the spark plugs in the chamber. The octane rating of the fuel is the only one logically to be considered in a discussion of fuels; the others pertain to engine design, supercharger design, or carburetor adjustment.

(6) The antiknock properties of a fuel are measured by comparing them with the properties of a mixture of heptane and iso-octane. Heptane is an extremely poor antiknock fuel while iso-octane is better than any of the ordinary fuels used in internal combustion engines until recently. For this reason, iso-octane is arbitrarily said to have an octane number or rating of 100. To measure the octane number of any fuel of lower knock quality, it is necessary to determine what percentage of iso-octane must be used with heptane to produce a mixture that will give just perceptible detonation at the same degree of compression as the other fuel. Thus, if a mixture of 78 percent iso-octane and 22 percent heptane is required, the fuel in question is said to have an octane rating of 78.

(7) The common hydrocarbon fuels vary greatly in their octane ratings. Many of the less expensive fuels, with high energy content per unit weight have low octane ratings. However, it has been found that by mixing such fuels with others of higher antiknock qualities, or by adding certain antiknock compounds, they can be used under much higher compression without detonation. Many antiknock compounds are known, but

the best product for general use which has been found so far is tetra-ethyl lead. The effect of this substance on various fuels differs greatly, but recently several fuel combinations or blends have been produced which have octane ratings of considerably more than 100 when tetra-ethyl lead is included. The color of gasoline is white before the addition of any dye. Blue aniline dye is added to a fuel containing tetra-ethyl lead to aid in distinguishing it from other gasolines. The blue color is also used as an aid in detecting fuel leaks.

b. Fuel combinations. Fuel combinations widely used in airplane engines today are composed of gasoline mixed with one or more of the aromatic hydrocarbons and tetra-ethyl lead, or of gasoline containing iso-octane and tetra-ethyl lead. Such blends not only have higher octane ratings than can be secured by the use of gasoline and lead compounds alone, thus making it possible to use higher compression ratios and increase engine outputs, but they accomplish this with the use of lead compound than would otherwise be required. This reduces the danger of lead oxide deposits in the combustion chamber. The grades of fuel for use in aircraft engines are listed in Technical Orders. They range from the 65 octane, unleaded type, used in block-testing, to the 130 octane, leaded type, used on high-output engines. An airplane must be serviced with the correct grade of fuel for safe and efficient operation.

c. Diesel fuels. The fuels used in high-speed Diesel engines of the type which might be suitable for certain airplanes must be of much better quality than those used in low-speed Diesels. Primarily, the ignition lag, that is, the delay period between the beginning of fuel injection and the instant at which ignition commences, must be as small as possible or "Diesel knock" will occur. One fuel factor which helps to reduce ignition lag is called the "cetane number." Cetane has the smallest ignition lag of any known fuel. The cetane number is measured by the percentage of cetane which must be mixed with alpha-methylnaphthalene to produce the same lag as that found for any given fuel. In general, a fuel with a high cetane number has a low octane number, and vice versa. Fuels obtained from the paraffin crude oils are better for Diesel engines, while those from the aromatic crude oils are poor.

d. Precautions in handling leaded fuels. Contact of the skin with fuels containing tetra-ethyl lead should be avoided as much as possible. Even though the presence of this compound is not sufficient to produce lead poisoning under normal conditions of use, serious skin irritations may occur. Extreme precautions should also be taken to avoid breathing the vapors, which are very poisonous. Kerosene, followed by a washing with soap and water, should be used to remove the leaded fuel from the skin surface.

3. ENGINE LUBRICATING OILS. a. A lubricant is any natural or artificial material used to reduce friction between moving parts. It is sometimes applied also to prevent rusting or corrosion of metallic surfaces. Animal and vegetable lubricants, while useful for many purposes, give poor performance at low temperatures and are chemically unstable at high temperatures. For these reasons, mineral oils are the principal lubricants used in aircraft engines. High-grade mineral oils have almost entirely replaced the blends of castor oil formerly used in high-output engines.

(1) Liquid lubricants are universally used in internal combustion engines because they may be pumped or sprayed readily, thus providing a good cushioning effect, and because they are effective in absorbing and dissipating heat. In theory, fluid lubrication is based on the actual separation of the surfaces so no metallic contact occurs. As long as the oil film is unbroken, metallic sliding friction is replaced by the internal friction (fluid friction) of the lubricant itself. Obviously, under such an ideal condition, no wear can occur. Many vital engine parts are given adequate protection by the use of oil under direct pressure. Where this is impractical, a mist or a spray of oil will generally give satisfactory results. Parts carrying heavy loads at high rubbing velocities are lubricated by direct pressure, if possible. As it circulates through the engine, the oil absorbs heat from the different parts and later dissipates most of it through suitable coolers or heat exchangers. Thus, oils protect engine parts from both wear and excessive temperatures.

(2) An ideal fluid lubricant would be capable of providing a strong oil film to prevent metallic friction and at the same time create a minimum amount of oil drag or fluid friction. Unfortunately, however, the viscosity of oils is affected by temperature changes to such an extent that ideal conditions are difficult to attain. Variations in climatic temperatures alone will often create an astounding change in oil viscosity. It is not at all uncommon for some grades of oil to become practically solid in cold weather, with consequent high oil drag and impaired circulation. Conversely, at high operating temperatures, oil may thin to such an extent that the oil film is broken and rapid wear of the moving parts results. The major problem in lubrication is to obtain a satisfactory compromise between the above conditions.

b. The oils used in airplane engines are not compounded, that is, no foreign substance has been added to adapt them for special mechanical purposes. Since airplanes operate under widely varying conditions, these oils are produced in many different grades. It is highly important that the oil best suited to each set of conditions be used. The most important properties of an engine oil are its viscosity, flash point, chemical stability, and pour point.

(1) Viscosity is generally considered as the resistance an oil offers to flow. Thus, if an oil flows slowly, it is a "viscous" oil, or one of high

viscosity; oil which flows readily has low viscosity. The viscosity of an oil is measured by the amount of fluid friction it exhibits while in motion.

(*a*) Ordinarily, oils of lower viscosity are used in colder weather and those of higher viscosity in warmer weather. It is desirable to select an oil of the lowest viscosity that will provide an unbroken film while the engine is at maximum temperature, in order that the friction may be held to a minimum when the engine is cold. However, when it is considered that the oil must often lubricate through a temperature range of —76°F. to 300°F., the problem becomes complex and requires extensive study. Table I shows three grades of engine lubricating oils in general use, with the recommended operating temperature ranges. These vary in each of the properties described.

Table I. Recommended operating ranges for three grades of lubricating oil

Grade of oil	Air temperature (ground)	Safe maximum "oil in" temperature[1]	Safe minimum "oil in" temperature[1]
1120	4° C. (40° F.) and above	95° C. (203° F.)	20° C. (68° F.)
1100	—7° to 27° C. (20° to 80° F.)	85° C. (185° F.)	10° C. (50° F.)
1080	10° C. (50° F.) and below	75° C. (167° F.)	0° C. (32° F.)

[1] "Oil in" temperature is the temperature of the oil prior to entering the engine. This is indicated by a thermometer bulb located in the oil system near the engine oil pump.

(*b*) Some airplanes are provided with oil-dilution systems to facilitate starting of engines in cold weather. In such systems, engine gasoline is added directly to the lubricating oil to thin it. The cold, diluted oil circulates quite readily and provides adequate lubrication. As the engine reaches to normal operating temperature the gasoline evaporates, leaving the oil in its original condition. The presence of ethyl fluid may cause some corrosion of engine parts, but the improved flow of the oil at engine-starting temperatures and the lower drain on electric power or manpower used for starting engines outweigh any disadvantage. This system of oil dilution, with the proper modifications in the oiling system, provides the first real solution to the problem of maintaining comparatively low viscosities in cold weather to facilitate starting, while also meeting the high temperature requirements of continuous operation. Airplanes equipped with an oil-dilution system can operate with grade 1120 oil at ground temperatures as low as 4°C. (40°F.). For operation at lower temperatures, grade 1100 oil with dilution is recommended. Oil lighter than grade 1100 should never be used for an airplane with an oil dilution system.

(*c*) No one grade of oil is satisfactory for all conditions of airplane operation, but the ground temperature during many operations will be 40°F. or above. For such operation, grade 1120 oil should be considered as standard. When there is doubt as to which of two oils of different viscosities to use at a certain time, the one with lower viscosity should be preferred provided it is satisfactory otherwise.

(2) The flash point of an oil is the temperature at which the amount of vapor given off is sufficient to form a combustible mixture with the air above the surface of the oil. The rate at which oil vaporizes depends on the grade of the oil and the temperature of the engine. When vaporized oil burns, the engine will not be properly lubricated. The operating temperature developed by an engine will determine the grade of oil which must be used.

(3) The chemical stability of an engine oil must be of high degree if it is to resist the action of the high temperatures, moisture, and acids often present in the crankcase. The use of an unstable oil may cause not only rapid consumption of the oil but also poor lubrication, resulting in damage to engine parts.

(4) The pour point of an oil is the lowest temperature at which it will flow, when chilled, without disturbance. The pour point should be within 5°F. of the average starting temperature of the engine. On the other hand, the oil must be viscous enough to provide an adequate oil film at operating temperatures. Choice of an oil with sufficiently low pour point and sufficiently high viscosity becomes a difficult problem in cold climates. Technical Orders must be consulted for specifications of oils to be used under such circumstances. When the engine is equipped with an oil-dilution system, however, it will usually solve the problem.

SECTION II
OIL SYSTEMS

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4. GENERAL. The oil system of the airplane provides storage for the oil required by the engines during a flight of maximum duration; it provides for the circulating and cooling of the oil; and it invariably includes equipment by means of which a portion of the oil may be diluted by gasoline, thus reducing oil viscosity and insuring easier starting of the engine in cold weather. The complete oil equipment includes the lubricating system of the engine itself, but only the external units will be discussed here. On multi-engine airplanes, each engine is supplied with oil by its own complete and independent system.

5. OILING SYSTEM UNITS. Although the arrangement of the oil systems in different airplanes varies widely, and the units of which they are composed may differ in construction details because they are made by different manufacturers, the functions of the parts of all such systems are the same. Study of one system will make clear the general operation and maintenance requirements of other systems. In any installation, the equipment is compactly arranged and placed as close to the engine as practicable. It is frequently fitted into the engine mount. The mechanic should consult the Technical Orders applying to the airplane on which he is working for a detailed description of the parts.

a. Oil supply tanks. Older airplanes and many noncombat type airplanes of recent design are equipped with riveted aluminum-alloy tanks. Some combat airplanes have self-sealing oil tanks similar in construction to those used for fuels. This greatly reduces the danger of engine failure resulting from gunfire which punctures an oil tank. Such tanks have the stiffeners, baffles, etc., required to provide necessary rigidity for fastening them in place and to provide for the proper flow of oil through them.

(1) The size of the oil tank depends upon the type of engine and the amount of gasoline carried. A radial, air-cooled engine requires approximately 1 gallon of oil with 8 to 11 gallons of fuel; those which are liquid-cooled generally use 1 gallon of oil for 14 to 18 gallons of fuel.

(2) The oil tank is held rigidly in place, frequently by aluminum straps with turnbuckle arrangements which facilitate installation and removal of

the tank. Some self-sealing tanks are fitted into prepared compartments which permit no shifting. A filler cap is conveniently located on each tank. In many cases, a scupper and scupper drain (see fig. 1) are provided to prevent oil which is spilled during filling from running down the side of the tank. An oil level gauge, a measuring rod, or petcocks at different levels may be used to determine the oil level in each tank. Two vent tubes extend from the top of the tank to the engine crankcase, to an oil separator, or to the outside.

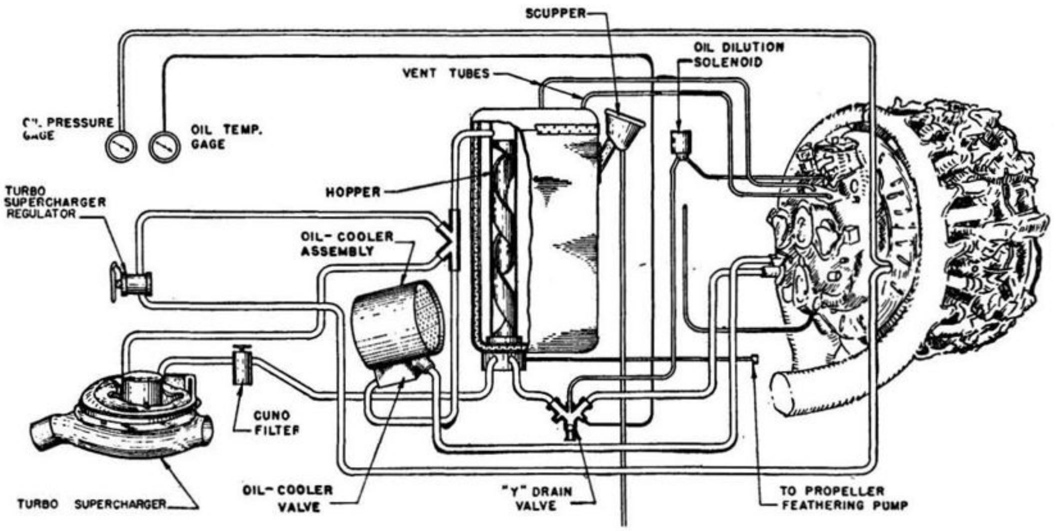


FIGURE 1. One type of lubrication system (for B-24).

(3) Usually the oil tank is equipped with a hopper extending from near the top to the sump on the bottom (see fig. 1). A fitting which passes through the outside wall delivers the return oil into the top of the hopper. The outlet is from the sump under the well. The hopper has three distinct functions:

(*a*) The well speeds the warming of the oil when the engine is started. It is really a small tank within the main one. The oil flowing through the system is confined to this smaller space as it passes through the tank, and the warm-up period is appreciably shortened. Small holes, near the bottom of the well, permit the flow of oil from the main tank to replenish the circulating supply as the engine consumes oil, and the level inside the well becomes lower than that outside.

(*b*) It insures that the old oil will be used up.

(*c*) It reduces foaming because the returning oil is discharged against the wall of the hopper in such a manner as to rotate, or spiral, down the sides.

b. Distribution system. (1) On most airplanes aluminum or copper tubing is used to transmit the oil between the tank and the engine. The tank is rigidly attached, but the engine is free to vibrate within certain limits. Flexible hose connections are used in each pipe line to prevent failures which would result from the metal fatigue produced by this vibration. The ends of the pipes are beaded and the hose is attached with clamps.

(2) On a few airplanes the oil lines are made from self-sealing, oil-resistant hose. These are less subject to failure from vibration and easier to install.

(3) In some oil systems, separate lines carry the coil to the engine and the supercharger. All the oil which passes through the supercharger passes directly into the main return line. Part of the oil from the engine passes through the turbo-supercharger regulator, but most of it passes through the oil-cooler assembly temperature regulator and into the return (scavenge) line.

c. Drain cocks. A "Y" drain valve is placed in the line between the sump and the engine. This is at the lowest point in the system and can be used to drain all the oil when necessary. The temperature of the oil entering the engine is usually taken as it leaves this valve and is indicated on the instrument panel.

d. Oil-cooler assemblies and oil-cooler valves. The purpose of the oil-cooler assembly temperature regulator (fig. 2) is to maintain a desired temperature and viscosity of the oil by controlling its passage through the unit.

(1) The cooler is built with two concentric cylinders of sheet brass. The inner cylinder is about 1 inch smaller in diameter than the outer one and houses the cooling core of the unit. The passage between the two cylinders provides a pathway by which the oil may be permitted to bypass the cooler. Figure 2 shows an arrangement of copper tubes carries the air longitudinally through the core. The oil which passes through the core is guided by baffles, so that it flows around these tubes and traverses the length of the core several times. The tubes have hexagonal-shaped ends, which form "honeycombs" in both ends of the cooler. The shaped ends are soldered together to prevent leakage between them.

(2) A thermostatic oil-cooler valve on the outside of the cooler directs the flow of the oil either through or around the core. In some cases an aluminum casting with two built-in passages and a thermostatic element is used (fig. 3). The oil flows around a flexible copper bellows regardless of which path it follows through the cooler. This bellows has sealed within it a charge of fluid which will expand when heated, and a spring which tends to compress it. A spring in the cap of the unit acts as a spring-loaded relief valve when the oil is hot or in event of a bellows failure. (See Technical Orders 03-15-5, 9, 14, and 17 for other types.)

(3) When cool oil from the engine flows into the oil-cooler assembly (fig. 2), the thermostatic oil-cooler valve is open. Most of the oil flows

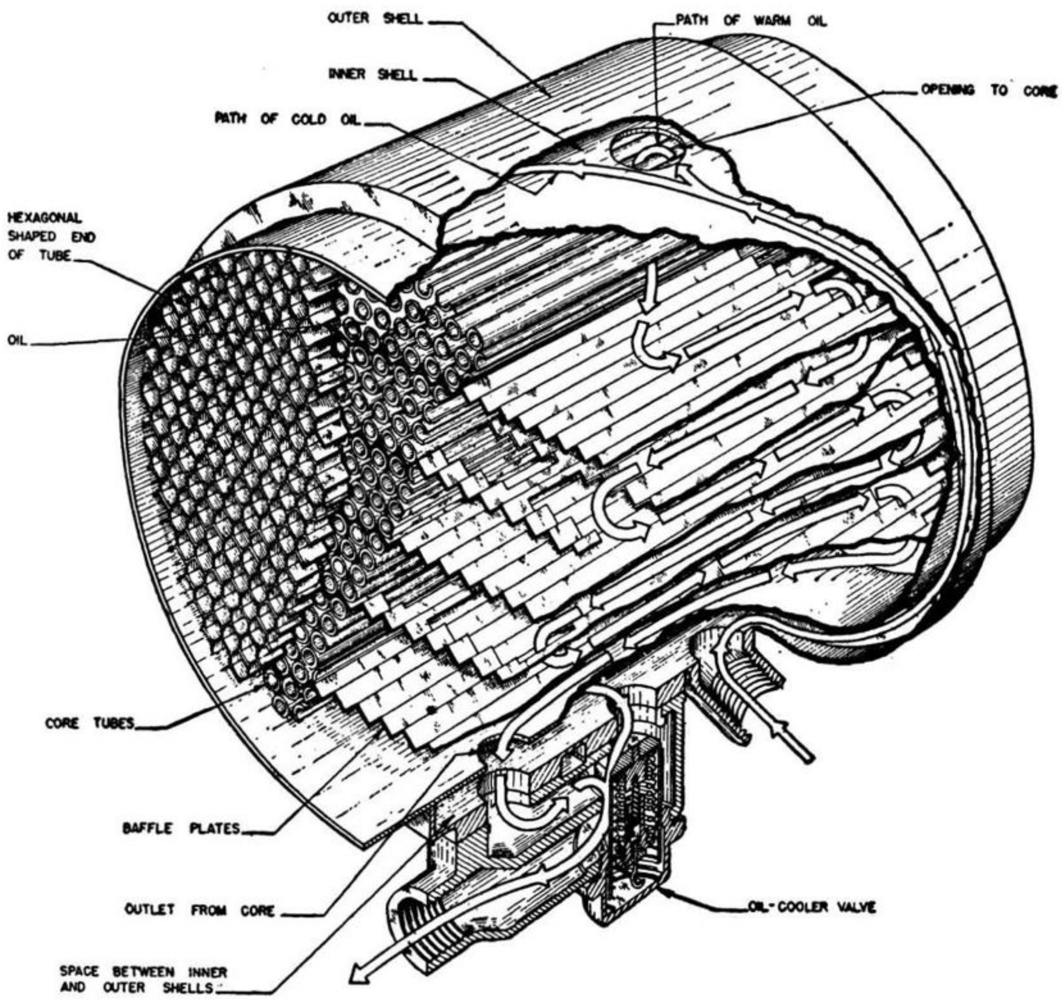


FIGURE 2. Oil-cooler assembly.

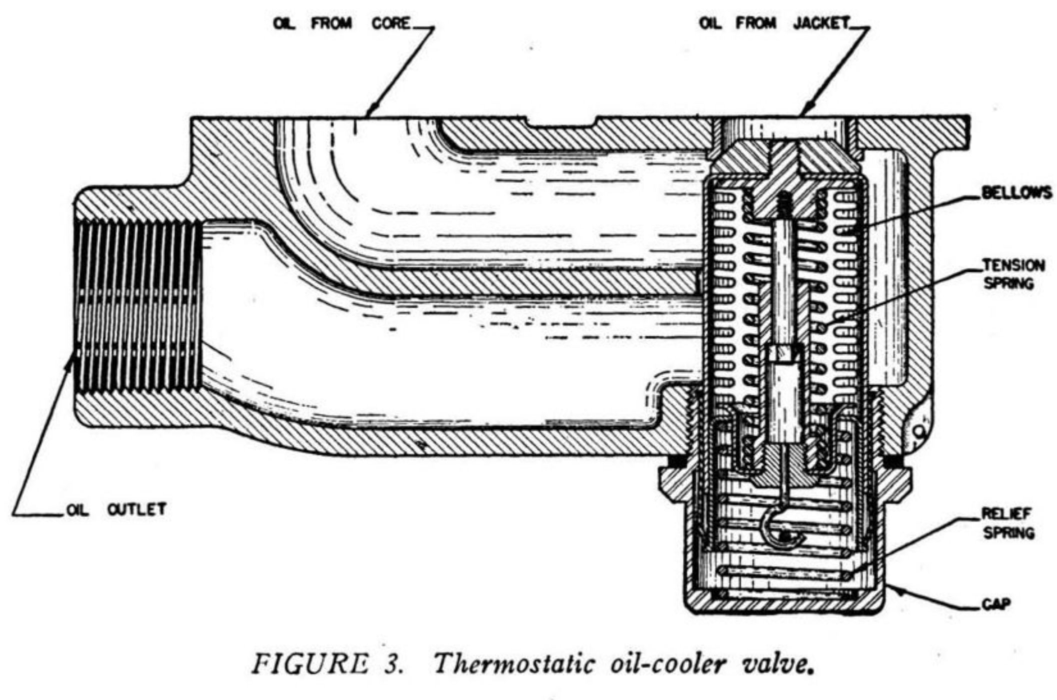


FIGURE 3. Thermostatic oil-cooler valve.

around the core between the inner and outer shells, through the path of least resistance, and is bypassed through the valve to the outlet without cooling.

(4) When the oil reaches the correct temperature, the fluid inside the bellows begins to expand and the valve starts to close. This blocks off the jacket outlet which forces oil through the cooling core. As the temperature increases, the expansion also increases until, at 90° C., the valve is completely closed and all the oil is forced to pass through the core.

(5) As the oil passes through the core in contact with the copper tubes through which the cool air is flowing, heat is given up to the air and sufficient oil viscosity is maintained to provide an adequate lubrication film.

(6) Another type of valve has a cylinder with holes in it to direct the flow of the oil. The temperature of the oil causes a helical, bimetallic thermostat to be coiled more or less tightly. This rotates the cylinder (fig. 4), so that cold oil bypasses the cooler core, or warm oil is directed through the core.

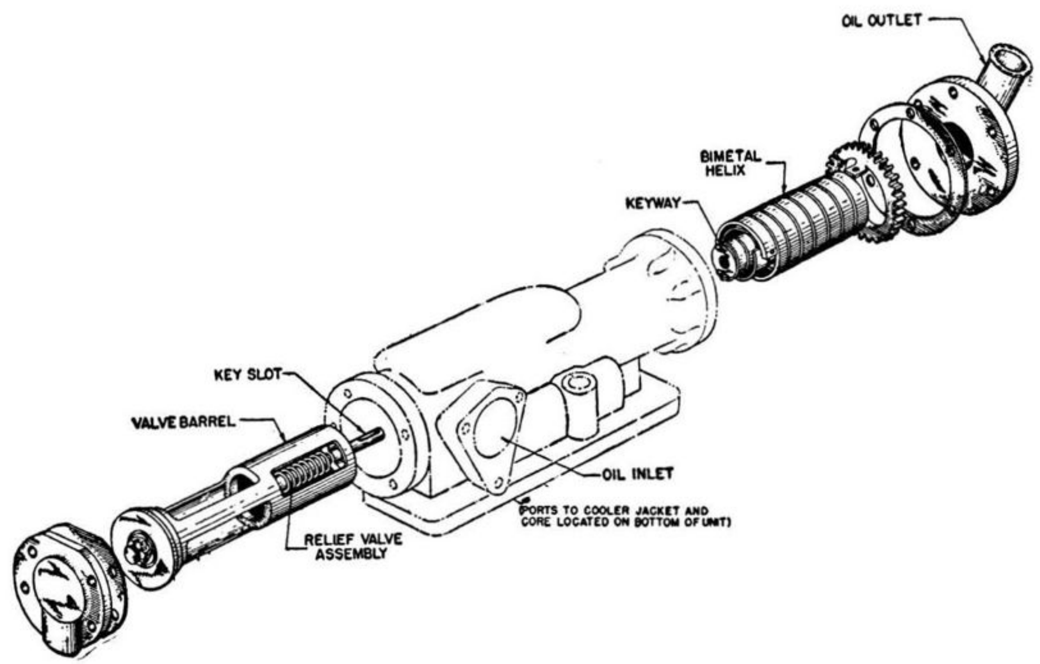


FIGURE 4. Rotary type oil-cooler valve.

(7) In some installations, the viscosity type oil-cooler valves are used to regulate the flow. This assembly has two springs (fig. 5), the stronger spring closing the valve to the cooler jacket and the weaker acting with the bellows to close the valve to the core. The bellows is filled, through the viscosity tube, with oil at the same pressure as that in the center chamber of the valve assembly. When the oil is cold and the pressure high, oil is forced past the valve to the cooler jacket and no cooling occurs. As the oil becomes warmer, the pressure is reduced, the valve to the core is partly opened, and the valve to the jacket is partly closed. The propor-

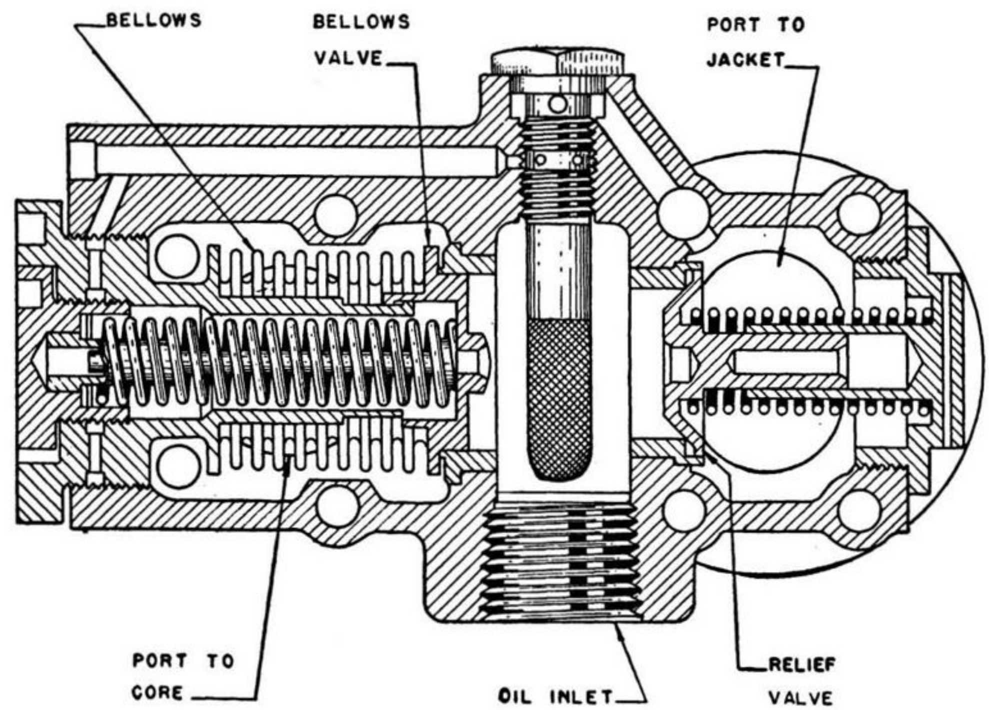


FIGURE 5. Viscosity type oil-cooler valve.

tion of oil passing through the core depends on the viscosity of the oil, and proper cooling is thus provided.

(8) The oil cooler is positioned with its drain plug down, to provide for complete drainage if necessary.

e. Automatic shutters. In some installations, oil-cooler shutters are incorporated with the cooler to control the flow of cool air through the core. Some of the oil is permitted to pass through a small vent into a cylinder which contains a spring-loaded piston connected to the shutters. Normally, the spring holds the piston back and the shutters open. The high oil pressure obtained while starting the engine in cold weather overcomes the tension of the spring, forces the piston forward, and closes the shutters. As the oil is warmed, the pressure decreases and the spring moves the shutters back toward the open position. If the unit has no shutters and low oil temperatures are reported, it is permissible to cover a part of the core and thus reduce the flow of air through the core tubes during cold weather operation. This is called "blanketing" the oil cooler. (See Technical Order 06–10–1.)

f. Strainers and Cuno filters. Solid particles of foreign material in the oil may injure an engine or cause it to fail completely. To eliminate this danger, the oil is passed through a filter before it enters the engine or supercharger. In strainer type filters, the oil passes through a tubular screen. The strainer is frequently arranged so that it will be collapsed by high oil pressure if it becomes clogged. This allows the oil to continue to reach the engine. In Cuno filters the oil passes through slots, 0.0035 inch wide between disks, into passages in the disks and the spacers between them, and thence to the engine. The particles will be stopped as the oil enters the slots. A stationary cleaner blade fits into each slot and combs out the foreign matter when the disks and spacers are rotated.

g. Oil pressure gauge. The flow of oil through the engine is indicated by the pressure. In cold weather, a lag in pressure indication may result from the high viscosity of the oil. The gauge line is filled with low-viscosity oil in cold weather to insure a true indication of oil pressure during the engine warm-up. This oil gauge line connects to the system near the outlet of the engine pressure pump.

h. Oil pumps. An engine-driven pressure pump (mounted on the accessory section) delivers oil to all parts of the engine. An engine-driven scavenger pump returns the oil from the engine through the oil-cooler assembly. Oil under pressure from the engine oiling system is also used to actuate the supercharger regulator in some aircraft (B–24, B–17) Each unit has incorporated in it a relief valve which passes some oil back into the intake line if the pressure in the outlet becomes too high.

6. OIL-DILUTION SYSTEM. a. Purpose. As indicated in paragraph 3, many airplanes are now equipped with oil-dilution systems by which gasoline may be added to the lubricating oil. This is done when it is expected that the next start will be made with low engine temperatures. Some units are controlled by simple hand-operated valves; others make use of valves which are operated by solenoids.

b. Units. The solenoid-operated oil-dilution valve (fig. 6) consists of—

(1) A solenoid controlled by a switch in the pilot's compartment.

(2) A plunger assembly in which are incorporated a valve, a magnetic iron plunger, and a spring which holds down the plunger and valve when the solenoid is not operating.

(3) An inlet connection and restricted fitting to carry gasoline from the pressure side of the engine carburetor.

(4) An outlet connection to deliver the gasoline into the engine oil line at the "Y" drain valve.

(5) An inspection plug for checking leakage through the valve.

c. Operation. Oil dilution is performed at the end of each engine run when it appears that dilution of the oil will be necessary for the next start. If engine temperatures exceed 50° C. (122° F.), the engines must be stopped and allowed to cool. At higher temperatures the gasoline will evaporate, creating a fire hazard and leaving the oil with its original viscosity. The best dilution temperature is 40° C. (104° F.). The engines should be run at a speed that will maintain the temperature within the required limits during the dilution process. The length of time required to

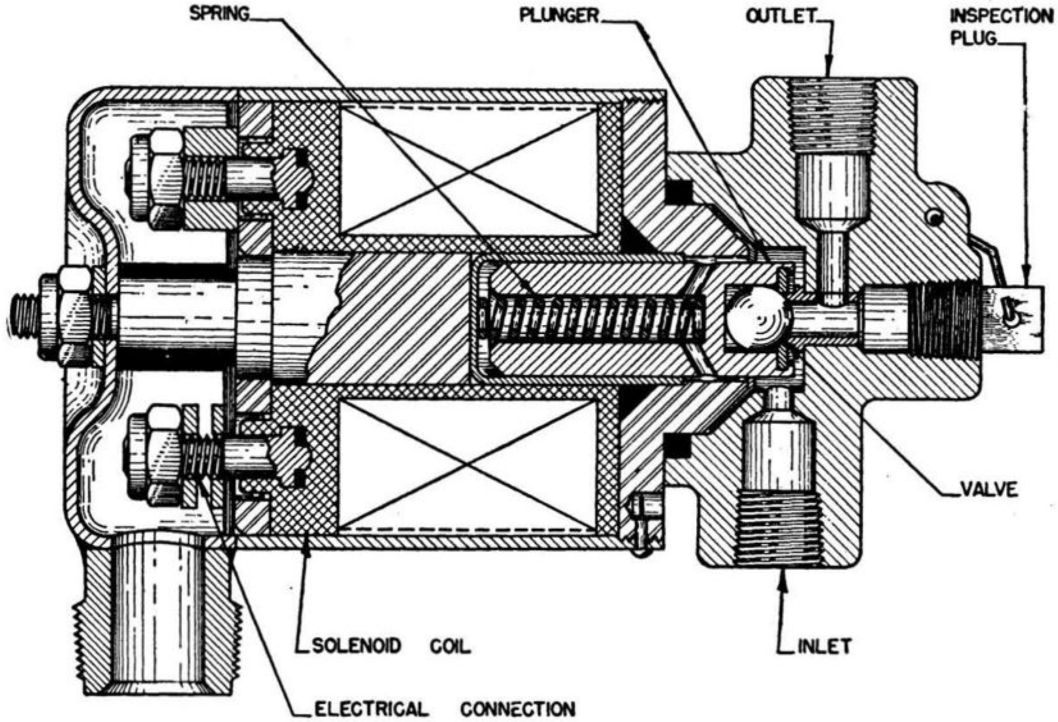


FIGURE 6. Oil-dilution valve, solenoid-operated.

dilute the oil for any engine will be found in Technical Order 02–1–29. During dilution, the pressure on the fuel-pressure gauge should drop from normal to one-half or one-third that value. If this pressure drop does not occur, check the dilution system for the source of the trouble. Keep the dilution switch on until the engine stops rotating. If the fuel gauges do not record normal pressure when an engine is being started, check to be sure that the dilution solenoid valve has closed.

7. SERVICING AND OPERATING INSTRUCTIONS. **a.** Do not attempt to fill an engine oil tank to the top. Space must be provided for the expansion of the oil. Ordinarily, the filler cap is so located that the tank cannot be filled above the correct level.

b. During the engine warm-up on the ground, the operation of the lubrication system must be checked carefully. The oil will generally be cold and its viscosity high. The rate of flow of the oil will, therefore, be low, even when the pressure is very high. For this reason, it is necessary to protect the engine against excessive wear by operating it at low speed until rising oil temperature indicates proper circulation. A take-off can be made safely after a short period of ground operation, provided the engine operates satisfactorily and the oil pressure is steady and within the required range. An airplane on which the engines are equipped with oil-dilution systems may take off much sooner than those not so equipped. Most high-output aircraft engines may be injured by prolonged periods of operation on the ground.

8. INSPECTION AND MAINTENANCE. Some of the more important inspection and maintenance requirements for engine oiling systems follow:

a. Tanks. (1) Oil tanks should be inspected for general condition of walls and seams, security of attachment, and signs of leakage. A tank need not be removed unless this inspection gives evidence of some defect which cannot be repaired with the tank in place.

(2) To remove a tank which requires repair—

(*a*) Drain the oil from the system by means of the "Y" drain valve.

(*b*) Disconnect the vent lines, oil return line, scupper overflow tube (if used in the system), and oil outlet tubes at the sump.

(*c*) Remove all attachment bolts, clamps, or straps.

(*d*) Lift the tank from its position in the airplane.

(3) To install an oil tank, follow the given instructions in the reverse order.

(4) When repairs are needed, the instructions in the Technical Orders applying to the airplane, or those which cover the repair of that type of tank, should be consulted. Emergency repairs, of self-sealing oil tanks will be made in the same manner as those of self-sealing fuel tanks par. 18c).

b. Oil tubing and fittings. All oil tubes, hose clamps, and pipe fittings must be free from dents, cracks, or holes. They must be properly installed and supported at frequent intervals. All flexible hose connections must be in good condition. Hose clamps should be examined at frequent intervals for tightness. They should remain at 25 inch-pounds torque (self-sealing, 3 to 4½ turns over finger tight; nonself-sealing, 1 to 1½ turns over finger tight). The attachment brackets must be checked for security. Plugs and drains in all parts of the system must be checked for leaks. Each part must be properly safetied.

c. Screens and filters. (1) When screens are used in the oil system, they must be removed, cleaned, and inspected for ruptures at each major inspection of the unit.

(2) The operation of automatic Cuno filters should be checked once each 10 hours.

(3) At the 25-hour inspection, Cuno filters must be washed with kerosene or other noncorrosive solvent, and inspected to see that the disks rotate freely and that disks and cleaner blades are straight and flat. Make no attempt to repair any damage, but replace the unit if defects are found.

(4) When inspection shows a defect in the motor unit which turns the disk of the automatic Cuno filter, the assembly will be removed and sent to the depot for repair.

d. Oil-cooler assembly temperature regulator. (1) Daily inspection of the oil-cooler assembly will be made to determine that—

(*a*) Temperature control has been satisfactory.

(*b*) All plugs, attachment bolts, etc., are tight and safetied.

(*c*) There are no obstructions to airflow.

(*d*) There are no fluid leaks.

(2) At engine change, a major inspection of the oiling system will be made. The following defects will be cause for the removal and repair of the unit (Technical Orders 03–15–5, 9, 14, 17):

(*a*) Collapsed or leaking tubes.

(*b*) Dents or bullet holes in the shell.

(*c*) Leaks at any soldered joint.

(*d*) Leaks or bullet holes in the core.

(*e*) If internal engine failure has occurred, the oil cooler must be rebuilt to remove metal particles.

(3) If the viscosity or temperature control valve does not operate to maintain the temperature at the required level, it must be removed for repair or replacement. To remove an oil-cooler assembly—

(*a*) Drain the oil system.

(*b*) Disconnect the inlet and outlet fittings.

(*c*) Remove connecting bolts or straps.

(*d*) Lift the unit from its place in the airplane.

(*e*) To install the unit, reverse the foregoing instructions.

(4) The cooler must be cleaned at each engine change or when removed for repair.

(*a*) Use cleaning solutions as directed in Technical Order 03-15-9, pertaining to the cleaning of the oil cooler.

(*b*) Clean the outside of the unit by immersing and rotating it in cleaning fluid.

(*c*) If a cleaning machine into which the unit will fit is available, use that machine according to instructions.

(*d*) If a cleaning machine is not available, fill the regulator three-fourths full with cleaning solution, and plug all openings.

(*e*) Shake and rotate the cooler briskly for 4 minutes, and then drain.

(*f*) Repeat two more times, using fresh cleaning solution each time.

(*g*) Dry the unit by blowing compressed air through it for at least 15 minutes.

(*h*) Test for leaks by applying air pressure of 100 pounds per square inch and then submerging unit in warm water.

(5) When inspection shows that repairs are needed, the instructions given in Technical Orders 03–15–9 should be consulted and followed.

(6) When leakage occurs at the control valve, the gasket should be replaced. The valves should be cleaned as directed in Technical Order 03–15–9.

e. Oil-dilution valve. (1) A manually operated oil-dilution valve will be checked at each 50-hour inspection to see that the linkage operates freely and that the valve closes completely.

(2) The closing of the valve on a solenoid-operated unit will be checked on the 25-hour inspection.

(3) To check the closing of the valve—

(*a*) Remove the inspection plug in the end of the unit and start the engine. *Caution: Keep away from the propellers.*

(*b*) If more than ten drops of gasoline per minute leak through the valve, replace the plug and operate the dilution control for ten 5-second periods. If the leakage is still too high on run-up after this, push the plunger in several times with a wire and let it spring back.

(*c*) If the leakage is still more than ten drops per minute, replace the solenoid valve assembly with a new one; if less, return the plug to its place and safety it.

SECTION III

FUEL SYSTEMS

9. GENERAL. a. Purpose. A well-designed fuel system provides for the storage of the required amount of fuel in the available space within the airplane, and for the delivery of fuel to the carburetor at the proper pressure and in sufficient quantity. A fuel system must be reliable under all conditions of flight and, if possible, simple in operation. Indicators, such as the fuel-pressure and fuel-level gauges, are installed to give a continuous indication of the functioning of the system.

b. Recent developments. The development of military airplanes has produced many problems relative to fuel systems. The practice of installing numerous small tanks rather than a few large ones has resulted in increased piping and pipe-fitting needs, although it has also permitted more efficient use of the available fuel storage space. Superchargers increase the demands placed on the fuel system, especially in regard to fuel pump capacity at high altitudes. The trend in new carburetors is toward increased pressures for fuel delivery and discharge. Obviously, the fuel system of a modern airplane is very complicated, requiring careful installation, adjustment, and maintenance.

c. Types. All present types of fuel circuits may be put into two broad groups, although individual systems vary in many ways. The general classification can be made as follows:

(1) Gravity-feed systems.

(2) Pressure fuel systems (series and parallel).

10. GRAVITY-FEED SYSTEM. Simplicity of design and operation, light weight, and ease of maintenance characterize the gravity-feed fuel system. However, its use is limited to low-powered aircraft, such as training airplanes. In tactical airplanes it would not meet requirements, because of the low operating pressure, the restricted tank location, and the limitation of maneuvers that it makes necessary. Since this system depends upon gravity to accomplish fuel flow to the carburetor, the fuel supply must be stored above the carburetor inlet. The pressure available from a gravity system can be calculated as approximately 1 pound per square inch for each 40-inch head of fuel. Thus, to produce a delivery pressure of 3 pounds per square inch, a vertical head of about 120 inches of fuel is necessary.

11. PRESSURE FUEL SYSTEMS. The pressure type of fuel system is employed extensively in higher-powered airplanes because of its advantages over the gravity fuel circuit.

a. The tank location is not limited, as is the case in the gravity circuit. Since the pressure system uses fuel pumps, gasoline can be drawn to the pump from any location in the airplane and discharged to the carburetor under positive pressure. This means that fuel tanks may be located below the fuel inlet to the carburetor, or wherever space is ample and convenient.

b. A pressure fuel system makes possible the high fuel pressure required by many modern aircraft carburetors.

c. With positive discharge of fuel to the carburetor insured, the tactical airplane can maneuver to a greater extent than is possible with a gravity fuel system.

d. Vapor locking, which is due to the effect of altitude and temperatures on the boiling point of gasoline, is prevented or reduced by the pressure in pressure systems.

12. FUEL-SYSTEM UNITS. a. Metal fuel tanks. (1) Aluminum and aluminum alloy are usually employed in the construction of aircraft metal fuel tanks. The design of the tank used will vary in accordance with the type of airplane in which it is to be installed. Figure 7 illustrates one type of metal fuel tank.

(2) Internal baffles increase the strength of large fuel tanks and prevent surging of the fuel during flight. Vent lines, which must be open at all times, are provided to allow gasoline vapors to escape and outside air to enter the tank. The tanks are serviced by means of a filler neck, each having a cap. The location of the filler neck provides for auto-

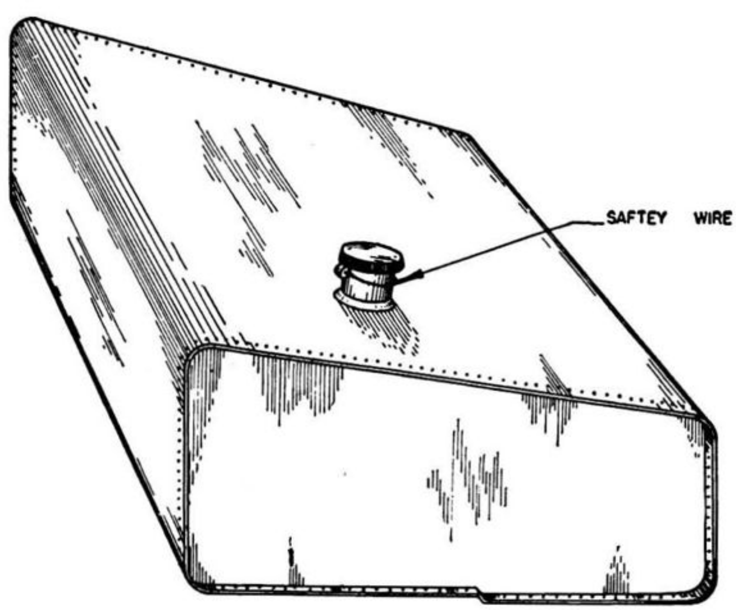


FIGURE 7. Metal fuel tank.

matic expansion in some tanks. A spill basin and an overflow line are used to prevent spilling fuel on the outside of the tank during servicing. The sump in the lowest part of the tank must be drained frequently since water may form in the tank as a result of condensation or careless servicing. This is accomplished by means of the drain in the lower part of the tank. Corrosion of the aluminum may be prevented by the use of a corrosion inhibitor, a capsule containing a chemical, which is placed in the sump.

