Chapter 6

Lubrication & Cooling Systems

Principles of Engine Lubrication

The primary purpose of a lubricant is to reduce friction between moving parts. Because liquid lubricants or oils can be circulated readily, they are used universally in aircraft engines. In theory, fluid lubrication is based on the actual separation of the surfaces so that no metal-to-metal contact occurs. As long as the oil film remains unbroken, metallic friction is replaced by the internal fluid friction of the lubricant. Under ideal conditions, friction and wear are held to a minimum. Oil is generally pumped throughout the engine to all areas that require lubrication. Overcoming the friction of the moving parts of the engine consumes energy and creates unwanted heat. The reduction of friction during engine operation increases the overall potential power output. Engines are subjected to several types of friction.

Types of Friction

Friction may be defined as the rubbing of one object or surface against another. One surface sliding over another surface causes sliding friction, as found in the use of plain bearings. The surfaces are not completely flat or smooth and have microscopic defects that cause friction between the two moving surfaces. *[Figure 6-1]* Rolling friction is created when a roller or sphere rolls over another surface, such as with ball or roller bearings, also referred to as antifriction bearings. The amount of friction created by rolling friction is less than that created by sliding friction and this bearing uses an outer race and an inner race with balls, or steel spheres, rolling between the moving parts or races. Another type of friction is wiping friction, which occurs between gear teeth. With this type of friction, pressure can vary widely and loads applied to the gears can be extreme, so the lubricant must be able to withstand the loads.

Functions of Engine Oil

In addition to reducing friction, the oil film acts as a cushion between metal parts. *[Figure 6-2]* This cushioning effect is particularly important for such parts as reciprocating engine crankshafts and connecting rods, which are subject to shock-loading. As the piston is pushed down on the power stroke, it applies loads between the connecting rod bearing and the crankshaft journal. The load-bearing qualities of the oil must prevent the oil film from being squeezed out, causing metal-to-metal contact in the bearing. Also, as oil circulates through the engine, it absorbs heat from the pistons and cylinder walls. In reciprocating engines, these components are especially dependent on the oil for cooling.

Oil cooling can account for up to 50 percent of the total engine cooling and is an excellent medium to transfer the heat from the engine to the oil cooler. The oil also aids in forming a seal between the piston and the cylinder wall to prevent leakage of the gases from the combustion chamber.

Oils clean the engine by reducing abrasive wear by picking up foreign particles and carrying them to a filter where they are removed. The dispersant, an additive, in the oil holds the particles in suspension and allows the filter to trap them as the oil passes through the filter. The oil also prevents corrosion on the interior of the engine by leaving a coating of oil on parts when the engine is shut down. This is one of the reasons why the engine should not be shut down for long periods of time. The coating of oil preventing corrosion will not last on

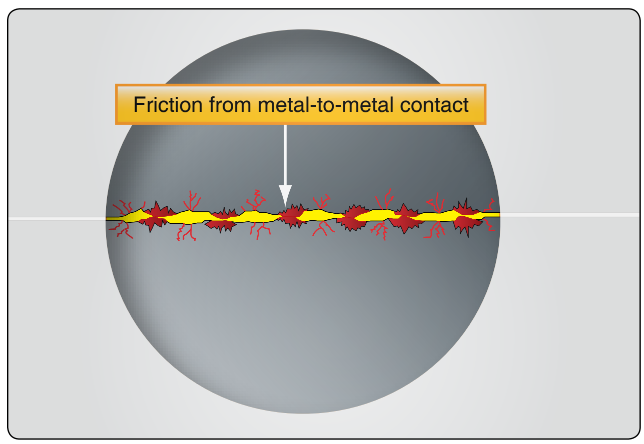

Figure 6-1. *Two moving surfaces in direct contact create excessive friction.*

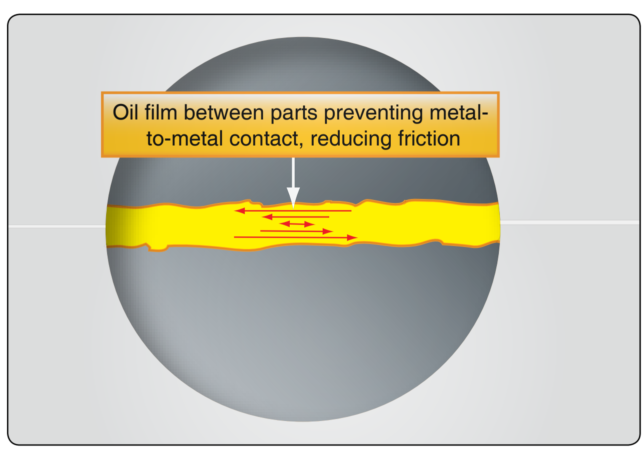

Figure 6-2. *Oil film acts as a cushion between two moving surfaces.*

the parts, allowing them to rust or corrode.

The engine's oil is the life blood of the engine and it is very important for the engine to perform its function and to extend the length between overhauls.

Requirements & Characteristics of Reciprocating Engine Lubricants

While there are several important properties that satisfactory reciprocating engine oil must possess, its viscosity is most important in engine operation. The resistance of an oil to flow is known as its viscosity. Oil that flows slowly is viscous or has a high viscosity; if it flows freely, it has a low viscosity. Unfortunately, the viscosity of oil is affected by temperature. It was not uncommon for earlier grades of oil to become practically solid in cold weather, increasing drag and making circulation almost impossible. Other oils may become so thin at high temperatures that the oil film is broken, causing a low load carrying ability, resulting in rapid wear of the moving parts.

The oil selected for aircraft engine lubrication must be light enough to circulate freely at cold temperatures, yet heavy enough to provide the proper oil film at engine operating temperatures. Since lubricants vary in properties and since no one oil is satisfactory for all engines and all operating conditions, it is extremely important that only the approved grade or Society of Automotive Engineers (SAE) rating be used.

Several factors must be considered in determining the proper grade of oil to use in a particular engine, the most important of which are the operating load, rotational speeds, and operating temperatures. The grade of the lubricating oil to be used is determined by the operating conditions to be met in the various types of engines. The oil used in aircraft reciprocating engines has a relatively high viscosity required by:

1. Large engine operating clearances due to the relatively large size of the moving parts, the different materials used, and the different rates of expansion of the various materials;
2. High operating temperatures; and
3. High bearing pressures.

Viscosity

Generally, commercial aviation oils are classified by a number, (such as 80, 100, 140, etc.) that is an approximation of the viscosity as measured by a testing instrument called the Saybolt Universal Viscosimeter. In this instrument, a tube holds a specific quantity of the oil to be tested. The oil is brought to an exact temperature by a liquid bath surrounding the tube. The time in seconds required for exactly 60 cubic centimeters of oil to flow through an accurately calibrated orifice is recorded as a measure of the oil's viscosity. If actual Saybolt values were used to designate the viscosity of oil, there would probably be several hundred grades of oil.

To simplify the selection of oils, they are often classified under an SAE system that divides all oils into seven groups (SAE 10 to 70) according to viscosity at either 130 °F or 210 °F. SAE ratings are purely arbitrary and bear no direct relationship to the Saybolt or other ratings.

The letter W occasionally is included in the SAE number giving a designation, such as SAE 20W. This W indicates that the oil, in addition to meeting the viscosity requirements at the testing temperature specifications, is satisfactory oil for winter use in cold climates. This should not be confused with the W used in front of the grade or weight number that indicates the oil is of the ashless dispersant type.

Although the SAE scale has eliminated some confusion in the designation of lubricating oils, it must not be assumed that this specification covers all the important viscosity requirements. An SAE number indicates only the viscosity grade or relative viscosity; it does not indicate quality or other essential characteristics. It is well known that there are good oils and inferior oils that have the same viscosities at a given temperature and, therefore, are subject to classification in the same grade.

The SAE letters on an oil container are not an endorsement or recommendation of the oil by the SAE. Although each grade of oil is rated by an SAE number, depending on its specific use, it may be rated with a commercial aviation grade number or an Army and Navy specification number. The correlation between these grade numbering systems is shown in *Figure 6-3*.

Viscosity Index

The viscosity index is a number that indicates the effect of temperature changes on the viscosity with the oil. When oil has a low viscosity index, it signifies a relatively large change of viscosity of increased temperature. The oil becomes thin at high temperatures and thick at low temperatures. Oils with a high viscosity index have small changes in viscosity over a wide temperature range.

Commercial Aviation No.	Commercial SAE No.	Army and Navy Specification No.
65	30	1065
80	40	1080
100	50	1100
120	60	1120
140	70	

Figure 6-3. *Grade designations for aviation oils.*

The best oil for most purposes is one that maintains a constant viscosity throughout temperature changes. Oil having a high viscosity index resists excessive thickening when the engine is subjected to cold temperatures. This allows for rapid cranking speeds during starting and prompt oil circulation during initial startup. This oil resists excessive thinning when the engine is at operating temperature and provides full lubrication and bearing load protection.

Flash Point & Fire Point

Flash point and fire point are determined by laboratory tests that show the temperature at which a liquid begins to give off ignitable vapors, flash, and the temperature at which there are sufficient vapors to support a fire. These points are established for engine oils to determine that they can withstand the high temperatures encountered in an engine.

Cloud Point & Pour Point

Cloud point and pour point also help to indicate suitability. The cloud point of oil is the temperature at which its wax content, normally held in solution, begins to solidify and separate into tiny crystals, causing the oil to appear cloudy or hazy. The pour point of oil is the lowest temperature at which it flows or can be poured.

Specific Gravity

Specific gravity is a comparison of the weight of the substance to the weight of an equal volume of distilled water at a specified temperature. As an example, water weighs approximately 8 pounds to the gallon; oil with a specific gravity of 0.9 would weigh 7.2 pounds to the gallon.

In the early years, the performance of aircraft piston engines was such that they could be lubricated satisfactorily by means of straight mineral oils, blended from specially selected petroleum base stocks. Oil grades 65, 80, 100, and 120 are straight mineral oils blended from selected high-viscosity index base oils. These oils do not contain any additives except for very small amounts of pour point depressant, which helps improve fluidity at very low temperatures, and an antioxidant. This type of oil is used during the break-in period of a new aviation piston engine or those recently overhauled.

Demand for oils with higher degrees of thermal and oxidation stability necessitated fortifying them with the addition of small quantities of nonpetroleum materials. The first additives incorporated in straight mineral piston engine oils were based on the metallic salts of barium and calcium. In most engines, the performance of these oils with respect to oxidation and thermal stability was excellent, but the combustion chambers of the majority of engines could not tolerate the presence of the ash deposits derived from these metal-containing additives. To overcome the disadvantages of harmful combustion chamber deposits, a nonmetallic (i.e., non-ash forming, polymeric) additive was developed that was incorporated in blends of selected mineral oil base stocks. W oils are of the ashless type and are still in use. The ashless dispersant grades contain additives, one of which has a viscosity stabilizing effect that removes the tendency of the oil to thin out at high oil temperatures and thicken at low oil temperatures.

The additives in these oils extend operating temperature range and improve cold engine starting and lubrication of the engine during the critical warm-up period permitting flight through wider ranges of climatic changes without the necessity of changing oil.

Semi-synthetic multigrade SAE W15 W50 oil for piston engines has been in use for some time. Oils W80, W100, and W120 are ashless dispersant oils specifically developed for aviation piston engines. They combine nonmetallic additives with selected high viscosity index base oils to give exceptional stability, dispersancy, and antifoaming performance. Dispersancy is the ability of the oil to hold particles in suspension until they can either be trapped by the filter or drained at the next oil change. The dispersancy additive is not a detergent and does not clean previously formed deposits from the interior of the engine.

Some multigrade oil is a blend of synthetic and mineral-based oil semisynthetic, plus a highly effective additive package, that is added due to concern that fully synthetic oil may not have the solvency to handle the lead deposits that result from the use of leaded fuel. As multigrade oil, it offers the flexibility to lubricate effectively over a wider range of temperatures than monograde oils. Compared to monograde oil, multigrade oil provides better cold-start protection and a stronger lubricant film (higher viscosity) at typical operating temperatures. The combination of nonmetallic, antiwear additives and selected high viscosity index mineral and synthetic base oils give exceptional stability, dispersancy, and antifoaming performance. Startup can contribute up to 80 percent of normal engine wear due to lack of lubrication during the start-up cycle. The more easily the oil flows to the engine's components at start up, the less wear occurs.