(3) Under ordinary conditions, damaged metal fuel tanks are replaced and sent to the proper depot for repairs.

b. Self-sealing fuel tanks. (1) PURPOSE. Self-sealing fuel tanks are being used extensively in combat airplanes. This type of tank prevents or minimizes fuel loss when the tank is punctured by bullets or shell fragments, and its importance is obvious, since leakage of fuel may result in a disastrous fire or loss of fuel may prevent return of the aircraft to its base. However, this safety feature is not gained without sacrifice; self-sealing tanks are heavier, more expensive, and require a great deal of maintenance.

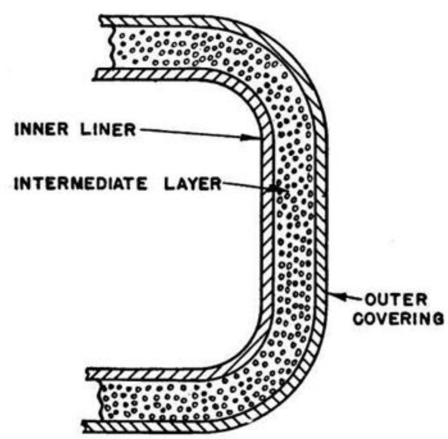


FIGURE 8. Self-sealing fuel tank.

(2) CONSTRUCTION. Many types of self-sealing tanks have been developed, but there are three fundamental elements in all types (fig. 8). The innermost element is the liner, which surrounds and contains the fuel itself. The liner is usually a thin sheet which may be rubber-coated fabric or cloth, Neoprene, Hycar, Buna synthetic rubber, or some flexible plastic material. This sheet is highly resistant to gasoline and prevents the fuel from reaching the second element, the sealant, which becomes active only on contact with the fuel. A fuel-resistant lacquer is used by some manufacturers to coat the side of the liner which is exposed to the gasoline. The sealant is generally the thickest of the three elements and may consist of one layer, or a composite of several layers,

of rubber latex, sponge, or a partially vulcanized rubber compound. If the fuel tank is penetrated by a bullet or other object and the fuel comes in contact with the sealant, the latter will become partially soluble, and will gum up and swell (fig. 9) several times its original size. This will prevent further escape of the gasoline. The third, or outer, element of the self-sealing bag is generally leather, fabric, or a composite plastic of relatively heavy construction, and provides strength and rigidity.

(3) EFFECTS OF AROMATIC FUELS. The use of fuels containing aromatics is becoming more extensive. Self-sealing tanks now being manufactured are treated to resist the effects of aromatic fuels, making special precautions unnecessary.

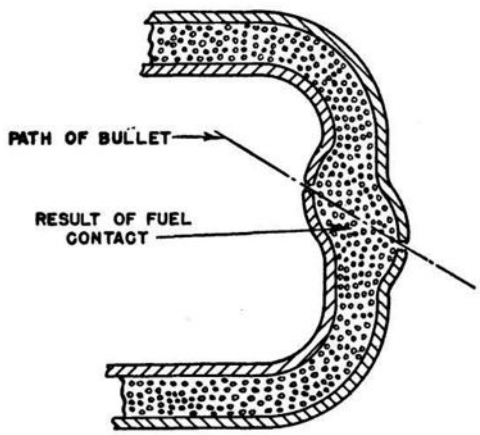


FIGURE 9. Sealing action in a self-sealing fuel tank.

c. Reserve fuel tanks. (1) Practically all fuel systems provide for a reserve fuel supply, either by the use of a separate reserve tank or by the arrangement in figure 10, which shows two standpipes in the tank, one extending farther into the tank than the other. The quantity of fuel between the top of the long standpipe and the top of the short standpipe constitutes the reserve fuel supply, which is generally sufficient for 20 minutes of operation at full rated power. A small finger screen is generally installed on each standpipe to filter out larger particles of foreign material.

(2) In some tactical airplanes, the addition of another tank to provide for an increased cruising range is often possible. This is commonly termed a "belly tank." It can be dropped, if necessary, during flight to allow for higher speed and better maneuverability, or to prevent a fire hazard upon landing.

(3) Installed in some airplanes is a system for draining fuel during flight to reduce the weight of the airplane. This jettison system may be utilized in emergencies.

d. Lines. Fuel lines are often made of annealed aluminum-alloy tubing connected by means of solderless fittings or hose connections. Re-

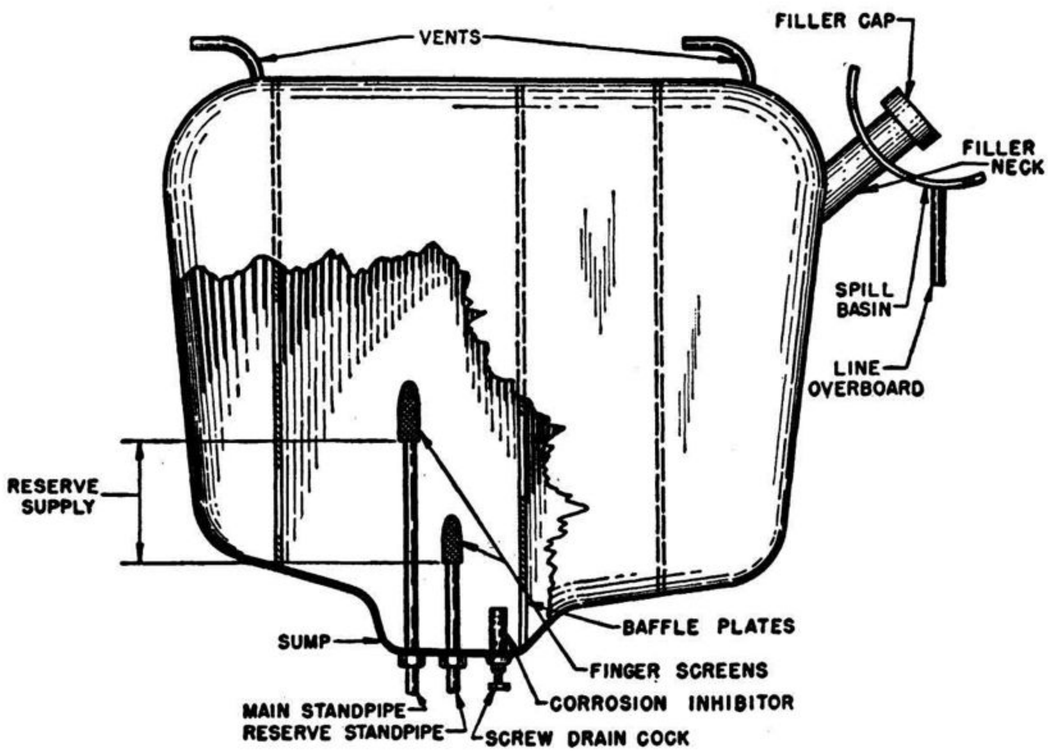


FIGURE 10. Fuel tank with two standpipes.

cently, flexible, self-sealing hose of synthetic rubber has been developed. Self-sealing fuel hose is constructed in much the same manner as the self-sealing fuel tanks described in *b* above. This type of fuel hose, used extensively on combat aircraft, is illustrated in figure 11. The size of tubing or hose is governed by the fuel-flow requirements of the engine. Fuel tubing must be installed so that there will be no chafing or stresses, and it should be properly supported by being clamped to structural members. Sharp bends and humps, or vertical rises, are to be avoided because they may restrict fuel flow or allow gathering of gasoline vapors in the line. A fuel line is identified by red bands of paint at various points on the tubing.

(1) Aromatic resistant, self-sealing hose has a red line along its entire length, and the name of the manufacturer appears every 12 inches. Aromatic resistant aircraft hose has a broken red line and a solid white line. Nonaromatic resistant hose has a solid red line and a solid white line.

(2) Fuel-hose connections and self-sealing fuel hose should be installed in such a manner that chafing will not occur, longitudinal stress will not be imposed, the bend radius of the hose will not be less than twelve times the inside diameter, and the hose will be supported at least every 18 inches. Under no circumstances will a hose connection be lubricated to provide easier installation.

e. Hose connections. (1) The application of hose connections to nipples and tubing is most important, especially in high-pressure fuel systems, oil systems, and coolant systems. Nipples and tubing are

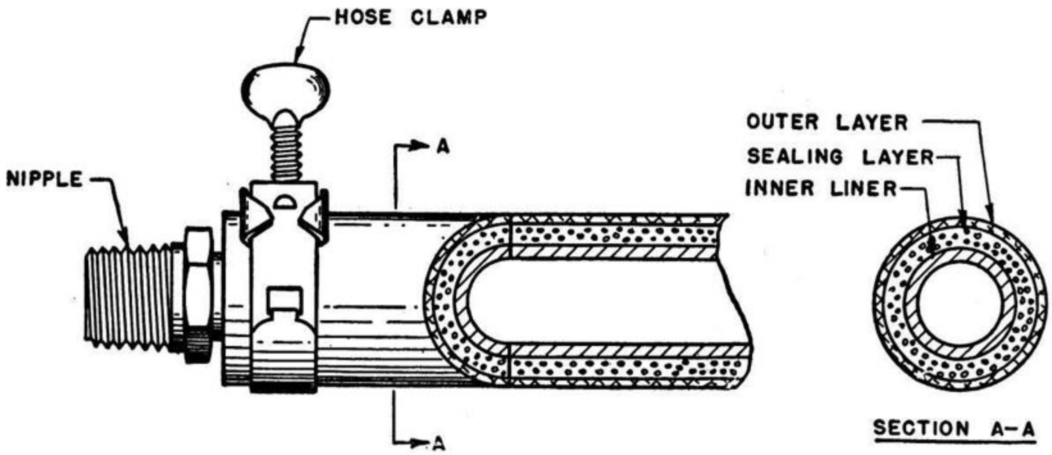


FIGURE 11. Self-sealing fuel hose.

"beaded" at or near their ends where the hose connection is to be made (fig. 12). A proper bead thus helps to effect a seal between the hose and tubing and, with proper application of a clamp, it also provides a lock whereby it will be practically impossible for a hose connection to "blow-off." Hose clamps should be installed to assure proper tightness, but overtightening should be avoided as this will tend to cut the hose. Twenty-five inch-pounds torque in tightening the clamp screw is considered adequate. This required tightness may be obtained approximately by adjusting the clamp to finger tightness; then, with pliers or wrench, apply two to two and a half turns to clamps on aromatic resistant self-sealing hose and one to one and a half turns to clamps on aromatic resistant aircraft hose and nonaromatic resistant hose.

(2) When a hose line is attached to metal nipples, pipes, etc., the clamp must not be turned more than finger tight.

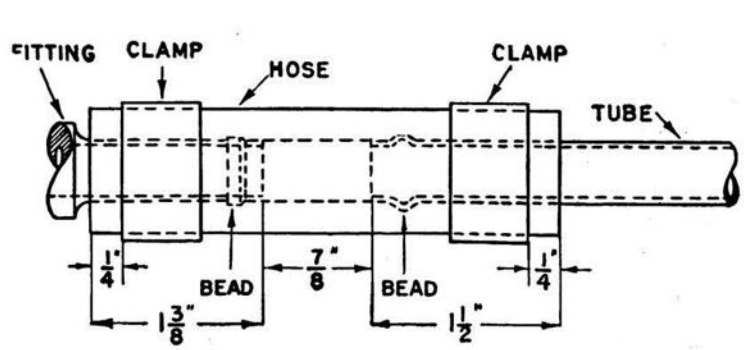


FIGURE 12. Correct application of hose connections to tubing and fittings.

f. Tank-selector valves. (1) There are three main types of selector valves now in use in aircraft fuel systems: the cone type, poppet type, and the disk type. They are used for fuel tank and/or engine selection in airplanes that have multiple fuel tanks and/or multiple engines. The sizes and number of ports of fuel cocks naturally vary according to the types of installations. For example, an airplane with three fuel tanks would require a valve having four ports (three inlets) to allow a selection of each tank and a common outlet. A fuel cock must have the full flow capacity of the fuel line, must be free from leakage, and at the same time must operate easily with a definite "feel" or "click" when it positions correctly. These fuel valves, moreover, are operated remotely through cable or other linkage from the cockpit; hence, there must be a minimum of play or backlash in the controls.

(*a*) *Cork-cone selector valves.* In low-pressure fuel systems the construction of fuel-tank selector valves varies. One of the types now used is the "friction release" cork-cone selector valve, illustrated in figure 13. This has a cone-shaped rotor fitted into an aluminum housing. The

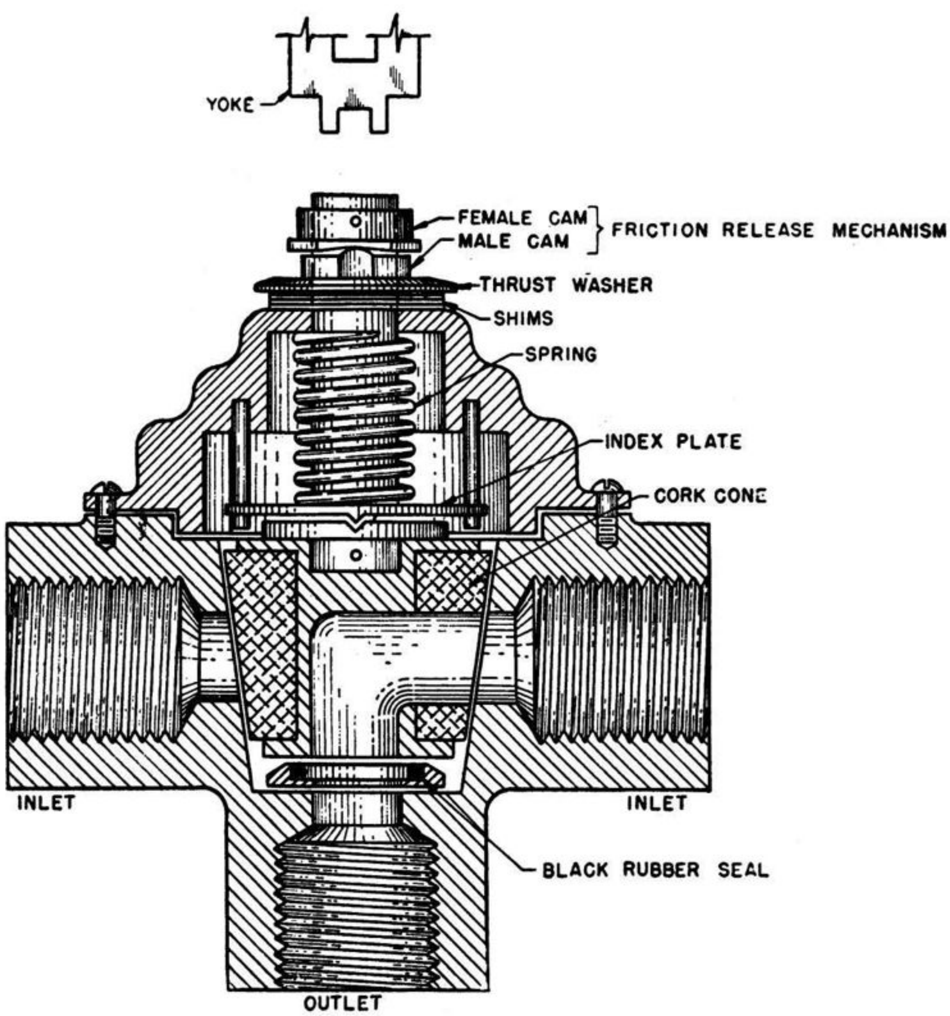


FIGURE 13. Fuel selector valve, cork-cone type.

cone itself has only one inlet and one outlet port, and the control from the cockpit operates the cork-cone directly. An indexing plate held against the cone provides an audible "click", which insures correct alignment of the cone with a particular port. Characteristic of this type of valve is the friction release mechanism, which not only reduces the turning torque but also allows for adjustment to prevent leakage. This is accomplished by a cam arrangement, as shown in figure 14. Specified clearance between the cams must be maintained to allow for proper operation.

(*b*) *Poppet type selector valves.* The poppet type selector valve contains individual poppet valves at each inlet port. These valves are opened by a cam which is connected through a link mechanism or cable to the control in the cockpit. When the cam is centered at one of the port positions, the valve stem drops into a small notch on the circumference of the cam. In addition to this notch, grooves are often cut in the bottom surface of the cam. A springloaded disk engages these grooves when the cam is correctly positioned.

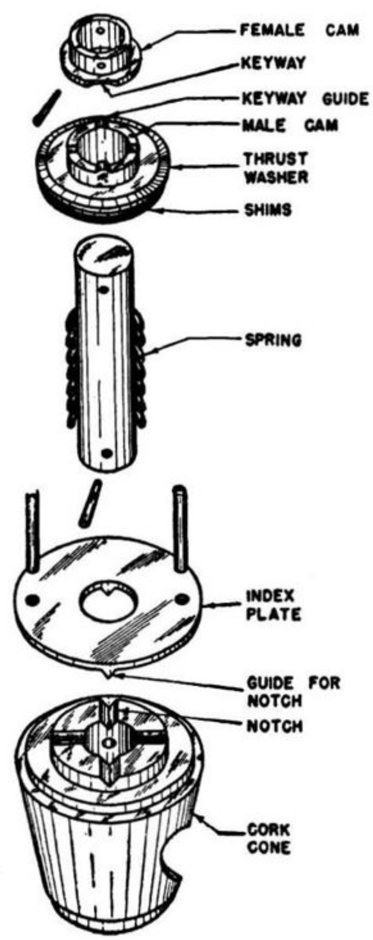


FIGURE 14. Friction release cam for cork-cone type of fuel selector valve.

(*c*) *Disk type selector valves.* In high-pressure fuel systems the disk valve consists of a fixed base with several inlet ports and a movable plate containing spring-operated disks. When this plate is rotated to the correct position, the disks drop into the ports, thereby closing the inlets. The movement of the disks provides the necessary "feel" for positioning.
(2) When control rods (fig. 15) are used to operate selector valves from the cockpit, it is often necessary to change the direction of motion of a rod. To accomplish this, a gear box is employed. Universal couplings are sometimes installed to allow for movement of the control linkage. When control cables (fig. 16) are used, pulleys serve to transmit the motion around certain structures or accessories. Periodic inspection of the control system is necessary to prevent an excessive amount of backlash or drag. Backlash is not objectionable, provided it does not exceed 15° on installations incorporating short controls with one universal joint, and 30° on complex installations incorporating long controls

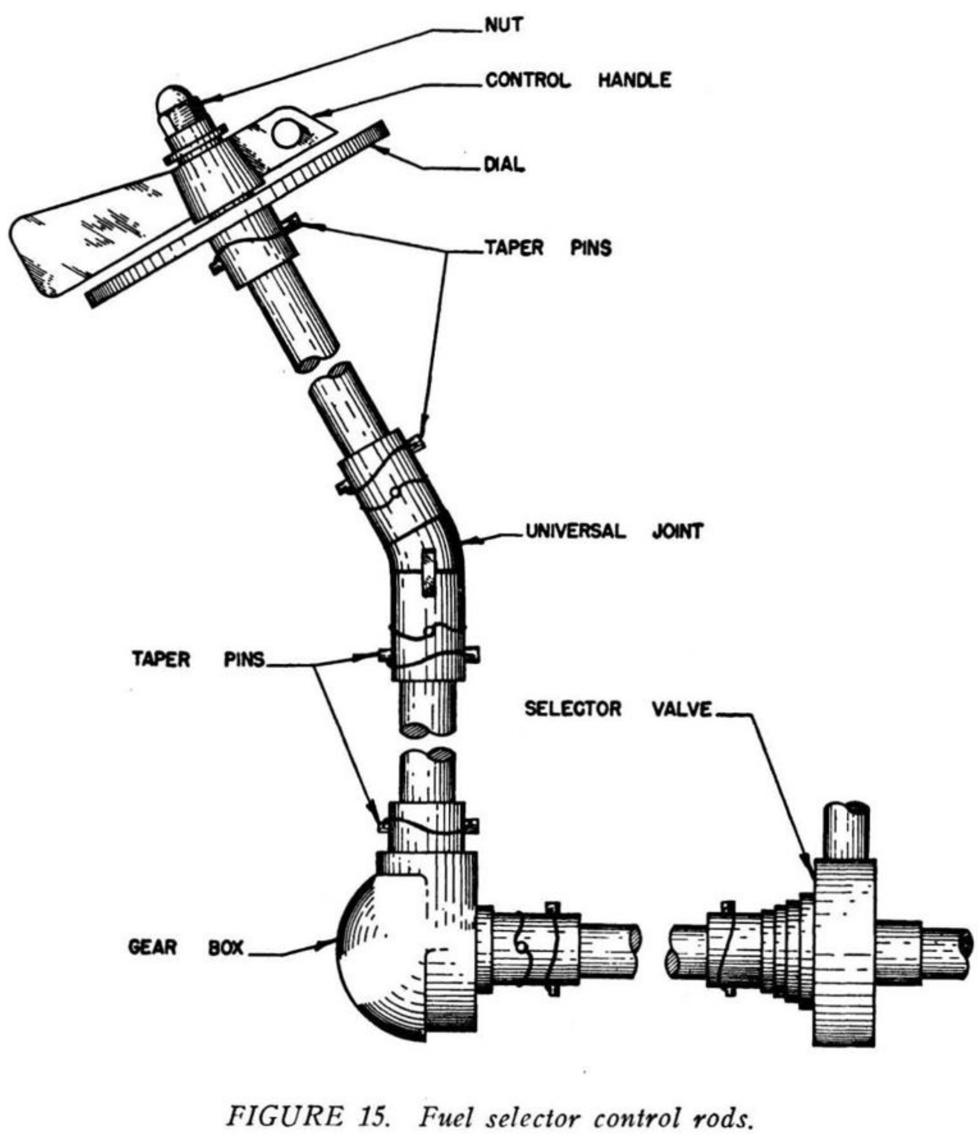


FIGURE 15. Fuel selector control rods.

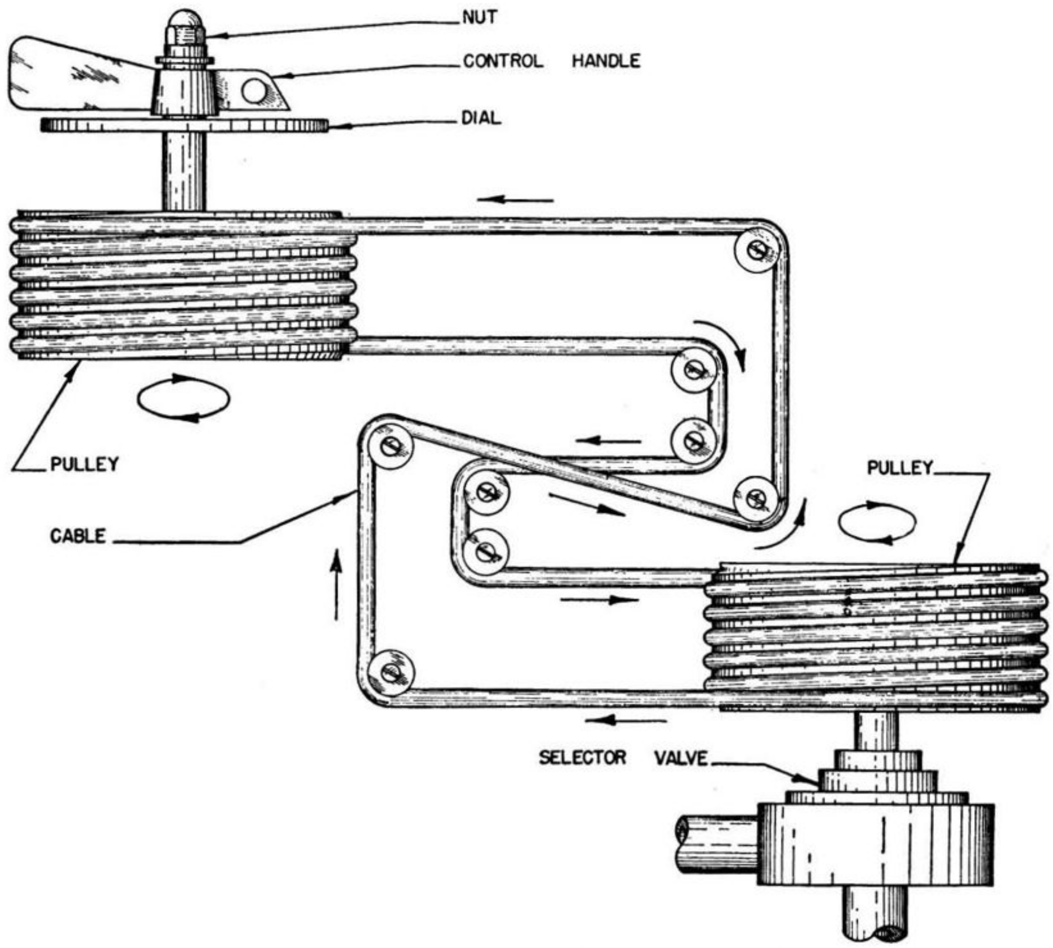


FIGURE 16. Selector valve control cables.

with several universal joints, gear boxes, etc. Excessive "drag" or friction in the fuel cock is indicated by stiffness and binding of the control and failure to hear the "click" or "feel" of the engagement when the indicator handle is turned. This is usually caused by excessive drag in the fuel cock or gear boxes, or by interference of the cables or rods with other parts.

g. Strainers. The main strainer is installed in a fuel system at the lowest point and its function is most important. This function is to prevent dirt or other foreign material from entering the fuel pump and carburetor. Because of its relatively low position in the system, any small amount of water present in the system will be trapped. A drain is provided at the bottom for frequent draining, and the entire screen may be easily removed for cleaning. The sectional view in figure 17 indicates the construction. Gasoline for the priming system is sometimes taken from the main strainer. Finger screens are used also at the fuel-tank outlets and the carburetor inlet, which provides for additional filtration of the gasoline.

h. Primers. A primer delivers gasoline to the engine to assist in starting. Two types are used at the present time: the manual and the electric.

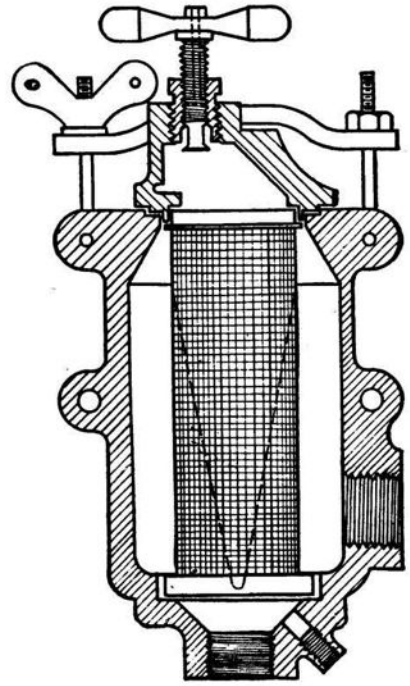


FIGURE 17. Fuel strainer with a drain.

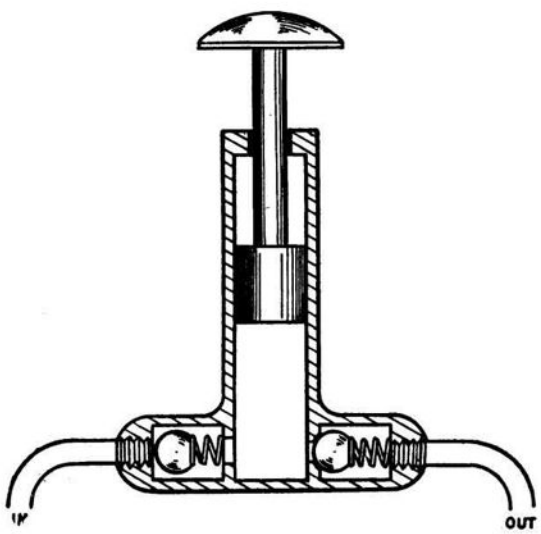


FIGURE 18. Manual primer.

(1) The manual primer (fig. 18) is essentially a single-acting piston pump with inlet and outlet check valves. Fuel may be supplied to the primer from almost any point in the fuel system. When the pump discharges gasoline, a priming distributor divides the flow among the cylinders to be primed.
(2) The electric primer used on some carburetors incorporates a solenoid-operated plunger, controlled by a switch in the cockpit. When the

primer is operated, the plunger opens a passageway allowing fuel to flow from the carburetor to the engine under pressure from the hand pump or fuel booster pump. The procedure to be followed in priming engines varies according to the type of engine and the atmospheric temperature; however, past experience with a particular engine will determine the amount of priming necessary. When not in use, the primer must be in the "off" position.

i. Hand pumps. The hand pump, or "wobble" pump, serves two purposes: it builds up sufficient fuel pressure for starting; and it acts as an emergency unit in case of engine pump failure. The pump is operated remotely by control rods or cables from the pilot's compartment. The common design is very reliable and quite simple in operation. The path of fuel flow may be determined by reference to figure 19. It will be

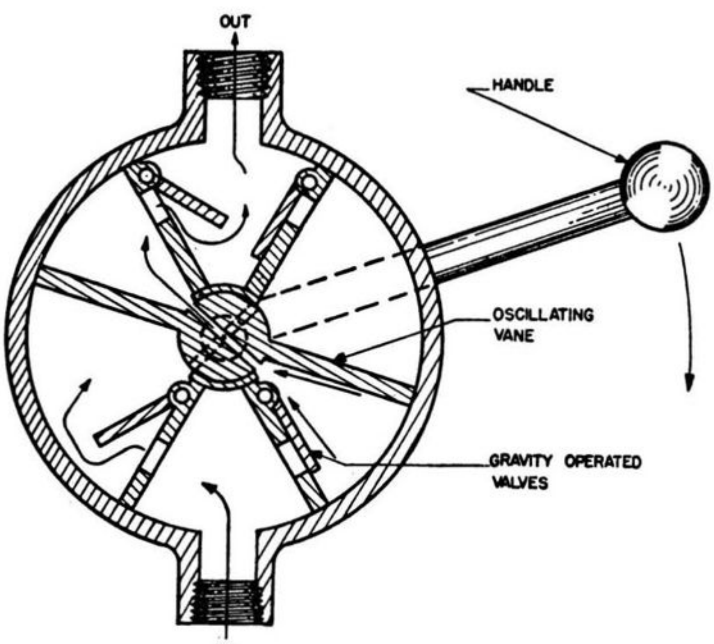
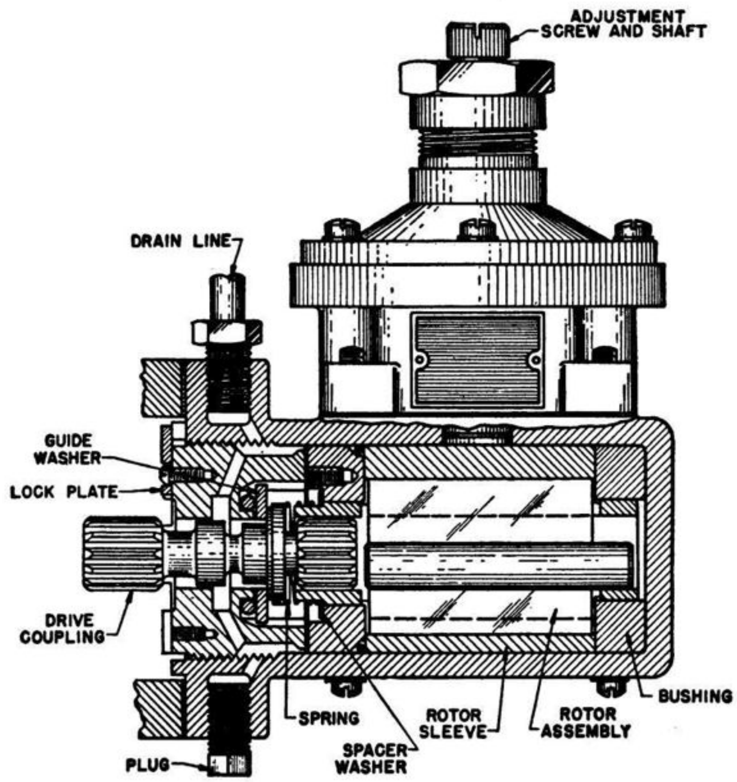


FIGURE 19. Hand or wobble pump.

noted that the chambers which are not delivering fuel are being filled, and will discharge when the handle motion is reversed. Therefore, a discharge of fuel is obtained when the pump handle is moved in either direction. These pumps may be installed in a vertical position to insure proper action of the gravity-operated valves. Caution should be exercised during operation of a hand pump to prevent creation of excessive fuel pressure and the possibility of a fire hazard. In most installations, relief valves are included in the system to prevent such a condition.

j. Fuel pumps. (1) Fuel pumps are driven by various means, but the principle of operation remains the same. The type most frequently used is the eccentric sliding-vane type (fig. 20). When the rotor is turned in the direction indicated, the vanes carry fuel from the inlet to



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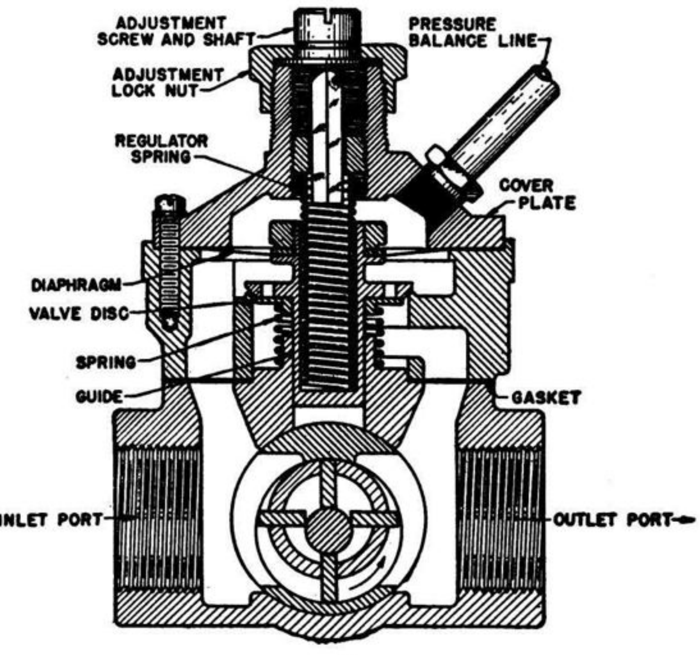


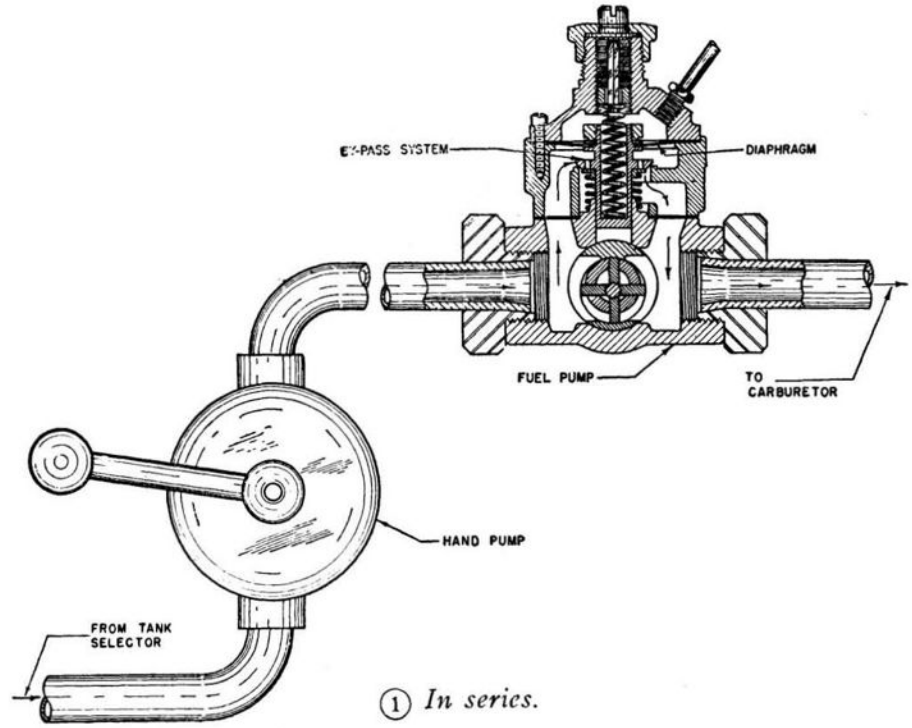
②

FIGURE 20. Vane type power-driven fuel pump.

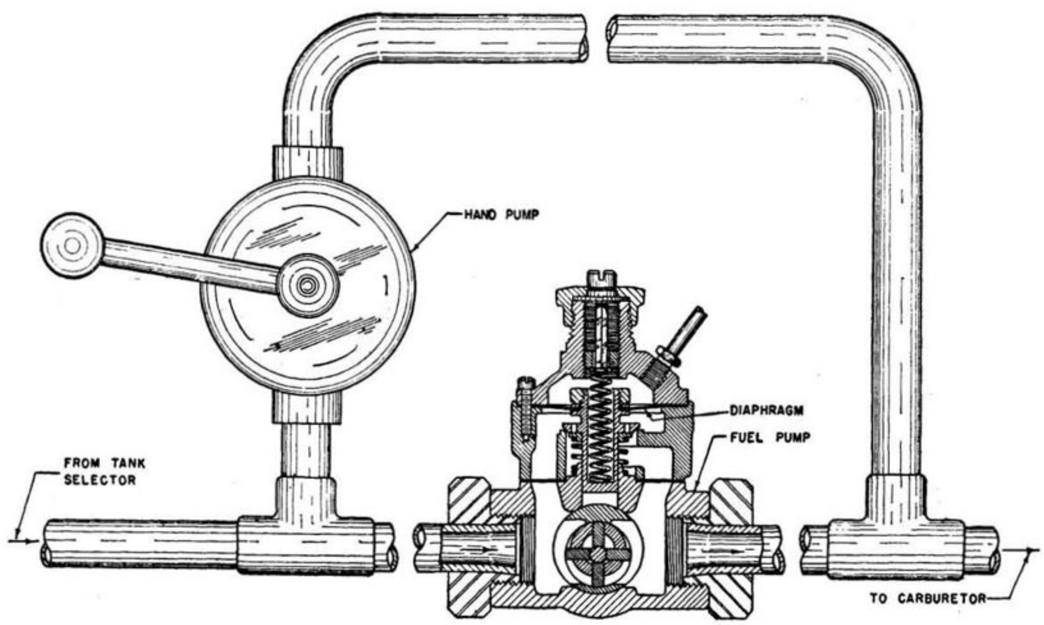
the outlet of the pump, the discharge being under pressure and in sufficient capacity to provide more fuel than the engine demands. Therefore, these pumps are said to be of "positive displacement." Since the pump

is symmetrical about a vertical axis, it will pump in the other direction with equal efficiency, if the direction of rotation is reversed. At the point where the drive member enters the pump body, there is a seal to prevent leakage. This consists of a steel seal, backed up by a neoprene seal cushion held by end pressure against one pump bearing, or a diaphragm type seal. A tap is provided to drain fuel in case of a leak at the seal. Lubrication is required for the drive member to reduce wear.
(2) To furnish a constant fuel supply to the carburetor under all conditions, a fuel pump is designed to deliver much more fuel at any speed than the engine actually requires. Therefore, a spring-loaded relief valve is placed in parallel with the pump so that surplus fuel may be directed to the intake side of the pump. By adjustment of the spring tension in the relief valve, the differential pressure generated by the pump is accurately controlled. The diaphragm in the relief valve is essential for two reasons: it provides venting to supercharger pressure or to the atmosphere; and by its balancing action, it helps to maintain a constant discharge pressure regardless of variations in pressure on the suction side of the pump.
(3) In order that the fuel will be maintained at a constant pressure above the pressure entering the carburetor, the relief valve must be vented to the atmosphere, or to the carburetor intake if a supercharger is employed. Failure to vent the valve to supercharger pressure would result in reduced fuel pressure at high altitudes. When connected to the atmosphere, the vent must be kept open at all times to prevent variation of fuel pressures. When properly connected in a system, one relief valve will accommodate both the hand pump and the engine pump. In certain installations, a separate or external relief valve is used. Its operation and adjustment are similar to those of the types of valves in the engine pumps.
(4) When the hand pump or booster pump is connected in series with the engine pump, it becomes necessary to provide a bypass system in the engine pump. This allows gasoline to be sent under pressure from the hand pump to the carburetor when the engine pump is inoperative. The bypass system is composed of either a swing check valve or a check plate directly under the relief valve face. The bypass system will function only in a series fuel system. Figure 21 shows the fuel flow in a series and in a parallel circuit when the hand pump (or booster pump) is operated.

k. Warning signals. (1) In an airplane having a number of fuel tanks, there is danger of allowing the fuel supply in one tank to become exhausted before the selector valve is switched to another tank. The pilot may be engaged in other duties and fail to notice the low fuel supply until the engine misfires from a lean mixture. Immediate action is required to prevent complete engine failure. To eliminate this danger, fuel-pressure warning signals are employed.



① *In series.*



② *In parallel.*

FIGURE 21. Connection of hand and engine-operated fuel pumps.

(2) The actuating mechanism of the warning signal is a diaphragm, vented to fuel pressure on the lower side and to either atmospheric pressure or external supercharger pressure on the upper side. A stud fixed to the diaphragm carries a movable contact point. A stationary contact point attached to the housing is located close to the movable point. (See fig. 22). These contacts are in turn connected to a source of power and

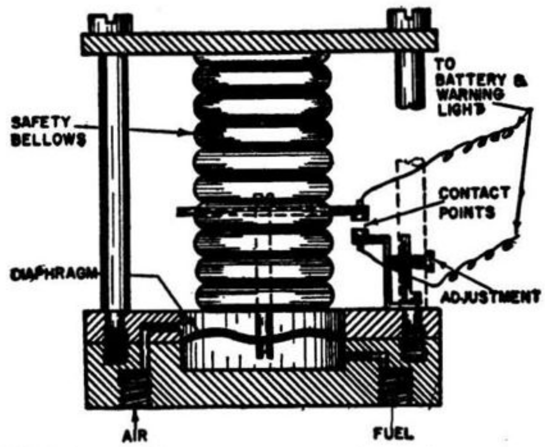


FIGURE 22. Fuel-pressure warning signal transmitter.

to a warning light in the pilot's compartment. During normal engine operation, the fuel pressure is sufficiently high to keep the contact points separated so that the warning light remains off. When a serious loss of fuel pressure occurs, the points close and the warning light calls the pilot's attention to the low fuel pressure.

(3) The signal switch is installed between the fuel-pressure gauge and the carburetor, approximately on the same level to eliminate pressure errors. Restrictor fittings, such as those used in the fuel-pressure gauge line, must not be installed between the carburetor and the warning signal switch. The switch is most effective when used with float-type carburetors, which store a small amount of fuel in the supply chamber. Carburetors which require continuous pressure to discharge the fuel will cut out very quickly after the initial drop in fuel pressure, and therefore in such systems the warning signal does not give adequate warning of fuel system failure. This undesirable feature is eliminated when a unit known as an air-vapor control valve is used with a vapor eliminator. These two units are discussed in **l** and **n** below.

(4) Failure to vent the air chamber to external supercharger pressure (if used) would result in a delayed warning or the possibility of getting no warning of a loss in fuel pressure. When an external supercharger is not employed, the vent is left open to the atmosphere. It is also important to maintain the proper setting of the signal switch, and this must be checked frequently. The stationary contact point can be adjusted to vary the pressure at which the warning light comes on.

(5) Fuel-level warning signals are also used on some airplanes. With these instruments, when the fuel level is sufficiently reduced, the float arm in the tank makes a contact which completes a circuit leading to the pilots warning light. The warning switch is integral with the tank unit of the electric fuel-quantity gauge. Thus the pilot receives direct indication that his fuel supply is becoming exhausted.

l. Fuel-pressure gauge. (1) A fuel-pressure gauge indicates to the pilot the actual fuel pressure available at the carburetor inlet. This gauge measures the difference in pressure between the air entering the carburetor and the fuel entering the carburetor at their respective inlets. The air connection of the instrument case is vented to supercharger pressure or to the atmosphere, and the fuel connection is made to the fuel inlet of the carburetor. The air vent must be properly connected if a supercharger is employed; otherwise, at higher altitudes erroneous readings will result.

(2) A restrictor is located on the pressure-gauge side of the warning signal in order to prevent fluctuation of the fuel pressure-gauge pointer. Fuel-pressure indications are constant checks on the operation of the complete system; therefore, frequent observation of the instrument is advisable.

m. Vapor eliminator. (1) In many fuel systems, fuel vapor is often present in the fuel line to the carburetor. The vapor forms chiefly because of the action of the fuel pump, especially when the pressure on the pump inlet is low, also at high fuel temperature and altitude. A float type carburetor is not disturbed to any great extent by a small amount of fuel vapor, because the float-chamber vents permit the vapor to escape. However, many high-pressure carburetors will malfunction when there is vapor formation. To remedy this condition, vapor eliminators are employed. The eliminator is located between the fuel pump and the carburetor, and actually it accomplishes two purposes: it purges the system of air and fuel vapors, and it maintains a small reserve of fuel to supply the carburetor for a short period when the fuel tank supply has diminished and tank switch-over is being accomplished.

(2) The operating mechanism of the unit is a float-and-needle valve. During operation, the upper part of the housing contains a quantity of air and vapor and the lower part contains fuel. When the vapor content increases, the float drops slightly, opening the needle valve and permitting some vapor to escape. As the vapor escapes, the liquid level rises and the float closes the needle valve to prevent loss of fuel. The needle-valve operation is generally rather intermittent but entirely effective in disposing of fuel vapors. The vapors are returned through a vent connection or to a fuel tank (see fig. 23).

(3) Since the vapor eliminator is generally used with a high-pressure carburetor, sufficient fuel-feed pressure to the carburetor must be maintained while the eliminator is purging the system of vapors. The purging operation normally would interrupt the high fuel pressure to the carburetor, and for this reason a pressure-limiting device (air-vapor control valve) is installed in the vapor vent line from the eliminator.

n. Air-vapor control valve. (1) In high-pressure carburetor installations the air-vapor control valve is used with the vapor eliminator. The valve preserves a predetermined pressure in the system during the purging operation of the vapor eliminator. Also, when the fuel becomes

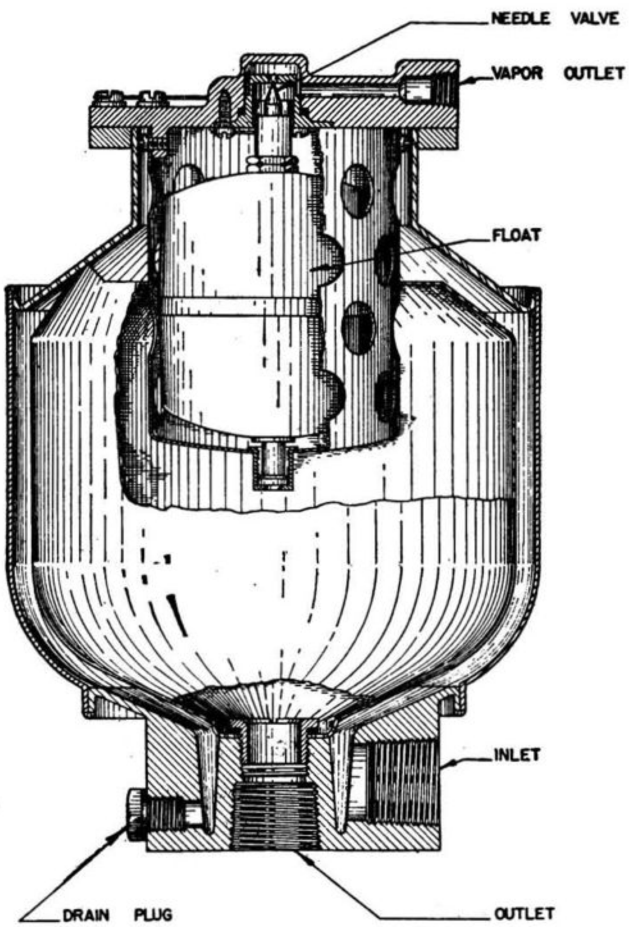


FIGURE 23. Fuel vapor eliminator.

low, the valve allows the warning signal to operate, but at the same time maintains sufficient pressure on the fuel going to the carburetor to allow a short period of continued engine operation. The pilot naturally must turn to a tank containing fuel as soon as possible after the warning light operates.

(2) The control valve is located in the vapor vent line between the vapor eliminator and a fuel tank. It consists of a bellows and a valve, with a spring adjustment similar to that of a bellows type relief valve. The bellows is vented to either the vapor line to the tank or, if an external supercharger is employed, to supercharger pressure. This venting is necessary in order to keep the setting of the valve independent of pressure or altitude changes. (See fig. 24.)

(3) When the eliminator discharges vapors through the return line to the tank, the normal fuel and vapor pressure is sufficient to keep the vapor control valve off its seat, allowing the air and vapor to be expelled to the tank. When the fuel supply is low, the reduced pressure in the system causes the control valve to close the vapor return line. Air and vapor in the eliminator then exert a pressure on the fuel going to the carburetor, and thus for a short time insure that a supply of fuel under

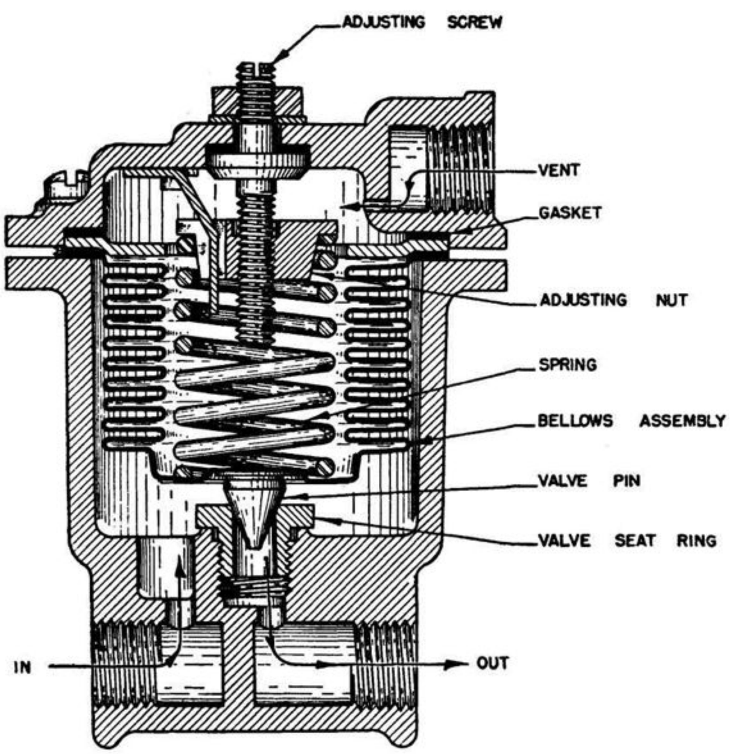


FIGURE 24. Control valve for vapor vent line—closed.

pressure will continue to reach the carburetor. (See fig. 25.) While this is occurring, the fuel-pressure warning signal light will be on, because the setting of the signal light is slightly higher than that of the control valve.

o. Summary. The fuel system units are typical of a single-engine fuel system. Specific installations vary with types of airplanes in service. Figure 26 illustrates a typical single-engine fuel circuit, showing the relative locations of the units and the make-up of the complete system.

13. VAPOR LOCKING IN FUEL SYSTEMS. a. Causes. Vapor locking may be defined as the partial or complete interruption of fuel flow due to the formation of vapor in the fuel-feed system. Because at high altitudes the vapor-locking tendency is increased, aircraft that operate at high altitudes, or that climb rapidly, are especially subject to this effect. There are three general causes of vapor locking: increase in fuel temperature, lowering of fuel pressure, and excessive fuel turbulence or agitation.

(1) High fuel temperatures naturally vaporize some of the fuel. The heat may be due to a number of causes, such as high atmospheric temperature or excessive heat transfer from the engine to the fuel lines or fuel units.

(2) During high-altitude flight, the low atmospheric pressure on the fuel in the tank will result in lowering of the boiling point of the

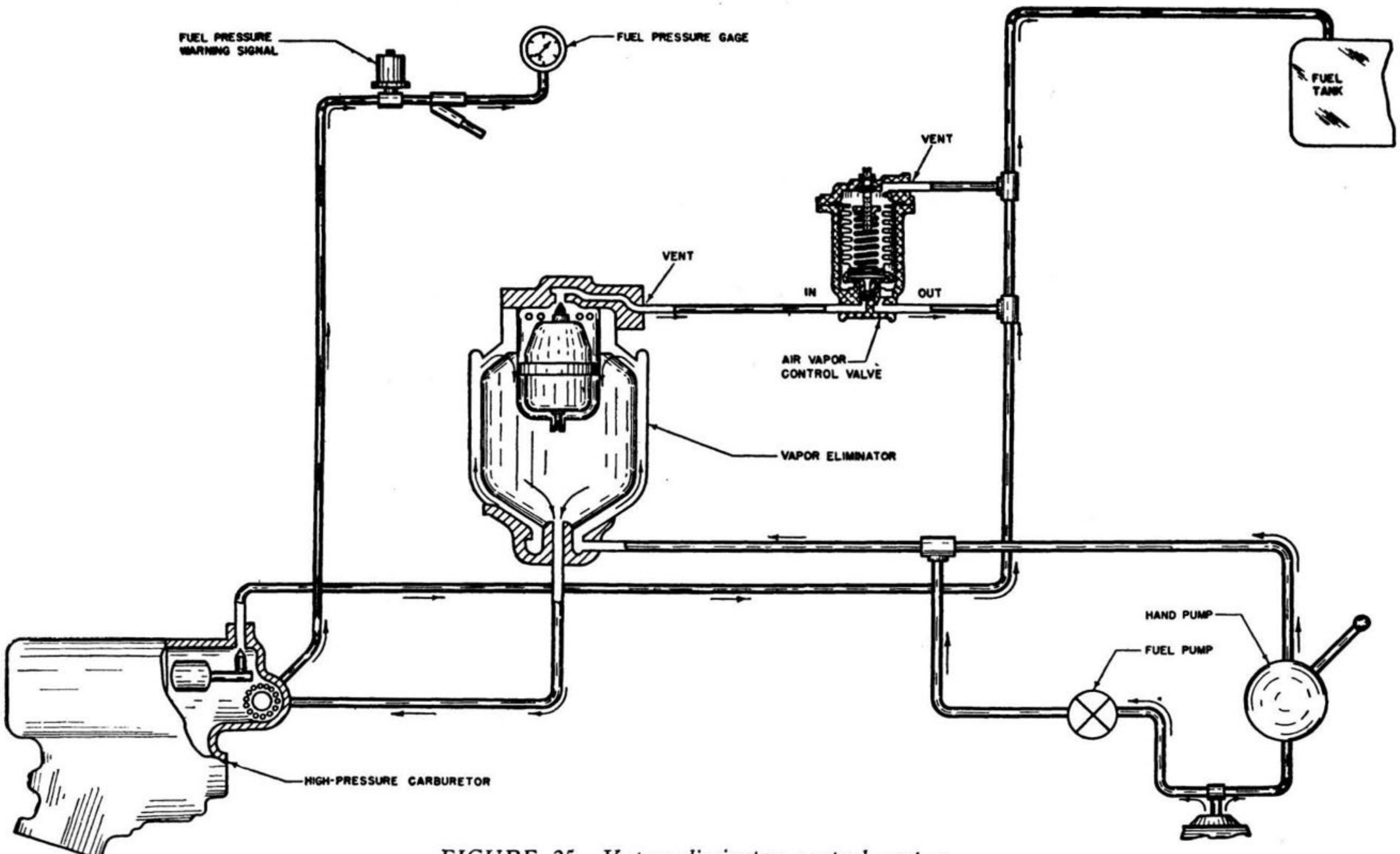


FIGURE 25. Vapor-eliminator control system.

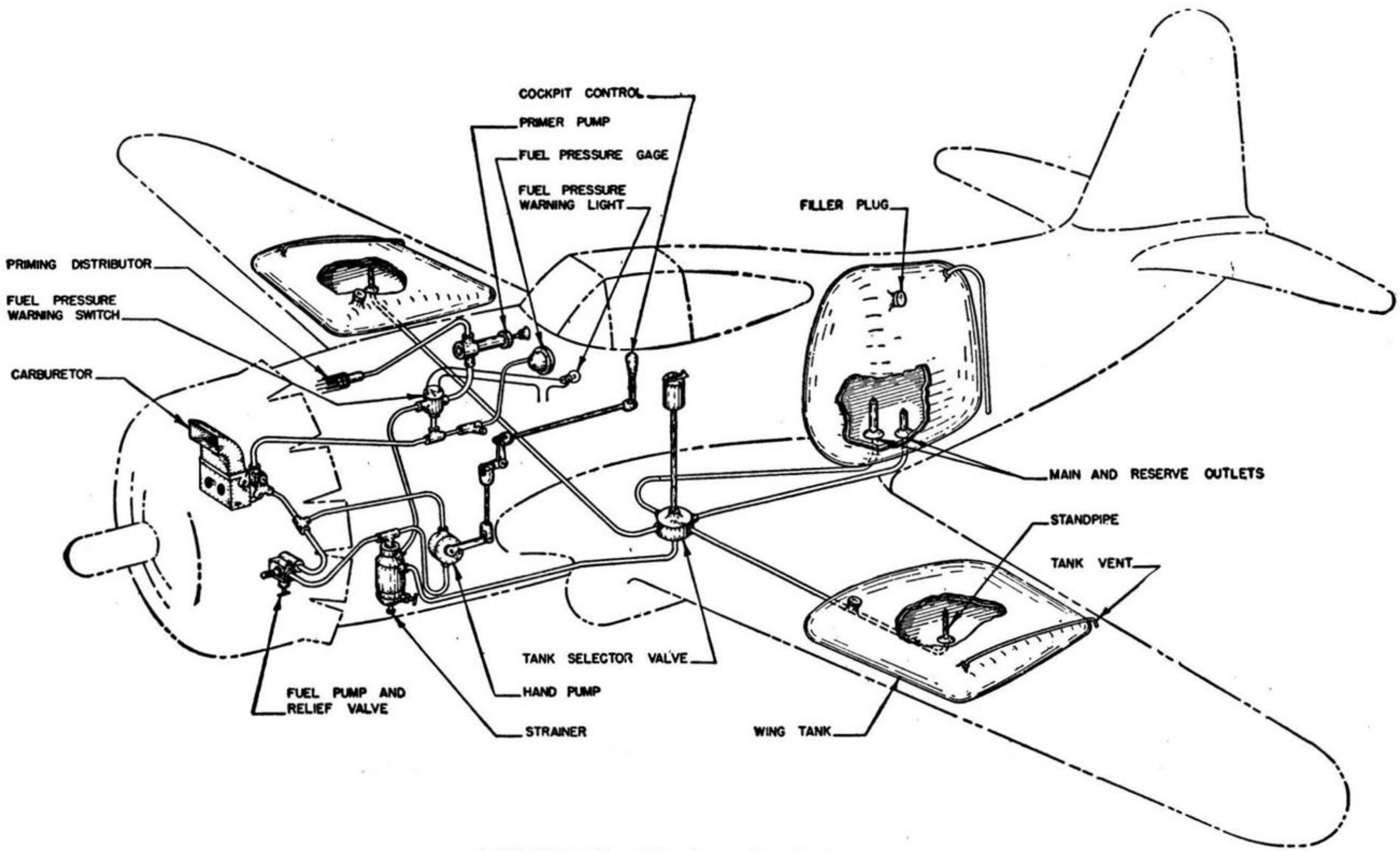


FIGURE 26. Single-engine fuel system.

gasoline and hence an increase in the formation of vapors. Since the fuel line on the suction side of the fuel pump carries fuel under a low pressure, here again there may be a formation and collection of vapors.

(3) Agitation or turbulence of a fuel will result in vapor formation. Agitation generally is caused by the mechanical action of the fuel pump. The constant bypassing of surplus fuel from the high-pressure side of the pump to the low-pressure side, as accomplished by a relief valve, will also cause turbulence.

(4) Vapor locking is likely to be due to a number of causes rather than one. Steps to correct it should be taken accordingly.

b. Effects. The result of vapor locking is in most cases serious, because the performance of the airplane is hampered. Small amounts of vapor in the suction line of a fuel pump restrict the passage of fuel and, if the fuel pump does not receive its proper quantity of fuel, the outlet pressures will be reduced. When this occurs, the amount of fuel entering the carburetor lessens while the airflow through the carburetor remains the same, so that a leaner mixture is delivered to the engine cylinders. In high-pressure carburetor installations this effect is extremely hazardous because of the high fuel pressure required at the carburetor inlet. The vapor formation may be so excessive as to restrict the liquid fuel flow completely and cause stoppage of the engine.

c. Remedies. (1) To prevent excessive heating of the fuel system, the system should be so designed that fuel lines will not be near sources of heat. These lines should have a minimum of bends or rises, which are conducive to vapor-gathering. Locating the fuel pump and relief valve farther from the heat of the engine is another remedy. Although actual fuel cooling may be the ultimate solution, proper fuel-system design is of immediate importance.

(2) The advantage of locating a fuel pump nearer the fuel tanks is two-fold: there is a reduction of heat in the vicinity of the pump, and the line of suction or low pressure is shortened. A fuel pump under the fuel tank does not have to *pull* fuel through the system; instead, from the beginning of the system, fuel is *pushed* through the lines and units, so that the possibility of vapor formation in the inlet side of the system is reduced.

(3) Turbulence around a fuel pump and relief valve may be reduced by utilizing a fuel pump that varies its output accurately to meet the engine demands, or by employing a relief valve that returns surplus fuel to a fuel tank or another part of the system, away from the inlet side of the fuel pump. Fuel systems at the present time are being revised, and others designed, to lessen or eliminate vapor formation.

14. AUXILIARY METHODS OF DRIVING FUEL PUMPS. Locating the fuel pump remotely has certain advantages over mounting it on the accessory section of the engine. First, remote location prevents heating of the fuel pump by the engine. Second, placing the fuel pump nearer the fuel tanks also not only makes possible a gravity fuel flow from some tanks to the inlet of the pump, but shortens the low-pressure line and thus reduces the tendency to vapor locking. Third, a remote drive for any unit reduces the number of accessories located on the rear of the engine. For these and other reasons, fuel pumps are driven by a number of auxiliary methods.

a. Flexible drives. The oldest means for remote driving is the flexible drive. This consists of a spring-steel shaft in a suitable housing, supported by the necessary adapters and couplings. To transmit the driving torque from the engine to the fuel pump at various angles, adapters are employed. The adapters allow for a change in transmission through 45°, 90°, and an extension of 180° (see fig. 27). Generally flexible drives are used when the fuel pump is located at a relatively short distance from the engine.

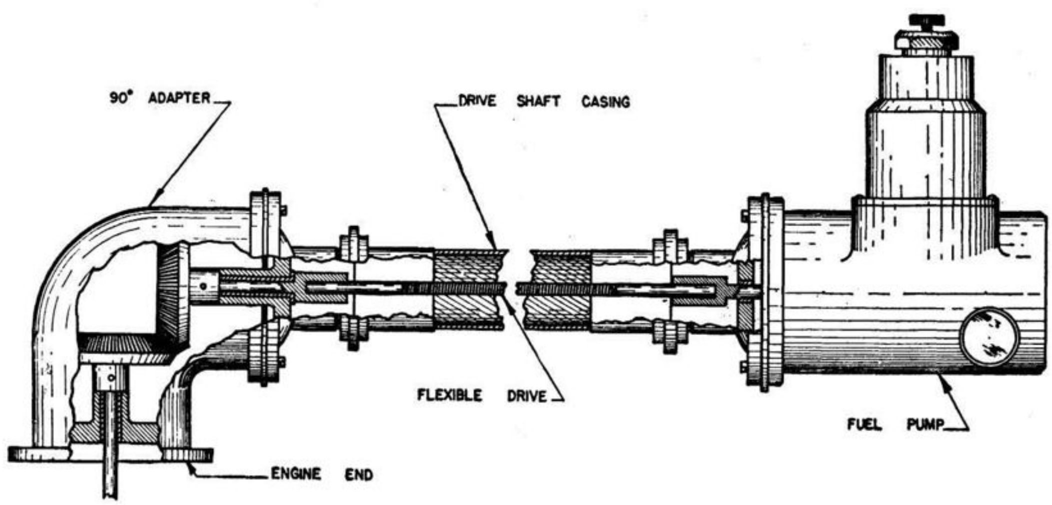


FIGURE 27. Adapter for flexible pump drives.

b. Hydraulic drives. When the fuel pump is located far from the engine, hydraulic drive may be used. Then the fuel pump can be located almost anywhere in the airplane. The hydraulic system used is independent of the main hydraulic system in the airplane. It consists of a reservoir, a hydraulic generator, a pressure-regulating device, and a motor coupled to the fuel pump. Because this system incorporates additional lines transmitting liquid under pressure, the possibilities of leakage and damage from gunfire are increased.

c. Electric drives. The most efficient system now in use is the electric drive. The fuel pump can be located anywhere, even directly under a fuel tank. The conventional sliding-vane type of pump, coupled to an electric motor, may be used. The motor derives its power from a battery or generator, and its operation is controlled by a switch in the cockpit. The wiring involved is not subject to the disadvantage of hydraulic lines.

15. FUEL BOOSTER PUMPS. a. Purpose. A fuel booster pump is used to maintain fuel pressure to the inlet of an engine fuel pump, to act as an emergency pump, and to provide fuel under pressure for priming. This is necessary, particularly at high altitudes, when the pressure on the fuel in the suction side of the engine pump becomes low enough to allow fuel boiling. The booster pump reduces vapor formation. It is mounted at a fuel-tank outlet or on a detachable sump (see fig. 28).

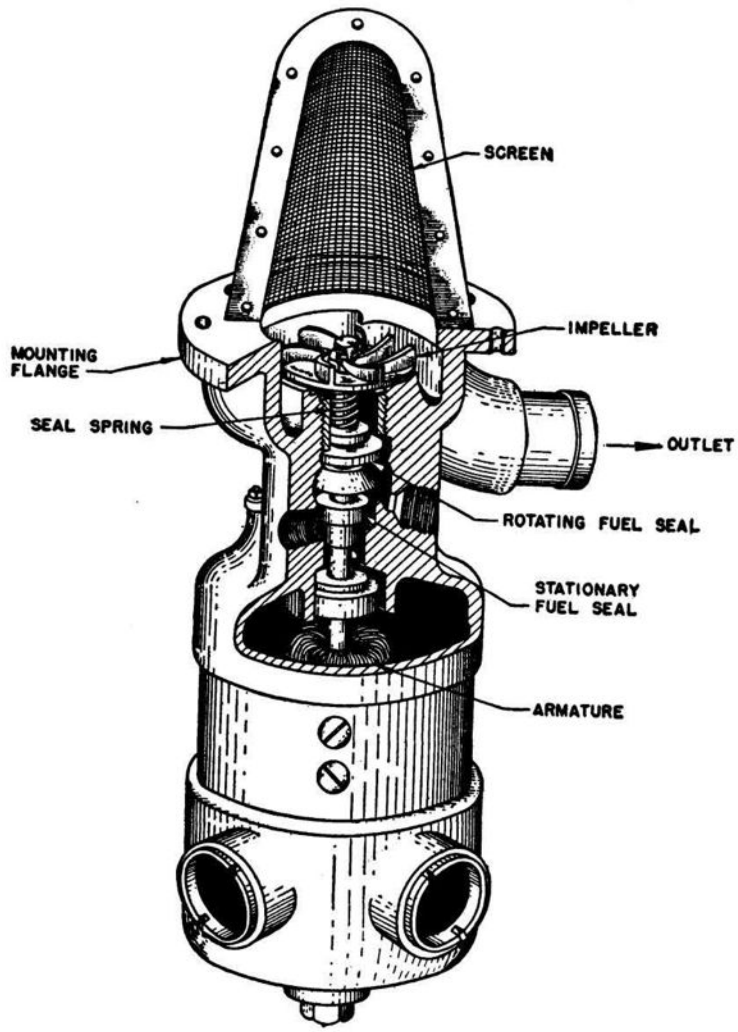


FIGURE 28. Fuel booster pump.

b. Description. The pump is generally of the centrifugal type, built as a unit with an electric motor. Power is obtained for the motor from a storage battery or a direct-current generator in the airplane. A suction drain line must be provided to eliminate any gasoline fumes which pass through the seal from the pump chamber and to insure circulation of air around the motor.

c. Operation. Fuel flows into the booster pump from the tank and, as it enters the rotating impeller, it is thrown out radially at a high velocity. Passing through an outlet tangent to the impeller, it enters the fuel system. This discharge maintains an inlet fuel supply to the pressure pump driven by the engine.

(1) Since a centrifugal pump does not have a positive displacement, no relief valve is necessary. As usual with a centrifugal pump, air and vapors will not pass through, but instead find their way back into the fuel tank. A further advantage of this pump is that it performs the same duties as the hand pump and makes the hand pump unnecessary. Also, booster-pump operation is possible when the engine is not running; and, in an emergency, the output of the booster pump can be made sufficient to supply the carburetor with the proper quantity of fuel at the correct pressure.

(2) The booster pump is used for starting the engine during take-offs and landings, and for emergency operation. It must be used during flight at high altitudes, for then it acts to prevent vapor locking. Specific operating instructions must be followed at all times.

(3) Other types of booster pumps in service do not incorporate the centrifugal impeller. Instead, a conventional sliding-vane pump is coupled to an electric motor near a fuel-tank outlet. This pump is in series with another sliding-vane pump, driven by the engine. The use of the auxiliary pump, like the booster pump, serves to prevent vapor formations in the system. Operation is controlled by a switch in the cockpit.

16. MULTI-ENGINE FUEL SYSTEMS. a. General. The design of a fuel system for an airplane having two or more engines will naturally present problems not normally encountered in single-engine fuel-system design. For example, the multi-engine aircraft will require more and longer fuel lines. Larger fuel capacities are necessary and systems are sometimes incorporated to transmit fuel from one location to another during flight. Vapor locking occurs in this type of system also, and preventive measures must be taken.

b. System arrangement. An outstanding difference between single-engine and multi-engine fuel circuits is in the fuel-tank arrangement. The fuel capacities must be large for multiple engines and long cruising ranges. With long-range aircraft the weight of the equipment to be carried must be considered in relation to the weight of the fuel load. When long flights are to be made, additional fuel tanks may be installed in bomb bays; consequently, the load carried must be reduced. If necessary, the bomb bay tanks can be dropped during flight, so that the fuel load in the airplane will be reduced considerably. Dump valves and jettison systems are used for the same purpose—to eliminate fuel weight in an emergency. In high-flying multi-engine aircraft, booster pumps are used rather extensively. The fuel systems generally include a combination of electric and mechanical drives for the fuel pumps.

c. Transfer and refueling systems. (1) Because of the necessity of large fuel capacities, fuel tanks are located in various parts of the airplane, for example, in the inboard and outboard sections of the wings, in the fuselage, or in the bomb bays. As a result, it is often necessary to include a fuel-transfer system to shift the fuel loads between the tanks, to avoid unbalance. Also, the fuel supply can be transferred when the fuel becomes low in some of the tanks. In certain installations, it is necessary to transfer fuel before it can be sent through the system to the carburetors. The transfer systems employ selector valves, or manual connections must be made; in either case, the fuel is taken from one tank or system and deposited in another. An electrically or hydraulically operated pump is used to effect this transfer (see fig. 29)

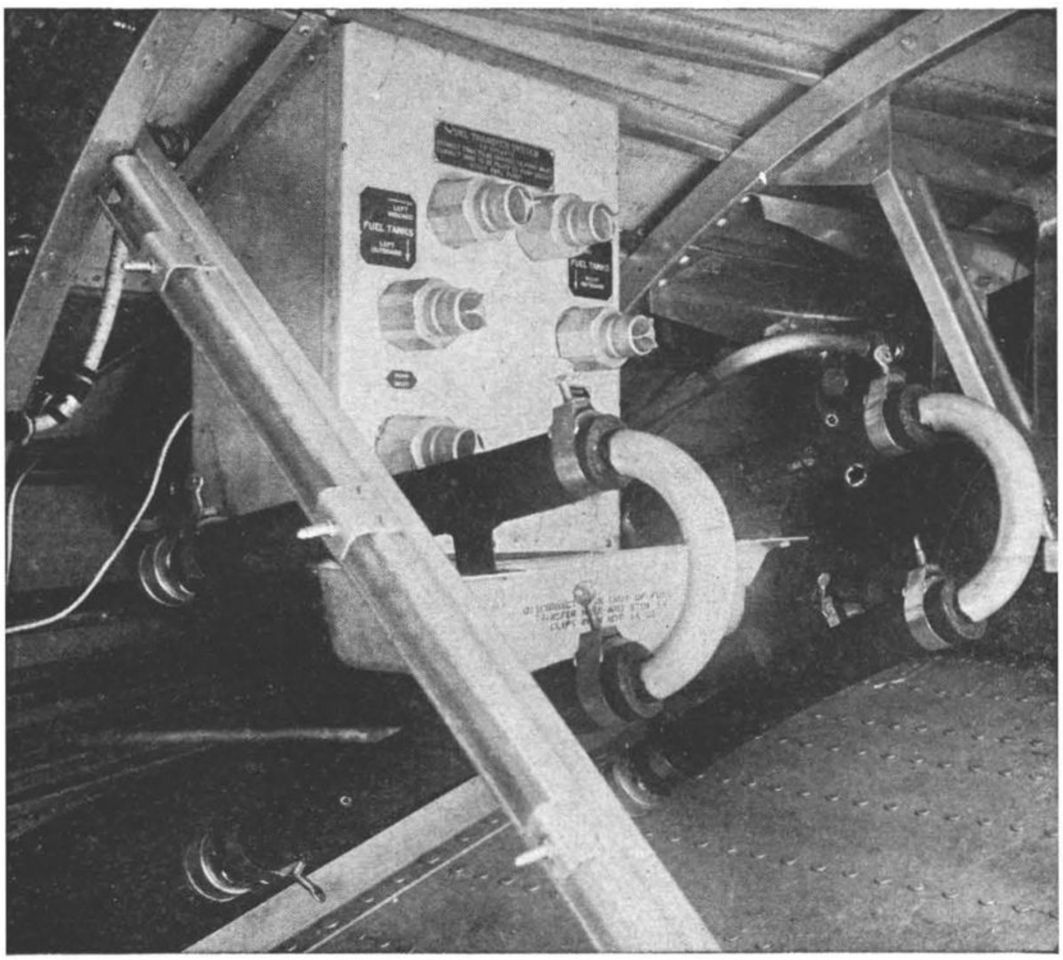


FIGURE 29. Fuel transfer pump.

(2) Refueling systems are sometimes installed to allow for servicing of the fuel tanks, particularly from an outside source, such as a drum

of gasoline. Specific operating instructions must be adhered to when transfer or refueling systems are operated because the arrangements of fuel circuits are so varied.

d. Cross-feed systems. To interconnect the two fuel systems of a twin-engine airplane, cross-feed systems are often used. (See fig. 30.) There are actually two cross-feed systems, one connecting the suction (inlet) sides of the fuel pumps and one connecting the pressure sides. To differentiate more clearly between them, they are often referred to as cross-suction and cross-pressure systems. It is possible with a cross-suction system to supply two engines with fuel from the same tank. This would be necessary in case of damage to tanks or, in some instances, lines. The cross-pressure circuit will supply two engines with fuel under pressure when one pump or a line fails. Four-engine airplanes do not always require cross-feed systems, because of provisions made for the transfer of fuel. (See fig. 31.)

e. Engine selector valves. To direct fuel flow to either of two engines or to both engines, engine selector valves are often used. This type of valve is more often used in starting, or in an emergency such as fire or line failure. Generally, four-engine systems are so designed as not to require engine selector valves.

17. OPERATION. Details as to the operation of the fuel system on a particular airplane are found in Technical Orders. The following instructions apply only generally.

a. During ground operation, the tank selector valve should be placed in all tank positions and set by the click-and-feel method with the engine operating, as a check on the fuel flow from each tank. The fuel-pressure gauge reading should be observed and the pressure adjusted if necessary. The signal light is checked for proper operation. The liquidometer indications are accurate only in the level-flight position. In multiengine airplanes, each system is checked separately with the cross-feed valves in the "off" position.

b. Take-off is accomplished with the fuel selector valve turned to the tank which is known to contain an adequate fuel supply. When both main and reserve fuel supplies are carried in the same tank, the fuel valve will be placed in the "reserve" position prior to take-off. When fuel tanks are switched in flight, the selector valve is moved to the proper position, and if any fluctuation in fuel pressure is observed, the hand pump or electric booster pump may be used. Under no circumstances should these pumps be operated in such a manner as to create excessive fuel pressure. The same general instructions concerning fuel-system operation apply in landing.

c. During normal tactical maneuvers, most fuel systems are entirely reliable and require no special considerations. However, no standard

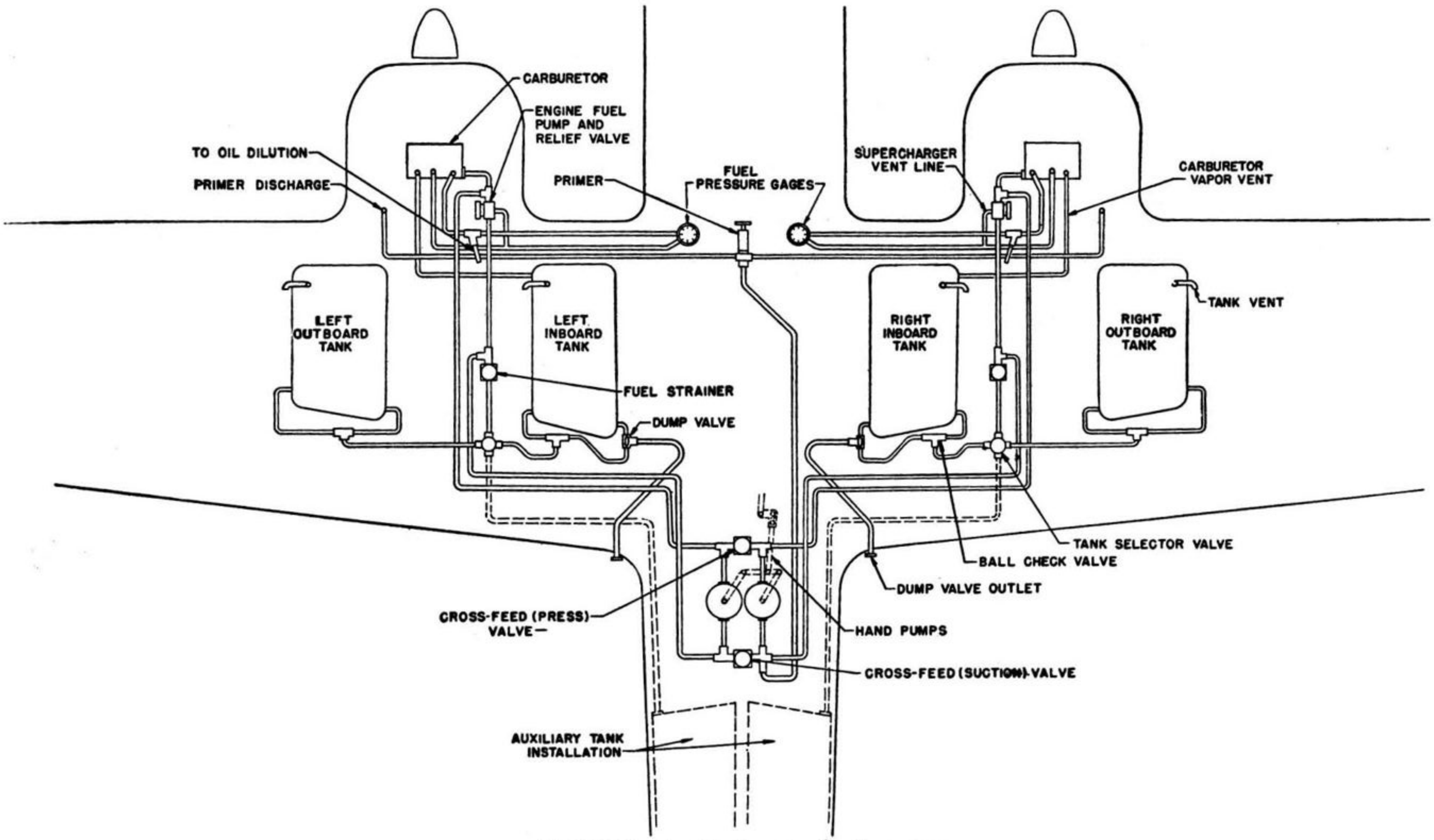


FIGURE 30. Fuel cross-feed system.

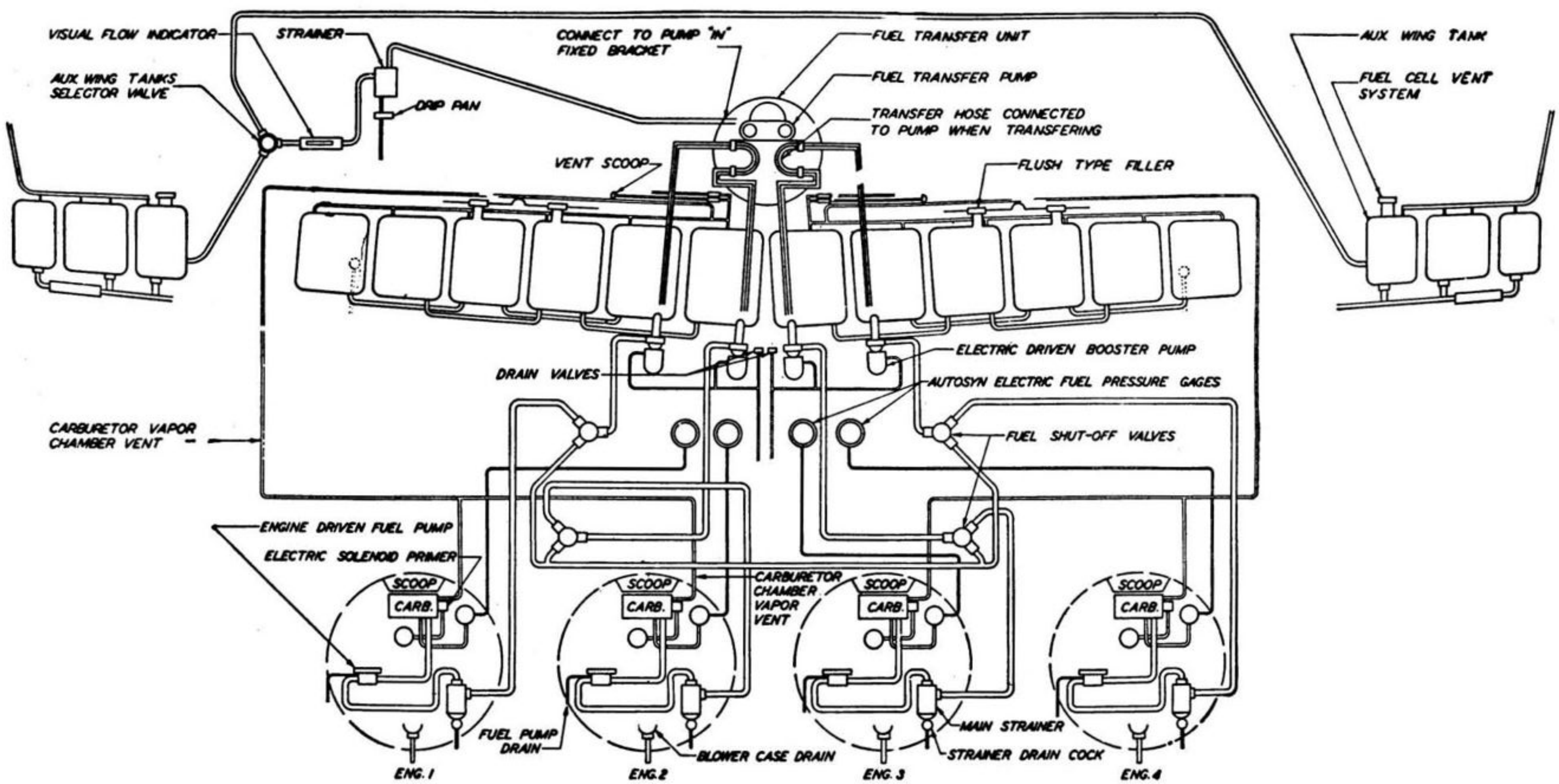


FIGURE 31. *Multi-engine fuel-transfer system.*

systems are designed to function properly in inverted flight or during other unauthorized maneuvers.

18. INSPECTION AND MAINTENANCE. Instructions for inspection and maintenance of a particular airplane fuel system should be consulted in Technical Orders. The following instructions apply generally.

a. Tanks. Metal fuel tanks are checked for security of mounting, dents, and leaks. Vent-line openings are checked and the sumps are drained periodically. The corrosion inhibitor, if used, is inspected at specific intervals. Self-sealing tanks are inspected for the following failures:

(1) Diffusion of liquid through the synthetic liner.
(2) Loosening of the seams in the liner.
(3) Loosening of fittings from the liner.
(4) Collapse of the cell.
(5) Leakage between the cell and the surrounding structure.
(6) Mechanical injury by bullets or shell fragments.

b. Inspection of self-sealing tanks. (1) To determine whether the three failures listed **a**(1), (2), and (3) above exist, visual inspection of the interior of the cell must be made. Any leakage or diffusion through the liner will be indicated by soft, swollen areas on the cell surface, wrinkles on the lining material, and separation of the sealing layers from the liner. Leakage to the exterior surface of the cell will not occur except in a very advanced stage, in which the sealing layers of the cell are completely deteriorated.

(2) The collapse of a cell may be determined by conducting a capacity check of the tank and comparing the results with the original capacity marked on the tank filler cap. If a reduction in capacity of more than 5 percent is found at any time, the cell will be removed and thoroughly inspected for the defects listed in **a**(1), (2), and (3) above.

(3) Leakage of fuel or oil between the cell and the surrounding structure may be caused by improper attachment of fittings or partial failure of any tank outlet connection. This failure will be immediately indicated by leakage of fluid to the outside of the airplane, except in the case of cells installed in a sealed structure. In a sealed structure, the first indication of this type of failure will be collapse of the cell.

(4) Inspections requiring the removal of cells are undesirable because of the possibility of inflicting damage. However, at the end of 6 months of service, inspect the interior of each self-sealing tank for indications of failure. This will be accomplished through inspection openings or, if necessary, by the removal of the tanks from the airplane. If evidence of deterioration is found, the affected cell will be repaired or replaced.

c. Repair of self-sealing tanks. (1) The repairs made in the field to self-sealing tanks generally involve the emergency or temporary repair of small bullet holes or swollen areas. Standard plugs are available for this type of repair.

(2) In general, if an inspection reveals a damaged area of over 25 square inches, the cell will be replaced.

(3) When inserting a liner into a wing or fuselage cavity, it must be ascertained that the lining is the correct one for the cavity or shell and that it faces in the correct direction. The cavity or shell must be free of all foreign matter such as loose rivets, nuts, etc. The outside of the bag may be dusted with soapstone or talc to lubricate surfaces and facilitate insertion.

(4) When removing self-sealing cells from the airplane, it is important to distort the cell as little as possible.

(5) Care should be exercised to prevent spilling the fuel on the outside of a cell lining. While the outer layer may be gasolineproof, some outer layers may be seriously injured by prolonged exposure to fuel.

(6) Some tank liners have built-in bulkheads, baffles, or stiffeners, whichever best suit the design involved. When installing, removing, or repairing any liners, do not damage any structures built into the liner.

d. All tanks must be checked for the presence of water which will settle to the bottom and may be circulated through the system. If an excessive quantity reaches the carburetor, it may restrict the gasoline flow and cause engine failure. The following precautions will help prevent this danger:

(1) Keep the water segregators of the servicing equipment in good condition so that water will not be pumped into the airplane fuel tanks.

(2) Fill the fuel tanks as soon as possible after flight to prevent condensation of moisture on the inner walls of tanks.

(3) Drain some fluid from the lowest point in the tank and test for the presence of water; if it is found, drain as much as needed to remove the water.

e. Lines and fittings must be inspected for cracks, proper support, and security of nuts and clamps. Self-sealing lines will be visually inspected for swollen areas.

f. Fuel-cock controls are rotated in order to check for free operation, backlash, and accuracy of pointer indication. If excessive backlash is noted, the entire operating mechanism will be checked for worn universal joints, loose pins, broken drive lugs, etc. Cable controls are checked for worn cables, backlash, and condition of pulleys.

g. Fuel strainers require periodic draining and cleaning of the screens.

h. Hand pumps should operate freely and develop the required fuel pressure. The engine pumps should be checked for security of mounting and proper adjustment of the relief valve. The pump drive mechanism and the flexible drive require periodic inspections and lubrication. Electric booster pumps are inspected for leakage and security. Electrical connections also are checked for condition and security.

i. Fuel-pressure warning signals can be conveniently checked for proper adjustment by operating the hand pump, or the booster pump with the ignition switch on, and observing the pressure at which the light is extinguished. Adjustment is sometimes required in the contact mechanism.

j. Engine primers are checked for free operation and for signs of fuel leakage at the packing. Adjustment or replacement of the packing may be necessary.

k. Vapor eliminators are checked for leaks, tightness of connections, and security of mounting.

l. Liquidometers must be accurate at all tank levels, from the "empty" to the "full" position. Adjustments for range and position are frequently required.

m. Vapor control valves are inspected for security of mounting and for evidence of leaks, particularly at connections.

n. The entire fuel system is carefully inspected for proper safetying, wear, or damage of any description. A final check is made by observing closely the fuel system with the engine in operation.