The ashless dispersant grades are recommended for aircraft engines subjected to wide variations of ambient temperature, particularly the turbocharged series engines that require oil to activate the various turbo controllers. At temperatures below 20 °F, preheating of the engine and oil supply tank is normally required regardless of the type of oil used.

Premium, semisynthetic multigrade ashless dispersant oil is a special blend of a high-quality mineral oil and synthetic hydrocarbons with an advanced additive package that has been specifically formulated for multigrade applications. The ashless antiwear additive provides exceptional wear protection for wearing surfaces.

Many aircraft manufacturers add approved preservative lubricating oil to protect new engines from rust and corrosion at the time the aircraft leaves the factory. This preservative oil should be removed at end of the first 25 hours of operation. When adding oil during the period when preservative oil is in the engine, use only aviation grade straight mineral oil or ashless dispersant oil, as required, of the viscosity desired.

If ashless dispersant oil is used in a new engine, or a newly overhauled engine, high oil consumption might possibly be experienced. The additives in some of these ashless dispersant oils may retard the break in of the piston rings and cylinder walls. This condition can be avoided by the use of mineral oil until normal oil consumption is obtained, then change to the ashless dispersant oil. Mineral oil should also be used following the replacement of one or more cylinders or until the oil consumption has stabilized.

In all cases, refer to the manufacturers' information when oil type or time in service is being considered.

Reciprocating Engine Lubrication Systems

Aircraft reciprocating engine pressure lubrication systems can be divided into two basic classifications: wet sump and dry sump. The main difference is that the wet sump system stores oil in a reservoir inside the engine. After the oil is circulated through the engine, it is returned to this crankcase-based reservoir. A dry sump engine pumps the oil from the engine's crankcase to an external tank that stores the oil. The dry sump system uses a scavenge pump, some external tubing, and an external tank to store the oil.

Other than this difference, the systems use similar types of components. Because the dry sump system contains all the components of the wet sump system, the dry sump system is explained as an example system.

Combination Splash & Pressure Lubrication

The lubricating oil is distributed to the various moving parts of a typical internal combustion engine by one of the three following methods: pressure, splash, or a combination of pressure and splash.

The pressure lubrication system is the principal method of lubricating aircraft engines. Splash lubrication may be used in addition to pressure lubrication on aircraft engines, but it is never used by itself; aircraft-engine lubrication systems are always either the pressure type or the combination pressure and splash type, usually the latter.

The advantages of pressure lubrication are:

1. Positive introduction of oil to the bearings.
2. Cooling effect caused by the large quantities of oil that can be pumped, or circulated, through a bearing.
3. Satisfactory lubrication in various attitudes of flight.

Lubrication System Requirements

The lubrication system of the engine must be designed and constructed so that it functions properly within all flight attitudes and atmospheric conditions that the aircraft is expected to operate. In wet sump engines, this requirement must be met when only half of the maximum lubricant supply is in the engine. The lubrication system of the engine must be designed and constructed to allow installing a means of cooling the lubricant. The crankcase must also be vented to the atmosphere to preclude leakage of oil from excessive pressure.

Dry Sump Oil Systems

Many reciprocating and turbine aircraft engines have pressure dry sump lubrication systems. The oil supply in this type of system is carried in a tank. A pressure pump circulates the oil through the engine. Scavenger pumps then return it to the tank as quickly as it accumulates in the engine sumps. The need for a separate supply tank is apparent when considering the complications that would result if large quantities of oil were carried in the engine crankcase. On multiengine aircraft, each engine is supplied with oil from its own complete and independent system.

Although the arrangement of the oil systems in different aircraft varies widely and the units of which they are composed differ in construction details, the functions of all such systems are the same. A study of one system clarifies the general operation and maintenance requirements of other systems.

The principal units in a typical reciprocating engine dry sump oil system include an oil supply tank, an engine-driven pressure oil pump, a scavenge pump, an oil cooler with an oil cooler control valve, oil tank vent, necessary tubing, and pressure and temperature indicators. *[Figure 6-4]*

Oil Tanks

Oil tanks are generally associated with a dry sump lubrication system, while a wet sump system uses the crankcase of the engine to store the oil. Oil tanks are usually constructed of aluminum alloy and must withstand any vibration, inertia, and fluid loads expected in operation.

Each oil tank used with a reciprocating engine must have expansion space of not less than the greater of 10 percent

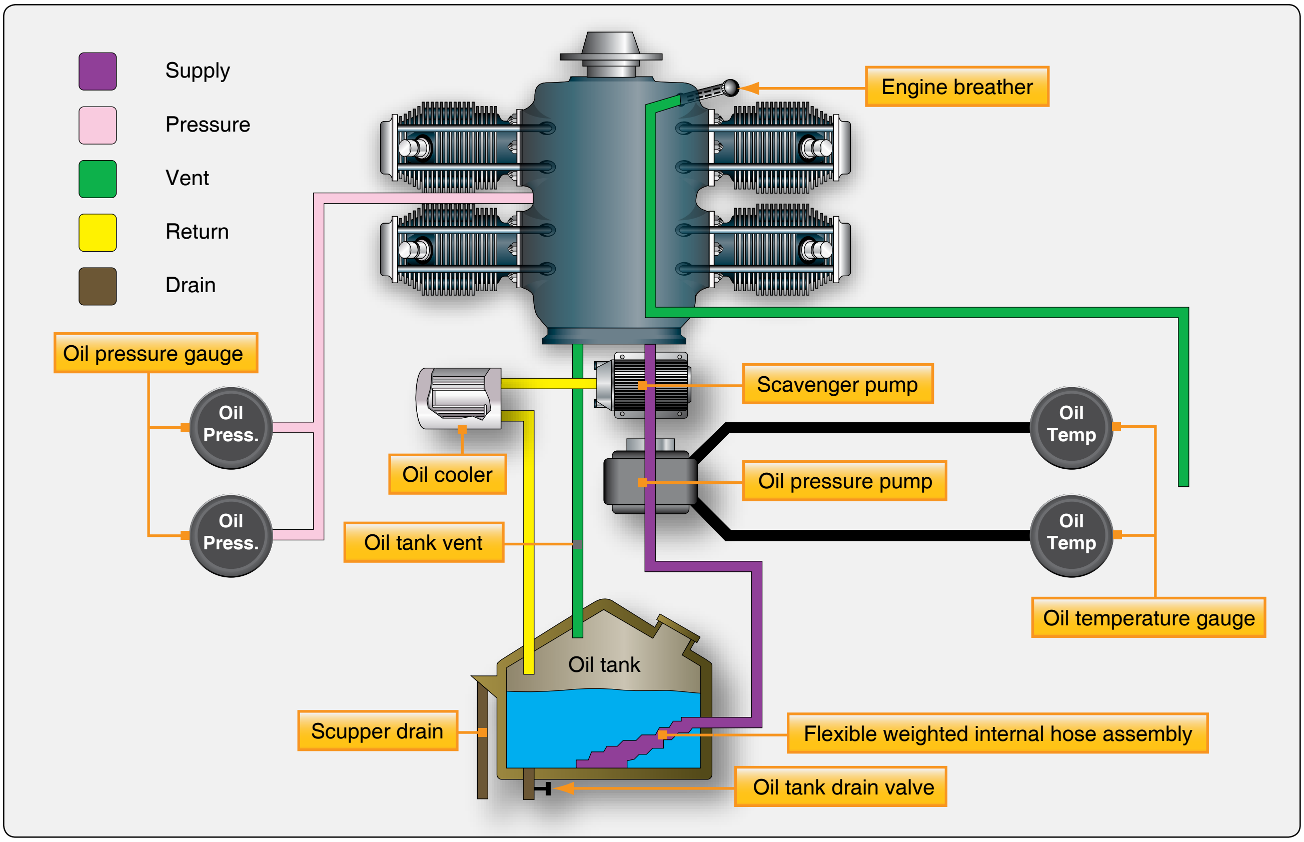

Figure 6-4. *Oil system schematic.*

of the tank capacity or 0.5 gallons. Each filler cap of an oil tank that is used with an engine must provide an oil-tight seal. The oil tank usually is placed close to the engine and high enough above the oil pump inlet to ensure gravity feed.

Oil tank capacity varies with the different types of aircraft, but it is usually sufficient to ensure an adequate supply of oil for the total fuel supply. The tank filler neck is positioned to provide sufficient room for oil expansion and for foam to collect.

The filler cap or cover is marked with the word OIL. A drain in the filler cap well disposes of any overflow caused by the filling operation. Oil tank vent lines are provided to ensure proper tank ventilation in all attitudes of flight. These lines are usually connected to the engine crankcase to prevent the loss of oil through the vents. This indirectly vents the tanks to the atmosphere through the crankcase breather.

Early large radial engines had many gallons of oil in their tank. To help with engine warm up, some oil tanks had a built-in hopper or temperature accelerating well. *[Figure 6-5]* This well extended from the oil return fitting on top of the oil tank to the outlet fitting in the sump in the bottom of the tank. In some systems, the hopper tank is open to the main oil supply at the lower end. Other systems have flapper-type valves that separate the main oil supply from the oil in the hopper. The opening at the bottom of the hopper in one type and the flapper valve-controlled openings in the other allow oil from the main tank to enter the hopper and replace the oil consumed by the engine. Whenever the hopper tank includes

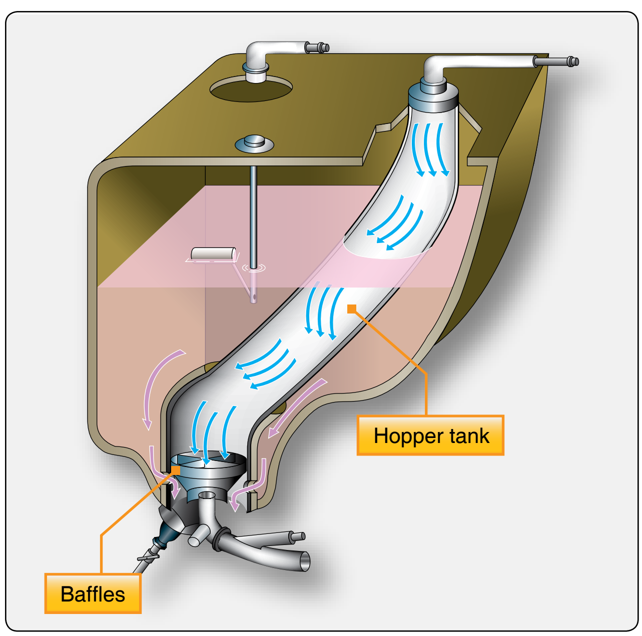

Figure 6-5. *Oil tank with hopper.*

the flapper controlled openings, the valves are operated by differential oil pressure. By separating the circulating oil from the surrounding oil in the tank, less oil is circulated. This hastens the warming of the oil when the engine was started. Very few of these types of tanks are still in use and most are associated with radial engine installations.

Generally, the return line in the top of the tank is positioned to discharge the returned oil against the wall of the tank in a swirling motion. This method considerably reduces foaming that occurs when oil mixes with air. Baffles in the bottom of the oil tank break up this swirling action to prevent air from being drawn into the inlet line of the oil pressure pump. Foaming oil increases in volume and reduces its ability to provide proper lubrication. In the case of oil-controlled propellers, the main outlet from the tank may be in the form of a standpipe so that there is always a reserve supply of oil for propeller feathering in case of engine failure. An oil tank sump, attached to the undersurface of the tank, acts as a trap for moisture and sediment. *[Figure 6-4]* The water and sludge can be drained by manually opening the drain valve in the bottom of the sump.

Most aircraft oil systems are equipped with the dipstick-type quantity gauge, often called a bayonet gauge. Some larger aircraft systems also have an oil quantity indicating system that shows the quantity of oil during flight. One type system consists essentially of an arm and float mechanism that rides the level of the oil and actuates an electric transmitter on top of the tank. The transmitter is connected to a flight deck gauge that indicates the quantity of oil.

Oil Pump

Oil entering the engine is pressurized, filtered, and regulated by units within the engine. They are discussed along with the external oil system to provide a concept of the complete oil system.