SECTION IV
CARBURETION SYSTEMS

19. GENERAL. Four processes must occur if an internal combustion engine is to operate: mixing and injecting a combustible charge; compressing this charge; igniting or firing the charge; and exhausting or scavenging the burned gases. The induction of fuel and air into the engine cylinder is a fundamental operation which must be clearly understood in order to obtain a complete understanding of an internal combustion engine, for engine speed, power, and efficiency are regulated principally by the quantity and nature of the charge.

20. CARBURETION PRINCIPLES. a. General. The conventional aircraft engine is a form of heat engine in which the burning process occurs inside a closed cylinder, and in which the energy of the fuel is converted into mechanical work.

b. Fluid pressures. (1) The carburetion system of an internal combustion engine provides for the movement of fluids (liquids and gases) through various passages and orifices. Liquids have a fairly constant volume and density, but gases will expand and contract under changing pressure. For example, a certain volume of air at sea level is approximately twice as heavy as an equal volume at 20,000 feet altitude.

(2) The weight of the earth's atmosphere causes it to exert pressure which acts in all directions. At sea level, this pressure is approximately 14.7 pounds per square inch. Since a mercurial barometer is often used to measure this pressure, it may be expressed as a pressure capable of supporting a mercury column 29.92 inches in height. Pressures are commonly given in pounds per square inch, or in inches of mercury. An absolute pressure includes the atmospheric pressure, whereas a relative pressure is based on the assumption that atmospheric pressure is zero. Fuel pressure gauges, steam gauges, etc., indicate relative or differential pressures.

(3) The relationship between velocity and pressure in a flowing gas must be considered. Common experience proves that any body of material at rest, fluid or solid, cannot be put in motion without applying force, nor can its velocity be increased without applying force. An opposing force must be applied if a body in motion is to have its velocity

decreased, or if it is to be brought to rest. A Venturi tube furnishes an excellent example of the relation between pressure (force per unit area) and velocity in a moving column of air. Examination of such a tube (fig. 32) shows that in equal periods of time, equal amounts of air flow through the section of greater area and the constriction, or section, of reduced area. The air must, therefore, be moving more rapidly at the constriction than it moves in the larger parts of the tube. This can be understood by use of a simple analogy. When men, marching 10 abreast on a street at a speed which permits 100 men per minute to pass a given point, reach an alley where only 5 can march abreast, they must double their speed for the same number to pass a point in the alley in 1 minute. If the area of the Venturi tube is five times that of the constriction, the air will have a velocity five times as great through the constriction as in the larger sections on either side. Since the velocity of air cannot be increased without applying force, that is, without having a greater pressure behind it than ahead, the velocity cannot be decreased without having an opposing force—a greater pressure—ahead. The pressure, therefore, is less in the constriction than on either side. The amount of fluid which passes through a given passage in any unit of time is directly proportional to the velocity at which it is moving, and the velocity is directly proportional to the difference in applied forces. If a fuel discharge nozzle is placed in the Venturi throat of a carburetor, the effective force applied to the fuel will depend upon the pressure reduction in the

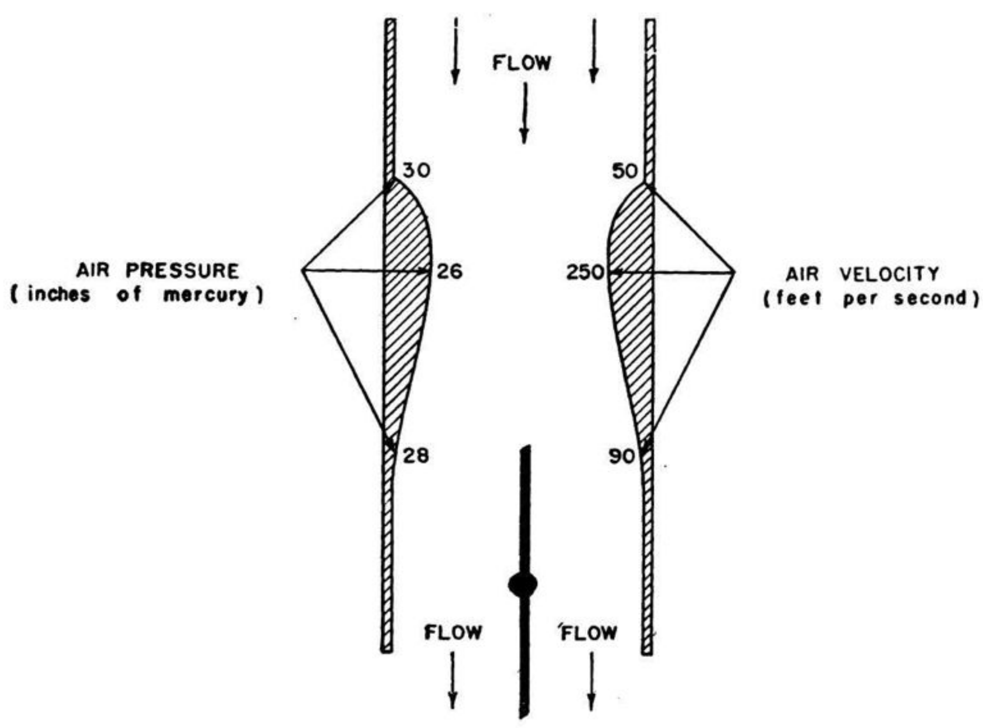


FIGURE 32. Simple Venturi tube.

Venturi, and therefore, upon the velocity of the air going through the Venturi. The rate of flow of fuel through the discharge nozzle will be proportional to the amount of air passing through the Venturi. This supplies the required mixture of fuel and air to the engine. A Venturi type carburetor is so constructed that the ratio of fuel to air may be varied within certain limits by use of controls.

21. FUEL AND AIR MIXTURES. a. Gasoline or other fuels in the liquid state will not burn. However, by uniting air with the fuel, that is, atomizing the fuel, a vaporous charge is formed that is highly combustible. Internal combustion engines are sensitive to the proportioning of the fuel and air charge. Therefore, the mixture ratios must be maintained within a certain range. Gasoline and air mixtures can be ignited in a cylinder when the ratio is as rich at 8 to 1, with the best power range between 12 to 1 and 14 to 1. In fuel-air mixtures, proportions are expressed on the basis of weight, since a volumetric measurement of air would be subject to inaccuracies resulting from pressure and temperature variations.

b. The proportions in a fuel mixture by weight may be expressed as a direct ratio, such as 12 to 1, or as a decimal, 0.083 (1/12-0.083). In either case the ratio is the same, but the decimal is more convenient and is quite often used in the calibration of instruments for indicating fuel-air ratios.

c. The relation between power output and mixture ratios is best illustrated by a curve similar to that shown in figure 33. The mixture strength for maximum power is not one particular ratio but, for practical purposes, any ratio between 0.087 and 0.075 gives approximately the same output. In this case, the 0.087 setting is known as the rich best power mixture, and the 0.075 as the lean best power.

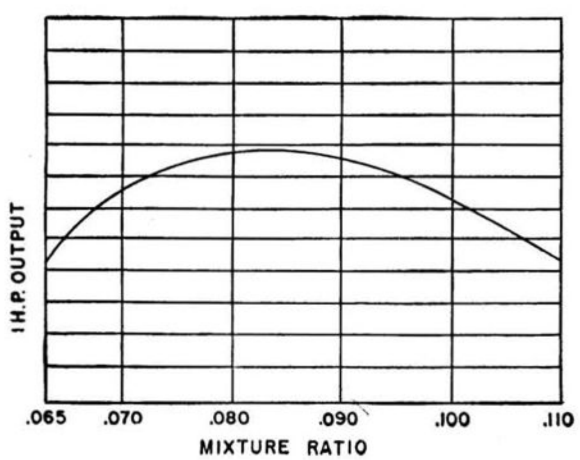


FIGURE 33. Horsepower variation with change in mixture ratio.

d. In order to provide a continuous instrument indication of mixture ratio, a fuel-mixture indicator and exhaust-gas analyzer are sometimes used. The principle of operation of these units is explained in TM 1-413.

e. Although specific instructions concerning mixture ratios are given for each type of engine, generally the rich mixtures should be used at high power output, and the leaner settings are desirable at a lower cruising power. Failure to observe the instructions pertaining to the use of the mixture control may easily result in overheating and detonation, either of which will affect the reliability and useful life of the engine. In case of doubt, a comparatively rich mixture is advisable.

f. Improper mixtures will cause variations in engine performance and in many cases will seriously damage vital engine parts. Excessively rich mixtures are accompanied by a loss of power. Black smoke (free carbon) will appear in the exhaust when a rich mixture is burned, and carbon monoxide, a colorless but poisonous gas, will also be present. Very lean mixtures cause a loss of power, and under certain conditions they will result in serious overheating of the engine cylinders. Lean mixtures must be avoided when an engine is operating near its maximum output, and it is well to observe closely the cylinder-head temperature whenever such mixtures are used. If the mixture is excessively lean, an engine may backfire through the induction system or stop completely. Backfiring is not to be confused with "kick-back", which is merely the tendency to reverse the direction of rotation when starting the engine and is sometimes caused by a highly advanced ignition timing. Pre-ignition gives somewhat the same effect. A backfire is caused by slow flame propagation, so that the charge is still burning when the cycle is completed. This ignites the fresh charge when the intake valve reopens. The flame travels back through the induction system, burning the combustible charge, and often will ignite any accumulation of gasoline near the carburetor.

g. Figure 34 shows graphically the fuel-air mixtures which give best engine performance at all engine speeds—from idling to full rated power. It will be noted that rich mixtures are required at both low and high speeds. At medium speeds, covering somewhat more than half the engine range, fuel may be conserved and good performance procured by using a lean mixture. An engine running near full power requires a very rich mixture to prevent overheating and detonation. Since full power is used only for relatively short periods, the high fuel consumption is not a serious matter.

22. CARBURETORS. a. General. A carburetor is a device which meters (measures) the required amounts of fuel and air and mixes them before they are passed into the combustion chamber. The carburetors

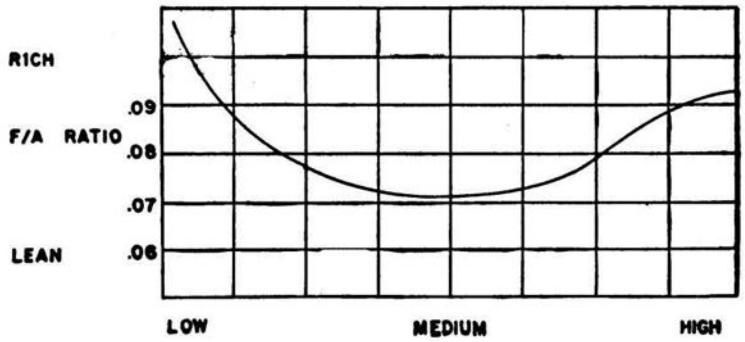


FIGURE 34. Fuel-air ratio and engine performance.

used at present on airplane engines are exceedingly complex. This is the direct result of the need for engine operation under widely diverse conditions. The carburetor must deliver an accurately metered fuel mixture for engine speeds and loads which vary between wide limits, and must provide for manual or automatic mixture correction for changing altitudes and temperature. Numerous accurately constructed and delicately adjusted parts are required in a carburetor assembly.

b. Basic principles. Fuel is transferred in a carburetor system by pressure difference, as described in paragraph 20**b**(3), or by use of some type of pump.

(1) Figure 35① shows a U-shaped glass tube containing a liquid. The liquid surfaces in the two arms of the tube will be even when the

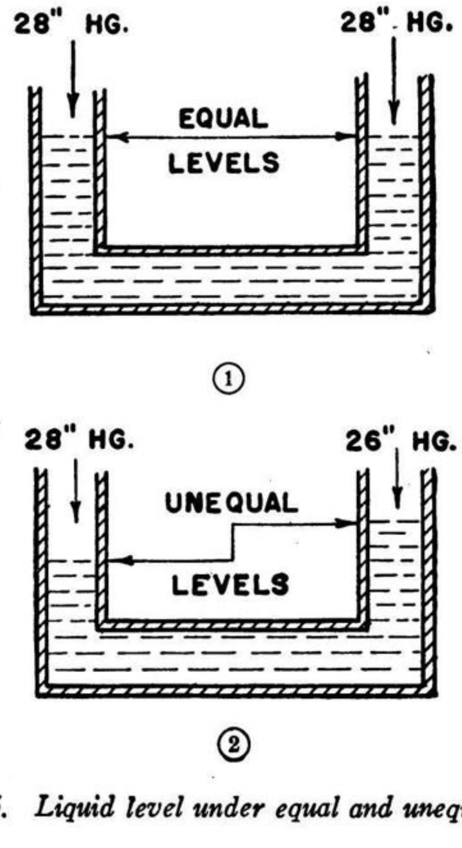


FIGURE 35. Liquid level under equal and unequal pressure.

pressures above them are equal. However, if the pressure in the right-hand arm of the tube is reduced while that in the left-hand arm remains the same, the liquid on the left will be pushed down while that on the right will be raised until the difference in the weights of the liquid in the two arms is exactly equal to the difference in the forces applied at the two surfaces. This condition is shown in figure 35②.

(2) Figure 36 shows the application of this principle in a simple Venturi tube carburetor. The rapid flow of air at the Venturi reduces the pressure at the discharge nozzle so that the pressure in the fuel chamber can force the fuel out into the air stream. This gives a fairly uniform fuel supply at medium and high engine speeds since the air speed in the tube and the resulting reduction in pressure at the nozzle are sufficiently high. However, since the nozzle is slightly higher than the fuel level in the fuel chamber to prevent overflow when the engine is not operating, and since the fuel breaks off in large drops because it tends to adhere to the nozzle, the discharge is very irregular when the engine

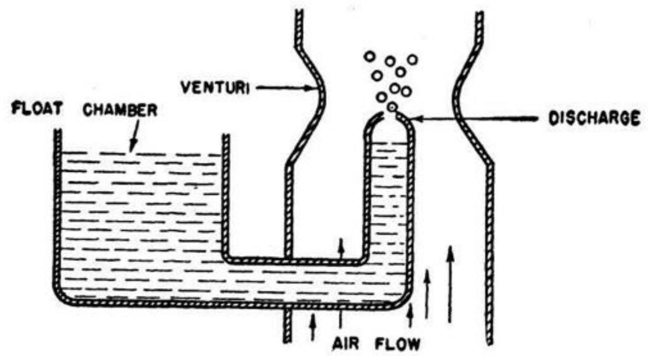


FIGURE 36. Simple Venturi tube carburetor.

speed is low, and the pressure drop is slight. If air is bled from behind the Venturi as shown in figure 37 and passed into the nozzle at a point slightly below fluid level, a finely divided mixture is formed and fed

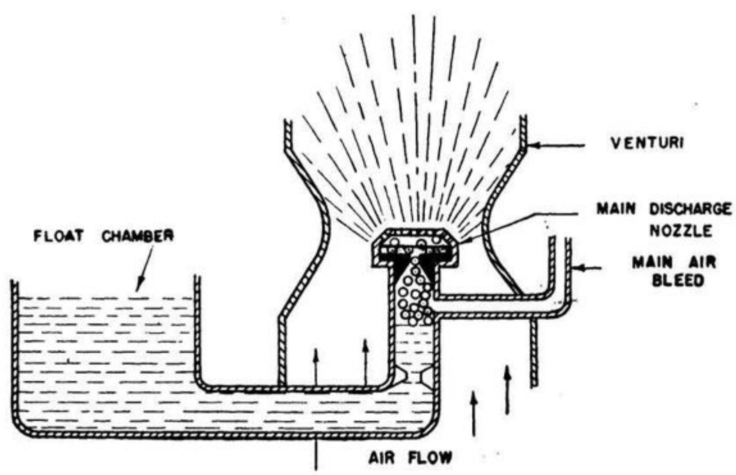


FIGURE 37. Simple Venturi tube carburetor with air-bleed.

into the air stream at the Venturi. A metering jet between the fuel chamber and the discharge nozzle controls the amount of fuel supplied to the nozzle.

(3) A throttle valve, commonly of the butterfly type, is incorporated in the fuel-air duct to control fuel-air output. As the valve is turned toward the closed position, the amount of air flowing through the tube is reduced. The pressure reduction at the Venturi will be less and consequently a smaller amount of fuel will be delivered to the engine. When the throttle valve is opened, the fuel-air flow to the engine is increased. Thus, the power output of the engine may be controlled by opening or closing the throttle valve.

23. FLOAT TYPE CARBURETOR. Atmospheric pressure in the fuel chamber forces fuel from the discharge nozzle when the pressure is reduced at the Venturi.

a. Float mechanism. In normal flight, a float in the fuel chamber operates a valve to close the inlet when the fuel reaches the required level. If the fuel is at the correct level, the discharge rate is controlled accurately by the amount of air flowing through the carburetor.

b. Idling system. At idling speeds, the air velocity in the Venturi is very low and the simple Venturi type carburetor shown in figure 37 does not deliver sufficient fuel to operate the engine. When the throttle is nearly closed, air velocity is high and pressure very low between the edges of the butterfly valve and the walls of the air passage. For this reason, an idling system is added with an outlet at the butterfly valve as shown in figure 38. This delivers fuel only when the valve is nearly closed and the engine running slowly. An idle cut-off valve (not shown in fig. 38) stops flow of fuel through this system when the engine is to be stopped. At idling speeds, the engine may not have sufficient air flow past the cylinders to cool it properly, so an increased amount of fuel is used in the idle range for engine cooling.

c. Economizer system. To obtain maximum economy in fuel consumption, the leanest mixture which will maintain maximum power at a desired rpm should be used. An economizer is essentially a valve which is closed at cruising speed, but is opened to provide an enriched mixture for high speed operation. Figure 39 shows a type which is opened by the throttle when it reaches a predetermined position. The type shown in figure 40 has a bellows which is compressed when the supercharger speed produces pressures above a certain value. The valve is opened by the movement of the bellows.

d. Accelerating systems. When the throttle is opened suddenly, there is a rapid increase in air flow through the carburetor. The increase in fuel flow lags behind and a lean mixture results temporarily. This may

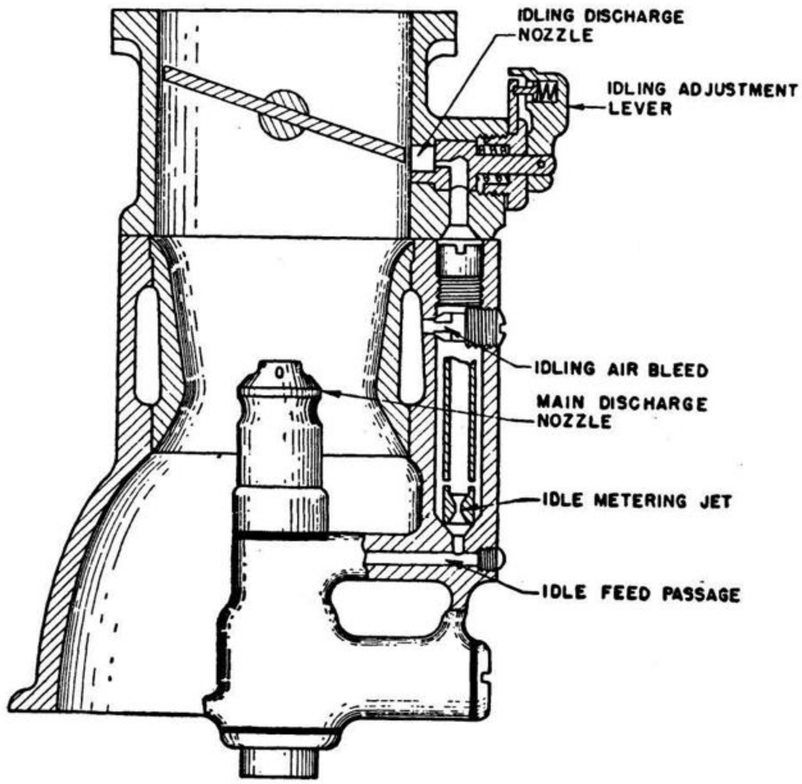


FIGURE 38. Carburetor with idling system.

cause backfire or faulty engine operation. Accelerating systems are now incorporated in all carburetors. Common types are shown in figures 41, 42, and 43. They are simple piston pumps operated by the throttle

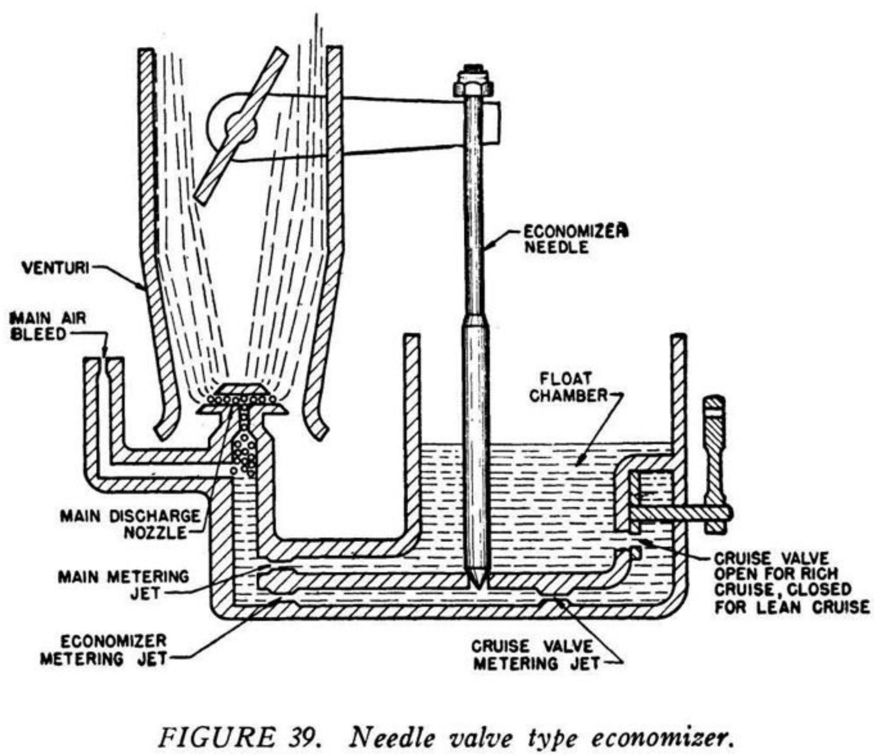


FIGURE 39. Needle valve type economizer.

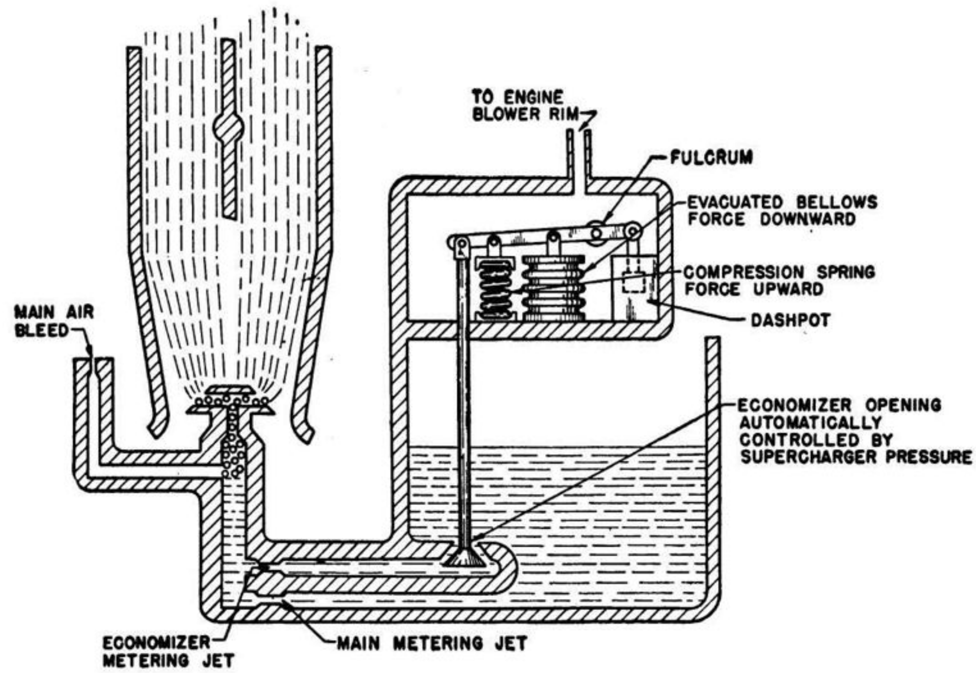


FIGURE 40. Manifold pressure-operated economizer.

control. When the throttle is closed, the piston moves back and fuel fills the cylinder. If the piston is opened slowly, the fuel seeps past the cylinder back into the fuel chamber. When it is opened rapidly, the extra charge of fuel forced through the passage to the nozzle enriches the mixture. In the type shown in figures 41 and 42 the spring forces the piston to close after a few seconds, so the accelerating fuel supply is available

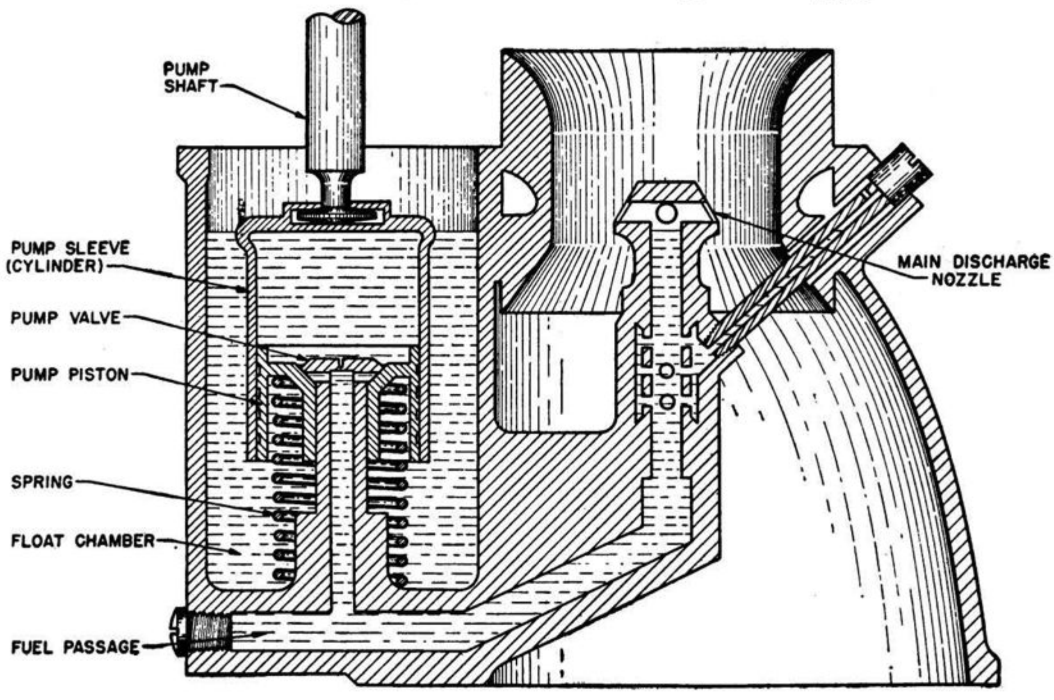


FIGURE 41. Accelerating pump—movable cylinder.

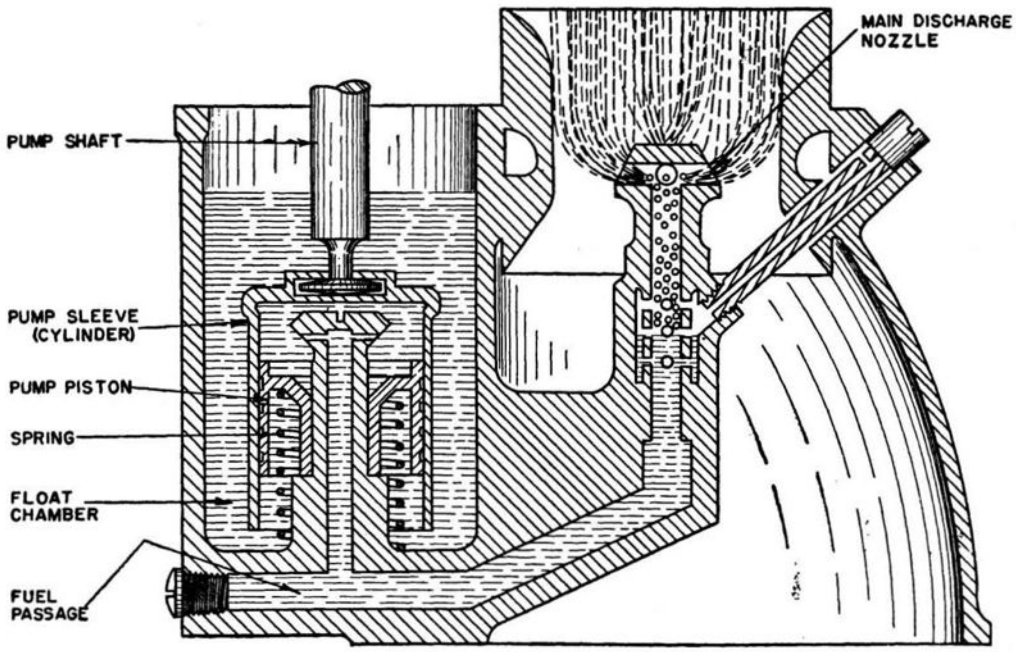


FIGURE 42. Accelerating pump—operating.

only during the time required for the engine to accelerate. Figure 44 shows a two-pump type accelerating system for use on a high-output engine.

e. Mixture control systems. The fuel-air mixture tends to become too rich for normal operation at high altitudes where air density is low. Lean mixtures also conserve fuel during cruising. Mixture control systems have been produced to regulate the richness of the mixtures entering the engine.

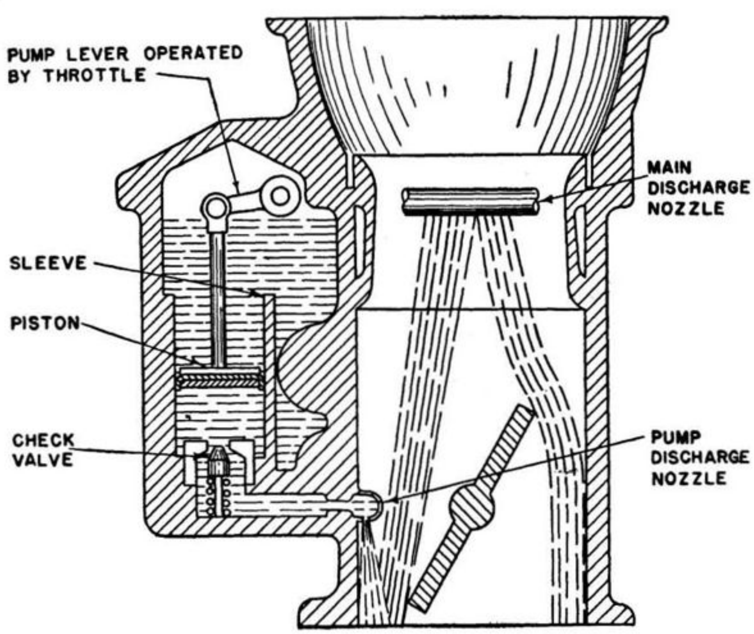


FIGURE 43. Accelerating pump—stationary cylinder.

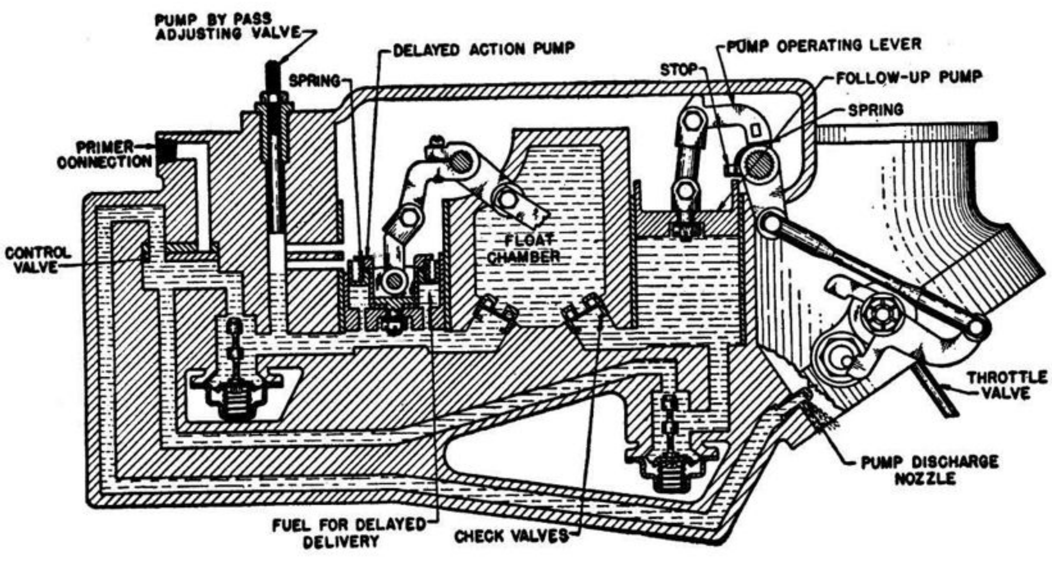


FIGURE 44. Two-pump accelerating system.

(1) Figure 45 shows a needle type mixture control. The needle valve is lowered when a leaner mixture is desired.

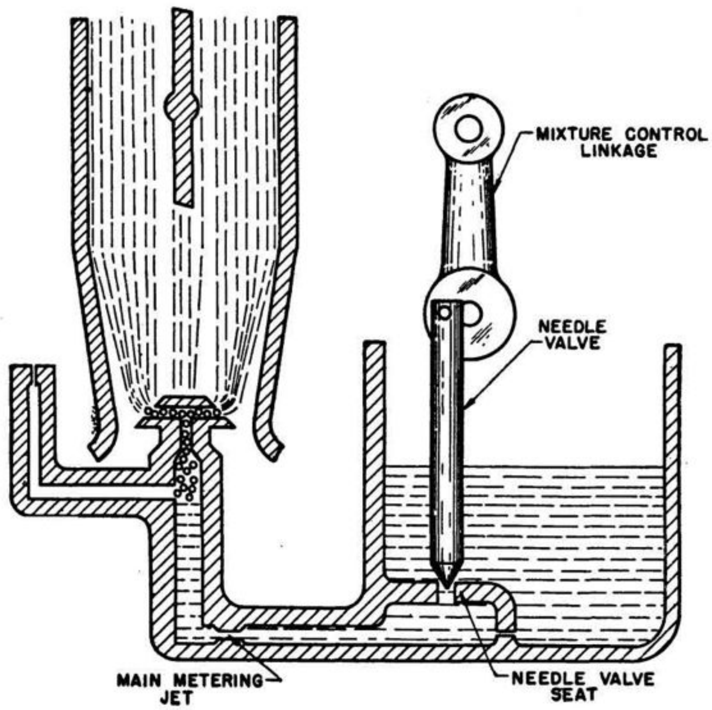


FIGURE 45. Mixture control with needle valve.

(2) Figures 46, 47, and 48 are schematic diagrams of the back-suction type of mixture control. When the control valve is closed, as in figure 47, atmospheric pressure is cut off from the space above the fuel in the fuel chamber and action of the Venturi air stream through the suction line

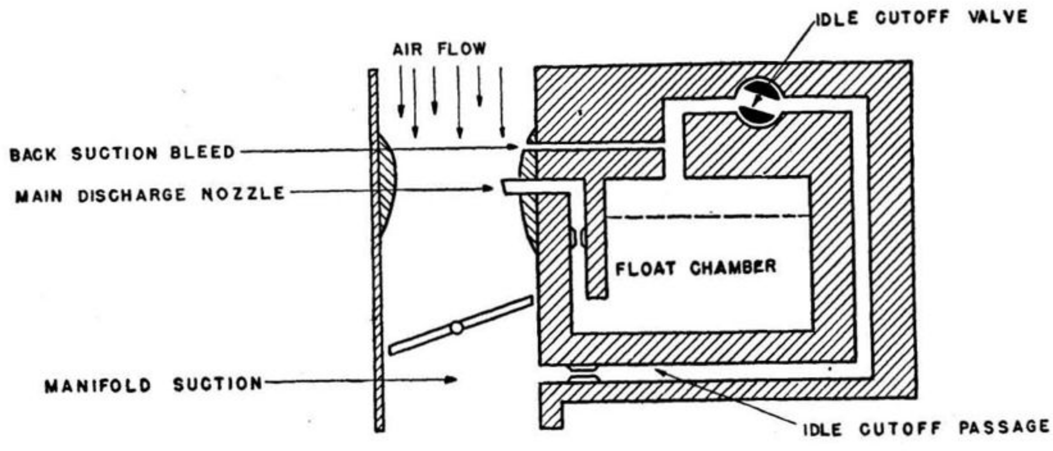


FIGURE 46. Back suction mixture control with idle cut-off valve

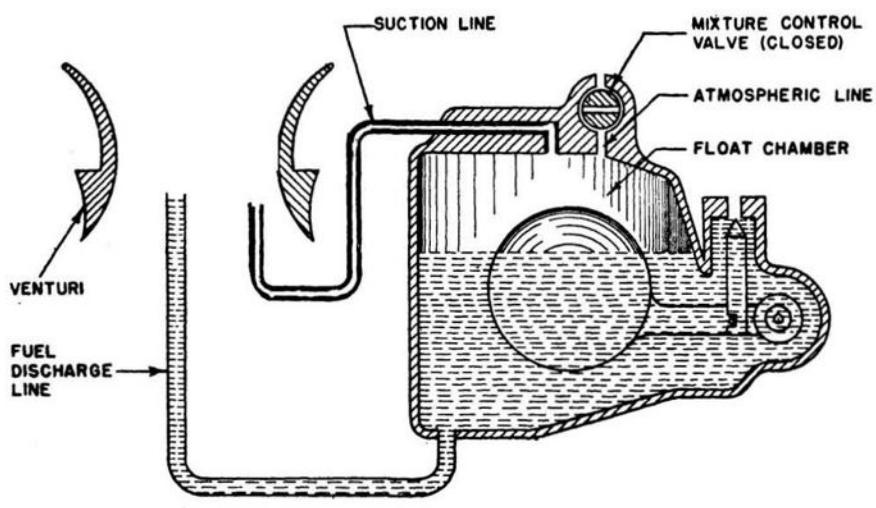


FIGURE 47. Back suction mixture control—valve closed.

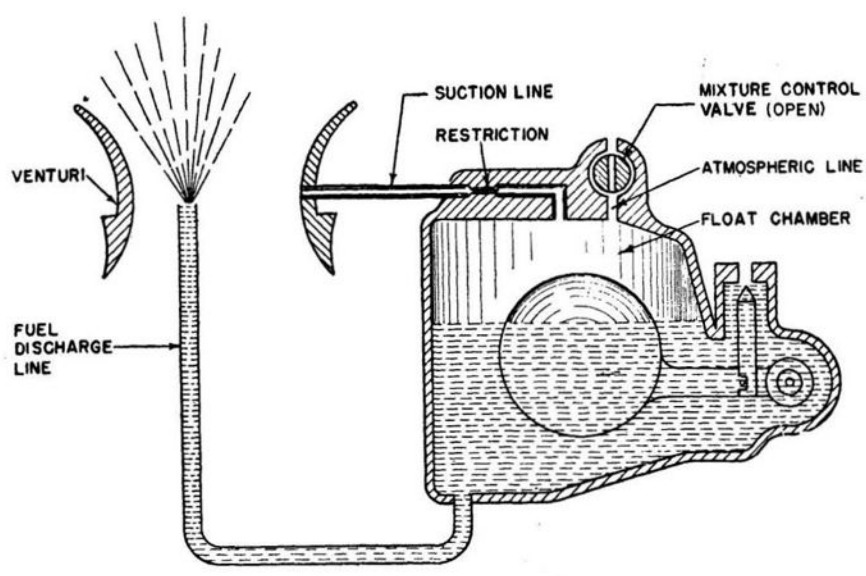


FIGURE 48. Back suction mixture control—valve open.

reduces the pressure until no fuel is delivered from the nozzle. As actually constructed, the end of the back-suction tube is located at a place where the pressure is somewhat higher than that at the nozzle. With this arrangement, the valve may be entirely closed without stopping the flow of fuel. The flow may be varied by partly closing the valve.

(3) Some mixture control valves are operated by bellows vented to the atmosphere (figs. 49 and 50). In this type the flow of fuel is proportional to the atmospheric pressure. On units with external superchargers, both the bellows and fuel chamber may be vented to the carburetor intake to give correct mixtures.

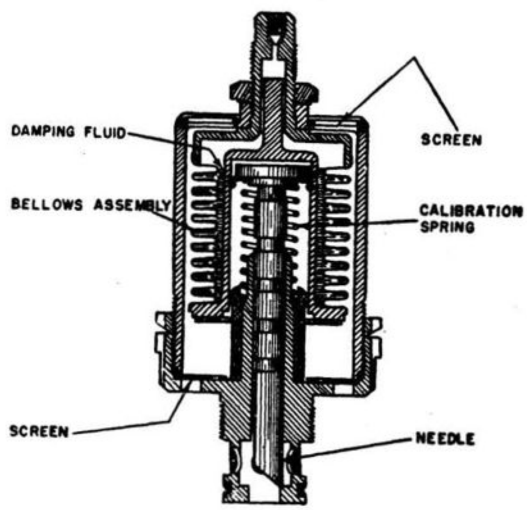


FIGURE 49. Automatic mixture control valve.

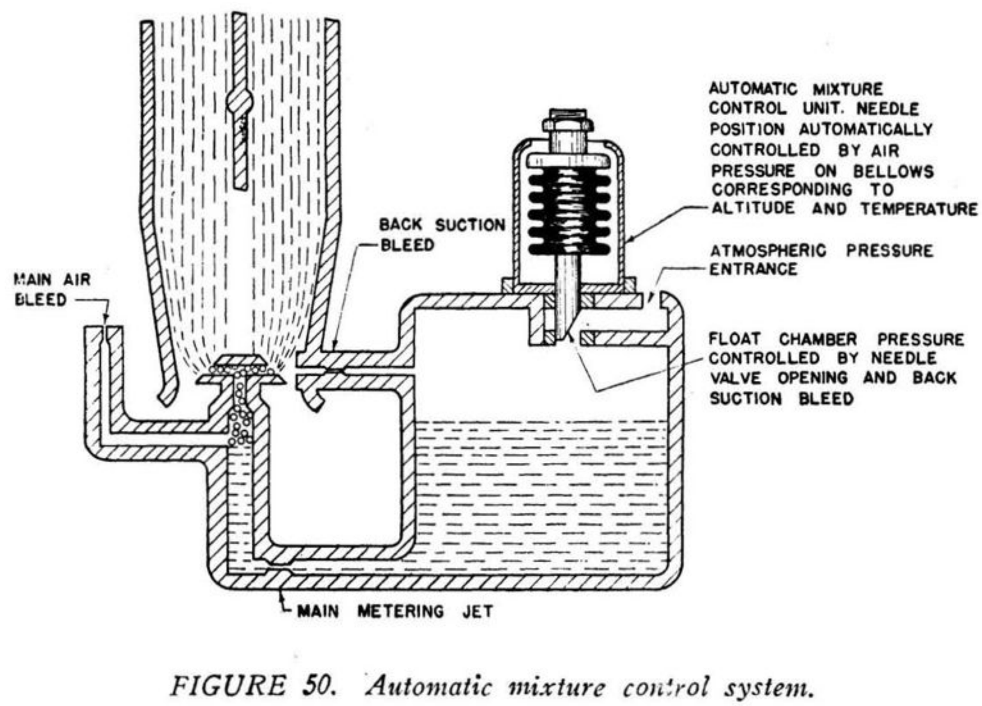


FIGURE 50. Automatic mixture control system.

f. Down-draft carburetors. The figures used above for illustrative purposes show up-draft carburetors. Down-draft carburetors use similar systems and function in the same way.

(1) Figure 51 shows a down-draft carburetor with two float chambers, two throttle valves and an automatic mixture control unit. Figure 52 shows an idling system for a down-draft carburetor. Note the path of

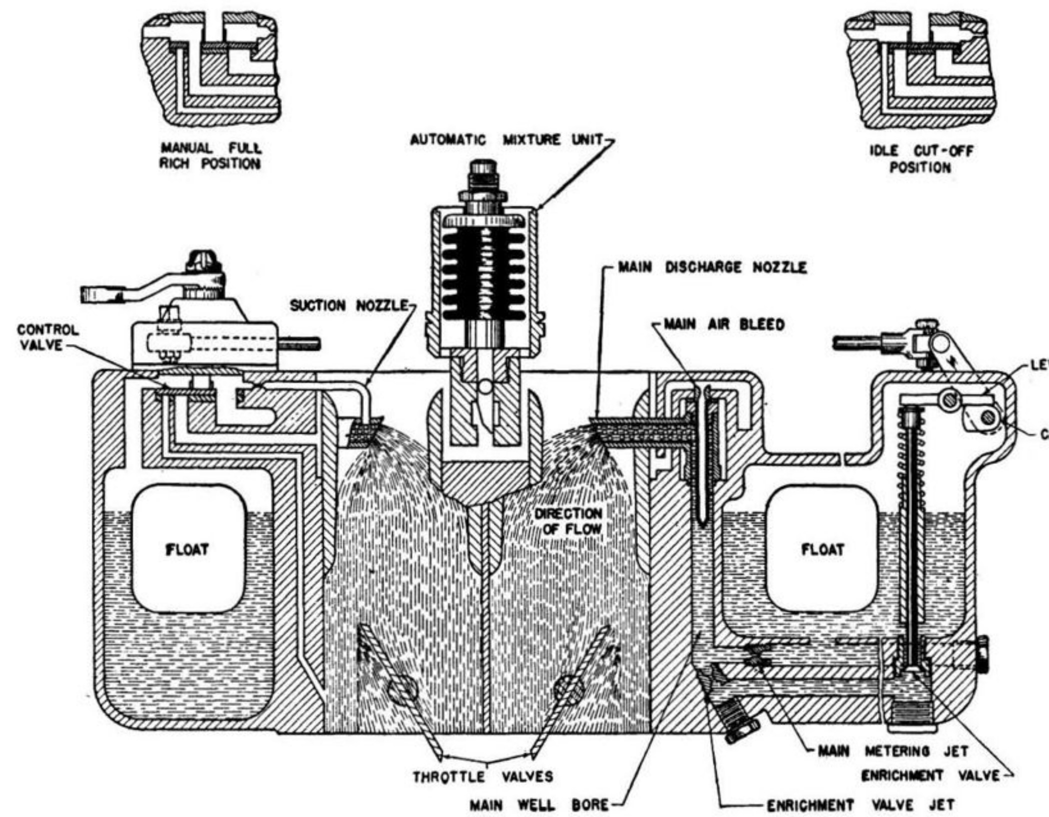


FIGURE 51. Down-draft carburetor.

the fuel as it leaves the float chamber, and the position of the idle air-bleed. This air-bleed also prevents siphoning of fuel when the engine is not operating. The series of vents at the entrance to the Venturi is used to supply an average intake pressure to the mixture control system.

(2) Although the principles discussed apply to all float type carburetors, Technical Orders should be consulted for specific information concerning the design of the unit being used.

g. Limitation of float type carburetors. Although the float type carburetors now in use are far superior to those of a few years ago, they have very marked limitations.

(1) The fuel flow disturbances produced in maneuvers very definitely interfere with the working of the float mechanism. This results in erratic fuel delivery and sometimes in engine failure.

(2) Since the fuel is discharged into the air stream ahead of the throttle, ice will form readily at the throttle valve when icing conditions prevail.

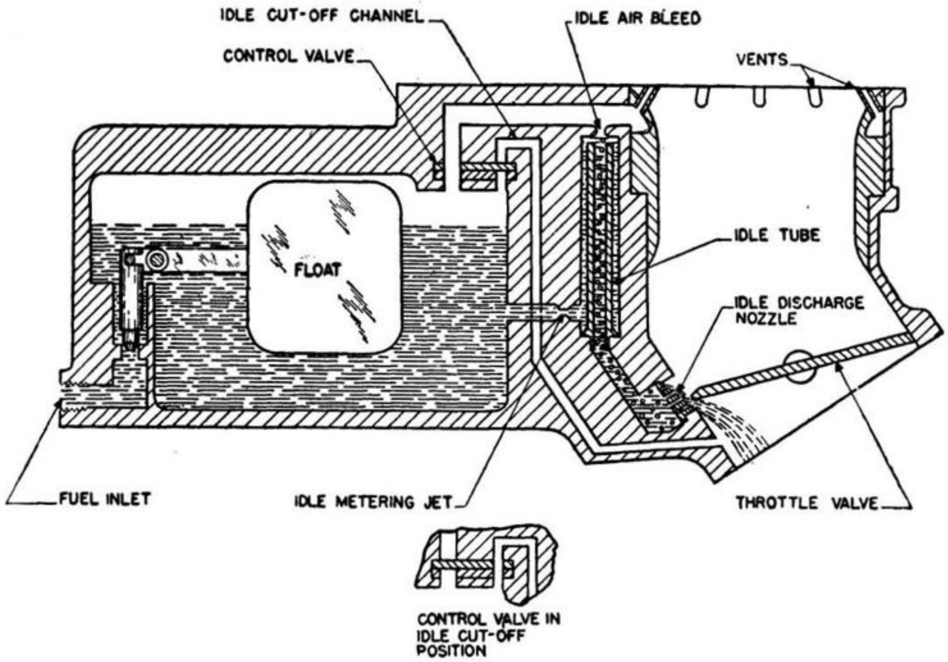


FIGURE 52. Down-draft carburetor with idling system.

24. VARIABLE VENTURI CARBURETOR. This type of carburetor produces dependable performance during maneuvers, and it is found to be much less subject to icing than the float type carburetor. It also partially compensates for low air density at high altitudes without the use of the mixture control.

a. Fuel chamber. (1) The fuel chamber of the variable Venturi carburetor (fig. 53) has two diaphragms, each with a lever attached at the center. The other end of each lever is attached to an intake valve at the bottom of the chamber. In operation, the space between the diaphragms is filled with fuel. The outlet is at the top. This arrangement eliminates the interruptions in fuel delivery that would occur during maneuvers if the fuel were permitted to splash about in the chamber.

(2) The space outside the diaphragm is connected to a vent ring at the carburetor intake (fig. 54), and the pressure acting on the diaphragms is the same as that at the carburetor intake.

(3) Fuel under pressure is delivered through the fuel valves into the fuel chamber by a fuel pump. As the fuel level rises to a predetermined height, the diaphragms move outward against the air pressure from the carburetor intake. The diaphragm levers attached to the fuel valves will cause the fuel valves to close completely and stop all fuel flow. When the pressure on the top of the fuel is reduced by the Venturi action at the discharge nozzle (fig. 54), the diaphragms will move inward, forcing fuel through the metering channel to the nozzle. At the same time, the intake valves will be opened and fuel will flow into the bottom of the chamber at the same rate it is discharged from the top. It is obvious that when the carburetor pressure is high, indicating a higher rate of air flow

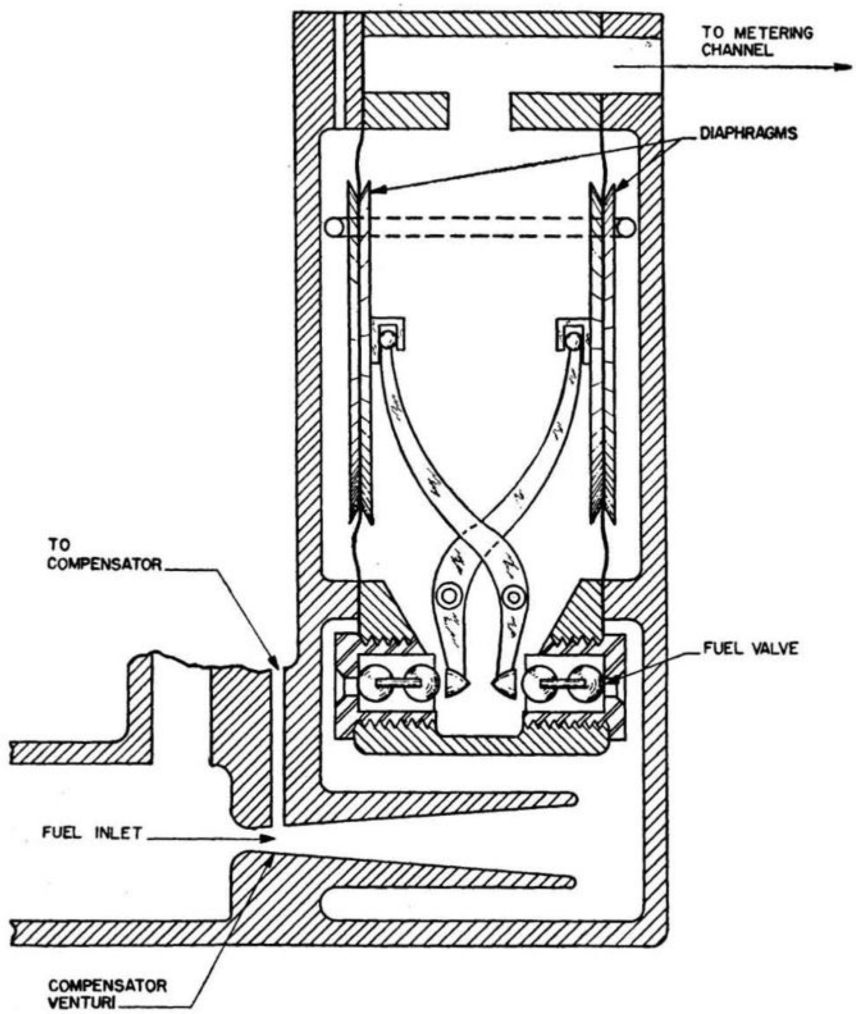


FIGURE 53. Fuel chamber of variable Venturi carburetor.

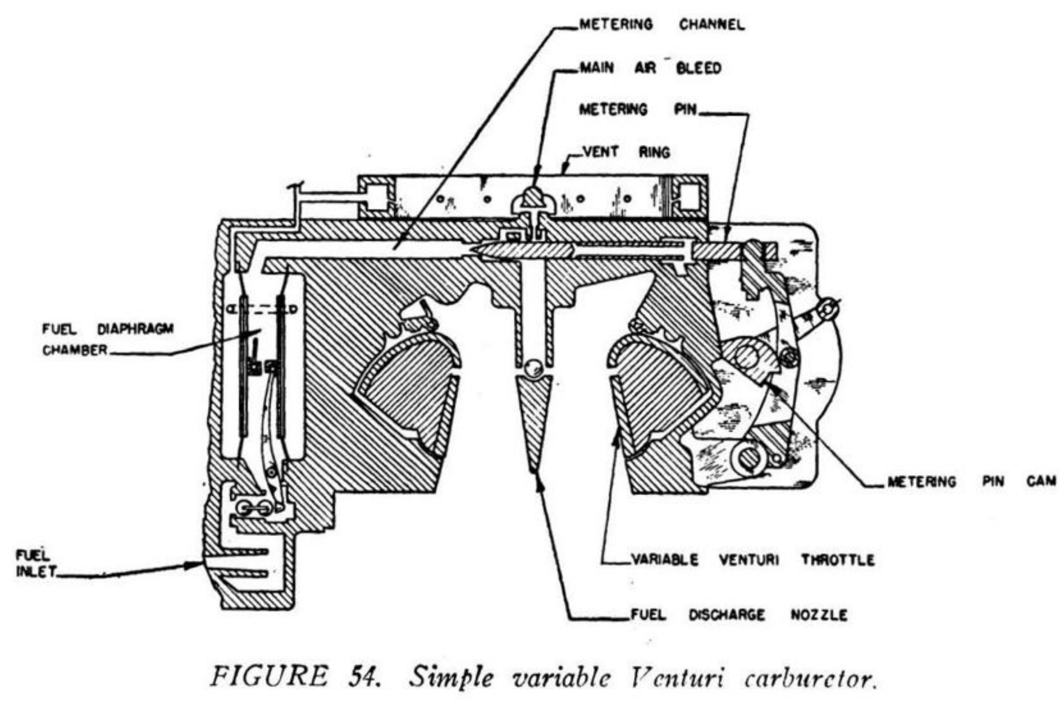


FIGURE 54. Simple variable Venturi carburetor.

to the carburetor, the diaphragms will move closer to each other, the valves will open wider, and the unit will deliver more fuel to the air stream than it will when the intake pressure is low. This partially compensates for altitude variations.

b. Metering channel. A tapered needle valve is located in the metering channel between the fuel chamber and the discharge nozzle. This valve is actuated by a cam which is operated by the throttle linkage (variable Venturi). Thus, when the Venturi throttle is opened to increase the air passage, the fuel passage opening is increased proportionally to provide the proper fuel flow. By using this arrangement, a mixture ratio which is approximately constant is obtained for all engine speeds above idling. An air-bleed in the metering channel serves the same purpose as the one in the float type carburetor fuel passage.

c. Power compensator. (1) On a variable Venturi carburetor, a power compensator, or fuel flow compensator, is employed to provide enrichment of the fuel-air mixture. Unlike the economizer used in the float type carburetor, this unit is automatically actuated by a differential fuel pressure. There is no mechanical connection between the power compensator and the throttle mechanism.

(2) As shown in figure 55, the compensator Venturi is utilized to produce the differential fuel pressure. As fuel flows through the throat of the Venturi, the pressure is less than that at the entrance. A vent leads from the throat of the Venturi to the spring side of a diaphragm. Another vent leads from the entrance of the Venturi to a needle valve attached to the other side of the diaphragm and operated by it. As the fuel flow increases, the difference in pressure on the two sides of the diaphragm equals the initial tension of the spring and the valve begins to open. Further increase in fuel flow causes the valve to open enough to permit the enrichment of the fuel-air mixture at the discharge nozzle by fuel flowing directly from the fuel line.

d. Accelerating system. (1) A vacuum-operated, diaphragm type pump is used to supply the extra fuel required for smooth and rapid engine acceleration when the throttles are opened quickly. (See fig. 56.) One side of the diaphragm is open to the partial vacuum which exists just below the carburetor when the Venturi throttle is nearly closed and the engine is running. On the other side is the fuel chamber with an inlet check valve at the bottom and an outlet above. The outlet leads to a spray nozzle just under the metering channel discussed in **b** above. Springs on the vacuum side of the diaphragm tend to apply pressure to the fuel. An accelerating pump lock valve, in the passage leading to the vacuum side of the diaphragm, is closed when the mixture control lever is moved to the "idle cut-off" position and prevents operation of the pump while the engine is being stopped.

(2) When the engine is idling, the pressure behind the diaphragm is

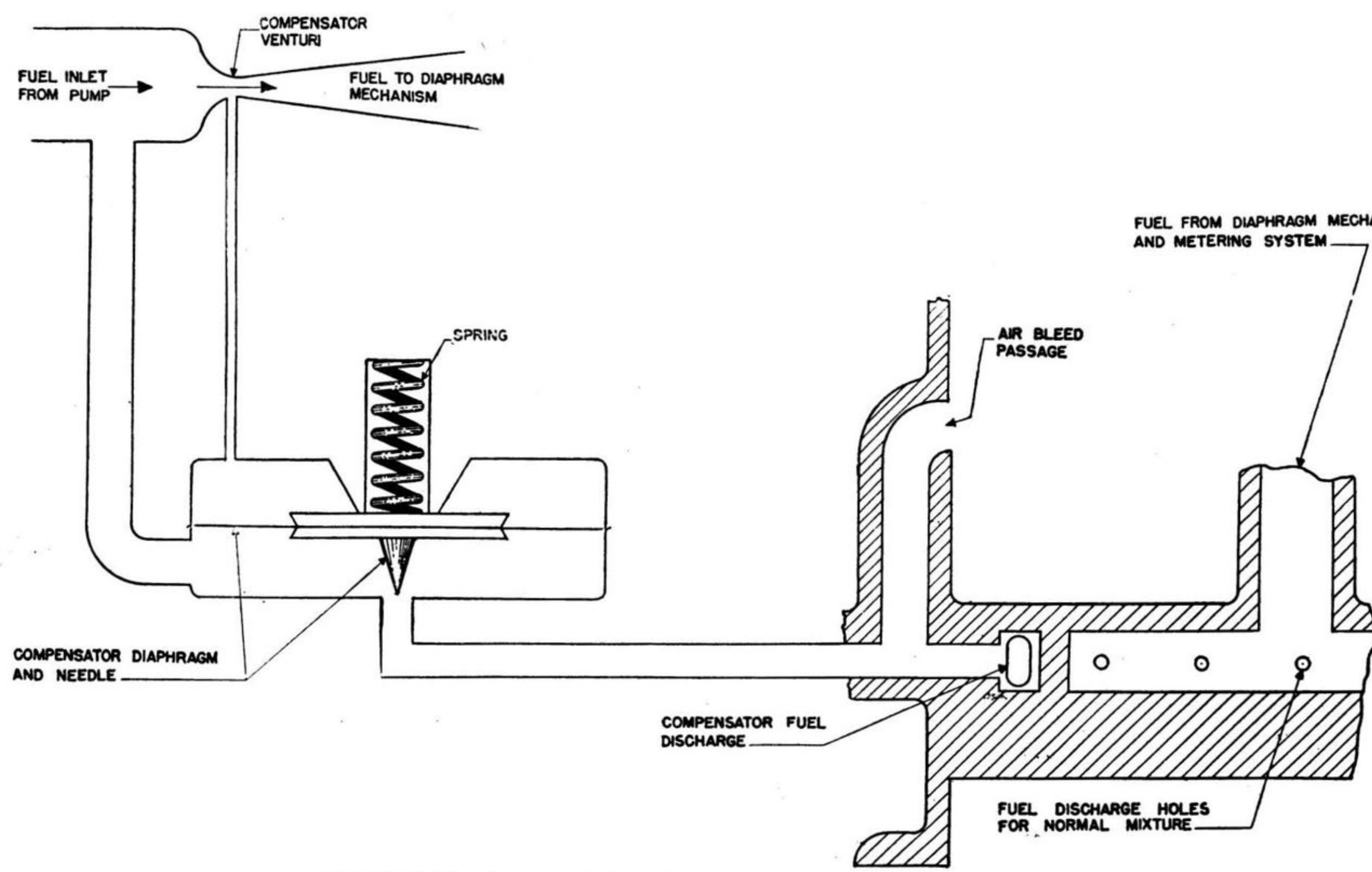


FIGURE 55. *Power compensator.*

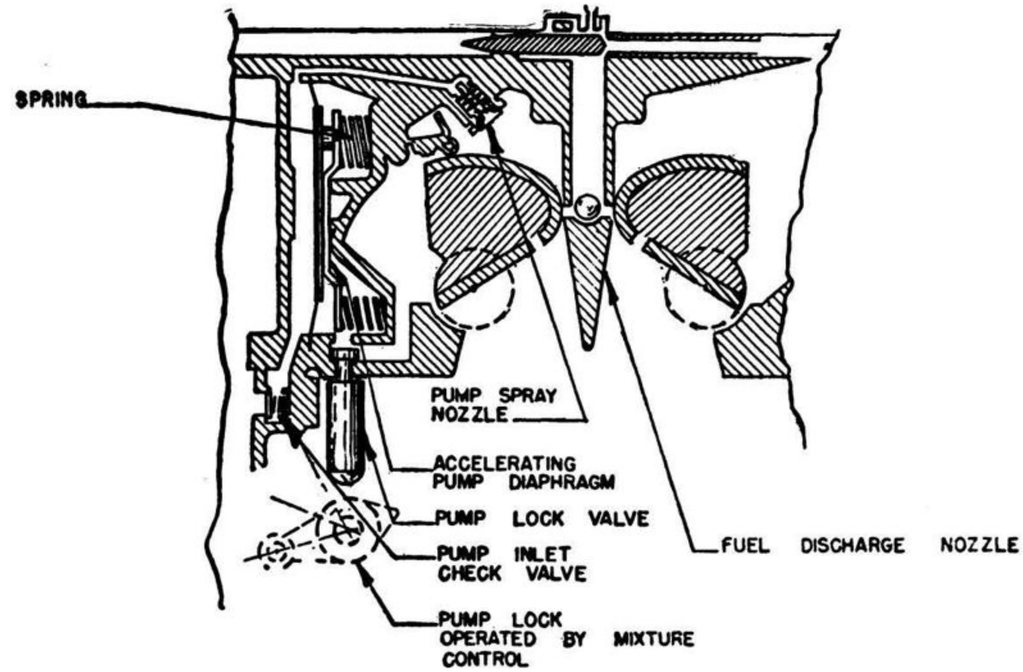


FIGURE 56. Accelerating pump—filled.

reduced and fuel under pump pressure enters the chamber through the inlet check valve. The diaphragm is moved back, compressing the springs. When the fuel reaches the required level, the weight of the fuel, combined with the reaction of the springs, causes the check valve to close. When the throttles are opened, pressure builds up in the vacuum chamber and assists the springs to discharge the fuel through the spray nozzle.

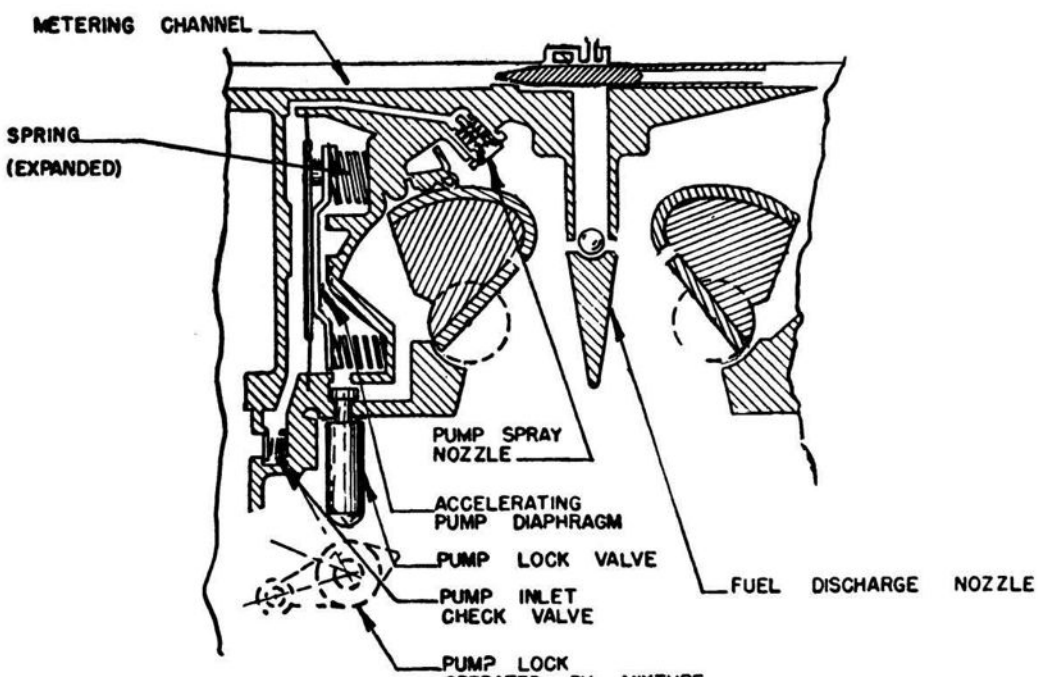


FIGURE 57. Accelerating pump—discharging fuel.

(See fig. 57.) The action of this pump is entirely automatic. Since there is no mechanical linkage between the throttles and the pump, the engine cannot be primed by opening and closing the throttles before starting.

e. Mixture control. (1) In addition to the automatic compensation for altitude discussed in **a** (3) above, a manual mixture control is provided. This permits leaning of the mixture for economy in cruising and also for more exact altitude compensation.

(2) Mixture ratios are varied by use of a vent between the air space outside the fuel chamber diaphragms and the low pressure at the metering needle. Part of the pressure difference between fuel chamber and the fuel-metering restriction is relieved, providing a decreased fuel flow through the discharge nozzle. The amount of reduction is regulated by a mixture control valve in the vent passage. With the control in the "full rich" position (fig. 58), the valve is fully closed and full carburetor intake pressure is applied to the diaphragms. As the control is moved toward the "lean" position, a small slot in the mixture control disk is gradually opened, relieving part of the pressure on the diaphragm.

(3) The mixture control also cuts off the flow of fuel, preventing afterfiring when the engine is stopped. If the mixture control is moved to its "full lean" position (fig. 59), the pressure at the diaphragms will be reduced practically to that at the metering restriction. The accelerating pump is locked at the same time, as mentioned in **d** (1) above. With the pressure equalized, the inlet valves to the fuel chamber will be closed and all fuel supply cut off.

f. Idling. (1) When the throttles are nearly closed, the metering pin almost rests on its seat. Only a small amount of fuel flows from the main fuel chamber to the discharge nozzle. Air is bled from above the Venturi past an adjustable air-bleed (idle adjustment) and through a passage in the metering pin to the discharge nozzle. The passage in the metering pin is cut off as soon as the pin moves away from its seat when the throttle is opened. The adjustable air-bleed can, therefore, be adjusted only while the engine is idling.

(2) To enrich the idling mixture, the idle adjustment is turned to restrict the air passage. This reduces the amount of air flowing to the discharge nozzle. To reduce the richness of the mixture, turn the adjustment to permit more air to pass.

(3) An adjustable stop regulates the minimum idling speed by setting a limit to the movement of the throttle toward the closed position.

g. Recent improvements. A type of variable Venturi carburetor recently designed has three added features which make possible accurate carburetor response to engine requirements over a greater operating range and also permit its longer continued use under normal maintenance.

(1) Fuel vapors, released by agitation of the fuel, are removed by a vapor separator valve as described in paragraph 12m(2).

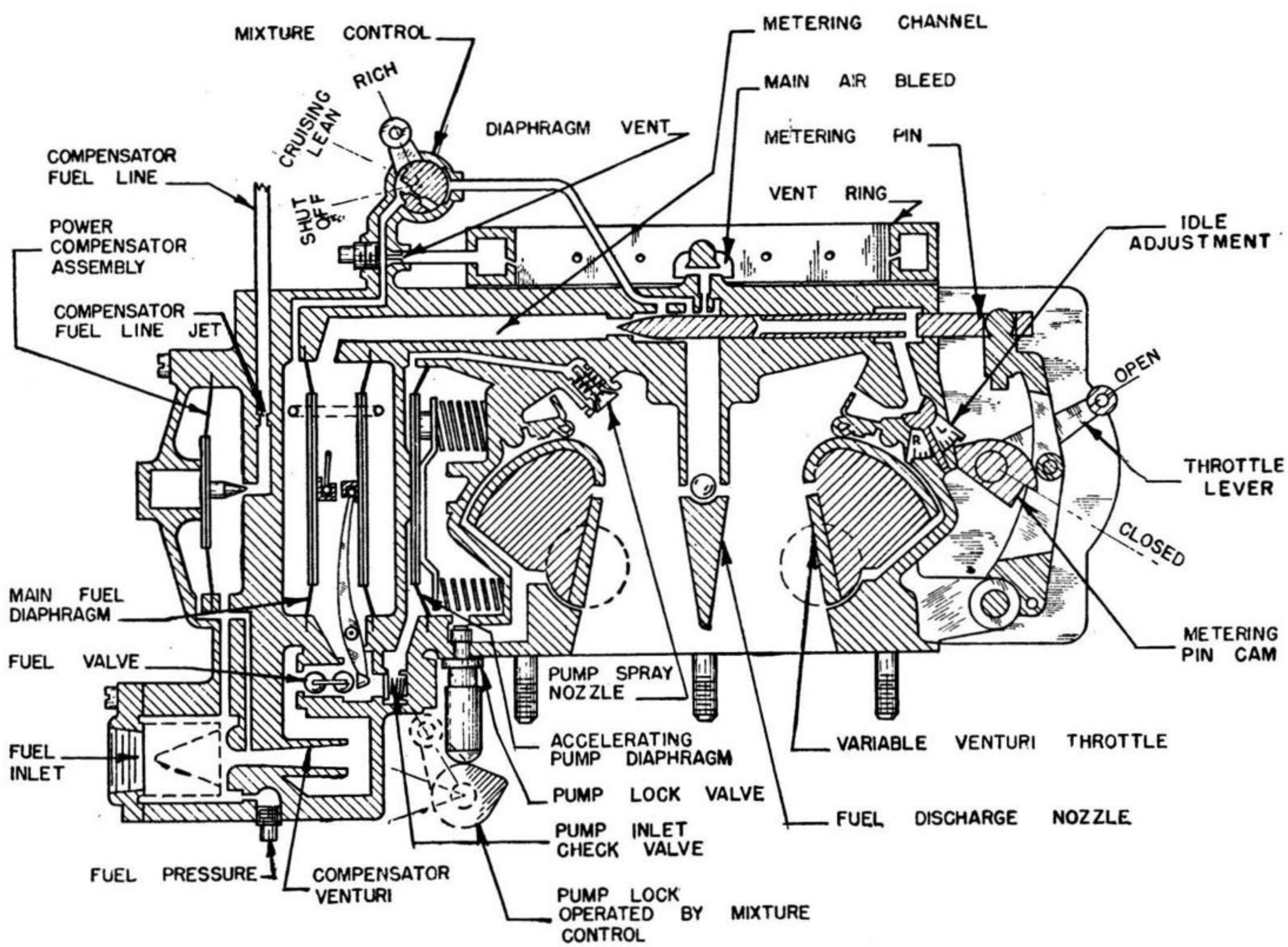


FIGURE 58. Variable Venturi carburetor with mixture control in "full rich" position.

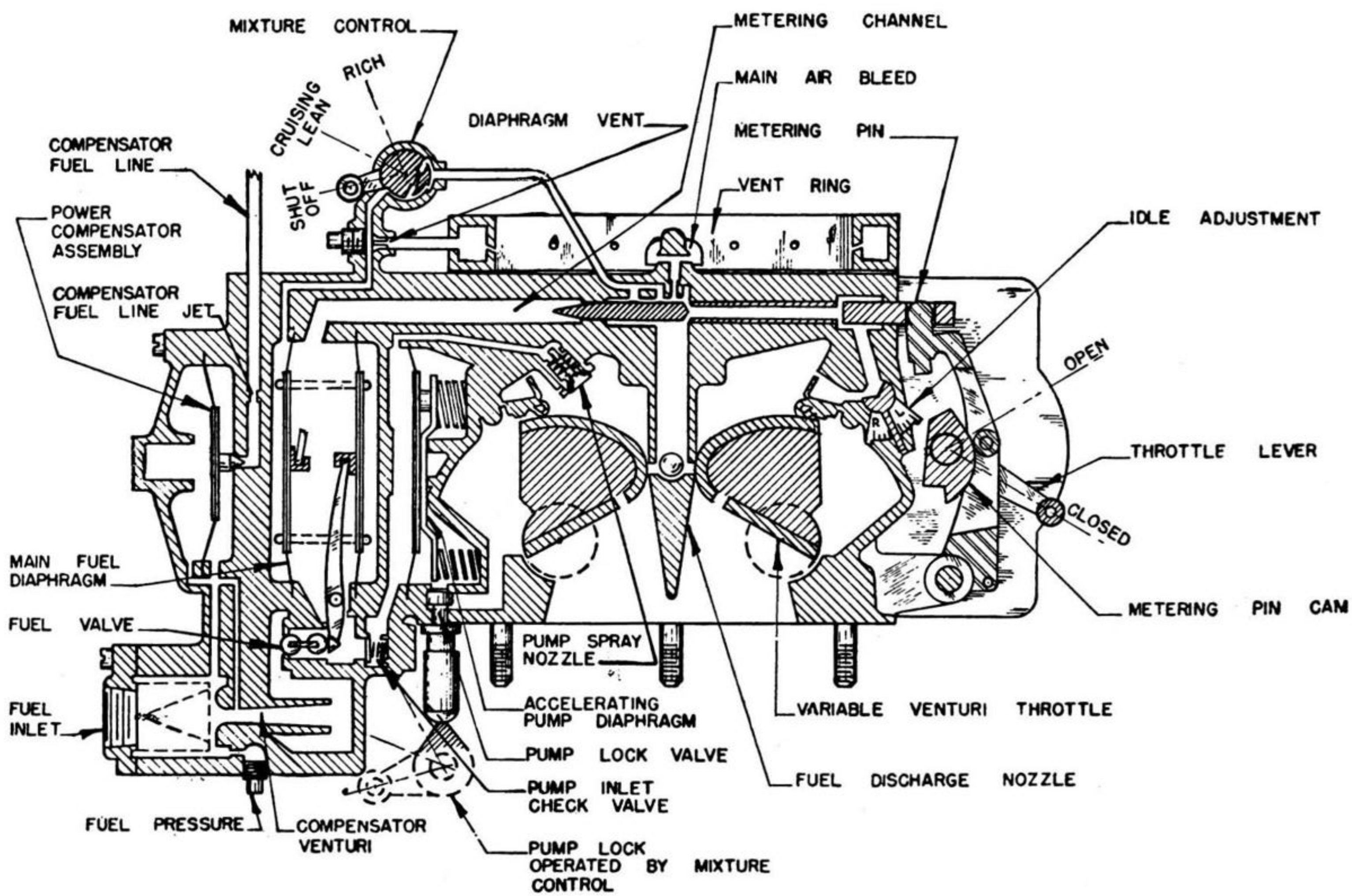


FIGURE 59. Variable Venturi carburetor mixture control in idle cut-off position.

(2) A stabilizer valve (fig. 60), connected to the discharge nozzle and to the outside of the main fuel chamber, operates at all times to compensate for changes in altitude, temperature, and engine load.

(3) A power mixture valve, connected in series with the manual mixture control, prevents damage to the engine which might result from operating it at high power output when the mixture control is set in the cruising "lean" position. If such a condition arises, the power mixture valve automatically provides the necessary full rich mixture. The unit is connected to the power compensator and closes when the latter unit is called upon to deliver more fuel than it is adjusted to handle. When the power is reduced, the power mixture valve will open and restore the proper mixture.

25. PRESSURE INJECTION TYPE CARBURETORS. This type of carburetor utilizes a pump to deliver fuel under pressure to nozzles located at the entrance of the internal supercharger. Since the system is entirely closed, it will have normal operation during all types of maneuvers. The fuel is metered correctly at all operating loads and altitudes. Atomizing the fuel under pressure results in economy and smooth operation. Figure 61 shows a typical injection carburetor installation.

a. Regulator unit. The regulator unit is divided into an air section and a fuel section (fig. 62). An air diaphragm divides the air section into two chambers and a fuel diaphragm divides the fuel section. The two diaphragms are the same size.

(1) Chamber *A* is supplied with air through impact tubes leading from the carburetor Venturi intake to a space surrounding the Venturi. A calibrated needle valve, operated by an automatic mixture control, regulates the flow of air into chamber *A* by compensating for changes in atmospheric temperature and density.

(2) A low pressure, proportional to that in the Venturi, is maintained in chamber *B* by connecting it to a boost Venturi with its outlet at the throat of the main Venturi. Having the Venturi tubes in series results in a more positive and rapid response to changes in air flow. A small bleed connecting the bottoms of the two chambers reduces the actual pressure difference acting on the diaphragm, but it is always proportional to the difference in pressures at the intake and in the Venturi.

(3) The end of the poppet-valve stem is attached to the center of the air diaphragm and extends through the fuel unit. The fuel diaphragm is also fastened to the stem at the point where it passes through the diaphragm, and all the parts move as one unit. When air pressure differences in *A* and *B* cause the air diphragm to fluctuate, this action will be transmitted to the fuel diaphragm through the oscillation of the poppet valve stem, or vice versa.

(4) Fuel is pumped into chamber *D* under a pressure of 12 to 17 pounds per square inch, and passes on through the metering jets into

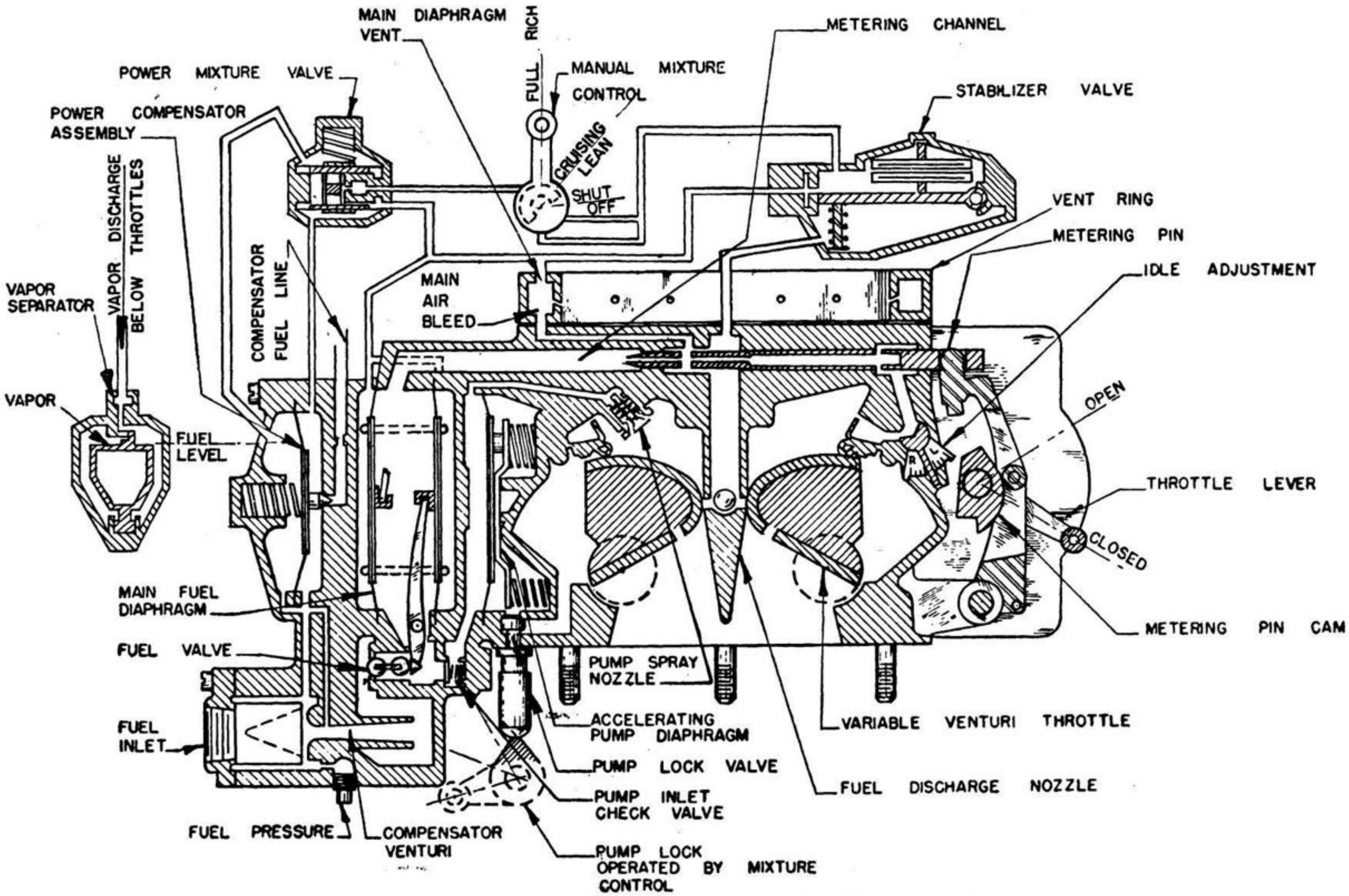


FIGURE 60. Stabilizer valve of a variable Venturi carburetor.

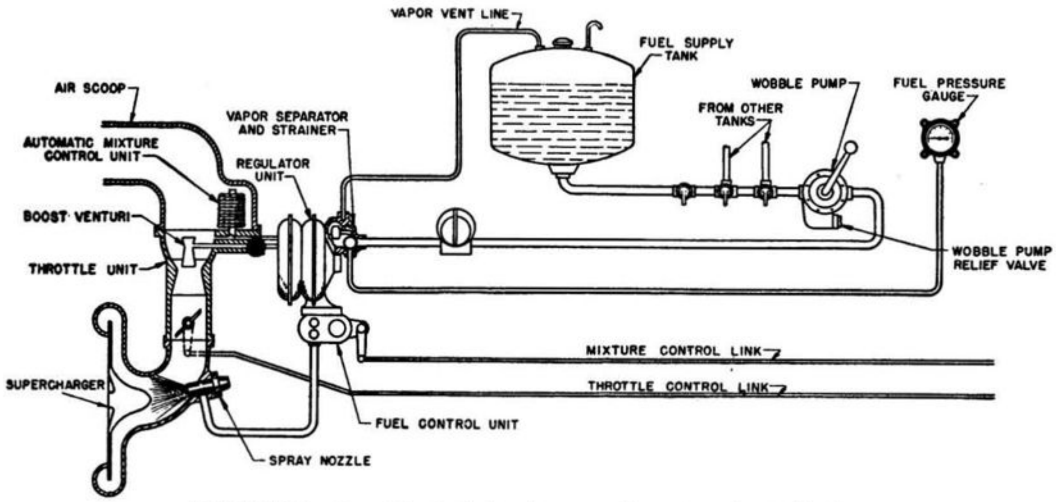


FIGURE 61. Fuel injection carburetor installation.

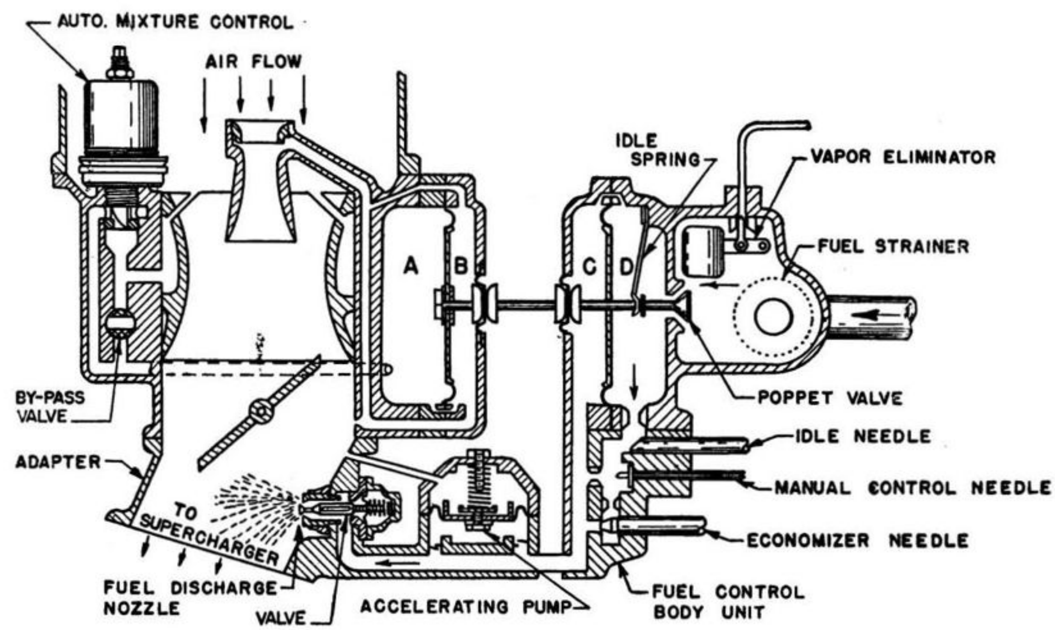


FIGURE 62. Injection carburetor.

passages connected to chamber *C*. From *C*, it passes without restriction to the discharge nozzle. A diaphragm-operated valve in the discharge nozzle prevents the discharge of fuel below a pressure of 4 to 5 pounds per square inch. Pressure builds up in *C*, but the discharge of fuel prevents it from rising appreciably above 5 pounds per square inch. When the pressure in *D* exceeds that in *C* by an amount greater than the pressure difference between *A* and *B*, the diaphragms will be moved back and the poppet valve will partially or completely close. When this valve is wide open, the pressure in *D* will be approximately equal to the output pressure of the fuel pump. When the valve is partly closed, the pressure in *D* will be reduced. The rate at which fuel is metered to the nozzle will depend upon the pressure in D. It will, therefore, readily be seen that the fuel pump supplies the pressure to deliver fuel through the system to the nozzle. But the rate at which fuel-air is delivered to the airflow is controlled jointly by the position of the throttle valve and by the temperature and pressure acting through the mixture control.