As oil enters the engine, it is pressurized by a gear-type pump. *[Figure 6-6]* This pump is a positive displacement pump that consists of two meshed gears that revolve inside the housing. The clearance between the teeth and housing is small. The pump inlet is located on the left and the discharge port is connected to the engine's system pressure line. One gear is attached to a splined drive shaft that extends from the pump housing to an accessory drive shaft on the engine. Seals are used to prevent leakage around the drive shaft. As the lower gear is rotated counterclockwise, the driven idler gear turns clockwise.

As oil enters the gear chamber, it is picked up by the gear teeth, trapped between them and the sides of the gear chamber, then it is carried around the outside of the gears and discharged from the pressure port into the oil screen passage. The pressurized oil flows to the oil filter, where any solid particles suspended in the oil are separated from it, preventing possible damage to moving parts of the engine.

Oil under pressure then opens the oil filter check valve mounted in the top of the filter. This valve is used mostly

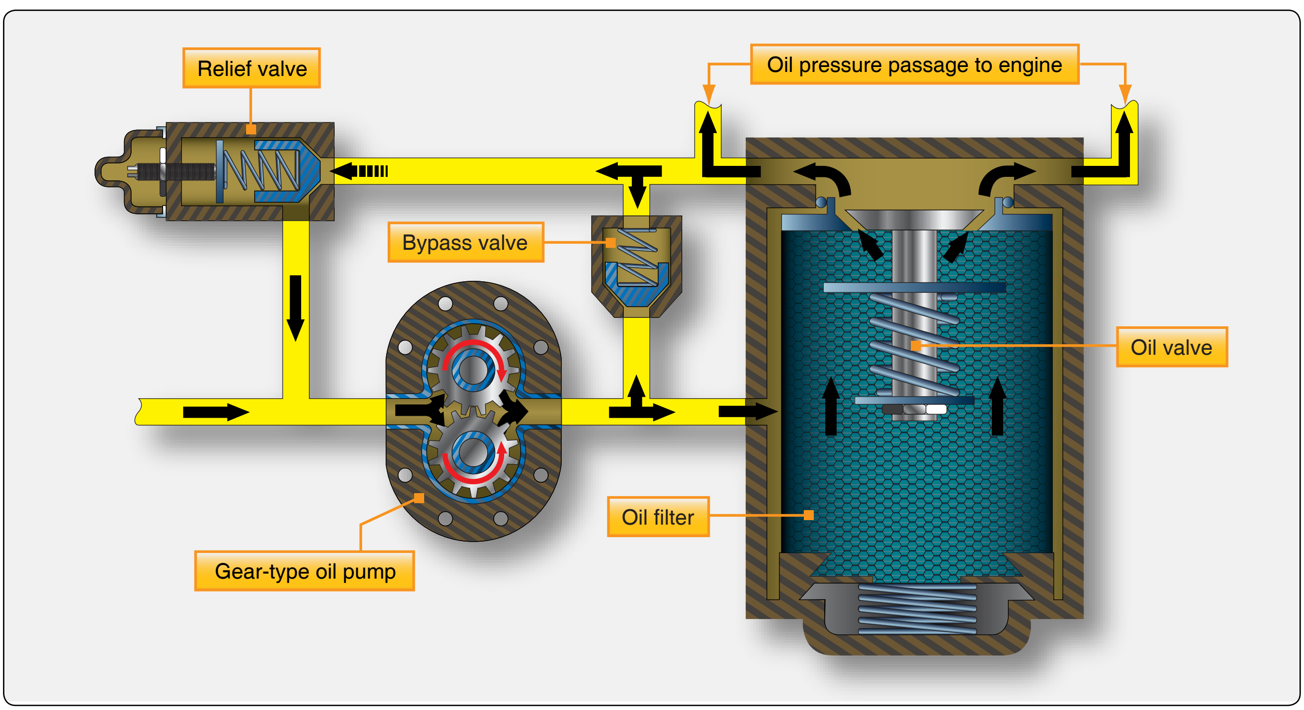

Figure 6-6. *Engine oil pump and associated units.*

with dry sump radial engines and is closed by a light spring loading of 1 to 3 pounds per square inch (psi) when the engine is not operating to prevent gravity-fed oil from entering the engine and settling in the lower cylinders or sump area of the engine. If oil were allowed to gradually seep by the rings of the piston and fill the combustion chamber, it could cause a liquid lock. This could happen if the valves on the cylinder were both closed, and the engine was cranked for start. Damage could occur to the engine.

The oil filter bypass valve, located between the pressure side of the oil pump and the oil filter, permits unfiltered oil to bypass the filter and enter the engine if the oil filter is clogged or during cold weather if congealed oil is blocking the filter during engine start. The spring loading on the bypass valve allows the valve to open before the oil pressure collapses the filter; in the case of cold, congealed oil, it provides a low-resistance path around the filter. Dirty oil in an engine is better than no lubrication.

Oil Filters

The oil filter used on an aircraft engine is usually one of four types: screen, Cuno, canister, or spin-on. A screen-type filter with its double-walled construction provides a large filtering area in a compact unit. *[Figure 6-6]* As oil passes through the fine-mesh screen, dirt, sediment, and other foreign matter are removed and settle to the bottom of the housing. At regular intervals, the cover is removed, and the screen and housing cleaned with a solvent. Oil screen filters are used mostly as suction filters on the inlet of the oil pump.

The Cuno oil filter has a cartridge made of discs and spacers. A cleaner blade fits between each pair of discs. The cleaner blades are stationary, but the discs rotate when the shaft is turned. Oil from the pump enters the cartridge well that surrounds the cartridge and passes through the spaces between the closely spaced discs of the cartridge, then through the hollow center, and on to the engine. Any foreign particles in the oil are deposited on the outer surface of the cartridge. When the cartridge is rotated, the cleaner blades comb the foreign matter from the discs. The cartridge of the manually operated Cuno filter is turned by an external handle. Automatic Cuno filters have a hydraulic motor built into the filter head. This motor, operated by engine oil pressure, rotates the cartridge whenever the engine is running. There is a manual turning nut on the automatic Cuno filter for rotating the cartridge manually during inspections. This filter is not often used on modern aircraft.

A canister housing filter has a replaceable filter element that is replaced with the rest of the components other than seals and gaskets being reused. *[Figure 6-7]* The filter element is designed with a corrugated, strong steel center

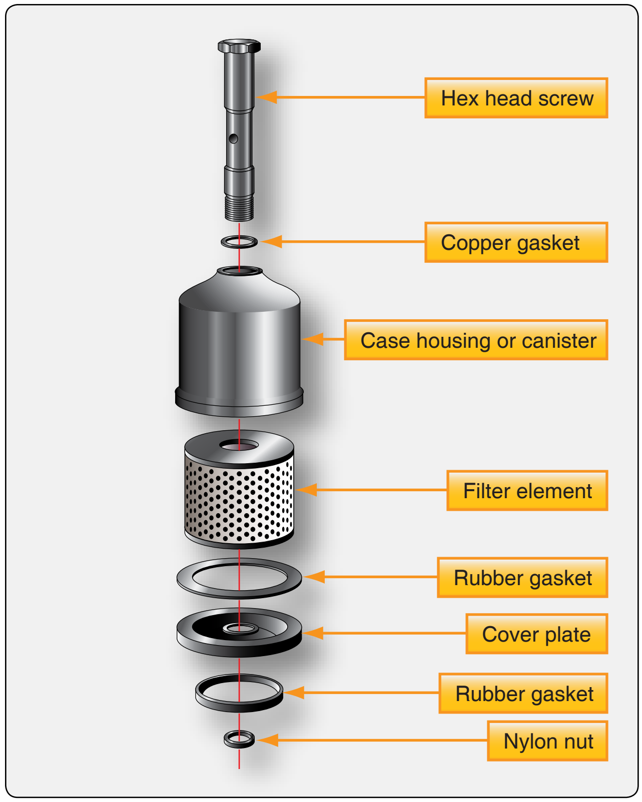

Figure 6-7. *Housing filter element type oil filter.*

tube supporting each convoluted pleat of the filter media, resulting in a higher collapse pressure rating. The filter provides excellent filtration, because the oil flows through many layers of locked-in-fibers.

Full flow spin-on filters are the most widely used oil filters for reciprocating engines. *[Figure 6-8]* Full flow means that all the oil is normally passed through the filter. In a full flow system, the filter is positioned between the oil pump and the engine bearings, which filters the oil of any contaminants before they pass through the engine bearing surfaces. The filter also contains an antidrain back valve and a pressure relief valve, all sealed in a disposable housing. The relief valve is used in case the filter becomes clogged. It would open to allow the oil to bypass, preventing the engine components from oil starvation. A cutaway of the micronic filter element shows the resin-impregnated cellulosic full-pleat media that is used to trap harmful particles, keeping them from entering the engine. *[Figure 6-9]*

Oil Pressure Regulating Valve

An oil pressure regulating valve limits oil pressure to a predetermined value, depending on the installation. *[Figure 6-6]* This valve is sometimes referred to as a relief valve, but its real function is to regulate the oil pressure at a preset pressure level. The oil pressure must be sufficiently high to ensure adequate lubrication of the engine and its

Figure 6-8. *Full flow spin-on filter.*

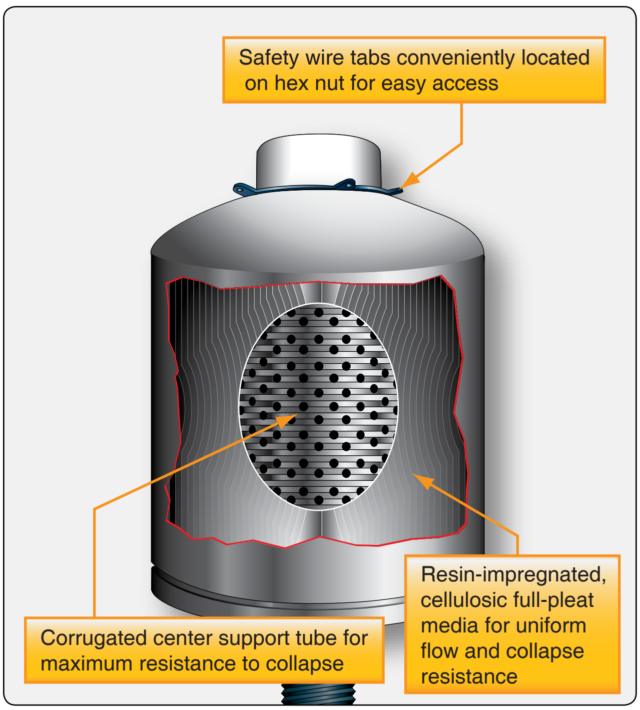

Figure 6-9. *Cutaway view of a filter.*

accessories at high speeds and powers. This pressure helps ensure that the oil film between the crankshaft journal and bearing is maintained. However, the pressure must not be too high, as leakage and damage to the oil system may result. The oil pressure is generally adjusted by loosening the locknut and turning the adjusting screw. *[Figure 6-10]* On most aircraft engines, turning the screw clockwise increases the tension of the spring that holds the relief valve on its seat and increases the oil pressure; turning the adjusting screw counterclockwise decreases the spring tension and lowers the pressure. Some engines use washers under the spring that are either removed or added to adjust the regulating valve and pressure. The oil pressure should be adjusted only after the engine's oil is at operating temperature and the correct viscosity is verified. The exact procedure for adjusting the oil pressure and the factors that vary an oil pressure setting are included in applicable manufacturer's instructions.

Oil Pressure Gauge

Usually, the oil pressure gauge indicates the pressure that oil enters the engine from the pump. This gauge warns of possible engine failure caused by an exhausted oil supply, failure of the oil pump, burned-out bearings, ruptured oil lines, or other causes that may be indicated by a loss of oil pressure.

One type of oil pressure gauge uses a Bourdon-tube mechanism that measures the difference between oil pressure and cabin, or atmospheric, pressure. This gauge is constructed similarly to other Bourdon-type gauges, except that it has a small restriction built into the instrument case, or into the nipple connection leading to the Bourdon tube. This restriction prevents the surging action of the oil pump from damaging the gauge or causing the pointer to oscillate too violently with each pressure pulsation. The oil pressure gauge has a scale ranging from 0–200 psi, or from 0–300 psi. Operation range markings are placed on the cover glass, or the face of the gauge, to indicate the safe range of oil pressure for a given installation.