(5) At idling speeds, the force obtained from the air diaphragms is insufficient to open the poppet valve as much as required. An idle spring in D is incorporated to hold the poppet valve open when the engine is not running or is operating at low speed. This supplies a slightly richer mixture at very low speeds.

b. Fuel control units or economizers. (1) The air-flow economizer operates to enrich the fuel-air mixture when the pressure in A exceeds that in B by an amount equal to or greater than the strength of a calibrated spring controlling a small diaphragm in the unit. An arm which opens and closes a fuel enrichment valve is attached to this diaphragm. Since mechanical linkage is eliminated, the action is automatic, but enrichment occurs as soon as the throttle is opened beyond a predetermined position. As the mass of air flowing to the carburetor increases, the volume of fuel delivered to the fuel control unit also increases through the opening of the fuel enrichment valve.

(2) The recently developed "fuel-head" enrichment valve (fig. 63) differs from the air-flow economizer in that it is controlled directly by the difference in fuel pressure in chambers C and D, and no lever system is required. The pressures are vented to the two sides of a small spring-controlled diaphragm. When air-flow in the carburetor exceeds a given rate, the main fuel valve is opened so that the pressure in D builds up and the spring at the small diaphragm is compressed. This opens a valve attached to the diaphragm and additional fuel is delivered into the passage leading to the nozzle.

c. Acceleration pumps. When an adapter is used between the supercharger and the throttle body of the carburetor, a vacuum-operated acceleration pump may be added to the unit.

(1) A single-diaphragm acceleration pump (fig. 64) has a vacuum chamber which is vented to the carburetor air stream just below the throttle valve. When the throttle is closed, the air presure in the vacuum chamber is reduced. Fuel pressure compresses the spring and the fuel chamber is filled. When the throttle is opened, the pressure in the vacuum chamber is increased and the fuel is forced quickly from the fuel chamber and discharged through the nozzle.

(2) In a double-diaphragm accelerating pump (fig. 65), fuel flowing to the nozzle under normal operating pressure will fill the inner chamber and the small outer chamber between the two diaphragms. When the air pressure is reduced in the vacuum chamber, more fuel flows into the

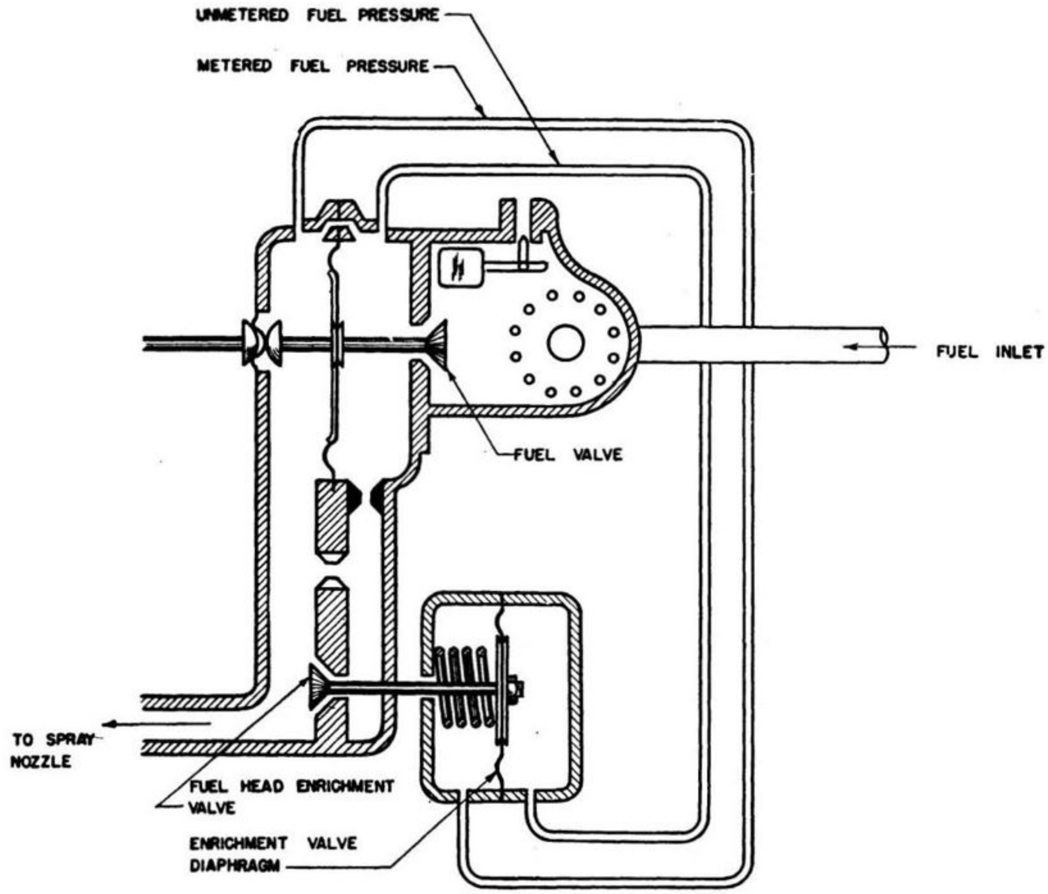


FIGURE 63. *Fuel head economizer.*

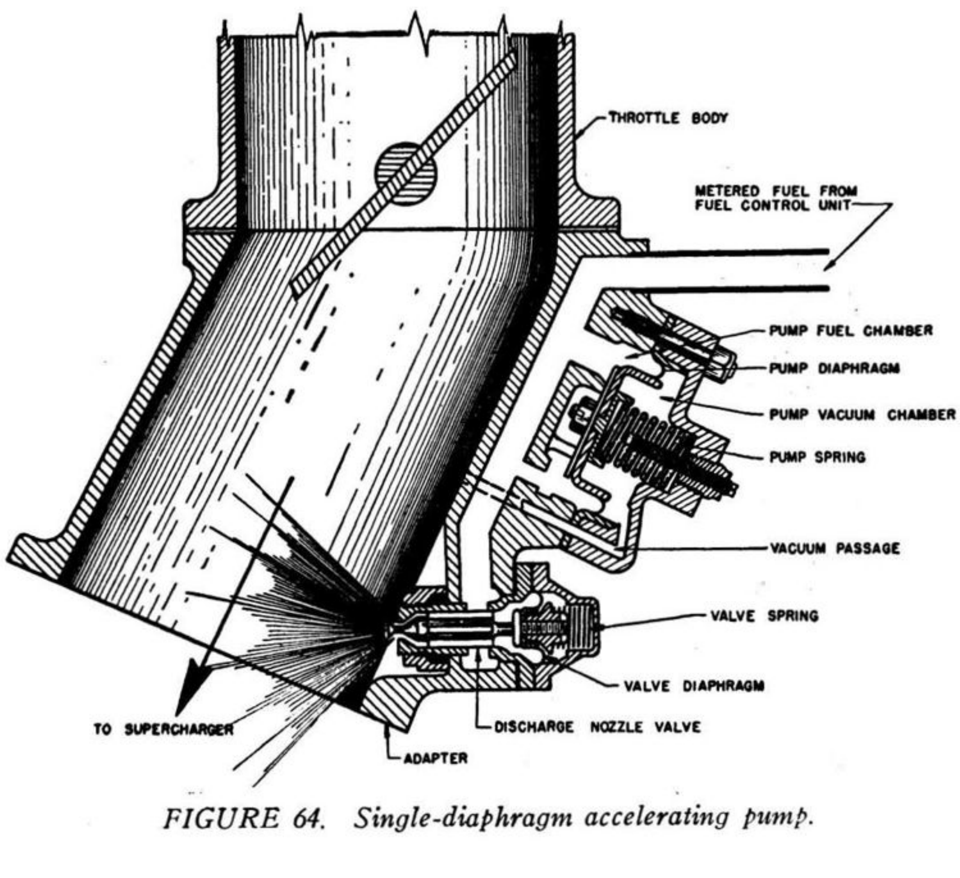


FIGURE 64. *Single-diaphragm accelerating pump.*

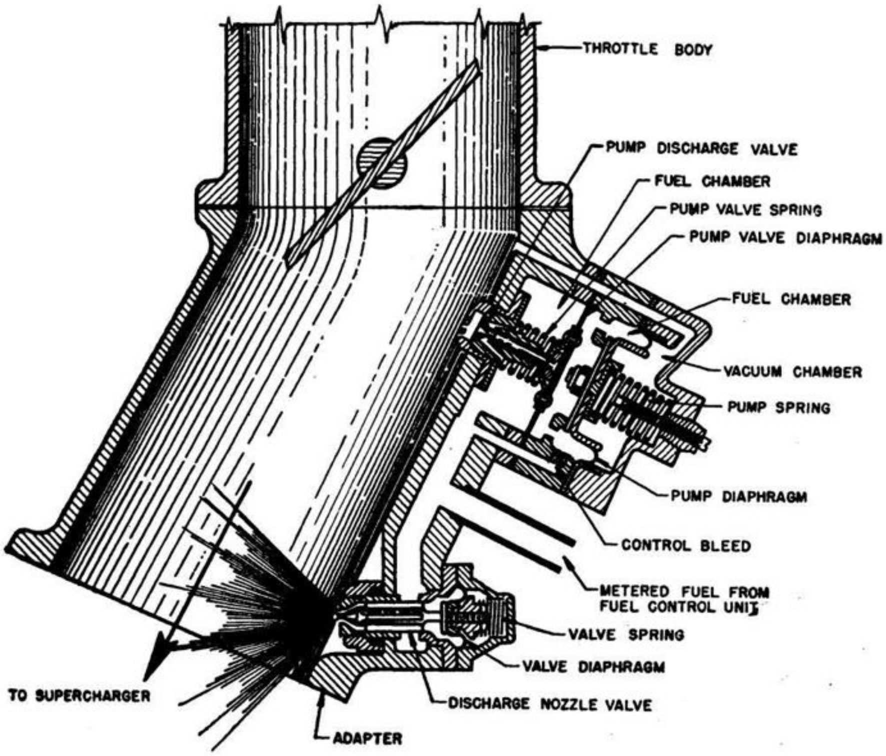


FIGURE 65. Double-diaphragm accelerating pump.

outer chamber to compress the outer spring and fill the entire available space between the diaphragms. When the throttle is opened, the pressure in the vacuum chamber is suddenly increased. Pressure is applied to the fuel in the outer chamber. This acts on the inner diaphragm to open a special acceleration pump discharge valve and deliver an accelerating fuel charge directly into the air stream. At the same time, pressure is transmitted along the fuel passage to the spray nozzle. The fuel in the outer chamber is forced out through the control bleed and replenishes the accelerating supply until the outer diaphragm reaches its normal position. The special accelerating valve closes as soon as the pressure in the outer chamber falls to near normal.

(3) The two types of accelerating pumps discussed in (1) and (2) above are entirely automatic and will not operate unless the engine is running. Recently, some pressure carburetors have been equipped with pumps actuated by mechanical linkage from the throttle. These pumps can be operated when the engine is not running. When this type of accelerating pump is included in the installation, the specific operating instructions for its use should be consulted, because serious fire hazard may result from incorrect use.

d. The idling system. The idle spring mentioned in **a**(5) above supplies a fuel-air mixture which is too rich for normal engine operation. An adjustable idling needle valve controls the flow from chamber *D* when the engine is operating at low speeds. Since this operates only during the first 10° of throttle movement, adjustments to change the richness of the idling mixture must be made while the throttle is within that range.

e. Manual mixture control. Paragraph 24**a**(1) gives a brief description of a mixture control valve. This operates at all times except when

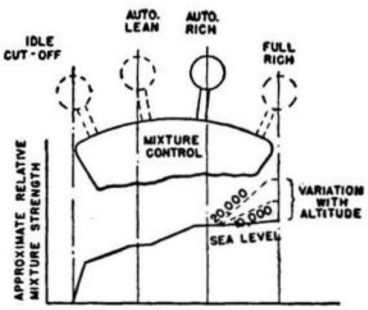


FIGURE 66. Manual mixture control lever.

the manual mixture control valve lever (fig. 66) has been set at the "full rich" position and the bypass valve (fig. 62) opened. The manual mixture control lever is operated from the cockpit. It can be set at the "full rich", "auto rich", "auto lean", or "idle cut-off" positions.

(1) IDLE CUT-OFF POSITION. When the mixture control lever is placed in the "idle cut-off" position, this stops the engine by preventing the flow of fuel through the metering units and into the air stream. The regulator fill valve also closes when the mixture control lever is in the "idle cut-off" position and fuel cannot flow through chamber *C* to reach the nozzle. The valve in the discharge nozzle (**a**(4) above), closes as soon as the pressure at the nozzle drops to 4 or 5 pounds per square inch, preventing any further fuel discharge from the nozzle.

(2) AUTO LEAN POSITION. With the lever in the "auto lean" position, the automatic lean jet is open, the automatic rich jet is closed, and sufficient fuel for cruising is supplied. The automatic mixture control operates to adjust fuel pressure and through that, the fuel flow, as altitude and temperature change.

(3) AUTO RICH POSITION. With the lever in the "auto rich" position, both the automatic rich and the automatic lean jets are open. Fuel is supplied for high engine output, with the automatic mixture control still adjusting for altitude and temperature.

(4) FULL RICH POSITION. When the lever is moved to the "full rich" position, the bypass valve opens and maximum flow of fuel occurs at any altitude or temperature.

26. FUEL VAPORIZATION—INDUCTION SYSTEM ICING. a. Water vapor in air. (1) In addition to the gases, air always contains some water vapor. The capacity of air to hold water increases with the temperature.

When air contains the maximum possible amount of moisture at a given temperature, it is said to be saturated; when it has less, its moisture condition is expressed as percent relative humidity. Thus, if air contains only half the moisture it is capable of holding at its present temperature, it has a relative humidity of 50 percent. If this air were heated without adding or removing moisture, its capacity for holding water vapor would be increased and its relative humidity would be less. If it should be heated until its capacity for moisture were doubled, the moisture present would then be only one-fourth the amount the air could hold, or it would have a relative humidity of 25 percent.

(2) On the other hand, if the air were cooled, its moisture-holding capacity would be reduced. Eventually, it would reach a temperature at which the amount of water vapor present would saturate it; that is, the relative humidity would be 100 percent. If it should be cooled still more and its moisture capacity be decreased further, part of the water vapor would condense. The temperature at which such condensation would occur is called the dew point. If the dew point is below 32° F., the moisture will be precipitated in the form of frost or ice.

b. Evaporating and freezing. (1) When a liquid evaporates, it uses heat in considerable quantity. This is called the latent heat of vaporization and may be taken from a heating unit, from the surroundings, or from the unevaporated liquid remaining. Evaporation is more rapid under low pressure than under normal pressure. It is possible to freeze water by the cooling effect of evaporation if a stream of dry air is passed over it in a partial vacuum.

(2) When fuel is discharged into the low-pressure area in the carburetor Venturi, it evaporates rapidly, cooling the walls, the air, and the water vapor. If the moisture content of the air is high and the metals are cooled below 32° F., ice will often form and interfere with engine operation. The fuel-air passages will be obstructed, the mixture flow will be cut down, and power output will drop. If not detected and corrected, this may continue until the reduced power causes engine failure. A gradual loss of engine speed or of manifold pressure or both, without change in throttle position, may indicate carburetor icing.

(3) A mixture thermometer, placed between the carburetor and intake valve, is of great assistance in obtaining correct mixture temperature. As long as the temperature is slightly above freezing, there is little or no danger of icing.

c. Carburetor air-intake heaters. (1) The exhaust heater (fig. 67) consists essentially of a tube or jacket through which the exhaust of one or more engine cylinders is passed. Air flows over the heated surfaces and is warmed before entering the carburetor. An adjustable valve arrangement is used to regulate the amount of warm air entering the system.

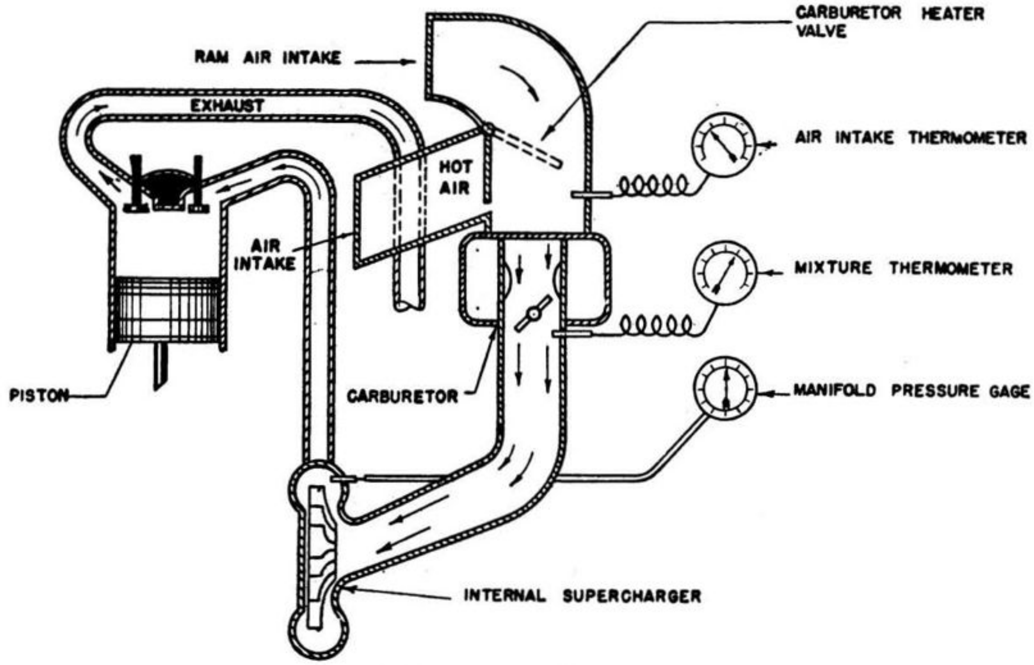


FIGURE 67. Exhaust heater.

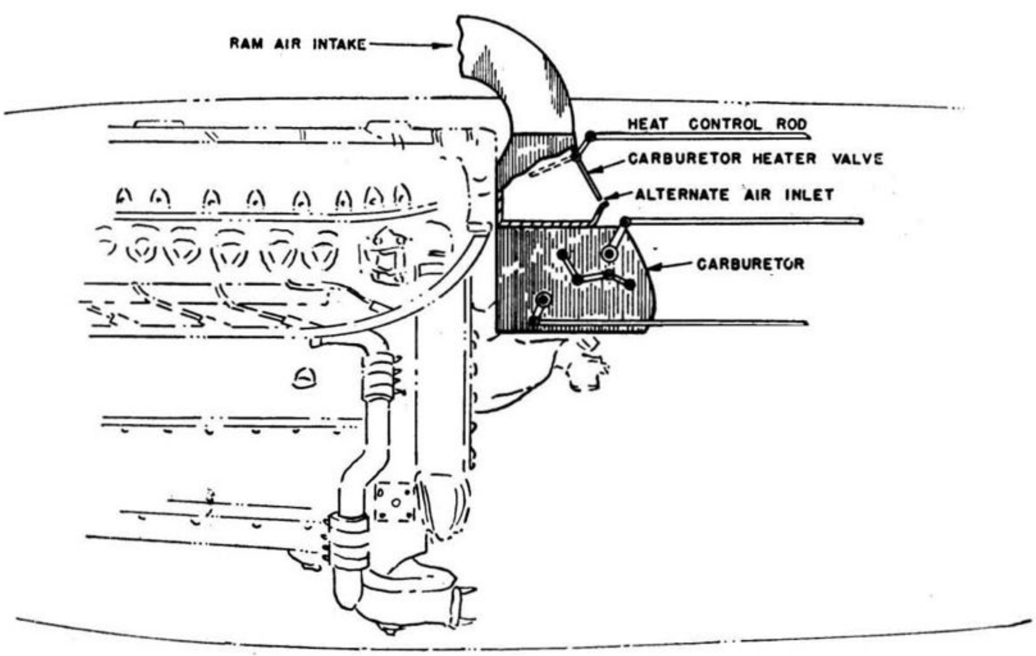


FIGURE 68. Alternate air-inlet heater system for carburetor.

(2) The alternate air-inlet system (fig. 68) has a two-position valve by means of which cold air may be admitted from the scoop. When the passage from the scoop is closed, the warm air is admitted from the engine compartment. The amount of heat available when an alternate inlet system is used depends on the free-air temperature, engine temperature, cowl-flap position, and other variables.

(3) In an installation with an external supercharger the air is heated by the compression which takes place in the supercharger. An intercooler

is needed to cool this air before it enters the carburetor. The degree of cooling is regulated by means of adjustable shutters at the rear of the intercooler.

(4) It must be realized that high air temperatures in the carburetor are undesirable. Excessive heat will expand the charge, reducing its density. Since the power output depends upon the mass of the charge in the cylinder, heating of the mixture will cause a loss in power. Air heaters will produce decided fluctuations in mixture content. High charge temperatures also increase detonation and preignition.

27. MIXTURE DISTRIBUTION. **a.** Even after the fuel and air are properly mixed, an engine will not give efficient and smooth operation unless the fuel is evenly distributed to the various cylinders. Efficient distribution is more easily attained with a down-draft carburetor than with an up-draft carburetor. Cold weather carburetion is better, and there is less fire hazard. Fuel distribution in a radial engine presents a number of difficult problems. The gear-driven impeller now used on many such engines provides correct distribution and, when operated at higher speeds, becomes an efficient internal supercharger. Since engines and carburetors vary so widely in design, only general information concerning distributing systems can be given here. The mechanic should make a special study of the type he is servicing.

b. Air filters are included in all carburetion and fuel- distributing systems to eliminate the malfunctioning of carburetors and excessive engine wear which might result from dust or other foreign matter. These filters may be placed in the scoop or in the carburetor itself. Some filters incorporate relief valves that allow air to enter the intake manifold when the filter becomes clogged with dust or covered with ice; some have manually operated bypasses which can be opened, admitting heated air if the filter is clogged with ice. When these are in use, the engines will have somewhat lower operating efficiency, but should not fail.

28. MAINTENANCE. Carburetor systems should be cleaned and inspected regularly. Filters should be removed and cleaned. Carburetor chambers must be drained and dirt and water removed by flushing. All plugs, gaskets, etc., must be inspected for leaks. Nuts, bolts, and studs must be tight and safetied. Mechanical linkages and throttle bearings must be lubricated as needed. The idling mixture may be adjusted by turning an adjustment screw in the idle needle valve assembly. This must be done when the engine is operating at idling speed. A screw type throttle stop may be adjusted to control engine idling speed. When an inspection shows that the carburetor is not functioning properly, it should be replaced. An engine should not be removed and an airplane kept from service when carburetor replacement is all that is required.

SECTION V
SUPERCHARGERS

29. GENERAL. a. Effects of increased manifold pressure. The purpose of supercharging an aircraft engine is to increase the manifold pressure above atmospheric pressure in order to provide high-power output for take-off and to sustain the maximum power output at high altitudes. Increased manifold pressure increases the power output in the following two ways:

(1) It increases the weight of the charge introduced into the cylinders. At a constant temperature the amount (weight) of fuel-air mixture that can be packed in a given volume is dependent upon the pressure of the mixture; that is, the higher the pressure on a given volume of gas, the heavier the gas. (See fig. 69.) Thus the higher the manifold pressure, the greater the quantity of fuel and air available for combustion.

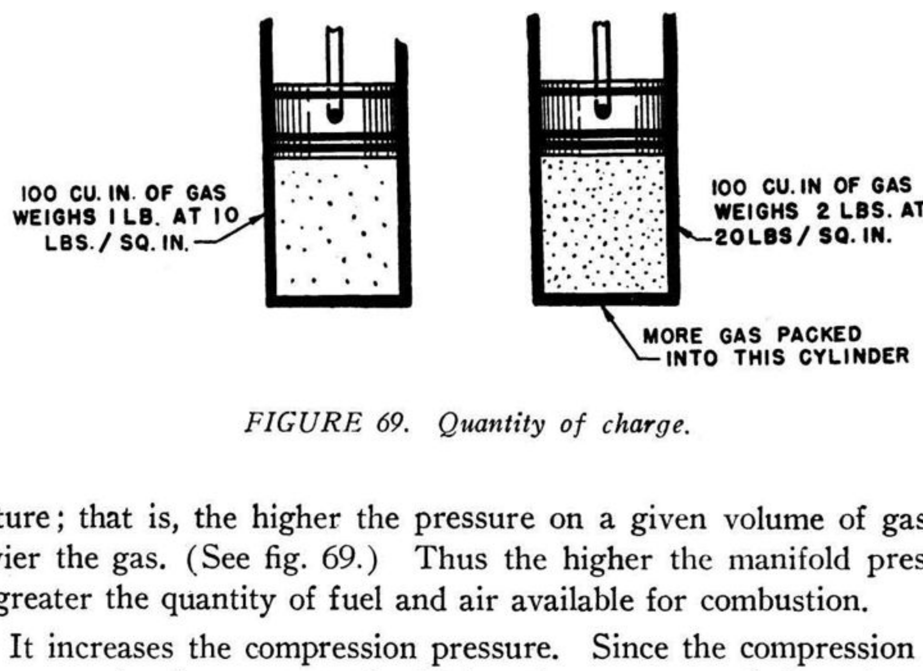


FIGURE 69. Quantity of charge.

(2) It increases the compression pressure. Since the compression ratio for any engine is constant, the higher the pressure of the mixture at the beginning of the compression stroke, the higher will be the compression pressure (the pressure of the mixture at the end of the compression stroke). Higher compression pressure results in higher mean effective pressure and thus in higher engine power output. The increase in compression pressure is shown in figure 70.

b. Specific purposes or functions of superchargers. (1) Increased manifold pressure provides more power for take-off and low-

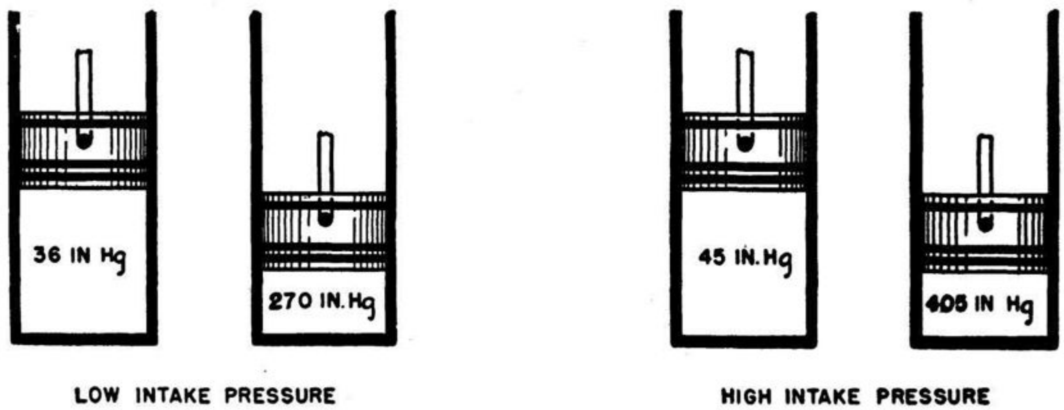


FIGURE 70. Pressure of charge.

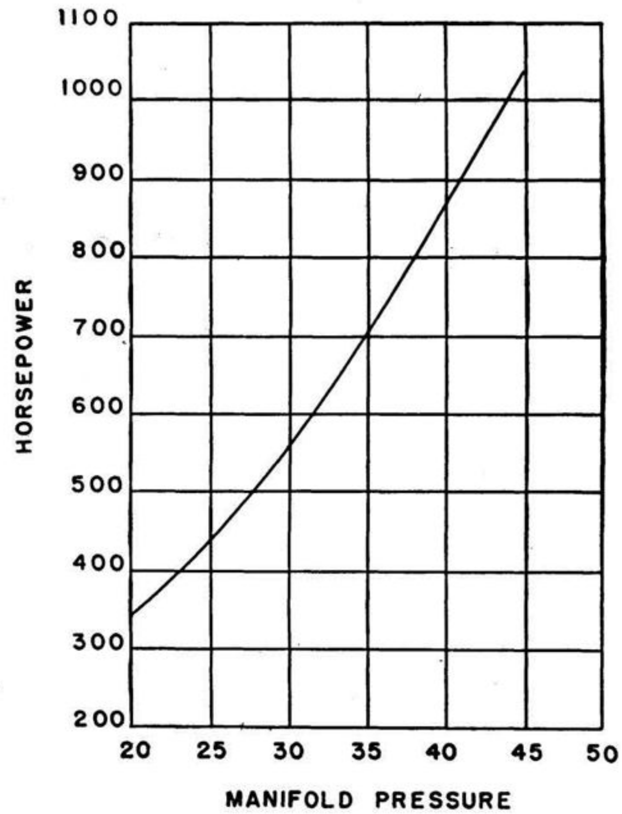


FIGURE 71. Relation between horsepower and manifold pressure.

altitude flying than would be possible at prevailing atmospheric pressure. Figure 71 shows the relation between manifold pressure and engine power output for a particular engine. If the engine is not supercharged, the maximum pressure in the intake manifold is assumed to be nearly 30 inches Hg (sea level atmospheric pressure). The power developed by the engine is then approximately 550 hp. If the manifold pressure is increased to 45 inches Hg by supercharging, the output of the engine is approximately 1050 hp. Manifold pressure must not, however, be indefinitely increased. Excessive manifold pressure is certain to cause damage to the engine.

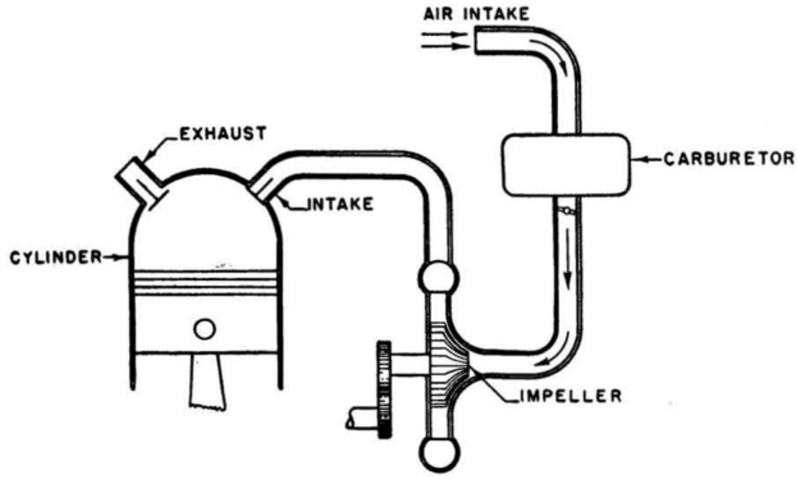


FIGURE 72. Single-stage supercharger system.

(2) Certain military aircraft must be able to fly with maximum power at high altitudes—in some cases 30,000 to 40,000 feet. It is necessary to equip the engines of such airplanes with superchargers in order to maintain the desired manifold pressure (and also the engine power output) at altitudes where atmospheric pressure is low.

(3) Another function of the supercharger (internal type) is to further atomize the fuel-air mixture and hence to facilitate complete combustion in the cylinders.

(4) Finally, the supercharger is designed to provide as nearly as possible an equal distribution of charge to every cylinder.

30. TYPES OF SUPERCHARGERS. All superchargers used by the Army Air Forces at present are alike in that an impeller or "blower" (rotating at high speed) is used to compress either the air before it is mixed with the fuel or the fuel-air mixture. Superchargers are generally classified according to their location in the airplane induction system.

a. Internal type. A supercharger located between the carburetor and the cylinder intake parts is called an "internal" supercharger (fig. 72). Air at atmospheric pressure enters the carburetor and is mixed with the fuel. The fuel-air mixture, leaving the carburetor at atmospheric pressure, is compressed in the supercharger to a pressure higher than atmospheric pressure and then enters the cylinders. Power to drive the supercharger impeller is derived from the engine crankshaft by means of a gear train. The gearing is such that the impeller rotates at a speed much greater than crankshaft speed. In some installations the gear ratio is adjustable for two different speeds, in which case the supercharger is said to be a "two-speed" supercharger. Internal superchargers are sufficient for engines which are not required to operate at extremely high altitudes or, for other reasons, do not require air under pressure to be delivered to the carburetor intake.

b. External type. A supercharger that delivers compressed air to the carburetor intake is of the external type. Air for the fuel-air mixture is compressed in the supercharger and then delivered through an air cooler to the carburetor. Power to drive the common type of external supercharger is derived from the action of the engine exhaust gases against a turbine or bucket wheel; therefore, it is called a "turbo-supercharger." Turbo-superchargers are multispeed superchargers, since the speed of the impeller depends only on the quantity and pressure of the exhaust gases directed against the bucket wheel.

31. CLASSIFICATION OF SUPERCHARGER SYSTEMS. Supercharger systems are classified according to the number of times an increase in pressure is accomplished in the system. Each increase in pressure is called a "stage." Thus it is possible to have single-stage, two-stage, or multiple-stage systems.

a. Single-stage system. The single-stage system employs either a single- or a two-speed internal supercharger. Figure 72 represents a typical single-stage system. Although a two-speed internal supercharger has two definite speeds at which the impeller may rotate, only a single "boost" in pressure is accomplished at any time. Thus the unit forms only a single-stage system.

b. Two-stage system. The common two-stage supercharger system

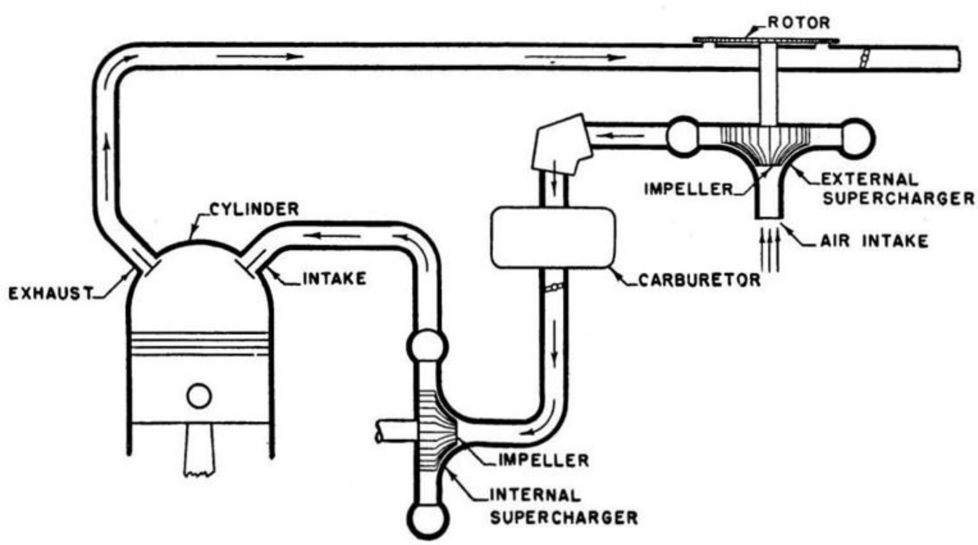


FIGURE 73. Two-stage supercharger system.

is illustrated in figure 73. It consists of an external turbo-supercharger, an air cooler, a carburetor, and a single-speed internal supercharger. In operation, air for the fuel-air mixture is compressed in the external supercharger and then delivered through an air cooler to the carburetor, where it is mixed with the fuel. Leaving the carburetor, still under pressure, the mixture enters an internal single-speed supercharger, receives a further pressure boost, and then enters the engine cylinders. Since two increases in pressure are accomplished, this system is a two-stage system.

32. COMPARATIVE PERFORMANCES OF SUPERCHARGERS AND SUPERCHARGER SYSTEMS. One means of comparing the performance of superchargers and supercharger systems is to compare the service ceilings of an airplane equipped with the various superchargers and supercharger systems and the same airplane not so equipped. Figure 74 makes this comparison.

33. INTERNAL SUPERCHARGERS — SINGLE-SPEED. a. Description. (1) The rear section of an engine is known as the "supercharger section" and forms the supercharger housing. On radial engines this section is usually made up of two pieces as shown in figure 75. The supercharger section, besides containing the drive, gearing, impeller, diffuser vanes, and distribution chamber, also provides a flange for mounting the carburetor.

(2) An accessory drive gear on the engine crankshaft drives one or more smaller gears, which in turn rotates the impeller shaft. The impeller shaft is supported by either ball or plain bearings to reduce the friction. These bearings are lubricated by an oil spray or by oil under pressure, depending on the installation.

(3) The impeller, installed in the inlet from the carburetor and designed with narrow clearances, is a circular aluminum alloy forging, designed to withstand the high centrifugal forces of rotation and accurately balanced for minimum vibration. It is fitted with radial vanes which catch the mixture entering from the carburetor. These vanes are curved in the direction of rotation in order to take in the fuel-air mixture without excessive shock and hence facilitate smooth operation.

(4) Around the inside of the housing, opposite the impeller buckets, are the fixed diffuser vanes, curving away from the impeller. The fuel-air mixture, highly atomized by the whirling impeller, is directed with increased velocity into the diffuser vanes. These are designed to slow the speed of the charge, and since there is no decrease in the quantity of the charge provided by the impeller, its pressure is increased.

(5) Surrounding the diffuser vanes is an annular passage called the "distribution chamber" or "scroll." This chamber, receiving the fuel-air mixture under pressure from the diffuser vanes, directs it to the engine cylinders. In radial engines (fig. 75) the mixture, after leaving the distributor chamber through radial ports, goes to the cylinders through individual pipes. In in-line engines, the mixture leaves the distributor chamber through a common manifold which branches into two manifolds, each supplying one bank of cylinders.

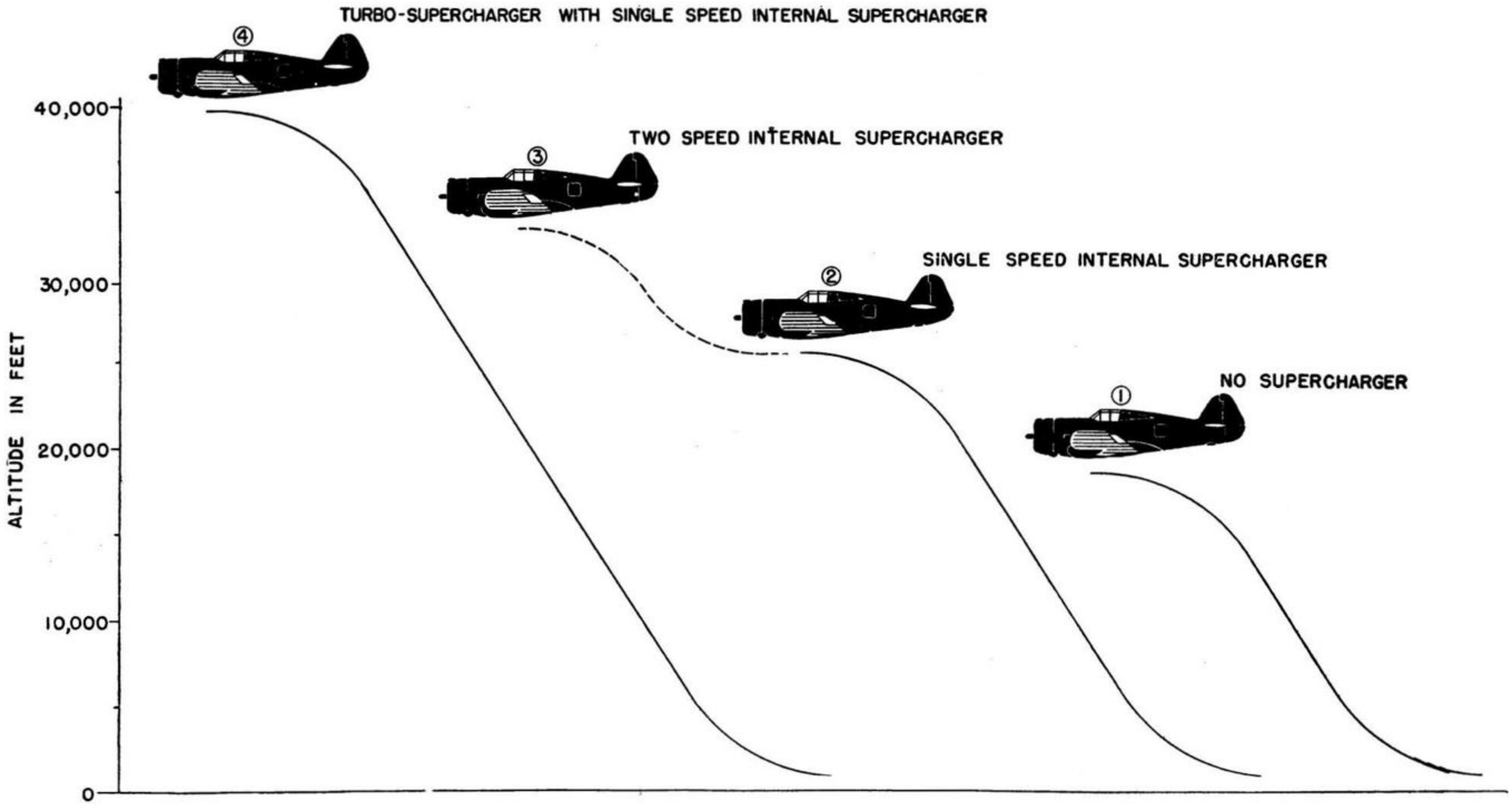


FIGURE 74. Comparative performance of superchargers.

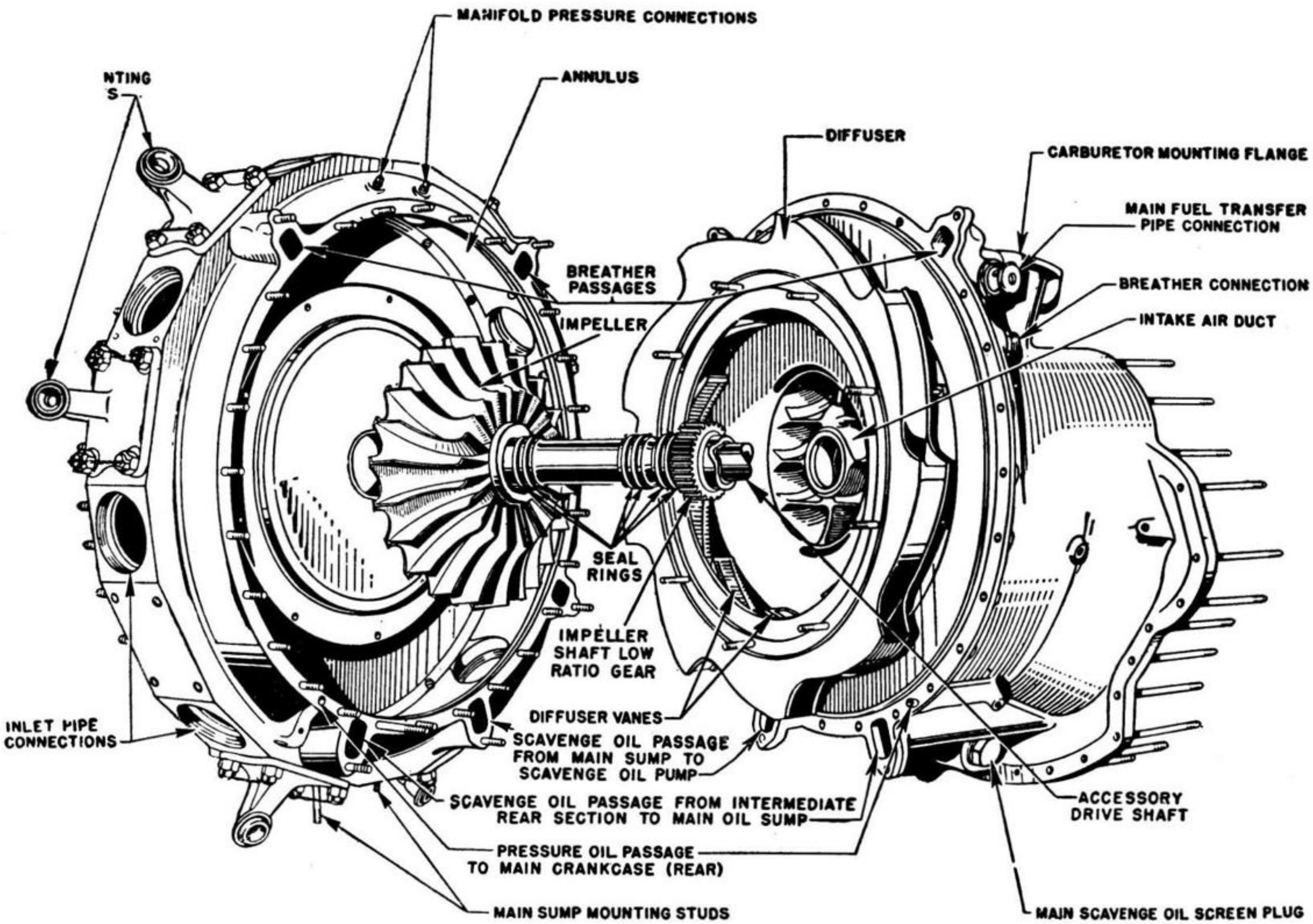


FIGURE 75. Typical internal supercharger—single-speed.

(6) A drain passage is provided from the lower rear portion of the supercharger inlet chamber to a point below the supercharger rear housing to prevent accumulation of excess fuel. The drain valve is in the form of a gravity-operated check valve which will assume an open position when the engine is not operating. This allows fuel drainage from the supercharger section. However, when the engine is in operation, the valve is closed by the suction (pressure below atmospheric) existing in the intake passage at the supercharger inlet, and this prevents air from entering. In some models a restricted air-bleed is provided through a small-diameter "gurgle" tube that leads up through the drain passage to the center of the impeller. During engine operation, any fuel that runs down the walls of the induction passage is prevented from draining into the atmosphere by the closed valve, and is drawn into holes drilled at the base of the "gurgle" tube, just above the air-bleed, where it is atomized and delivered to the impeller. If the engine is equipped with a turbo-supercharger, a special drain-valve assembly is required for the internal supercharger because, when turbo-supercharger pressure is employed, the pressure at the mouth of the impeller is at or above atmospheric pressure and would cause the drain valve to open; to prevent this, manifold pressure is vented to the valve in such a manner as to close the drain valve, and operation continues normally.

(7) A tube extends from the atmosphere at the top of the supercharger housing, through the housing, to a groove around the impeller oil-seal assembly on the impeller shaft. This arrangement does not allow any suction or pressure to build up in the area between the oil seals and the impeller. The effectiveness of the seals is thus greatly increased, and leakage of oil through the seals to the supercharger is prevented. It is essential that the vent always be kept open so as not to defeat the purpose of the unit.

(8) To measure supercharger output, a manifold pressure-gauge line is connected at a point in the supercharger section that is subject to the exact supercharger discharge pressure (fig. 75). The instrument itself consists simply of a pressure-sensitive mechanism, which expands or contracts, depending upon the value of the pressure affecting it. A multiplying mechanism increases the movement and transmits the indication to the instrument pointer. Calibration of the unit is in inches of mercury (2.04 inches Hg equals 1 pound per square inch).

b. Operation. (1) Operation of the internal supercharger depends on engine speed, which in turn is controlled by the throttle valve position. The speed ratio of the impeller to the crankshaft is a fixed gear ratio; therefore, in order to vary the manifold pressure, the setting of the throttle control or the propeller governor control must be changed.

(2) When the engine is not running, the pressure in the manifold is atmospheric, which at sea level is approximately 30 inches Hg. When

the engine is operated at low speeds, there is a low pressure or partial vacuum in the manifold between the carburetor throttle valves and the intake ports of the cylinders. This low pressure causes the manifold pressure gauge to indicate a pressure below atmospheric pressure; at idling speeds the value may be approximately 15 inches Hg. When the throttle is advanced, engine speed increases; consequently, the supercharger output increases correspondingly, causing a higher manifold pressure. Engine operation at an advanced throttle setting may cause oversupercharging, which is an extremely dangerous practice in view of the high compression pressures produced in the engine cylinders. Detonation and mechanical failure are a direct result of excessive operating pressures and temperatures; hence, close observation of the manifold pressure gauge and operation within the specified safe range are necessary.

34. INTERNAL SUPERCHARGERS—TWO-SPEED. a. Description. (1) If the gear ratio (and impeller speed) of a single-speed supercharger is high enough to provide desired manifold pressure at very high altitudes, this ratio will provide excessive manifold pressure at low altitudes. If, on the other hand, the gear ratio is proper for desired manifold pressure at low altitudes, it will be too low for desired manifold pressure at high altitudes. The gearing of some internal superchargers is therefore designed so that two gear ratios are provided: a high ratio for high altitude operation, and a low ratio for low altitude operation. These gear ratios are known, respectively, as "high blower" and "low blower." Impeller gear low-blower ratios vary from 6:1 to 8:1. High-blower ratios range from 9:1 to 11:1. These blower ratios are changed by means of friction-clutch plates, of either a cone or a disk type, operated by engine oil pressure. Selection of blower positions is made possible by a blower ratio-selector valve which directs engine oil pressure to the proper clutches. This valve control, located in the pilot's cockpit, is connected through appropriate linkage to the valve on the engine accessory section.
(2) Figure 76 illustrates the construction of a typical two-speed supercharger. Power is obtained from the crankshaft through a shaft carrying the accessory spring drive gear. This drive gear is spring-loaded to reduce the shock during acceleration or deceleration. The impeller and impeller shaft fit over the accessory drive shaft. Actually, the accessory shaft is used as a bearing surface by the impeller shaft. The high- and low-ratio drive gears are meshed to the high- and low-blower impeller gears. Only one of the drive gears will be actually driving an impeller gear at any time. When one drive gear is accomplishing the driving, the other drive gear will be rotating freely on the rotating intermediate impeller shaft.
(3) If low-blower operation is desired, the selector valve is moved to the low-blower position as shown in figure 76. Engine oil pressure is

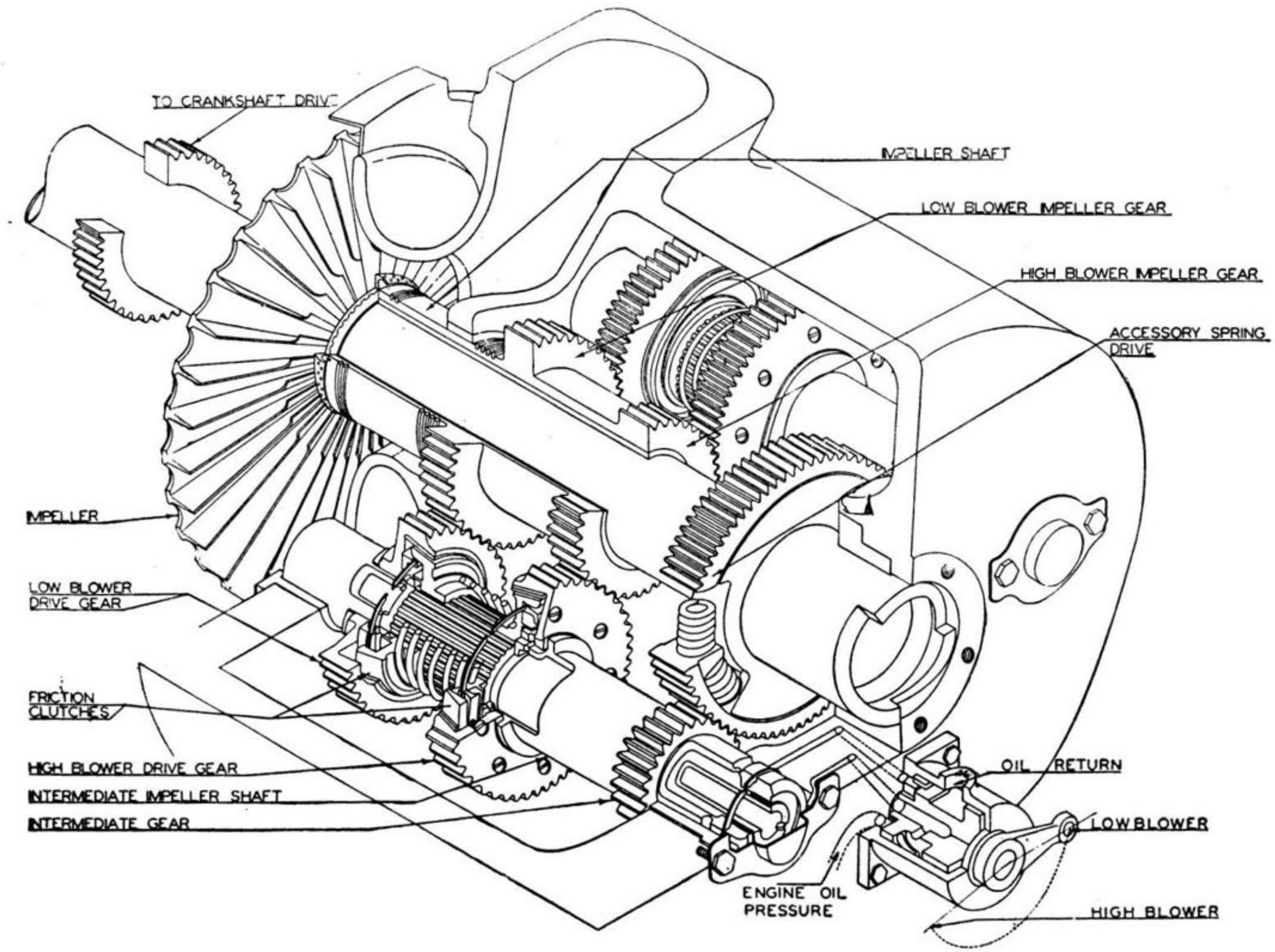


FIGURE 76. Typical internal supercharger—two-speed.

thus directed against the low-ratio clutch, which, moving to the left on the rotating intermediate impeller shaft, engages the low-blower drive gear. Being splined on the shaft, the clutch forces the gear to rotate. The rotation of this gear causes rotation of the low-blower impeller gear and the impeller shaft, so that the impeller itself rotates. During this process there is no oil pressure directed against the high-ratio clutch; hence the clutch does not engage the high-blower drive gear, which, driven by the high-blower impeller gear, rotates freely on the intermediate shaft.

(4) High-blower operation is attained in a like manner. Oil pressure is directed to the high-ratio clutch, which locks the high-ratio gear to the intermediate impeller shaft. The low-blower clutch is released by the spring because of removal of the oil pressure. The transmission of drive in this case is from the accessory spring drive gear through the intermediate shaft to the high-ratio drive gear, then to the high-blower impeller gear and to the impeller shaft and impeller.

b. Operation. (1) When an engine equipped with a two-speed supercharger is started, the blower control should be in the "low" position, to prevent excessively high manifold pressure immediately after starting.

(2) The engine should be warmed up with low blower. During the warm-up, however, there should be two shifts from low to high blower (with a return to low blower), to clean the system of congealed oil. The shift should be made rapidly and positively, with no hesitation in the movement of the control. There should be an interval of 2 minutes or more between shifts to allow the clutches to cool. It should be ascertained that the clutches do not stick, and that a change in manifold pressure or rpm takes place after a shift. During the ground check, caution must be taken against oversupercharging.

(3) Take-off requires the low-blower setting, as do low-altitude flying and cruising.

(4) The shift to high blower is generally made after the critical altitude of the low blower has been reached. (Critical altitude is the altitude up to which the unit can produce maximum rated manifold pressure, and above which this pressure decreases.) As always, the shift must be made quickly and positively. Before the shift from low to high blower is made, the throttle should be partially closed. This will prevent excessive manifold pressure when the higher supercharger output is attained in the high-blower position.

(5) During flight, the ratios should be changed periodically to prevent oil sludge from accumulating and interfering with normal operation.

(6) Landing is accomplished with the supercharger in low-blower position.

(7) Specific operating instructions for the particular installation must be followed in order to keep the supercharger in proper mechanical condition

and to operate the engine safely. Excessive manifold pressures may result in serious damage either during flight or during ground checks. A complete understanding of the supercharger and its operation is necessary.

35. AUTOMATIC MANIFOLD-PRESSURE REGULATOR. a. Purpose and use. The purpose of the automatic manifold pressure regulator is to maintain a selected manifold pressure, independent of altitude, up to the limit of the supercharger's capacity. It is employed in conjunction with internal superchargers, and relieves the pilot of the task of constantly adjusting the throttle position during changes in altitude or flight conditions.

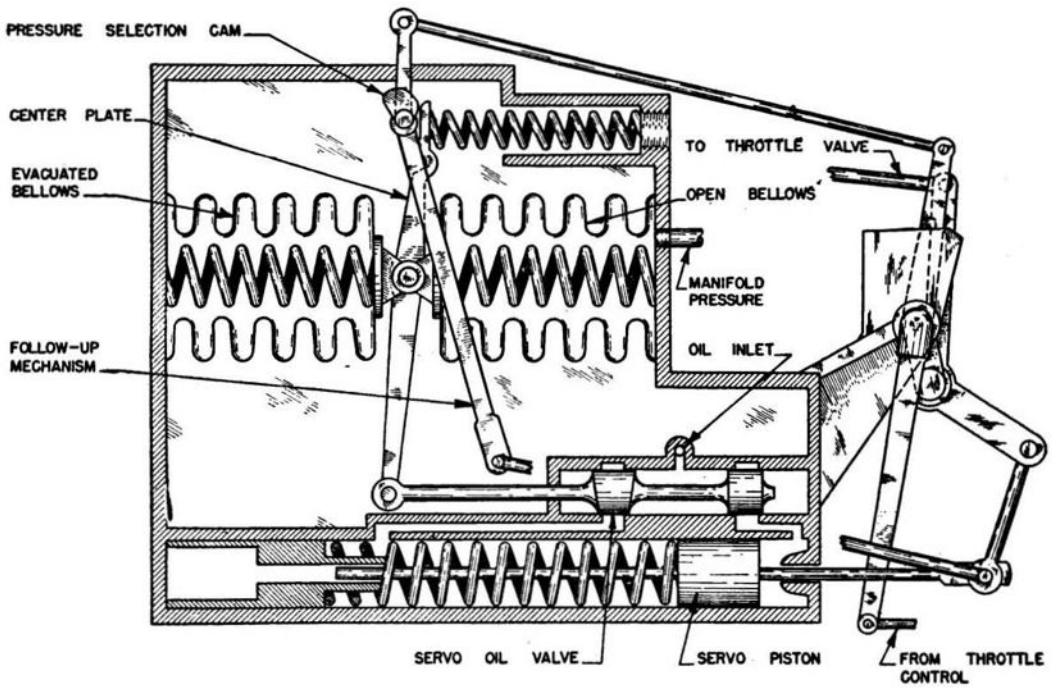


FIGURE 77. Automatic manifold-pressure regulator—internal operating parts.

b. Description. (1) Figure 77 illustrates the construction of this unit. The regulator consists of two bellows, one an aneroid from which the air has been evacuated, the other an open bellows vented to manifold pressure. Between the two bellows, and attached to both, is a post or centerplate. One end of this centerplate bears against an eccentric cam (pressure-selection cam), and the other end is attached to a servo oil valve. The piston in the servo cylinder is operated by engine oil or hydraulic oil pressure that is directed to either side of it by the servo oil valve. This piston is connected to the carburetor throttle valves by mechanical linkage; therefore, changes in piston position will vary the setting of the throttle valves and increase or decrease the manifold pressure.

(2) Surging might be caused by vibration of the regulator in frequency with the vibration of other power plant controls. To prevent surging

and to reduce "hunting" of the carburetor throttle valves, a follow-up system is incorporated. (See fig. 78.) This mechanism provides for more stable control and also more accurate control over engine power.

c. Operation. (1) In operation, the pilot advances the throttle control until the desired manifold pressure is obtained. Manifold pressure will now be maintained at a fixed value by the regulator. The dif-

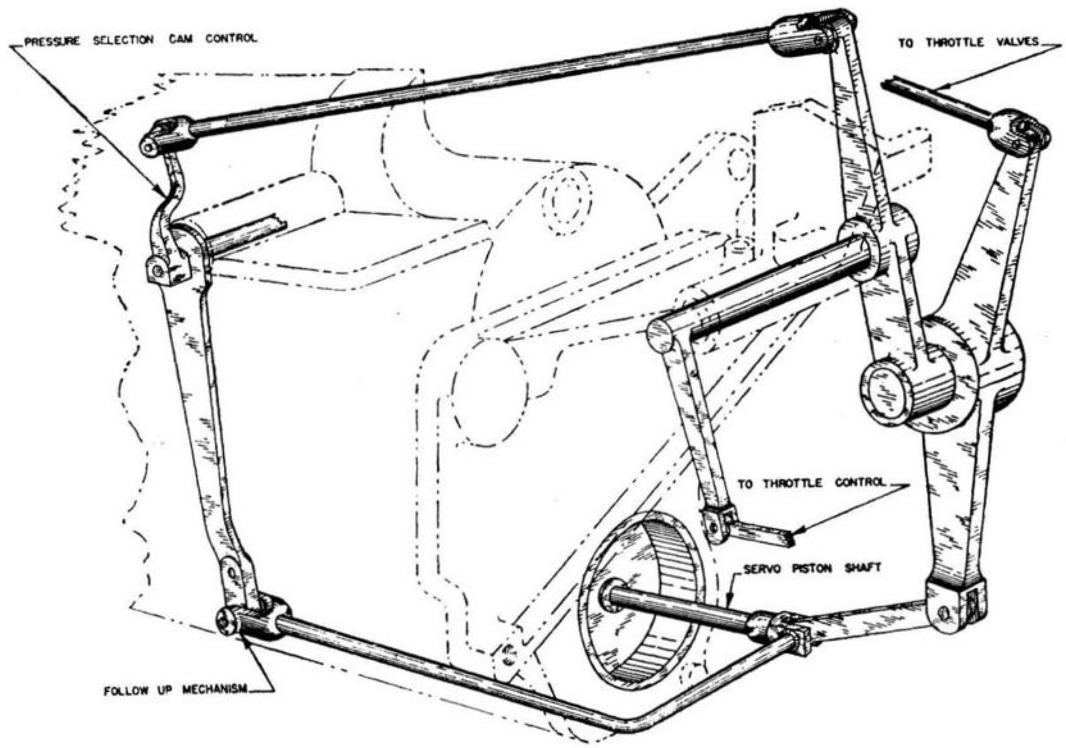


FIGURE 78. Automatic manifold-pressure regulator—external controls.

ferential linkage (fig. 78) is so designed that movement of the throttle control sets the position of the pressure-selection cam in the regulator, and also adjusts the carburetor throttle valves.

(2) When the throttle control is set in one position, no further changes are necessary to maintain a constant manifold pressure up to the critical altitude of the supercharger. Through a line venting the open bellows to the engine intake manifold, the regulator is in communication with the manifold pressure entering the engine. If an increase in manifold pressure takes place above the value desired, the open bellows extends to the left, moving the servo oil valve also to the left. This allows oil pressure to enter to the left of the piston and force the piston to the right. Through the differential linkage, this action closes the throttle valves; however, no change in the throttle control position occurs. As the manifold pressure decreases to its former value, the open bellows resumes that position which causes the servo oil valve to take a neutral

setting. Then the servo piston will maintain a fixed position. With a decrease in manifold pressure, the action of all units is reversed.

(3) In the foregoing sequence of action, the follow-up mechanism also operates. The movement of the servo piston to the right causes, through the mechanical linkage, a counterclockwise movement of the pressure selection cam. Thus the top of the center plate, under spring pressure, moves to the left, the bottom of the center plate moves somewhat to the right, and the servo oil valve begins to close off the flow of oil to the left of the servo piston. In this manner the increase manifold-pressure sequence is dampened somewhat before the expansion of the open bellows ends it altogether; the result is a minimizing of "hunting" in the system.

(4) To summarize, the pressure-selection cam is adjusted only by changes in the throttle control position. When the pressure-selection cam is set in one position, the manifold pressure will remain practically constant because of the action of the open bellows in moving the servo oil valve when a change in manifold pressure begins. Oil pressure, as directed by the oil valve, moves the piston in or out, opening or closing the throttle valves to maintain the desired manifold pressure.

(5) Take-off manifold pressure for each particular engine is indicated by an adjustable detent (throttle stop) at the throttle-lever quadrant. This setting is made upon installation of the regulator. A small, light wire is sometimes stretched across the path of cockpit throttle-lever travel, at the position corresponding to take-off, so that the wire will be broken when the pilot uses emergency power. When emergency power is utilized, the engine is subjected to extremely high operating pressures and temperatures; hence, failure of parts of the engine is quite possible, and the engine must be carefully inspected at the first opportunity. Careful inspection will determine whether the condition of the engine is safe for continued operation.

36. EXTERNAL (TURBO-) SUPERCHARGERS. a. General. (1) Internal superchargers boost the charge pressure after the charge leaves the carburetor. Carburetor air pressure, temperature, and mixture density are substantially those of the atmosphere at the particular altitude. An exhaust-driven supercharger boosts the pressure of the air before it enters the carburetor and functions to supply the carburetor with air under a pressure, temperature, and density similar to sea-level conditions. Consequently, in flight, up to the critical altitude of the supercharger, the carburetor operates as it does at sea level and engine intake pressure is the same as that obtained at low altitudes. An internal supercharger is employed in conjunction with the external supercharger. Therefore, a boost in pressure occurs twice. In addition to allowing for a normal power output at high altitudes, this two-stage system will provide increased power for take-off and low-altitude flight.

(2) The method of designating turbo-superchargers is similar to that for designating military aircraft engines. The designation of a supercharger is changed whenever a modification is made which affects either the performance or the installation in an airplane. The letter in the designation indicates the type, and the numeral designates the model.
(3) The turbo-supercharger may be divided functionally into many parts, the most important of which are the exhaust system, the air-induction system, and the pump and bearing casing.

b. Exhaust system. (1) The exhaust gases from the engine are collected in a manifold and transmitted to a nozzle box through an ex-

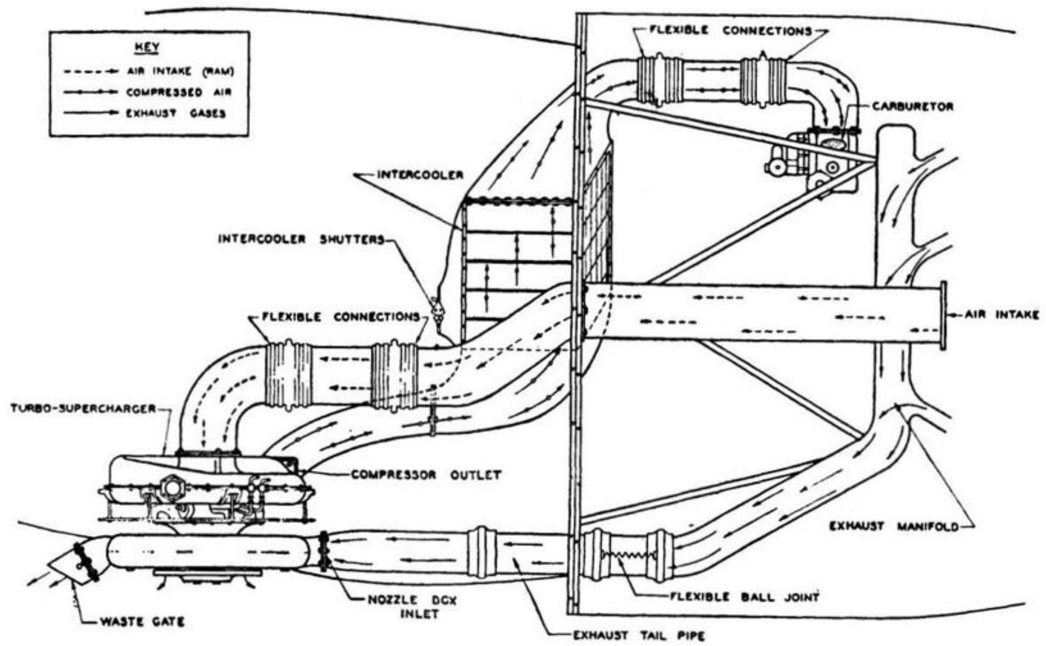


FIGURE 79. Supercharger ducting system.

haust stack (fig. 79). Materials employed in the construction of this system must be heat-resistant because of the high temperatures of the exhaust gases passing through it. The exhaust shroud, a pipe concentric around the exhaust stack, provides a safety factor in case of exhaust stack failure. A cooling blast of air from a ramming-air intake passes between the shroud and the exhaust stack. The use of the shroud is twofold; it forms a firewall around the exhaust stack and allows for cooling of the exhaust gases before they enter the nozzle box.
(2) One type of supercharger installation provides a single inlet and single outlet to the nozzle box. A butterfly type valve, called a "waste gate", is located in the outlet (fig. 79). If the waste gate is open, the exhaust gases pass through the nozzle box to the atmosphere. However, if the waste gate is closed, the gases are directed, by diaphragms in the nozzle box, against the buckets of a rotor or bucket wheel which is mounted on a shaft. These buckets are arranged radially around the

outer edge of the rotor and are so shaped that the pressure of the gases against them causes the rotor to rotate. The gases pass through the buckets and thus reach the atmosphere. In another installation no nozzle-box outlet is provided, and the waste gate is located in a short branch-off pipe attached to the exhaust stack. In this case an open waste gate bypasses all of the exhaust gases around the nozzle box and rotor.

(3) A bucket-wheel cooling cap (fig. 80) is employed to reduce the temperature of the wheel during operation. Cooling air from the slipstream is directed through the cap to the rim of the wheel, where the buckets are fitted into the wheel. This part of the wheel is especially subject to extreme stresses and temperatures; therefore, proper cooling is a necessity to prevent warping or other failure. Exhaust gases that spill from between the nozzle diaphragms and the bucket wheel will tend to gather in the rear of the wheel as well as the rear of the nozzle box. This occurrence ordinarily would cause excessive quantities of heat to be dispersed to the surrounding area. However, a duct carrying cold air discharges in such a manner as to ventilate this area. The cooling air is directed to the pump and bearing casing, and a portion of this air is deflected to the rear of the bucket wheel to provide the circulation desired.

c. Induction system. (1) Air intake occurs by means of a ram, which may be located in the engine nacelle, the leading edge of the wing, or any other point subject to the pressure originating from the airplane's movement through the air or from the action of the propeller. (See fig. 81.)

(2) After entering the intake, the air is directed into the compressor casing. In the compressor casing, and rotating on the same shaft as the rotor, is an aluminum alloy impeller similar to those used in internal superchargers. Its size is dependent upon the supercharger capacity desired. A steel bushing in the hub of the impeller provides for attachment of the impeller to the shaft by means of locking keys. Air entering the compressor casing passes into the center of the rotating impeller and is thrown out radially through the impeller vanes into the diffuser section.

(3) The diffuser vanes, which are removable, surround and curve away from the impeller. Air discharged radially from the impeller passes through these vanes, and its pressure is increased. A large outlet port in the compressor casing allows the high-pressure air to pass out toward the carburetor.

(4) Compression of the air by the impeller generates considerable heat, so that the temperature of the air as it leaves the compressor casing is higher than it should be for the charge. If the charge entered the cylinder at too high a temperature, preignition and a reduction of volu-

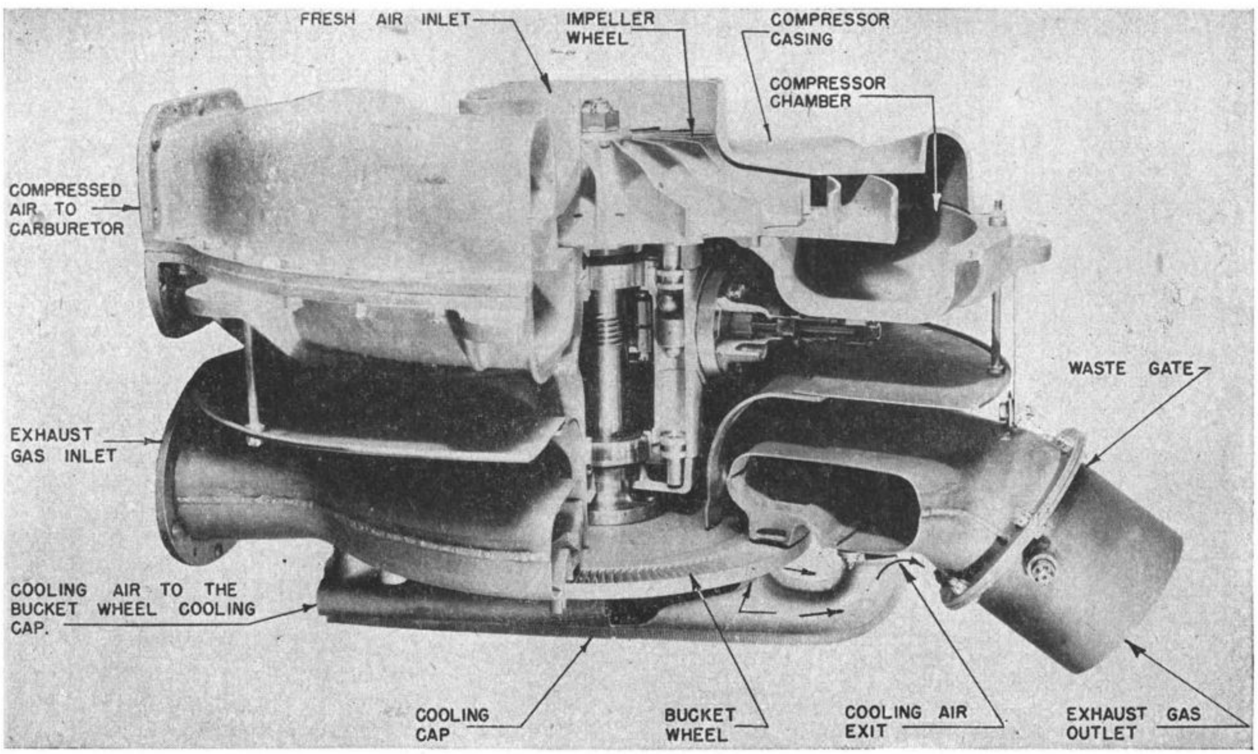


FIGURE 80. Turbo-supercharger construction.

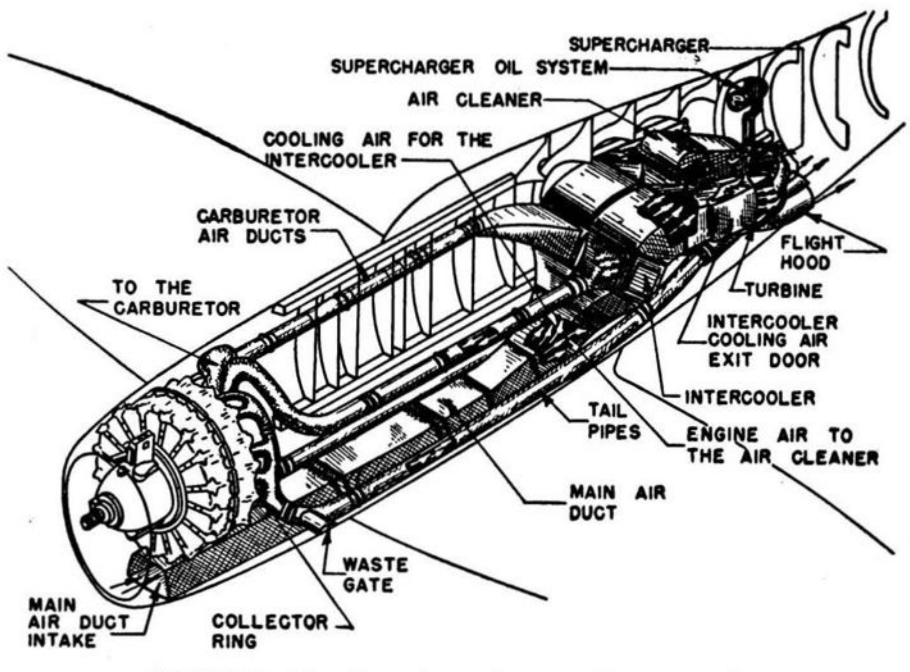


FIGURE 81. Location of supercharger units.

metric efficiency would result. To cool the air, a unit called an "intercooler" (see figs. 79 and 81) is installed between the compressor casing and the carburetor. The cooler consists of a radiator element similar to a radiator for oil or liquid cooling. There are tubes in the core through which the compressed air passes; cooling air passes around these tubes. The degree of cooling can be regulated by shutters located at the rear of the intercooler. Open shutters will provide for a greater degree of cooling; conversely, closed shutters reduce the cooling and hence can be used for heating to eliminate carburetor icing tendencies. The shutters may be controlled from the cockpit or pilot's compartment.

(5) The induction system incorporates a number of flexible joints. Installation of these joints generally will occur between the ramming intake and the supercharger compressor, between the compressor and intercooler, and between the intercooler and the carburetor. Flexible joints eliminate some of the objectionable vibration and possibility of failure resulting from movement between a nonrigidly mounted unit and a rigidly mounted unit, for example, between the intercooler and the carburetor. The flexible joints may consist of a neoprene or synthetic rubber sleeve, clamped to adjoining ends of a ducting section. These connections must be made in order to prevent leakage of the compressed air; however, the attachment must not be rigid or tight enough to induce failure due to warping of the duct.

d. Pump and bearing casing. (1) The pump and bearing casing (fig. 80) is essentially the housing which supports the shaft to which the impeller and bucket wheel are attached. For reference, the bucket-wheel end of the casing is called the "front" and the impeller end, the "rear." An oil seal and bearing is installed at each end of the casing. The oil seals are of the labyrinth type and consist of metal oil deflectors and the bearing caps. The rear oil seal includes a spacer between the plain side of the impeller and the oil deflector. The front bearing (adjacent to the bucket wheel) is a roller bearing and the rear bearing (adjacent to the impeller) is a ball bearing. The lubrication pump which is mounted on the casing is driven by a spur gear which meshes with a worm gear fastened to the impeller shaft.

(2) The lubrication pump, mounted on the pump and bearing casing, consists of two positive-displacement elements on the same drive shaft. One element is the pressure pump employed to deliver oil to the pump drive gears and the impeller shaft bearings. The other element is a scavenging pump that draws used oil from the bearing housing and discharges it through the outlet line, which returns it to either the pressure element of the pump or an external oil tank. A gravity-operated valve prevents the scavenging pump from drawing air from the casing until all of the used oil has been removed. The external oil tank, if used, generally has a capacity of 1 to 3 gallons.

e. Supercharger system. Figures 82 and 83 illustrate the complete supercharger system. Figure 82 illustrates the system when the turbo-supercharger is producing no additional boost, while figure 83 shows the position of the units when full boost is being produced. The sequence of operation of the various parts may be summarized as follows: exhaust from the engine is transmitted through a stack to the nozzle box of the supercharger. The waste gate is so adjusted that the exhaust gases cannot escape directly to the atmosphere, but are directed against the turbine wheel. This wheel rotates with a speed dependent on the quantity (pressure) of exhaust gases acting against it, and its rotation causes rotation of the impeller. Air entering from the ramming intake is compressed by the rotating impeller and the diffuser section, and directed into the intercooler, where its increased temperature is reduced. From the intercooler the air passes into the carburetor and is mixed with the fuel; then it is further compressed in the internal gear-driven supercharger and delivered through the intake manifold to the engine cylinders.

f. Accessory units and modifications. (1) PRESSURIZED CABIN. For aircraft that fly at very high altitudes, air pressure in the cabin may be kept at or near sea-level pressure by means of a supercharger.

(2) MANIFOLD-PRESSURE GAUGE. A manifold-pressure gauge is installed on the instrument panel and connected by a line from the cylinder intake manifold.

(3) FUEL PUMP. On a turbo-supercharged engine installation the fuel pump should be located below the fuel tank to avoid vapor locking due to the fuel vapor pressure and the effect of high altitude. The

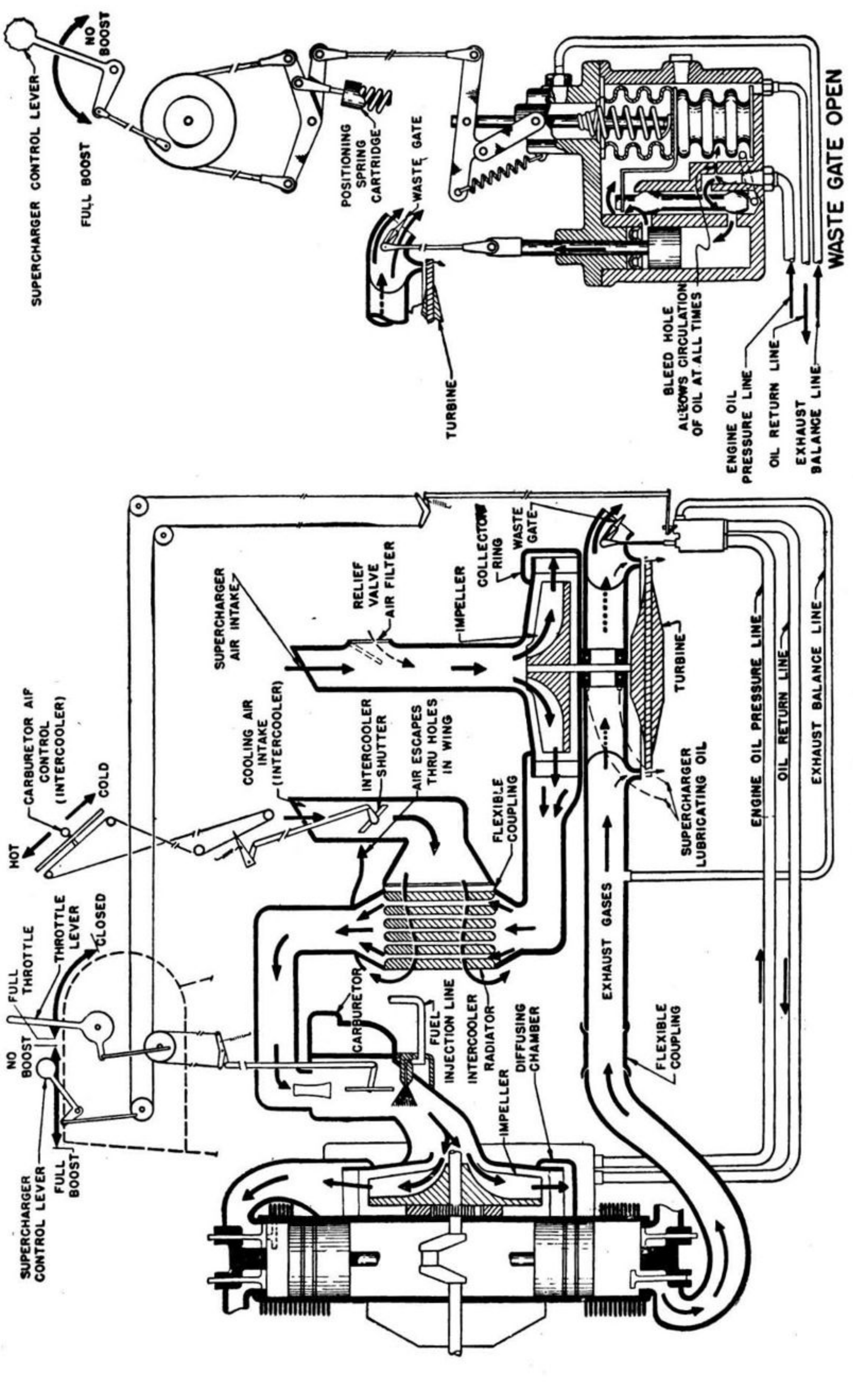


FIGURE 82. Supercharger system—no boost.

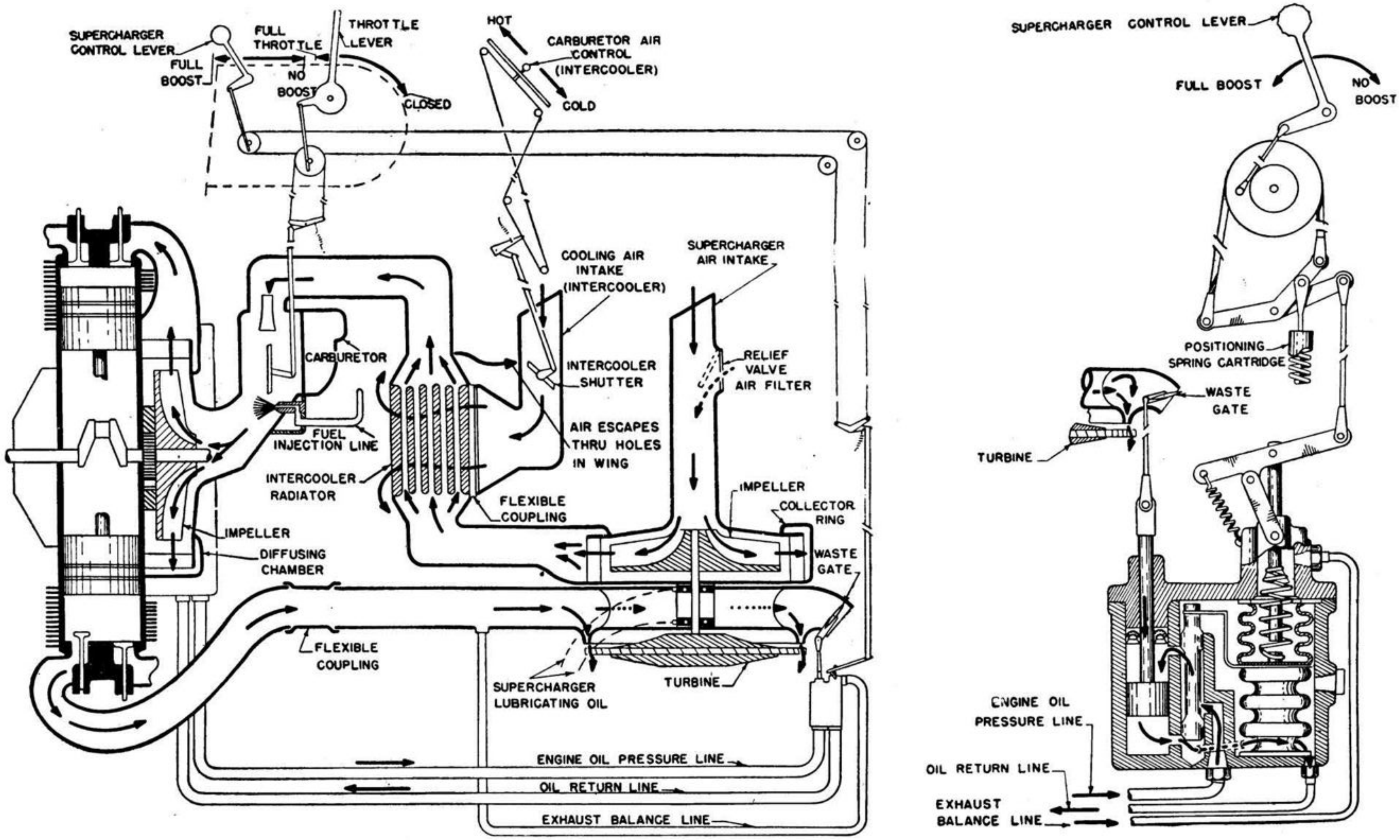


FIGURE 83. Supercharger system—full boost.

pump should be at the lowest practical location in the fuel system and should have inlets from the tank of such size as to keep the pressure drop, due to flow friction, as low as possible and to permit any vapor bubbles forming in the line to flow back to the tank. The fuel-pump relief valve, rather than being vented to the atmosphere (as it is in the fuel system of an engine not equipped with an external supercharger), must be vented to supercharger pressure (the pressure at which the external supercharger delivers air to the carburetor). This will provide a fuel pressure above the carburetor inlet pressure and insure fuel flow.

(4) FUEL PRESSURE GAUGE. The fuel pressure indicated for turbo-supercharged engines is the pressure of the fuel in excess of the carburetor air inlet pressure. This indication is obtained by means of a fuel pressure gauge with a sealed case, which is vented to the carburetor air inlet duct.

(5) CARBURETOR. Specially designed carburetors are required for turbo-supercharged engines. Such a carburetor has airtight joints at throttle and mixture control shaft bearings and parting surfaces and a mixture control which is not affected by supercharger operation. The ducts leading from the supercharger to the carburetor must be airtight to prevent losses of pressure due to leaks.

37. TURBO-SUPERCHARGER REGULATOR. a. Description. (1) Instead of controlling manifold pressure by regulating the throttles, which is the case with the regulator used with internal superchargers, the turbo-supercharger regulator controls manifold pressure by regulating the quantity and pressure of the exhaust gases directed against the turbine wheel. This regulator (fig. 84) is essentially a barometric device. Two bellows, one evacuated and the other vented to exhaust pressure, are separated by a center plate carrying a balanced oil valve. The oil valve is fed by engine oil or hydraulic-system oil under pressure. Movement of the bellows causes oil to flow under pressure to either side of a servo piston, and movement of the piston causes opening or closing of the supercharger waste gate. The linkage between waste gate and regulator is usually spring-loaded to compensate for wear and to provide for automatic locking of the waste gate (in a predetermined position) in case of failure of the linkage.