A dual-type oil pressure gauge is available for use on

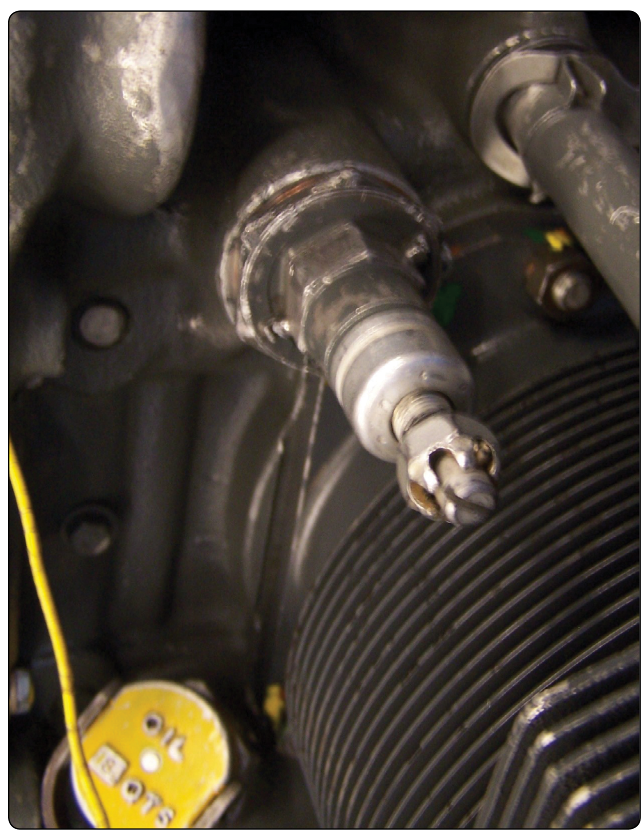

Figure 6-10. *Oil pressure adjustment screw.*

multiengine aircraft. The dual indicator contains two Bourdon tubes, housed in a standard instrument case; one tube being used for each engine. The connections extend from the back of the case to each engine. There is one common movement assembly, but the moving parts function independently. In some installations, the line leading from the engine to the pressure gauge is filled with light oil. Since the viscosity of this oil does not vary much with changes in temperature, the gauge responds better to changes in oil pressure. In time, engine oil mixes with some of the light oil in the line to the transmitter; during cold weather, the thicker mixture causes sluggish instrument readings. To correct this condition, the gauge line must be disconnected, drained, and refilled with light oil.

The current trend is toward electrical transmitters and indicators for oil and fuel pressure-indicating systems in all aircraft. In this type of indicating system, the oil pressure being measured is applied to the inlet port of the electrical transmitter where it is conducted to a diaphragm assembly by a capillary tube. The motion produced by the diaphragm's expansion and contraction is amplified through a lever and gear arrangement. The gear varies the electrical value of the indicating circuit, which in turn, is reflected on the indicator in the flight deck. This type of indicating system replaces long fluid-filled tubing lines with an almost weightless piece of wire.

Oil Temperature Indicator

In dry-sump lubricating systems, the oil temperature bulb may be anywhere in the oil inlet line between the supply tank and the engine. Oil systems for wet-sump engines have the temperature bulb located where it senses oil temperature after the oil passes through the oil cooler. In either system, the bulb is located so that it measures the temperature of the oil before it enters the engine's hot sections. An oil temperature gauge in the flight deck is connected to the oil temperature bulb by electrical leads. The oil temperature is indicated on the gauge. Any malfunction of the oil cooling system appears as an abnormal reading.

Oil Cooler

The cooler, either cylindrical or elliptical shaped, consists of a core enclosed in a double-walled shell. The core is built of copper or aluminum tubes with the tube ends formed to a hexagonal shape and joined together in the honeycomb effect. *[Figure 6-11]* The ends of the copper tubes of the core are soldered, whereas aluminum tubes are brazed or mechanically joined. The tubes touch only at the ends so that a space exists between them along most of their lengths. This allows oil to flow through the spaces between the tubes while the cooling air passes through the tubes.

The space between the inner and outer shells is known as

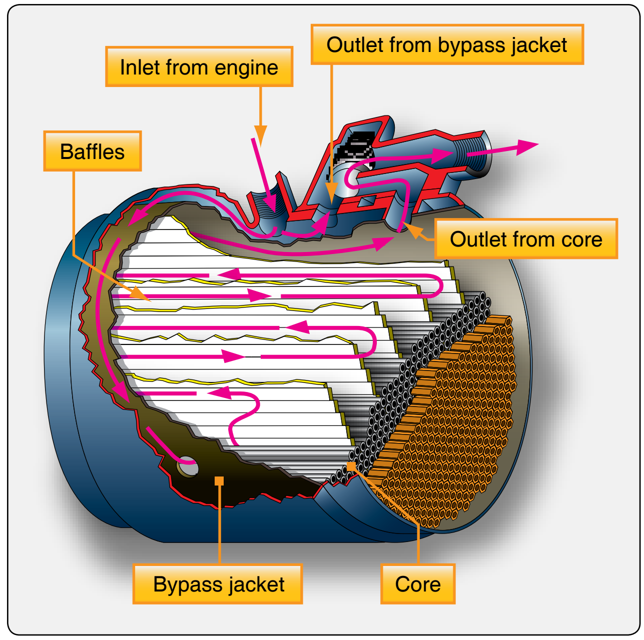

Figure 6-11. *Oil cooler.*

the annular or bypass jacket. Two paths are open to the flow of oil through a cooler. From the inlet, it can flow halfway around the bypass jacket, enter the core from the bottom, and then pass through the spaces between the tubes and out to the oil tank. This is the path the oil follows when it is hot enough to require cooling. As the oil flows through the core, it is guided by baffles that force the oil to travel back and forth several times before it reaches the core outlet. The oil can also pass from the inlet completely around the bypass jacket to the outlet without passing through the core. Oil follows this bypass route when the oil is cold or when the core is blocked with thick, congealed oil.

Oil Cooler Flow Control Valve

As discussed previously, the viscosity of the oil varies with its temperature. Since the viscosity affects its lubricating properties, the temperature at which the oil enters an engine must be held within close limits. Generally, the oil leaving an engine must be cooled before it is recirculated. Obviously, the amount of cooling must be controlled if the oil is to return to the engine at the correct temperature. The oil cooler flow control valve determines which of the two possible paths the oil takes through the oil cooler. *[Figure 6-12]*

There are two openings in a flow control valve that fit over the corresponding outlets at the top of the cooler. When the oil is cold, a bellows within the flow control contracts and lifts a valve from its seat. Under this condition, oil entering the cooler has a choice of two outlets and two paths. Following the path of least resistance, the oil flows around the jacket and out past the thermostatic valve to the tank. This allows the oil to warm up quickly and, at the same time, heats the

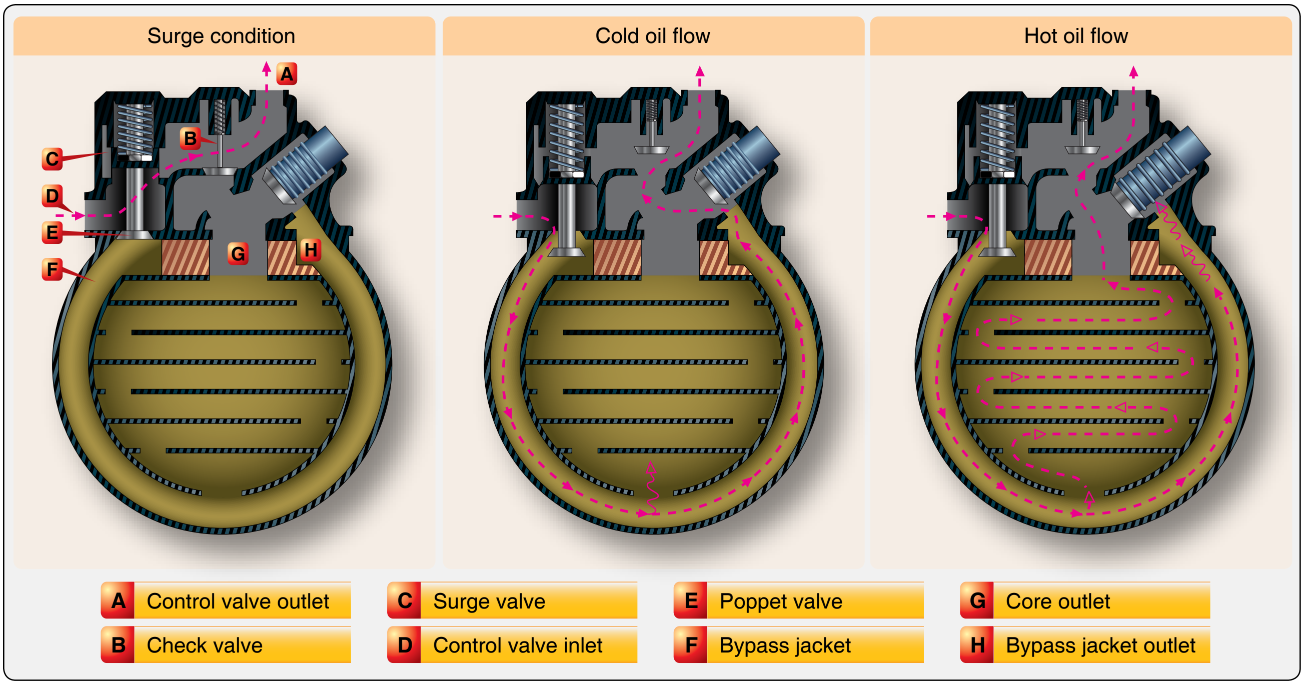

Figure 6-12. *Control valve with surge protection.*

oil in the core. As the oil warms up and reaches its operating temperature, the bellows of the thermostat expand and closes the outlet from the bypass jacket. The oil cooler flow control valve, located on the oil cooler, must now flow oil through the core of the oil cooler. No matter which path it takes through the cooler, the oil always flows over the bellows of the thermostatic valve. As the name implies, this unit regulates the temperature by either cooling the oil or passing it on to the tank without cooling, depending on the temperature at which it leaves the engine.

Surge Protection Valves

When oil in the system is congealed, the scavenger pump may build up a very high pressure in the oil return line. To prevent this high pressure from bursting the oil cooler or blowing off the hose connections, some aircraft have surge protection valves in the engine lubrication systems. One type of surge valve is incorporated in the oil cooler flow control valve; another type is a separate unit in the oil return line. *[Figure 6-12]*

The surge protection valve incorporated in a flow control valve is the more common type. Although this flow control valve differs from the one just described, it is essentially the same except for the surge protection feature. The high-pressure operation condition is shown in *Figure 6-12*, in which the high oil pressure at the control valve inlet has forced the surge valve (C) upward. Note how this movement has opened the surge valve and, at the same time, seated the poppet valve (E). The closed poppet valve prevents oil from entering the cooler proper; therefore, the scavenge oil passes directly to the tank through outlet (A) without passing through either the cooler bypass jacket or the core. When the pressure drops to a safe value, the spring forces the surge and poppet valves downward, closing the surge valve (C) and opening the poppet valve (E). Oil then passes from the control valve inlet (D), through the open poppet valve, and into the bypass jacket (F). The thermostatic valve, according to oil temperature, determines oil flow either through the bypass jacket to port (H) or through the core to port (G). The check valve (B) opens to allow the oil to reach the tank return line.

Airflow Controls

By regulating the airflow through the cooler, the temperature of the oil can be controlled to fit various operating conditions. For example, the oil reaches operating temperature more quickly if the airflow is cut off during engine warm-up. There are two methods in general use: shutters installed on the rear of the oil cooler, and a flap on the air-exit duct. In some cases, the oil cooler air-exit flap is opened manually and closed by a linkage attached to a flight deck lever. More often, the flap is opened and closed by an electric motor.