(2) A range shifter spring in the bellows assembly can be adjusted from the pilot's compartment or cockpit to provide for maintenance of the desired manifold pressure. When the control is moved to the "off" position, tension is removed from the spring and manifold pressure can be adjusted manually by the throttle control. When the supercharger control is moved toward the "on" position, tension is produced in the spring and automatic manifold pressure control begins.

b. Operation. (1) For automatic operation, the regulator (range shifter) control is placed at the desired manifold pressure setting and the

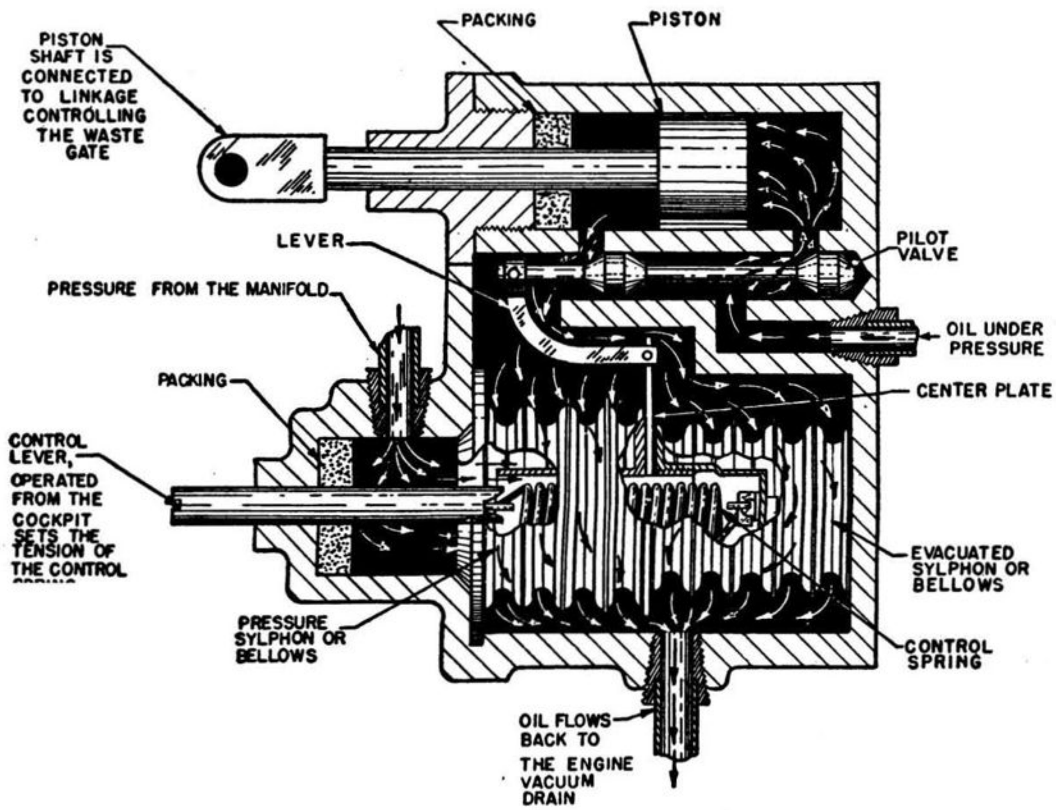


FIGURE 84. Typical supercharger regulator.

regulator bellows will assume a neutral position. It is assumed that the open bellows is vented to exhaust pressure. When exhaust pressure increases, tending to raise manifold pressure above the desired value, the open bellows expands toward the right against the spring tension. The center plate is likewise forced to the right. This movement causes the oil valve also to move to the right. Oil pressure is thus admitted to the right side of the servo piston, which moves to the left. Through the mechanical linkage, this movement of the piston begins to open the waste gate and reduce the exhaust pressure entering the nozzle box. This reduces the speed at which the turbine wheel rotates and thus reduces the manifold pressure. When the exhaust pressure has been reduced to the value necessary for the desired manifold pressure, the vented bellows moves back to the neutral position. When exhaust pressure decreases, causing a decrease in manifold pressure, the opposite sequence of operation occurs. Thus manifold pressure is kept at approximately the desired value.

(2) The range shifter spring is connected to the cockpit control through direct linkage, such as push-pull rods and bell cranks, or through a cable-and-pulley system (figs. 81 and 82). Multiengine airplanes usually employ the cable-and-pulley system because of the distances and changes of direction of the linkage between the cockpit control and the regulator in the engine nacelle. To identify the "on" and "off" cables, bands of different colors may be painted on the cables.

(3) The regulator servo piston and the waste gate are connected by direct mechanical controls, involving push-pull rods, torsion tubes, or bell cranks.

38. TURBO-SUPERCHARGER OPERATION. Various turbo-supercharger installations involve somewhat different details of operation. Technical Orders for a specific installation must be studied before operation is attempted. The following instructions for operation apply only generally. They are observed for each engine in multi-engine airplanes.

a. Starting and warm-up. (1) Before starting each engine, spin the turbine wheel by hand to make sure that it turns freely.

(2) Set the intercooler control lever to the "cold" position.

(3) Set the regulator control in the "off" position, so that when the engine is started the exhaust gases can escape readily through the manifold without being stopped by the waste gate. Inspect the waste gate to make sure that it is open when the regulator control is in the "off" position. Then, with the regulator still off, start the engine.

(4) Proceed with the engine warm-up as usual, varying engine speed with the throttle control. Check again to make certain that the regulator control is off.

(5) After sufficient warm-up, check the operation of the regulator control. At low engine speed the control lever should be given full travel from off to on, *slowly*. The first few degrees of travel unlock the regulator; further movement toward the "on" position sets the regulator to operate the waste gate. Look at the waste gate at this time to see that it travels from open to closed. During this check, the throttle control *must* be at a relatively low setting; approximately 1,000 rpm should be sufficient.

(6) Check the regulator further by operating the engine at a higher speed. Watching the manifold pressure gauge, move the control slowly toward "on position" until manifold pressure increases, indicating that the regulator is functioning. Watch the gauge carefully to make certain that engine operation is within a safe manifold pressure range. Since regulator action always lags behind the movement of the control lever, excessive manifold pressure may build up if the lever is moved too rapidly toward the "on" position when the throttle is advanced. This pressure might cause detonation and engine failure; hence the need for careful operation of the control.

(7) Check the take-off manifold pressure as follows: adjust the propeller to the specified rpm and advance the throttle to the full open position. If supercharger boosting is required for take-off, advance the regulator control until the desired manifold pressure is attained. Then retard this control and bring back the throttle control. Always reduce the supercharger output before throttling. When the throttle control is being retarded, it should be moved slowly; rapid movement may cause backfires that would cause damage to the waste gate. If backfiring has occurred, inspect the waste gate for proper operation.

(8) If the airplane is ready for take-off, set the regulator at the "take-off" position or, if take-off requires no supercharging, in the "off" position.

b. Take-off. For take-off (with engines requiring supercharging), after the propeller controls are adjusted to specified take-off rpm and the regulator has been set, the throttle should be advanced slowly so that the regulator can control the supercharger properly.

c. Climb. During the climb, the manifold pressure should be reduced to that specified for climb. Adjustments of the regulator should be made as often as necessary to maintain the desired manifold pressure, care being taken to move the control slowly.

d. Cruising. (1) During cruising, when it is desired to operate under reduced power, the supercharger control should be adjusted to lower the manifold pressure. Unless manifold pressure cannot be controlled readily by the regulator control (as in older installations), it is not good practice to reduce power by closing the throttles while supercharger operation continues, since this practice forces the engine to exhaust against a high back pressure and also tends to build up excessive operating speeds of the turbine wheel.

(2) For cruising below 5,000 feet altitude and at a power not requiring supercharging, set the throttle for the manifold pressure and power which the mission requires; then advance the regulator control and raise the manifold pressure 1 inch Hg to insure turbine operation; then retard the throttle to establish the previous manifold pressure. *CAUTION*: Never turn off the supercharger suddenly, or the rapid cooling of the bucket wheel from a high temperature may result in warping or other damage. Move the regulator control from the "on" to the "off" position by degrees, to allow for slow cooling of the bucket wheel.

(3) During flight, oil may congeal in the supercharger and regulator lines while supercharger is not operating. It is advisable to operate the supercharger periodically and thus keep the oil warm.

(4) A supercharger is rated at a certain speed at the critical altitude. This altitude is not the maximum attainable, but it is the altitude at which the bucket wheel attains its maximum allowable speed. A further increase in altitude without a corresponding decrease in the regulator setting for manifold pressure will result in overspeeding of the turbine and probable damage to it. If higher than rated altitude is to be attained, usually it is safe to adjust the regulator in order to decrease manifold pressure 1 inch Hg for every 1,000 feet gain in altitude. For example, if rated altitude is 25,000 feet with a rated manifold pressure of 35 inches Hg, for 28,000 feet the manifold pressure should be 32 inches Hg. Engine speed may remain constant.

(5) Turbo-supercharger instability, indicated by manifold pressure fluctuation, may occur at altitudes from 15,000 to 30,000 feet at engine

speeds between 1,500 and 1,700 rpm. Such instability may be partially eliminated by operation at lower than normal manifold pressures for these altitude and speed ranges. Engine operation usually will be within a horsepower range much above the range at which instability is likely to occur.

e. Descent. During descent from high altitudes, sufficient power should be used to keep the engine warm. When maneuvers are made near the ground, it must be kept in mind that response to sudden opening of the throttle in turbo-supercharged engines is slow. Landings can be made with or without supercharger operation, but ample power should be available in case landing cannot be made.

f. Engine malfunctioning. In event of malfunctioning of the engine, the supercharger control should be immediately placed in the "off" position until the trouble is corrected or until the pilot decides that operation with supercharging may safely be resumed.

g. Caution. During engine and supercharger operation, extreme care must be exercised. Excessively lean or excessively rich mixtures, or supercharging in excess of the recommended manifold pressures, are likely to cause damage to the supercharger or engine. Checks on the operation of the units and the controls must be accomplished carefully. Technical Orders must be consulted for specific directions regarding the use of each particular installation.

39. REMOVAL AND INSTALLATION. a. Internal superchargers. Since internal superchargers are integral parts of the engines in which they are used, removal and installation are performed at air depots and not by service activities.

b. Removal of turbo-superchargers. (1) Removal of external superchargers is accomplished according to the available directions for each particular installation.

(2) Before removal of a supercharger, the cooling cap should be removed and replaced by the standard bucket-wheel cover which is shipped with each supercharger.

(3) After any removal, the supercharger must be examined to ascertain that no nuts, bolts, pieces of safety wire, tools, etc., have dropped into the unit.

c. Installation of turbo-superchargers. Detailed directions for the installation of turbo-superchargers are given in Technical Orders. The following instructions are of general application only:

(1) Follow carefully the latest approved outline for the arrangement, relationship of openings, and installation of the unit.

(2) If no welded stop is provided for the waste gate, adjust the connecting rod between the gate and the regulator so that the gate will be open not less than 1/32 inch at all times.

(3) A flexible joint is provided between the exhaust manifold and a pipe rigidly bolted to the nozzle box inlet in order to protect the supercharger from all movement of the exhaust stack.

(4) Exhaust stack (or manifold) connections to the nozzle box inlet are made so that engine vibration and most of the weight of the exhaust stack are isolated from the nozzle box. The total load on the nozzle-box flange should not exceed 20 pounds in any direction; the total movement should be as indicated in the applicable Technical Order.

(5) When sections of the exhaust manifold are being mounted, connections must be made properly. This is particularly true of the connection between the tail pipe and the nozzle box, since any undue strain at this point may cause the clearance between the nozzle box and bucket wheel to decrease. Joints in the system must not allow any leakage; at the same time, care must be exercised to prevent misalignment of parts that may result from excessive tightening.

(6) The adapter connecting the supercharger air discharge outlet with the intercooler inlet should be as short as practicable, with a flexible intermediate connection.

(7) The intercooler should be so placed as to get the benefit of ram air.

(8) If there is incomplete combustion of the fuel, "afterburning" (burning of exhaust gases after they leave the cylinders) may occur after the gases have passed through the rotor. The high temperatures so produced in the exhaust gases make it necessary to exercise precautions in installation so that no damage to the airplane will result.

(9) After the supercharger has been securely mounted on the airplane and all connections have been completed, the turbine wheel cover is removed and the cooling cap installed. The air intake of the cap is placed in the line of the slipstream to catch the maximum amount of cooling air. The air should not exceed 300° F. in temperature, and should not contain exhaust gas. The cap of the type *B* supercharger is installed with a clearance of 0.095 to 0.160 inch between the rotor rim and the rim of the cap. For the type *C*, the clearance is 0.125 to 0.200 inch. Stainless steel shim spacers, furnished for adjustment of this clearance, may be inserted between the mounting lug and the cap. Safetying must be done with great care.

(10) Since the presence of loose cotter pins, safety wire, nuts, bolts, tools, etc., in the supercharger will almost certainly cause damage during operation, installation is not considered complete until it has been ascertained that no loose objects have been left in the unit.

40. INSPECTION AND MAINTENANCE. The controls of internal superchargers will be periodically checked for freedom of movement; lost motion; fraying, wear, or other deterioration of linkage; bent rods; broken or loose pulleys; safetying; and general condition. The following parts of a turbo-supercharger system must be inspected periodically, as specified in Technical Orders, if they are to be kept in proper operating condition: supercharger, exhaust system, air intake system, intercooler, control system, and regulator. Each unit must be checked for security of mounting as well as evidence of failure. The supercharger must be kept clean at all times so that defects can be readily noted in visual inspection.

a. Rotor. (1) Inspect the rotor for loose buckets, cracks, or any evidence of or liability to failure. Overstretched buckets are reason for replacement of the rotor.

(2) To check the buckets for looseness, apply pressure to the bucket tips at right angles to the wheel. With a thickness gauge, check the clearance between bucket wheel and nozzle box. If the clearance is too narrow, expansion of the metal during operation may cause contact of the two units. The clearance should be checked at several points. It can be reduced by adding the available spacer shims to the nozzle box supports, or increased by removing shims.

(3) Check the end play of the rotor as follows: push it inward toward the nozzle box and insert a thickness gauge between the wheel and the box. Read the clearance. Then pull the wheel outward toward the cooling cap, and read the clearance again. The difference between the two clearances is the end play, which indicates the condition of the ball bearing. If the play exceeds the specified tolerance, a replacement is necessary. End play can be measured also by means of a dial indicator.

(4) Check the rotor for radial shake (side play) as follows: force the wheel as far as possible in a radial direction—then set a dial indicator against the rim and pull the wheel against the indicator. The reading should not be in excess of a specified value. Excessive radial shake usually indicates failure of the roller bearing.

(5) Check the rotor for warping or "run-out". To do this, spin the wheel; if warping is noted, insert a thickness gauge at one point between the wheel and the nozzle box and, by rotating the wheel by hand, measure the amount of warping. If it exceeds the specified value, the rotor must be replaced.

b. Waste gate. Ascertain that the waste gate operates freely in the pipe. Slight binding may often be relieved by the application of a light oil, such as penetrating oil. If the pipe is warped, it may be necessary to dress the spindle edges of the waste gate.

c. Oil system. (1) If a separate oil tank is used, the oil level should be checked when the oil level in the engine tank is checked. The proper level must be maintained.

(2) Oil lines are to be inspected for security, for any evidence of deterioration, and for leaks, especially at connections.

(3) Since most bearing failures are due to dirt or other foreign material in the oil, the oil must be kept clean. Periodically, draw off a small amount of oil from the supply tank and inspect it for dirt or sediment; if any is found, the tank and lines must be drained and flushed and the system refilled with clean oil. So long as the oil remains clean it is usable. The oil filter, if used, is to be rotated frequently and cleaned at the specified intervals. Only the proper grade of oil should be employed. In an emergency the same grade of oil as the engine oil, or a somewhat lighter grade, may be used. But at the first opportunity thereafter the system should be drained, flushed, and refilled with the specified grade.

(4) Higher oil pressures than those specified may indicate that an oil lubrication jet, or some other part of the system, has been partially or wholly plugged. Such a condition should be corrected as soon as possible. For remedies for other oil pump troubles, Technical Orders pertinent to the particular installation will be consulted.

d. Control and gauge lines. Inspect all control and gauge lines for wear, fraying, or other deterioration. Check for broken, cracked, or loose pulleys; bent rods; insecure safetying. See that the controls operate properly with freedom of movement and no lost motion. Check the gauge line connections for tightness by establishing a closed system and then making and breaking connections as necessary at the proper points. If there is no gauge in the system, a water U-tube may be used. If there is no leak in the system and if pressure is produced in the system and then cut off by a valve, the pressure will be maintained indefinitely; if there is a leak, the pressure will return to zero. Leaks must be repaired immediately.

e. Exhaust system. Inspect the exhaust system for security of mounting and attachments; loose bolts, nuts, etc.; insecure safetying; cracks or leaks; deteriorated gaskets; snugness of packing nuts. Lightly tap the exhaust stacks to loosen scale, or brush them with a wire brush. Leaks should be repaired at once, since they will impair the performance of the supercharger. If the exhaust manifold emits smoke when the engine begins firing, a leak is indicated.

f. Air-induction system. Inspect the air-induction system generally for cracks, leaks, or other deterioration; for loose bolts, nuts, etc.; for security of mounting and attachments. Inspect the intercooler for general condition. Leaks in the system are likely to cause low or erratic readings of the manifold pressure gauge and malfunctioning of the engine—detonation, preignition, or loading due to the high exhaust pressure automatically built up to drive the rotor at high enough speeds to supply the air pressure required. Pressure testing of induction systems is described in Technical Orders. Leaky joints may be made airtight with shellac or gasket paste. Carburetor shaft packings should be adjusted so that they neither leak nor bind the shaft.

g. Regulator. Inspect the regulator for proper mounting, security of attachment, and proper connections of oil pressure and drain lines. Check for faulty gaskets and excessive oil leakage at the servo piston rod. Slight oil leakage at this point is unavoidable; leakage beyond the specified maximum is cause for replacement of the seals. Before each flight, check the operation of the regulators individually. The regulator may be rendered inoperative or caused to operate erratically by damaged bellows, a sticking or binding control valve, leaking or clogged oil or air lines, range shifter spring fatigue, defective oil seals or gaskets causing oil leaks, loose connections, or improper assembly of the lock ring on the range shifter tension rod. Any of these difficulties is reason for replacement of the unit, except when clogged oil or air lines can be readily cleared by service activities.

h. Air intake filter. Clean the screen.

i. Lubrication. Periodically, as specified, replenish the supply of oil in the tanks and turbo-supercharger lubricating systems and check the condition of oil pumps and lines. Apply the approved grease to grease-lubricated superchargers.

j. Repairs. Minor repairs, such as on cracks in sheet metal parts or damaged cores of the intercooler, may be made by service activities. Silver solder will be used for repairs to intercooler headers, and hard solder for the cores. The exhaust manifolds, being of corrosion-resistant steel, are welded only with the specified type of welding rod.

k. Special precaution. Foreign objects, such as broken cotter pins, must not be allowed to fall into the supercharger. Such objects are likely to cause disintegration of the bucket wheel during high-speed operation. Although a screen is provided to reduce this hazard, it is not wholly effective in preventing foreign material from passing through. During maintenance work, particular care must be taken to see that no bits of safetying wire or other articles, including tools, rest on the supercharger.

SECTION VI

ENGINE CONTROL SYSTEMS

41. GENERAL. a. Purpose and use. Engine controls are the mechanisms by means of which the engine and engine accessories are controlled from the pilot's compartment or cockpit. Each accessory must be controlled not only as a unit, but with regard to its effect on the other engine accessories. Accurate manipulation of the controls is essential for proper engine operation. Control systems consist of rods and tubing, cables and pulleys, or a combination of these with necessary connections and accessory parts. There is no fixed rule for choosing the type of control linkage to be used. The various types of linkages will be discussed generally in the paragraphs below.

b. Rods and tubing. (1) CHARACTERISTICS. Rods or tubing that transmit control lever movement are commonly called "push-pull rods." Successful operation of a push-pull rod depends on its ability to withstand compression and tension; therefore, the diameter and the wall thickness required is determined by the amount of force to be exerted on the member. These rods are generally constructed of steel tubing. They must be installed so that bends are not required, because compression tends to increase a bend and tension tends to decrease it. This change in length would change the adjustment of the mechanism being controlled. Guides are often incorporated to prevent flexing and to aid in supporting control rod members. The tubing fits through the guide with a smooth sliding fit, designed to produce minimum friction. This is particularly important when long control rods are employed.

(2) ROD AND TUBE ENDS. There are four types of attachment used in securing the ends of the control rods. These are known as the clevis and pin rod end, the threaded rod end, ball joints, and the ball-bearing rod ends. (See fig. 85.) Close inspection and care of the rod ends will eliminate much of the undesirable "give and slack" in the control linkage.

(3) BELL CRANKS. It is seldom possible to install control linkage direct from the control in the cockpit to the engine accessories. Consequently, bell cranks are often employed to obtain the proper relative movement between the cockpit control lever and the engine unit which it controls. For example, it may be necessary to change a horizontal movement to a vertical movement (fig. 85(1)), or a forward movement to a

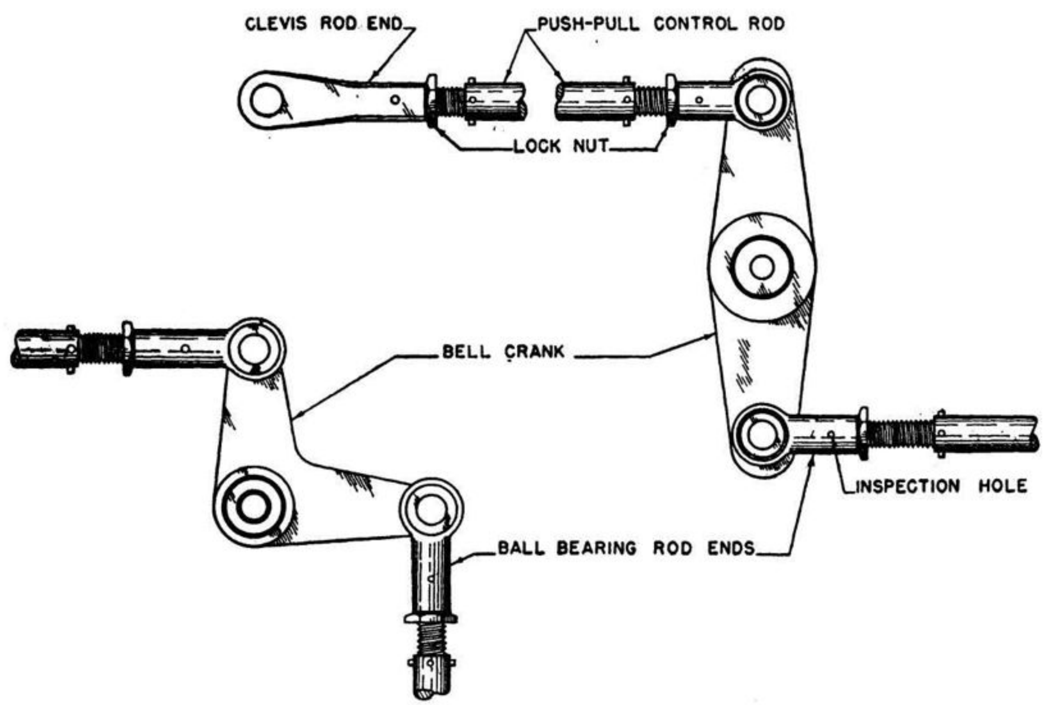


FIGURE 85. Bell cranks and rod ends.

rearward movement (fig. 85(2)), without a loss or gain in movement of the linkage. However, through the use of a bell crank with unequal arms, a gain or loss in movement may be obtained if desired. With this arrangement, a small movement of the cockpit control may produce a proportionately greater movement of the engine unit adjustment; conversely, greater travel of the control lever may produce a smaller movement of the engine unit adjustment. The exact results obtained depend upon the method of installing the bell crank. Bell cranks are generally supported by ball bearings, so that there will be a minimum of drag or friction during operation.

c. Cable and pulley systems. Control system installation in multi-engine airplanes is often difficult. Distances between control levers and engine units frequently make it impracticable to install push-pull control rods. Consequently, cable-and-pulley control systems are often incorporated as shown in figure 86.

(1) In the pilot's compartment, a control pedestal may be employed with pulleys attached to the control levers (fig. 87). Movement of the controls produces a turning of the pulleys, so that transmission of movement is obtained through the cables to the respective engine units. The cables are usually of flexible steel, properly load-tested prior to installation. Pulleys may be of a phenolic or micarta composition and may be supported on antifriction bearings. The flexible cables are attached to the outer edges of the pulleys, and other pulleys support the cables and direct them around units and accessories, changing the direction of movement until the engine unit is reached. Fairleads at various points along the system aid in supporting each cable.

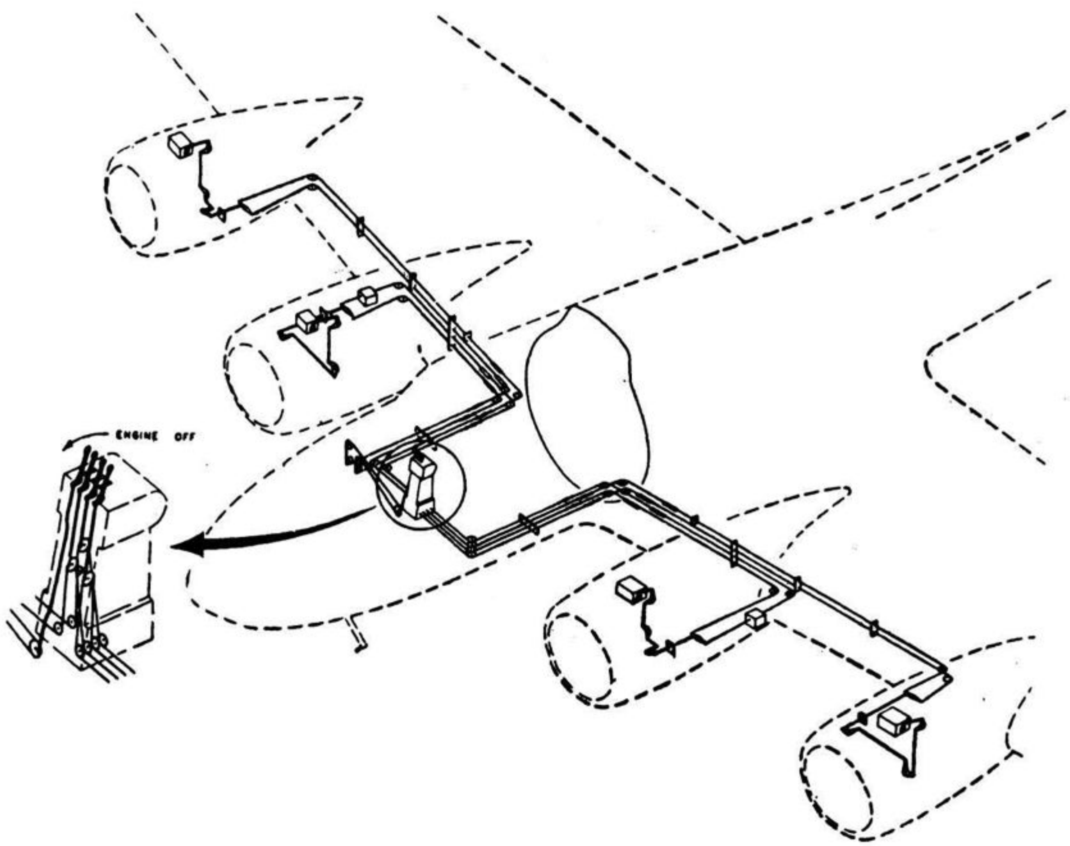


FIGURE 86. Cable and pulley control systems.

(2) Some installations employ complete cable systems, with cables extending from the control levers to the engine units. Other systems incorporate combinations of cables and rods. (See fig. 86). The cables are extended from the control levers to the firewall of each engine nacelle. Push-pull control rods are used between the firewall and the engine units.
(3) To facilitate adjustment of tension and cable lengths, turnbuckles, adjusting links, or adjustable pulleys clusters (fig. 88), are employed. Adjustments must be such that the control handles in the cockpit reach their fore and aft stops at the same time that the stops in the engine sections are reached. If, during the adjustment of any control, a "spring-back" is noticed at either end of the control quadrant, the system is readjusted so that the "spring-back" is apportioned equally to each end of the quadrant.

d. Control assemblies. (1) The control assemblies in cockpits or pilot's compartments differ for single-engine airplanes and multi-engine airplanes. A single-engine aircraft requires only a single quadrant for a combination installation of the throttle, mixture, propeller, and supercharger controls. Individual control levers would then be used for such accessories as the carburetor air heat, cowling shutters, and radiator or oil-cooler shutters. Sufficient friction in the quadrant assemblies will prevent the controls from creeping.

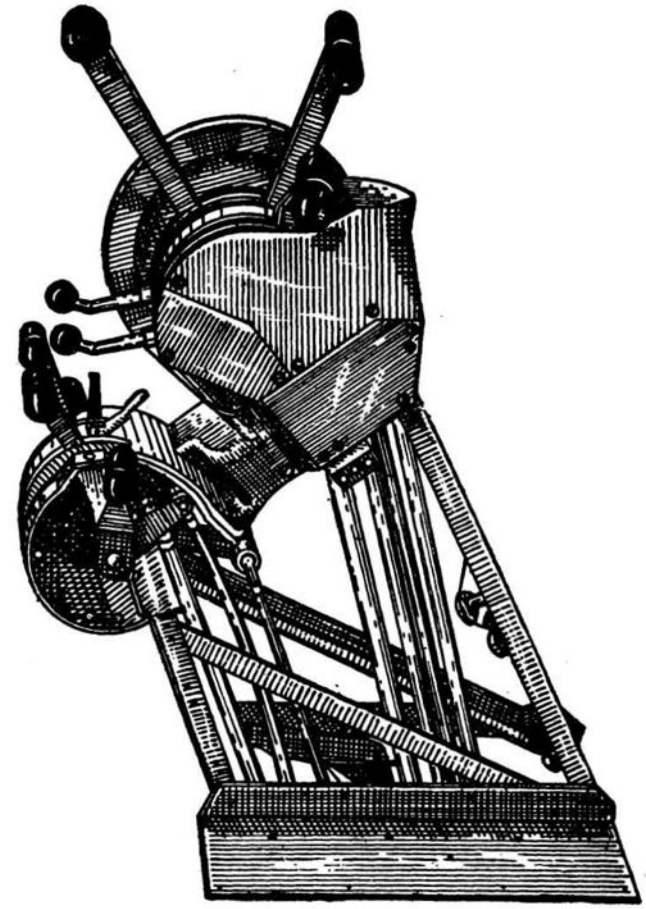


FIGURE 87. Control pedestal.

(2) In a multi-engine airplane a control pedestal is located in the pilot's compartment. The majority of engine controls are mounted on this pedestal and are, therefore, centralized. Friction clutch adjusting units or control locks are often installed to prevent any undesirable tendency of the controls to change position.

42. THROTTLE. a. The throttle control lever is the most conspicuous control and is generally marked by the letter *T* to facilitate rapid identification (fig. 89). The open and closed positions of the throttle are marked on the quadrant. Movement of the lever toward the open position produces an increase in engine power, and movement toward the closed position decreases power output.

b. An adjustable throttle stop may be installed for use with highly supercharged engines to limit the opening of the throttle valves. The manifold pressure should be observed closely during all adjustments of the throttle.

c. Multi-engine installations are often designed to allow two or more throttles to be moved simultaneously since this is desirable in many instances.

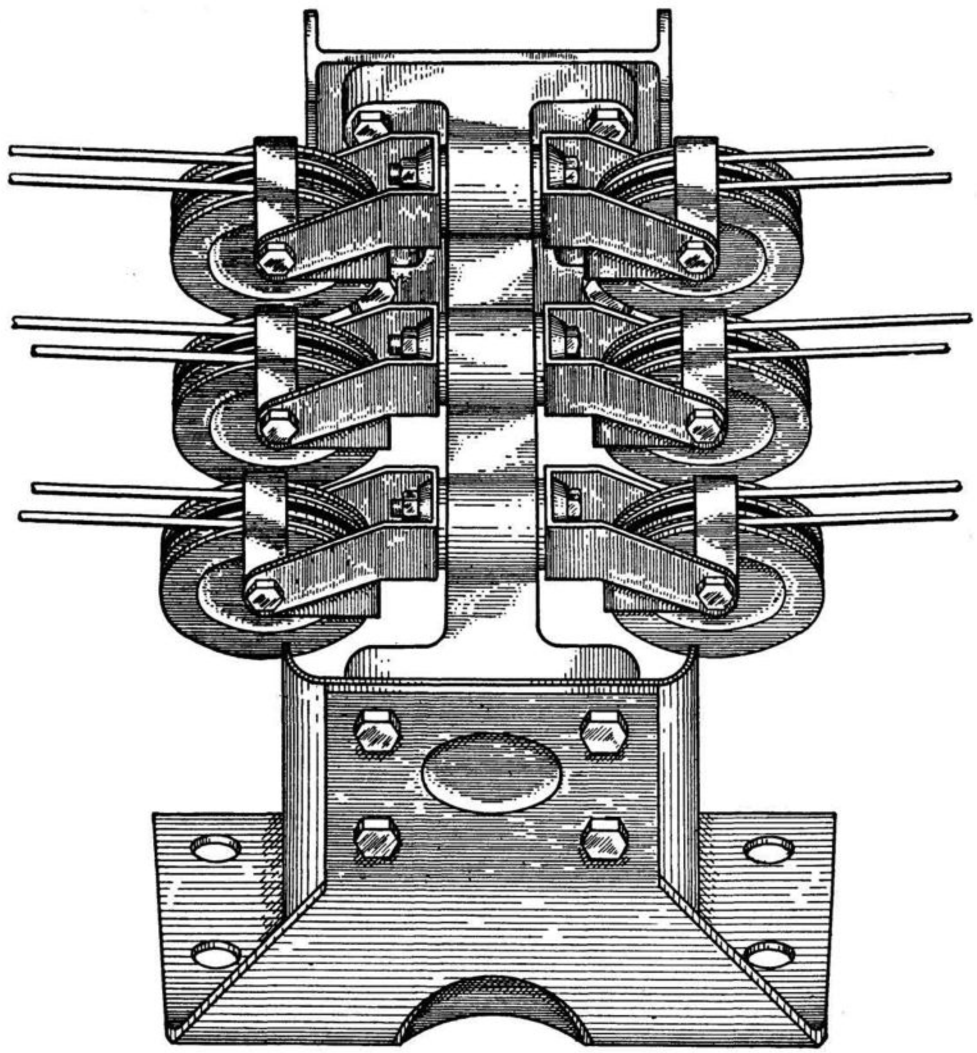


FIGURE 88. Adjustable pulley clusters.

d. The linkage is designed to permit a fine adjustment of the throttle valve, and is installed with sufficient friction to prevent creeping. Many installations provide safety units in the form of springs which, in the event of cable or control failure, automatically set the throttle valves at a predetermined position and so insure safe operation.

43. MIXTURE. **a.** Operation of the mixture control is very important. The control is usually marked with the letter *M* (fig. 89), and the quadrant may have the various positions of the control clearly indicated—idle cut-off or full lean, automatic lean, automatic rich, and full rich.

b. The idle cut-off control is incorporated in carburetors to allow for stoppage of the engine. The extreme position toward lean is marked "Idle cut-off," and includes approximately 10° of travel of the control. The engine is stopped with this control at the specified idling speed.

c. To hold the mixture control in a fixed position, a rack and pawl mechanism, or a ratchet arrangement or control lock, is often employed.

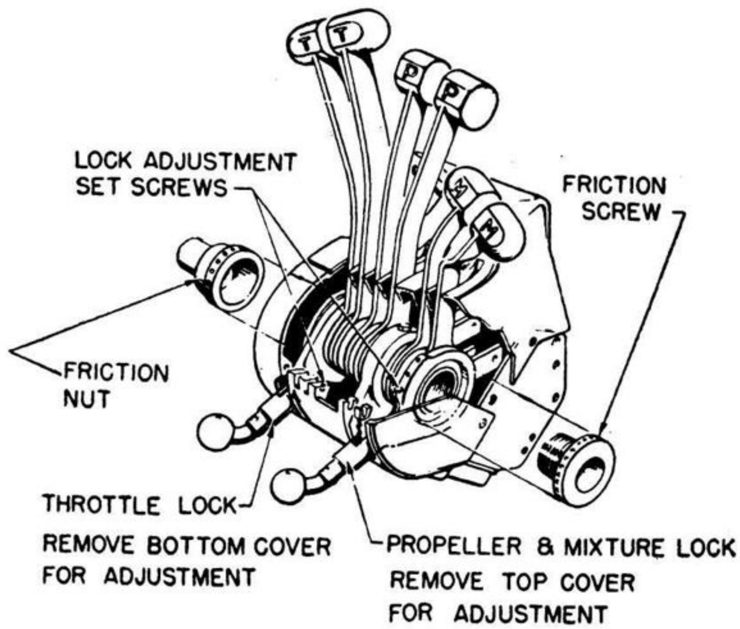


FIGURE 89. Control quadrant.

44. CARBURETOR AIR HEAT. The control for carburetor air heat may be an individual control with a locking mechanism, or it may be included in a combined control assembly. Heaters may be of two types: a two-position selection only, or a type with which a number of intermediate selections may be chosen between the "open" and "closed" positions. The control operates a gate valve in the main air intake to the carburetor, directing either cold air or warmed air to the carburetor. When the control is in the "on" (hot) position, heated air is allowed to enter the induction system. The "off" (cold) position allows outside air at atmospheric temperature to enter the system. The gate valves will automatically assume some predetermined position in case the control is severed.

45. SUPERCHARGER. There are two types of controllable superchargers in service at the present time. One type is a variable-speed unit, operated by exhaust gases; the second is a two-speed gear-driven unit, with low and high impeller speeds.

a. Exhaust-driven supercharger. (1) With an exhaust-driven supercharger, the manual control lever is usually incorporated as part of the combined engine control assembly. It is generally marked with the letter *B,* and the control quadrant is marked with "On" and "Off" at the extreme positions of the control lever.

(2) An automatic regulator is installed in the control system between the control lever and the blast gate. Movement of the control lever sets the regulator to direct oil under pressure against a piston. The blast or waste gate, which is linked to the piston, is then actuated toward either

the "on" (closed gate) or "off" (open gate) position. The regulator will hold the manifold pressure approximately constant when the control is set at a definite position.
(3) A safety spring is sometimes installed so that in the event of supercharger control failure, the waste gate is forced to a predetermined position.

b. Two-speed superchargers. A different type of supercharger control is used in conjunction with engines equipped with two-speed, mechanically driven superchargers. This control is mounted in the cockpit and properly marked to designate the high- and low-speed position. The two-position control operates an oil valve in the engine oil pump, which selects one of two gear ratios. Usually the control is supplied with a lock mechanism, which will positively keep the control in one position.

46. SUPERCHARGER INTERCOOLER SHUTTERS. a. The intercooler is installed in an external supercharger system to reduce the temperature of the compressed air before it enters the carburetor. Essentially the unit is a radiator. Heated air from the supercharger passes through the core tubes, and cooling air passes around the core tubes. Shutters installed at the rear of the intercooler regulate the passage of the cooling air.

b. When the shutters are in the "open" position, the maximum amount of cooling air is allowed to pass through, thus producing a maximum cooling effect. However, to provide a carburetor air-intake temperature sufficient to prevent icing, the shutters must sometimes be brought toward a closed position. This position will decrease the flow of cooling air through the intercooler and allow air of a higher temperature to enter the carburetor.

c. The intercooler shutter controls may be operated by either mechanical linkage (control rods, cables, etc.) or electric motors. The control quadrants are generally marked "Open" and "Closed" to indicate shutter position. Regulation of the shutters is governed by the carburetor air-intake temperature or carburetor mixture temperature.

47. RADIATOR SHUTTERS. a. General. Radiator shutters may be installed in aircraft with liquid-cooled engines to control the flow of air through the coolant radiators and the oil coolers. In single-engine equipment the control is mounted in a convenient position in the cockpit. In a multi-engine installation, the shutter controls are incorporated in the combined engine control assembly. Shutter control quadrants are usually marked "Open" and "Closed." In the "open" position, cold air is allowed to pass through the radiator and cool the liquid. When partial cooling is desired, the shutters are moved toward the "closed" position to decrease the flow of cold air through the radiator.

b. Thermostatic valve. A thermostatic valve is sometimes incorporated in the radiator shutter control system for liquid-cooled engines. This valve functions automatically, opening or closing the shutters through appropriate linkage when the coolant temperature changes.

c. Oil coolers. An oil-cooler radiator also employs shutters, similar to the radiator shutters. In many installations, shutters control the air flow simultaneously for the oil and coolant radiators. The oil-cooler flaps, or shutters, are operated by various methods. The air-exit flaps may be actuated by direct mechanical control (either push-pull rods or flexible cables), or by an electric motor controlled by a switch in the pilot's compartment. With either of these two systems, the control is manual and is operated according to the oil temperature indication.

(1) A recent type of installation provides an automatic shutter control actuated by oil pressure. If the oil becomes cold, relatively high pressure is necessary to cause the oil to flow. This pressure causes a piston to move, and by means of a connecting linkage the air exit flaps are brought toward a closed position. This allows for an increase in oil temperature.

(2) When oil temperature is high, the shutters are moved toward the open position, allowing a greater air flow through the oil cooler and thus causing a decrease in oil temperature. The oil temperature gauge must be observed during operation, so that the shutters can be properly adjusted to maintain the correct temperature.

48. COWLING SHUTTERS. a. Cowling shutters or flaps are installed on the ring cowling of an air-cooled engine to regulate the passage of air around the engine cylinders. When the flaps are open, the maximum amount of air passes around each cylinder and leaves at the rear of the cowling. This causes maximum cooling of the cylinders. Closing the shutters decreases the flow of cooling air and allows an increase in temperature.

b. The shutters are operated from a control in the cockpit. This control may be an individual control, or it may be included in the combined engine control assembly. Mechanical linkage transmits the movement of the control to the flaps. However, operation of the flaps is often obtained from the cockpit by an electric toggle switch mounted on or near the instrument panel. The switch operates a small electric motor installed in a position adjacent to the cowling flaps. The switch is marked "Open" and "Closed" and must be held in one position or the other to operate the motor. Linkage from the electric motor to the cowling shutters is through a worm-gear drive assembly.

c. Engine cylinder temperature must be maintained within a definite range in order to insure normal operation. Frequent observation of the cylinder-head temperature gauge is necessary, and regulation of the shutters is governed by the reading on the instrument.

49. PROPELLER. The type of cockpit propeller control employed with the controllable pitch propeller depends upon the principle of operation of the propeller. Propeller pitch is changed either hydraulically or electrically. Movement of the control in the pilot's compartment or cockpit is transmitted from the engine control quadrant to the propeller governor. The control lever knob is usually indicated by the letter *P* (See fig. 89). An electric propeller is controlled by switches located on or near the instrument panel. An electric switch is also provided to control the feathering and unfeathering operation of the propeller.

50. INSPECTION AND MAINTENANCE. The engine control system must be in normal operating condition at all times. Frequent inspections as designated by Technical Orders are necessary. The following are general instructions only:

a. The control unit in the cockpit is inspected for security of mounting, free operation, proper travel of the levers through their extreme range, and lost motion. To determine whether lost motion exists, it is necessary to check the control system from both ends.

b. Inspect the push-pull rods for bends and wear. Any undue strain upon the rods will cause bending or twisting. Note movement of the rods for evidence of this condition.

c. Check each rod end and determine that the rod is screwed into the socket body until it is visible through the inspection hole.

d. Inspect the bell cranks for security of mounting, wear, and lubrication.

e. Inspect generally for proper safetying, broken or misaligned pulleys, loose or missing bolts, and frayed cables.

f. Clean all moving connections and lubricate with engine oil. Where sealed bearings are employed, no lubrication is necessary.

g. All control cables should be cleaned where they pass over pulleys or through fairleads, and should be covered with the approved rust preventive.

h. Engine controls must be properly adjusted to provide smooth and correct operation for the pilot. In multi-engine installations, if the throttle levers were not together at equal positions of the throttle valves in the carburetors, individual adjustment of each throttle control would be required. This would be dangerous during take-off, and particularly so at the approach for landing. Even in the two-position carburetor airheat controls, accurate adjustment and elimination of play are essential. If the carburetor airheater valve in the carburetor intake is not tightly closed when the control lever is in the "cold" position, hot air will leak in and mix with the cold air taken in by the air scoop, causing possible loss of considerable horsepower and higher fuel consumption.

i. On completing a new installation, or after an adjustment has been made, operate the controls and check for play and binding. Play may be eliminated by making sure that all rod and bolts, check nuts, shaft bolts, and mounting bolts are tight.

j. If ball-bearing rod ends or bell crank bearings are causing lost motion in the system, they should be replaced. If rods bind excessively on the guides, the guides are not installed properly, and the condition should be corrected. Care should be taken that binding of rods on guides is not mistaken for "spring-back".

k. The lengths of push-pull rods may be adjusted by screwing in or backing out the control ends. Make certain that the lock nuts are properly retightened.

l. The correct tension of cables must be maintained constantly. A tensiometer is employed to determine the tension setting. Turnbuckles and adjusting links are used to vary the tension of a cable. Make certain that the turnbuckles are properly safetied after each adjustment.

m. If rods, cables, pulleys, or bell cranks must be removed, each part should be clearly marked to show its location in the system. This will save considerable time in reassembly.

n. For a complete and detailed inspection procedure applicable to a specific installation, refer to pertinent Technical Orders.

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