One of the most widely used automatic oil temperature control devices is the floating control thermostat that provides manual and automatic control of the oil inlet temperatures. With this type of control, the oil cooler air-exit door is opened and closed automatically by an electrically operated actuator. Automatic operation of the actuator is determined by electrical impulses received from a controlling thermostat inserted in the oil pipe leading from the oil cooler to the oil supply tank. The actuator may be operated manually by an oil cooler air-exit door control switch. Placing this switch in the "open" or "closed" position produces a corresponding movement of the cooler door. Placing the switch in the "auto" position puts the actuator under the automatic control of the floating control thermostat. *[Figure 6-13]* The thermostat shown in *Figure 6-13* is adjusted to maintain a normal oil temperature so that it does not vary more than approximately 5° to 8 °C, depending on the installation.

During operation, the temperature of the engine oil flowing over the bimetal element causes it to wind or unwind slightly. *[Figure 6-13B]* This movement rotates the shaft (A) and the grounded center contact arm (C). As the grounded contact arm is rotated, it is moved toward either the open or closed floating contact arm (G). The two floating contact arms are oscillated by the cam (F), which is continuously rotated by an electric motor (D) through a gear train (E). When the grounded center contact arm is positioned by the bimetal element so that it touches one of the floating contact arms, an electric circuit to the oil cooler exit-flap actuator motor is completed, causing the actuator to operate and position the oil cooler air-exit flap. Newer systems use electronic control systems, but the function or the overall operation is basically the same regarding control of the oil temperature through control of the air flow through the cooler.

In some lubrication systems, dual oil coolers are used. If the typical oil system previously described is adapted to two oil coolers, the system is modified to include a flow divider, two identical coolers and flow regulators, dual air-exit doors, a two-door actuating mechanism, and a Y-fitting. *[Figure 6-14]* Oil is returned from the engine through a single tube to the flow divider (E), where the return oil flow is divided equally into two tubes (C), one for each cooler. The coolers and regulators have the same construction and operations as the cooler and flow regulator just described. Oil from the coolers is routed through two tubes (D) to a Y-fitting, where the floating control thermostat (A) samples oil temperature and positions the two oil cooler air-exit doors through the use of a two-door actuating mechanism. From the Y-fitting, the lubricating oil is returned to the tank where it completes its circuit.

Dry Sump Lubrication System Operation

The following lubrication system is typical of those on small, single-engine aircraft. The oil system and components are those used to lubricate a 225 horsepower (hp) six-cylinder, horizontally opposed, air-cooled engine. In a typical dry sump pressure-lubrication system, a mechanical pump supplies oil under pressure to the bearings throughout the engine. *[Figure 6-4]* The oil flows into the inlet or suction side of the oil pump through a suction screen and a line connected to the external tank at a point higher than the bottom of the oil sump. This prevents sediment that falls into the sump from being drawn into the pump. The tank outlet is higher than the pump inlet, so gravity can assist the flow into the pump. The engine-driven, positive-displacement, gear-type pump forces the oil into the full flow filter. *[Figure 6-6]* The oil either passes through the filter under normal conditions or, if the filter were to become clogged, the filter bypass valve would open as mentioned earlier. In the bypass position, the oil would not be filtered. As seen in *Figure 6-6*, the regulating (relief) valve senses when system pressure is reached and opens enough to bypass oil to the inlet side of the oil pump. Then, the oil flows into a manifold that distributes the oil

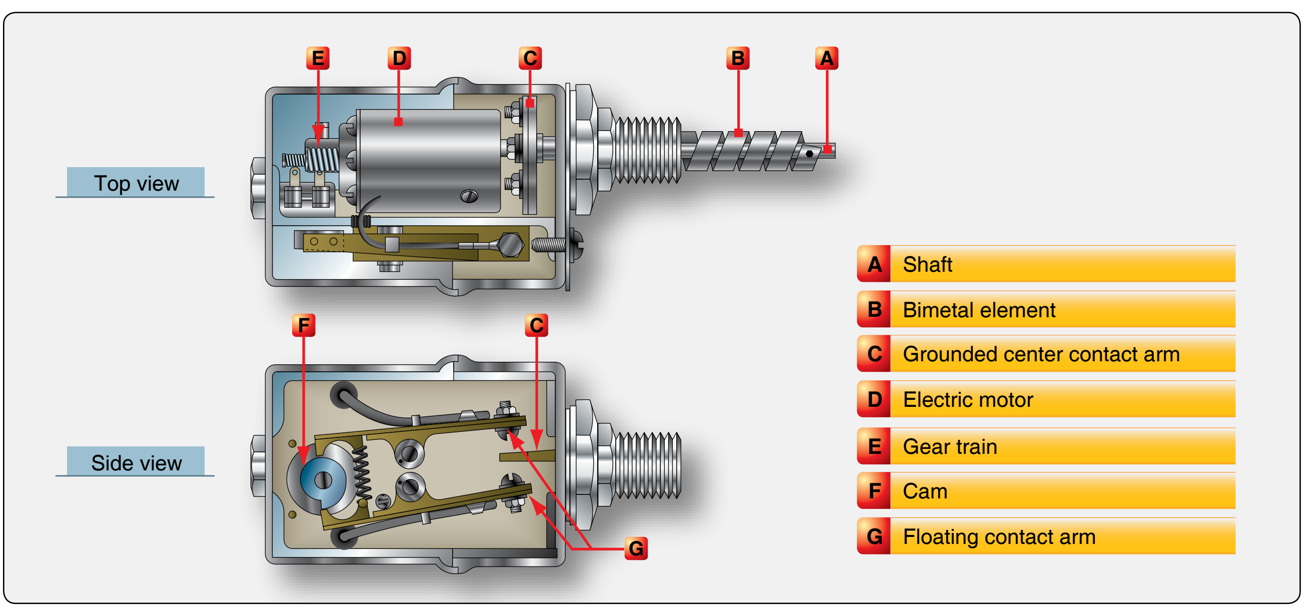

Figure 6-13. *Floating control thermostat.*

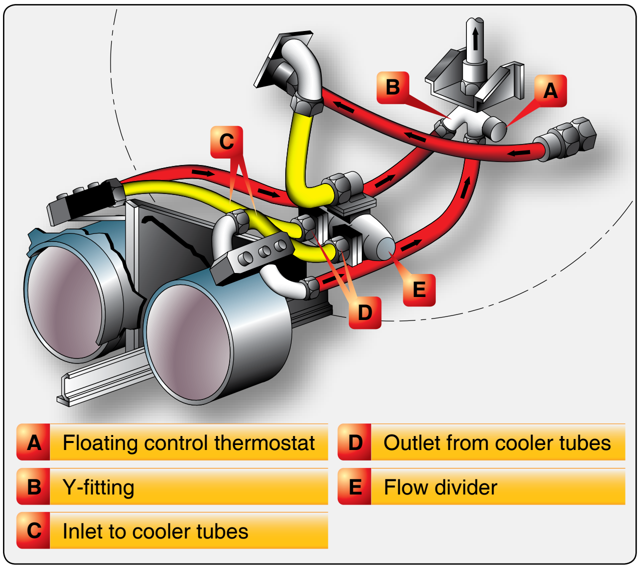

Figure 6-14. *Dual oil cooler system.*

through drilled passages to the crankshaft bearings and other bearings throughout the engine. Oil flows from the main bearings through holes drilled in the crankshaft to the lower connecting rod bearings. *[Figure 6-15]*

Oil reaches a hollow camshaft (in an inline or opposed engine), or a cam plate or cam drum (in a radial engine), through a connection with the end bearing or the main oil manifold; it then flows out to the various camshaft, cam drum, or cam plate bearings and the cams.

The engine cylinder surfaces receive oil sprayed from the crankshaft and also from the crankpin bearings. Since oil seeps slowly through the small crankpin clearances before it is sprayed on the cylinder walls, considerable time is required for enough oil to reach the cylinder walls, especially on a cold day when the oil flow is more sluggish. This is one of the chief reasons for using modern multiviscosity oils that flow well at low temperatures.

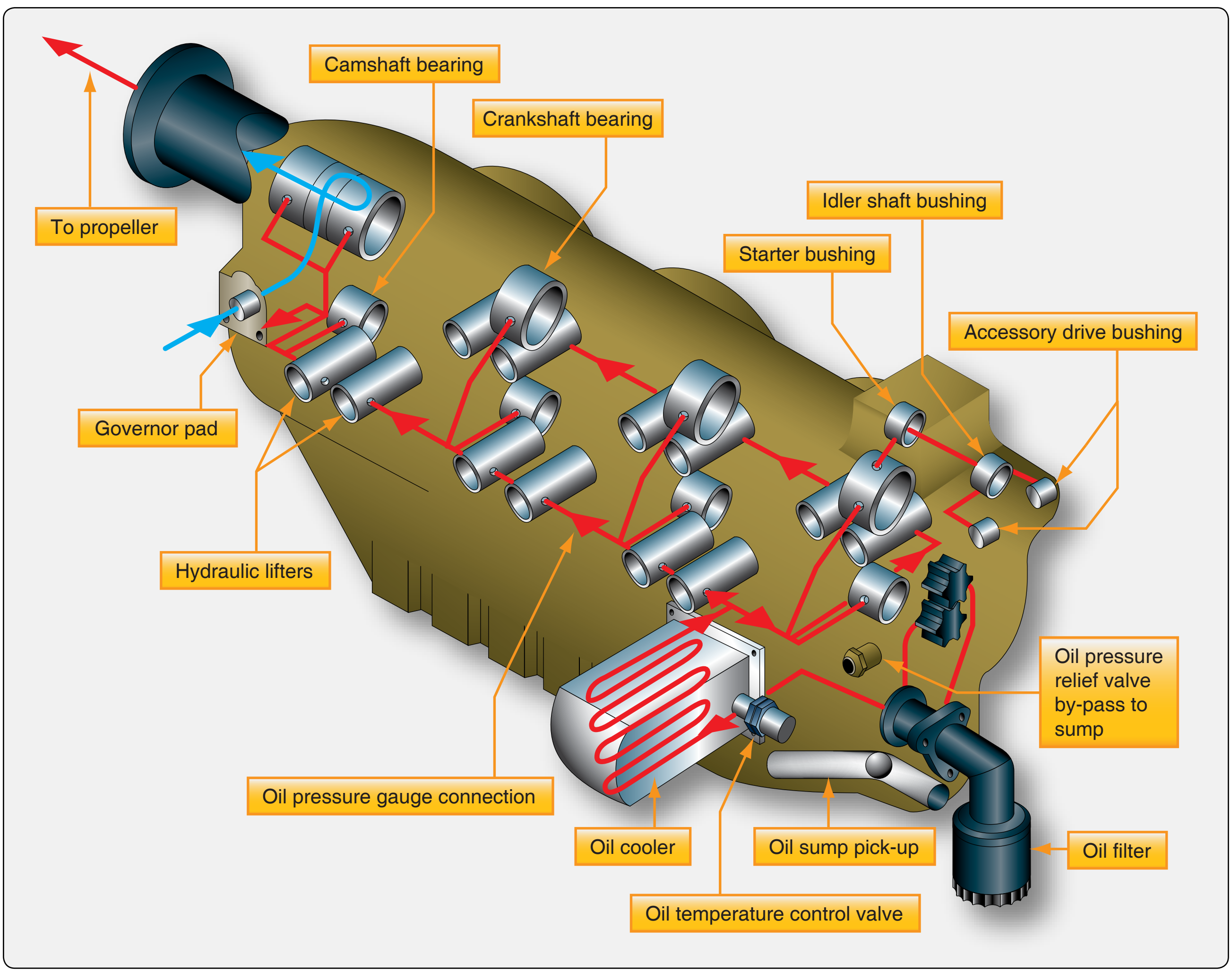

Figure 6-15. *Oil circulation through the engine.*

When the circulating oil has performed its function of lubricating and cooling the moving parts of the engine, it drains into the sumps in the lowest parts of the engine. Oil collected in these sumps is picked up by gear or gerotor-type scavenger pumps as quickly as it accumulates. These pumps have a greater capacity than the pressure pump. This is needed because the volume of the oil has generally increased due to foaming (mixing with air). On dry sump engines, this oil leaves the engine, passes through the oil cooler, and returns to the supply tank.

A thermostat attached to the oil cooler controls oil temperature by allowing part of the oil to flow through the cooler and part to flow directly into the oil supply tank. This arrangement allows hot engine oil with a temperature still below 65 °C (150 °F) to mix with the cold uncirculated oil in the tank. This raises the complete engine oil supply to operating temperature in a shorter period of time.

Wet-Sump Lubrication System Operation

A simple form of a wet-sump system is shown in *Figure 6-16*. The system consists of a sump or pan in which the oil supply is contained. The oil supply is limited by the sump (oil pan) capacity. The level (quantity) of oil is indicated or measured by a vertical rod that protrudes into the oil from an elevated hole on top of the crankcase. In the bottom of the sump (oil pan) is a screen strainer having a suitable mesh, or series of openings, to strain undesirable particles from the oil and yet pass sufficient quantity to the inlet or (suction) side of the oil pressure pump. *Figure 6-17* shows a typical oil sump that has the intake tube running through it. This preheats the air-fuel mixture before it enters the cylinders.

The rotation of the pump, which is driven by the engine, causes the oil to pass around the outside of the gears. *[Figure 6-6]* This develops a pressure in the crankshaft oiling system (drilled passage holes). The variation in the speed of the pump from idling to full-throttle operating range of the engine and the fluctuation of oil viscosity because of temperature changes are compensated by the tension on the relief valve spring. The pump is designed to create a greater pressure than required to compensate for wear of the bearings or thinning out of oil. The parts oiled by pressure throw a lubricating spray into the cylinder and piston assemblies. After lubricating the various units it sprays, the oil drains back into the sump and the cycle is repeated. The system is not readily adaptable to inverted flying since the entire oil supply floods the engine.

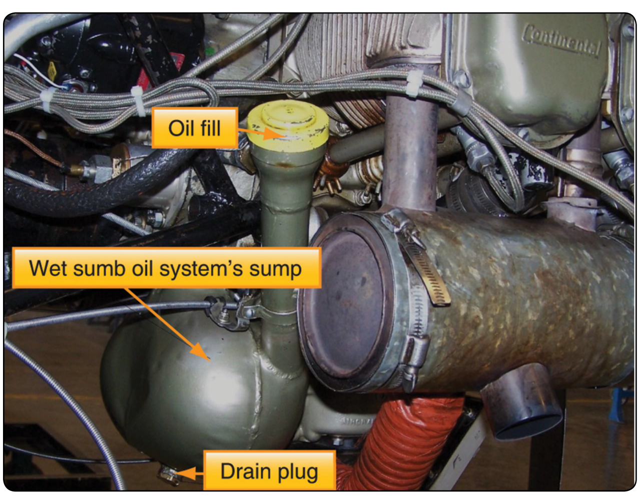

Figure 6-16. *Basic wet-sump oil system.*

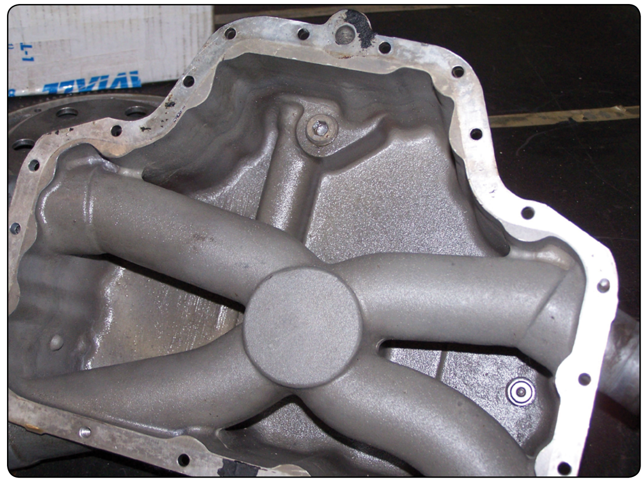

Figure 6-17. *Wet-sump system's sump with intake tube running through it.*

Lubrication System Maintenance Practices

Oil Tank

The oil tank, constructed of welded aluminum, is serviced (filled) through a filler neck located on the tank and equipped with a spring-loaded locking cap. Inside the tank, a weighted, flexible rubber oil hose is mounted so that it is repositioned automatically to ensure oil pickup during all maneuvers. A dipstick guard is welded inside the tank for the protection of the flexible oil hose assembly. During normal flight, the oil tank is vented to the engine crankcase by a flexible line at the top of the tank. The location of the oil system components in relation to each other and to the engine is shown in *Figure 6-18*.

Repair of an oil tank usually requires that the tank be removed. The removal and installation procedures normally remain the same regardless of whether the engine is removed or not. First, the oil must be drained. Most light aircraft provide an oil drain similar to that shown in *Figure 6-19*. On some aircraft, the normal ground attitude of the aircraft may prevent the oil tank from draining completely. If the amount of undrained oil is excessive, the aft portion of the tank can be raised slightly after the tank straps have been loosened to complete the drainage.

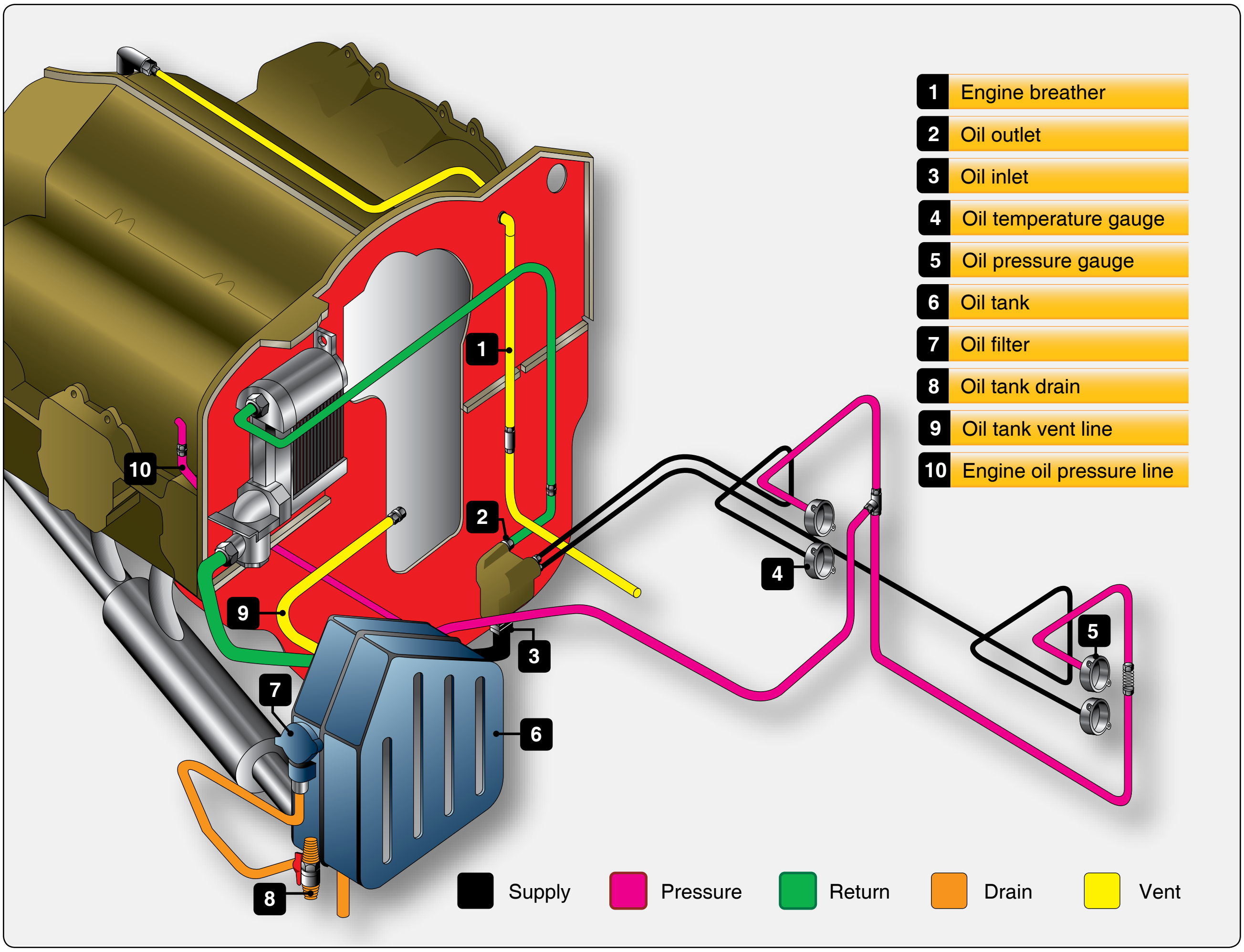

Figure 6-18. *Oil system perspective.*

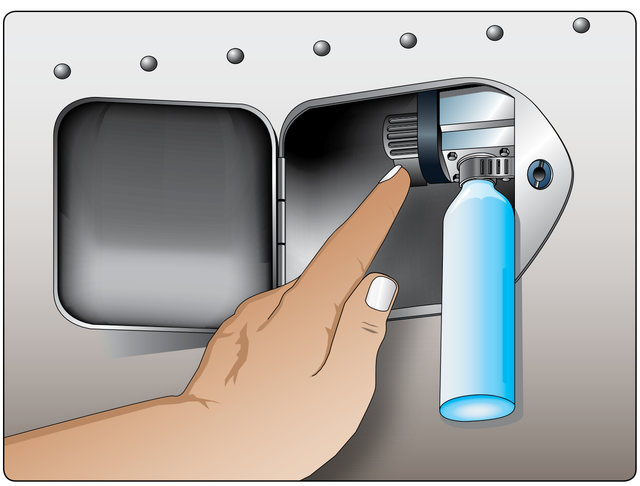

Figure 6-19. *Oil tank drain.*

After disconnecting the oil inlet and vent lines, the scupper drain hose and bonding wire can be removed. *[Figure 6-20]* The securing straps fitted around the tank can now be removed. *[Figure 6-21]* Any safety wire securing the clamp must be removed before the clamp can be loosened and the strap disconnected. The tank can now be lifted out of the aircraft. The tank is reinstalled by reversing the sequence used in the tank removal. After installation, the oil tank should be filled to capacity. *[Figure 6-22]*

After the oil tank has been filled, the engine should be run for at least two minutes. Then, the oil level should be checked and, if necessary, sufficient oil should be added to bring the oil up to the proper level on the dipstick. *[Figure 6-23]*

Oil Cooler

The oil cooler used with this aircraft's opposed-type engine is the honeycomb type. *[Figure 6-24]* With the engine operating and an oil temperature below 65 °C (150 °F), oil cooler bypass valve opens allowing oil to bypass the core. This valve begins to close when the oil temperature reaches approximately 65 °C (150 °F). When the oil temperature reaches 85 °C (185 °F), ±2 °C, the valve is closed completely, diverting all oil flow through the cooler core.

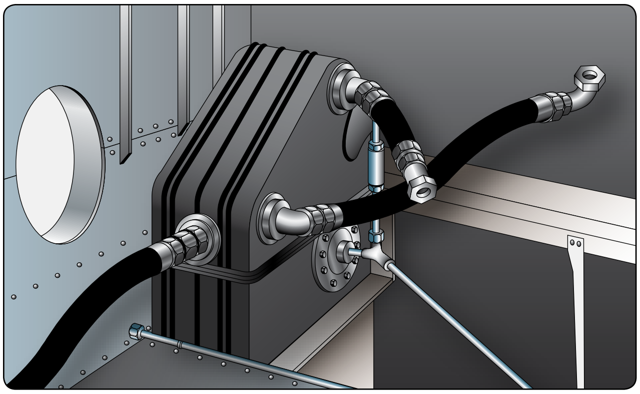

Figure 6-20. *Disconnect oil lines.*

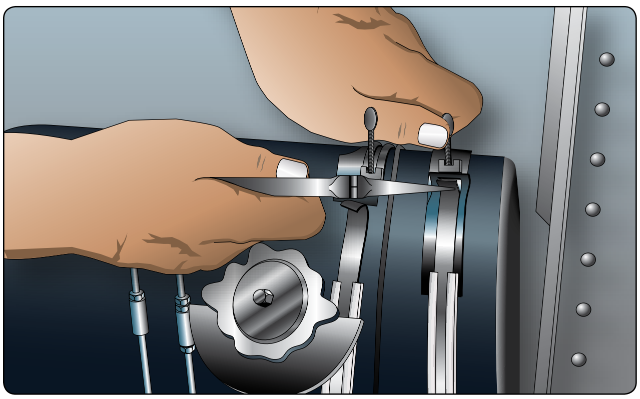

Figure 6-21. *Removal of securing straps.*

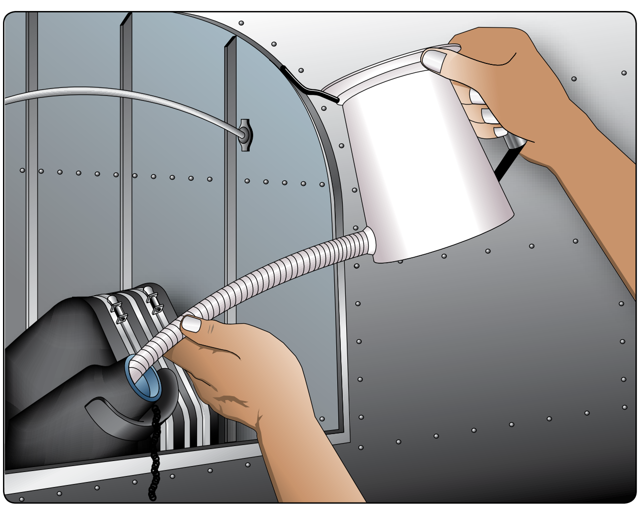

Figure 6-22. *Filling an oil tank.*

Oil Temperature Bulbs

Most oil temperature bulbs are mounted in the pressure oil screen housing. They relay an indication of engine oil inlet temperature to the oil temperature indicators mounted on the instrument panel. Temperature bulbs can be replaced by removing the safety wire and disconnecting the wire leads from the temperature bulbs, then removing the temperature bulbs using the proper wrench. *[Figure 6-25]*

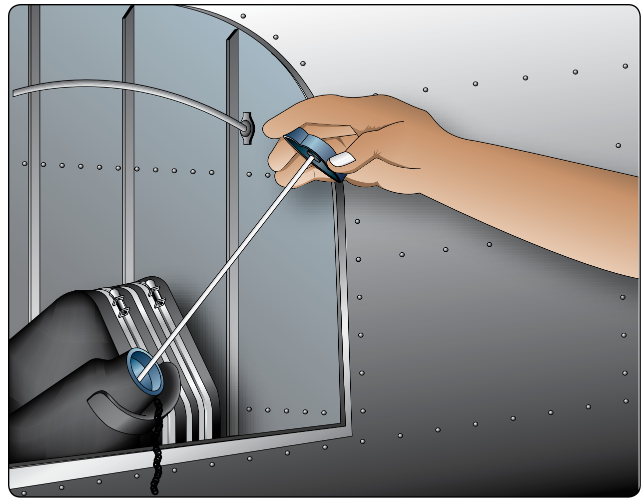

Figure 6-23. *Checking oil level with dipstick.*

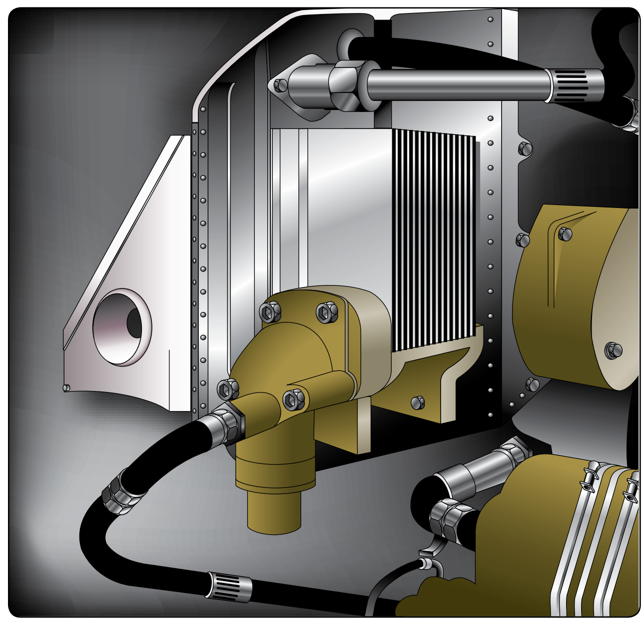

Figure 6-24. *Oil cooler.*

Pressure & Scavenge Oil Screens

Sludge accumulates on the pressure and scavenges oil screens during engine operation. *[Figure 6-26]* These screens must be removed, inspected, and cleaned at the intervals specified by the manufacturer.

Typical removal procedures include removing the safety devices and loosening the oil screen housing or cover plate. A suitable container should be provided to collect the oil that drains from the filter housing or cavity. The container must be clean so that the oil collected in it can be examined for foreign particles. Any contamination already present in the container gives a false indication of the engine condition. This could result in a premature engine removal.

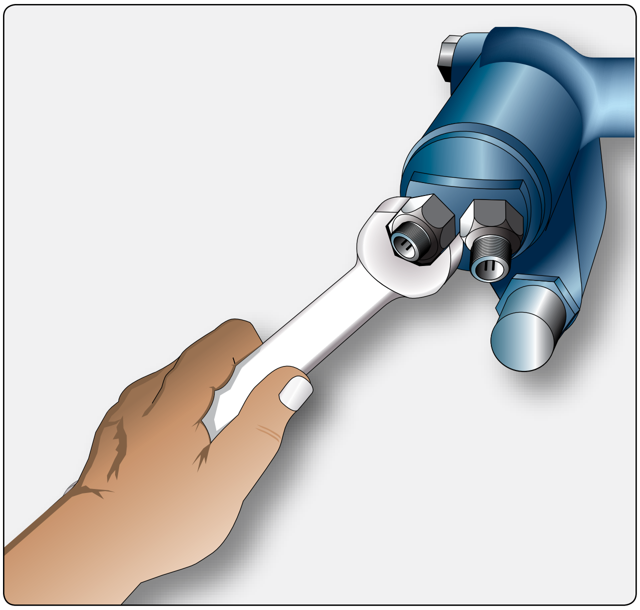

Figure 6-25. *Removing oil temperature bulb.*

After the screens are removed, they should be inspected for contamination and for the presence of metal particles that may indicate possible engine internal wear, damage, or in extreme cases, engine failure. The screen must be cleaned prior to reinstalling in the engine. In some cases, it is necessary to disassemble the filter for inspection and cleaning. The manufacturer's procedures should be followed when disassembling and reassembling an oil screen assembly. When reinstalling a filter or screen, use new O-rings and gaskets and tighten the filter housing or cover retaining nuts to the torque value specified in the applicable maintenance manual. Filters should be safetied as required.

Oil Pressure Relief Valve

An oil pressure regulating (relief) valve limits oil pressure to the value specified by the engine manufacturer. Oil pressure settings can vary from around 35 psi minimum to around 90 psi maximum, depending on the installation. The oil pressure must be high enough to ensure adequate lubrication of the engine and accessories at high speeds and power settings. On the other hand, the pressure must not be too high, since leakage and damage to the oil system may result. Before any attempt is made to adjust the oil pressure, the engine must be at the correct operating temperature and a check should be made to assure that the correct viscosity oil is being used in the engine. One example of adjusting the oil pressure is done by removing a cover nut, loosening a locknut, and turning the adjusting screw. *[Figure 6-27]* Turn the adjusting screw clockwise to increase the pressure, or counterclockwise to decrease the pressure. Make the pressure adjustments while the engine is idling and tighten the adjustment screw lock-nut after each adjustment. Check the oil pressure reading while the engine is running at the rpm specified in the manufacturer's maintenance manual. This may be from around 1,900 rpm to 2,300 rpm. The oil pressure reading should be between the limits prescribed by the manufacturer at all throttle settings.

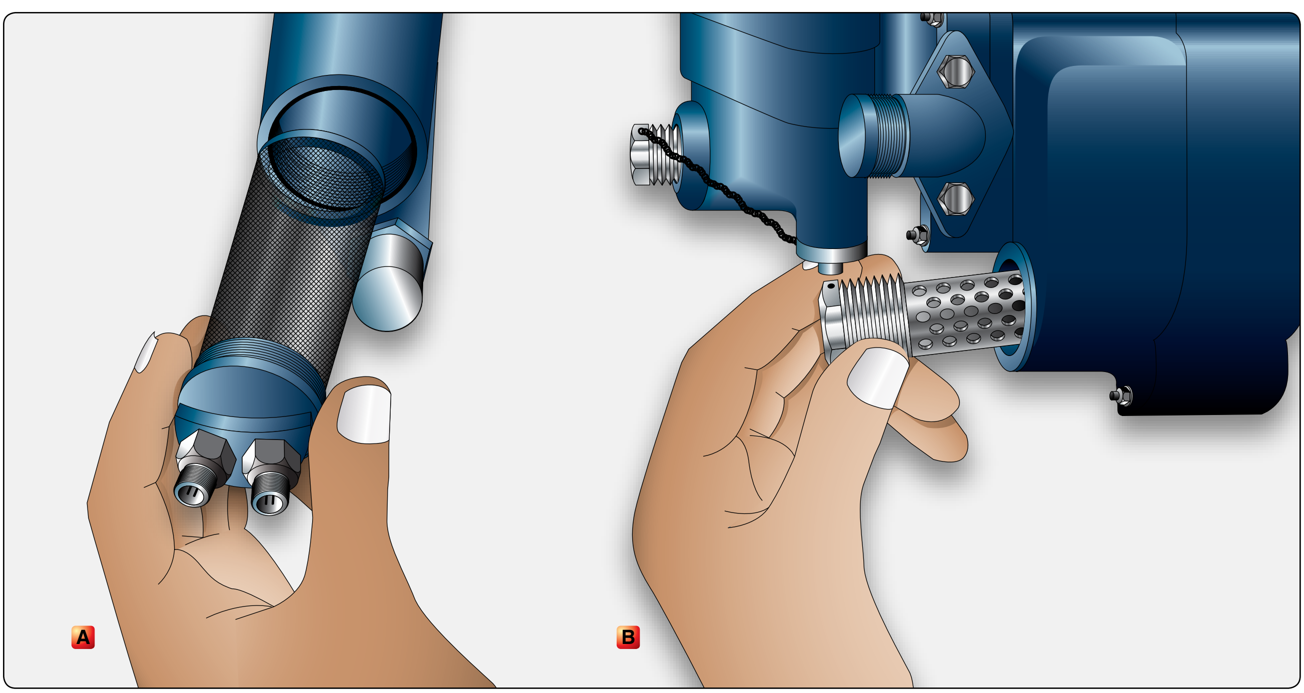

Figure 6-26. *Oil pressure screen (A) and scavenge oil screen assembly (B).*

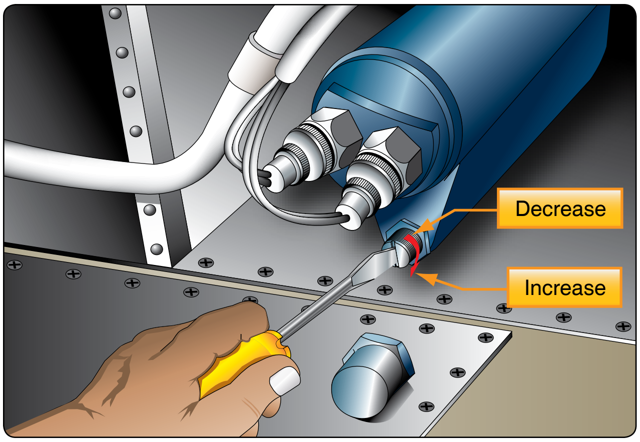

Figure 6-27. *Oil pressure relief valve adjustment.*

Recommendations for Changing Oil

Draining Oil

Oil, in service, is constantly exposed to many harmful substances that reduce its ability to protect moving parts. The main contaminants are:

- Gasoline,
- Moisture,
- Acids,
- Dirt,
- Carbon, and
- Metallic particles.

Because of the accumulation of these harmful substances, common practice is to drain the entire lubrication system at regular intervals and refill with new oil. The time between oil changes varies with each make and model aircraft and engine combination.

In engines that have been operating on straight mineral oil for several hundred hours, a change to ashless dispersant oil should be made with a degree of caution as the cleaning action of some ashless dispersant oils tends to loosen sludge deposits and cause plugged oil passages. When an engine has been operating on straight mineral oil, and is known to be in excessively dirty condition, the switch to ashless dispersant oil should be deferred until after the engine is overhauled.

When changing from straight mineral oil to ashless dispersant oil, the following precautionary steps should be taken:

1. Do not add ashless dispersant oil to straight mineral oil. Drain the straight mineral oil from the engine and fill with ashless dispersant oil.
2. Do not operate the engine longer than 5 hours before the first oil change.
3. Check all oil filters and screens for evidence of sludge or plugging. Change oil every 10 hours if sludge conditions are evident. Repeat 10-hour checks until clean screen is noted, then change oil at recommended time intervals.
4. All turbocharged engines must be broken in and operated with ashless dispersant oil.

Oil & Filter Change & Screen Cleaning

One manufacturer recommends that for new, remanufactured; or newly overhauled engines and for engines with any newly installed cylinders, the oil should be changed after the first replacement/screen cleaning at 25 hours. The oil should be changed, filter replaced, or pressure screen cleaned, and oil sump suction screen cleaned and inspected. A typical interval for oil change is 25 hours, along with a pressure screen cleaning and oil sump suction screen check for all engines employing a pressure screen system. Typical 50-hour interval oil changes generally include the oil filter replacement and suction screen check for all engines using full-flow filtration systems. A time maximum of 4 months between servicing is also recommended for oil system service.

Oil Filter Removal Canister Type Housing

Remove the filter housing from the engine by removing the safety wire and loosening the hex head screw and housing by turning counterclockwise and removing the filter from the engine. *[Figure 6-7]* Remove the nylon nut that holds the cover plate on the engine side of the filter. Remove the cover plate, hex head screw from the housing. To remove the spin-on type of filter, cut the safety wire and use the wrench pad on the rear of the filter to turn the filter counterclockwise, and remove filter. Inspect the filter element as described in the following paragraph. Discard old gaskets and replace with new replacement kit gaskets.

Oil Filter/Screen Content Inspection

Check for premature or excessive engine component wear that is indicated by the presence of metal particles, shavings, or flakes in the oil filter element or screens. The oil filter can be inspected by opening the filter paper element. Check the condition of the oil from the filter for signs of metal contamination. Then, remove the paper element from the filter and carefully unfold the paper element; examine the material trapped in the filter. If the engine employs a pressure screen system, check the screen for metal particles. After draining the oil, remove the suction screen from the oil sump and check for metal particles. *[Figure 6-28]* If examination of the used oil filter or pressure screen and the oil sump suction screen indicates abnormal metal content, additional service may be required to determine the source and possible need for corrective maintenance. To inspect the spin on filter the can must be cut open to remove the filter element for inspection.

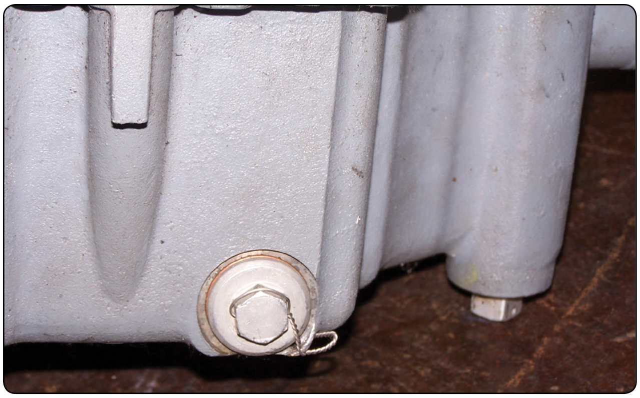

Figure 6-28. *Oil sump screen.*

Using the special filter cutting tool, slightly tighten the cutter blade against filter and rotate 360º until the mounting plate separates from the can. *[Figure 6-29]* Using a clean plastic bucket containing varsol, move the filter to remove contaminants. Use a clean magnet and check for any ferrous metal particles in the filter or varsol solution. Then, take the remaining varsol and pour it through a clean filter or shop towel. Using a bright light, inspect for any nonferrous metals.

Assembly of & Installation of Oil Filters

After cleaning the parts, installation of the canister or filter element type filter is accomplished by lightly oiling the new rubber gaskets and installing a new copper gasket on the hex head screw. Assemble the hex head screw into the filter case using the new copper gasket. Install the filter element and place the cover over the case, then manually thread on the nylon nut by hand. Install the housing on the engine by turning it clockwise, then torque and safety it. Spin-on filters generally have installation instructions on the filter. Place a coating of engine oil on the rubber gasket, install the filter, torque and safety it. Always follow the manufacturer's current instructions to perform any maintenance.

Troubleshooting Oil Systems

The outline of malfunctions and their remedies listed in *Figure 6-30* can expedite troubleshooting of the lubrication system. The purpose of this section is to present typical troubles. It is not intended to imply that any of the troubles are exactly as they may be in a particular aircraft.

Requirements for Turbine Engine Lubricants

There are many requirements for turbine engine lubricating oils. Due to the absence of reciprocating motion and the presence of ball and roller bearings (antifriction bearings), the turbine engine uses a less viscous lubricant. Gas turbine engine oil must have a high viscosity for good load-carrying ability but must also be of sufficiently low viscosity to provide good flowability. It must also be of low volatility to prevent loss by evaporation at the high altitudes at which the engines operate. In addition, the oil should not foam and should be essentially nondestructive to natural or synthetic rubber seals in the lubricating system. Also, with high-speed antifriction bearings, the formation of carbons or varnishes must be held to a minimum. Synthetic oil for turbine engines are usually supplied in sealed one-quart cans.

The many requirements for lubricating oils are met in the synthetic oils developed specifically for turbine engines. Synthetic oil has two principal advantages over petroleum oil. It has a lower tendency to deposit lacquer and coke (solids left after solvents have been evaporated) because it does not evaporate the solvents from the oil at high temperature. Oil grades used in some turbine engines normally contain thermal and oxidation preventives, load-carrying additives, and substances that lower the pour point in addition to synthetic chemical-base materials. MIL-L-7808, which is a military specification for turbine oil, is a type I turbine oil. Turbine synthetic oil has a viscosity of around 5 to 5.5 centistokes at 210º F that is approved against the military specification MIL-PRF-23699F. This oil is referred to as type II turbine oil. Most turbine oils meet this type II specification and are made with the following characteristics:

1. Vapor phase deposits—carbon deposits formed from oil mist and vapor contact with hot engine surfaces.
2. Load-carrying ability—provides for heavy loads on

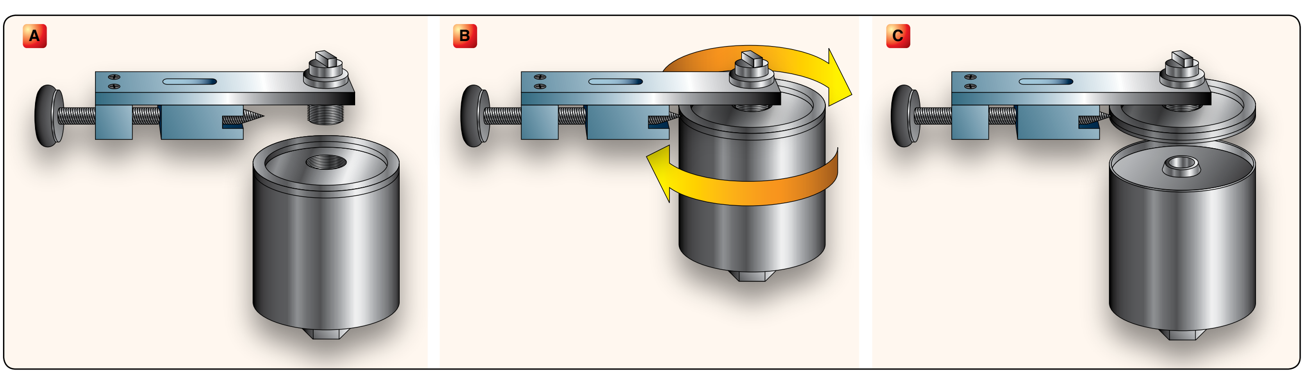

Figure 6-29. *Cutting open a spin-on type oil filter using a special filter cutter.*

Trouble	Isolation Procedure	Remedy
1 Excessive oil consumption		
Oil line leakage.	Check external lines for evidence of oil leakage.	Replace or repair defective lines.
Accessory seal leakage.	Check for leak at accessories immediately after engine operation.	Replace accessory and/or defective accessory oil seal.
Low grade of oil.		Fill tank with proper grade oil.
Failing or failed bearing.	Check sump and oil pressure pump screen for material particles.	Replace engine if metal particles are found.
2 High or low indicated oil pressure		
Defective pressure gauge.	Check indicator.	Replace indicator if defective.
Improper operation of oil pressure.	Erratic pressure indications either excessively high or low.	Remove, clean, and inspect relief valve accessory oil seal.
Inadequate oil supply.	Check oil quantity.	Fill oil tank.
Diluted or contaminated oil.		Drain engine and tank; refill tank.
Clogged oil screen.		Remove and clean oil screen.
Oil viscosity incorrect.	Make sure correct oil is being used.	Drain engine and tank; refill tank.
Oil pump pressure relief valve adjustment incorrect.	Check pressure relief valve adjustment.	Make correct adjustment on oil pump pressure relief valve.
3 High or low indicated oil temperature		
Defective temperature gauge.	Check indicator.	Replace indicator if defective.
Inadequate oil supply.	Check oil quantity.	Fill oil tank.
Diluted or contaminated oil.		Drain engine and tank; refill tank.
Obstruction in oil tank.	Check tank.	Drain oil and remove obstruction.
Clogged oil screen.		Remove and clean oil screens.
Obstruction in oil cooler passages.	Check cooler for blocked or deformed passages.	Replace oil cooler if defective.
4 Oil foaming		
Diluted or contaminated oil.		Drain engine and tank; refill tank.
Oil level in tank too high.	Check oil quantity.	Drain excess oil from tank.

Figure 6-30. *Oil system troubleshooting procedures.*

the bearing systems of turbine engines.

3. Cleanliness—minimum formation of sludge deposits during severe operation.

4. Bulk stability—resistance to physical or chemical change resulting from oxidation. Permits long periods of service operation without significant increase in viscosity or total acidity, the main indicators of oxidation.

5. Compatibility—most turbine oil is compatible with other oils that meet the same military specification. But, most engine manufacturers do not recommend the indiscriminate mixing of approved oil brands and this is not a generally accepted practice.

6. Seal Wear—essential for the life of engines with carbon seals that lubricant properties prevent wear of the carbon at the carbon seal face.

Turbine Oil Health & Safety Precautions

Under normal conditions, the use of turbine oil presents a low health risk for humans. Although each person reacts somewhat differently to exposure, contact with liquids, vapors, and mist of turbine oil should be minimized. Information on established limits on exposure to turbine oil can generally be found in the material safety data sheets (MSDS). Prolonged breathing of hydrocarbon vapor concentrations in excess of the prescribed limits may result in lightheadedness, dizziness, and nausea. If turbine oil is ingested, call a doctor immediately; identify the product and how much was ingested. Because of the risk of ingestion, petroleum products should never be siphoned by mouth.

Prolonged or repeated contact of turbine oil with the skin can cause irritation and dermatitis. In case of skin contact, wash the skin thoroughly with soap and warm water. Promptly remove oil-soaked clothing and wash. If turbine oil contacts the eyes, flush the eyes with fresh water until the irritation subsides. Protective clothing, gloves, and eye protection should be used when handling turbine oil.

During operation, it is possible for the oil to be subjected to very high temperatures that can break it down and produce a product of unknown toxicity. If this happens, all precautions to avoid explosives should be taken. It can also have a tendency to blister, discolor, or remove paint whenever it is spilled. Painted surfaces should be wiped clean with a petroleum solvent after spillage.

Spectrometric Oil Analysis Program

The Spectrometric Oil Analysis Program allows an oil sample to be analyzed and searched for the presence of minute metallic elements. Due to oil circulation throughout an aircraft engine, every lubricant that is in service contains microscopic particles of metallic elements called wear metals. As the engine operates over time, the oil picks up very small particles that stay suspended in the oil. Oil analysis programs identify and measure these particles in parts per million (PPM) by weight. The analyzed elements are grouped into categories, such as wear metals and additives, and their measurement in PPM provides data that expert analysts can use as one of many tools to determine the engine's condition. An increase in PPM of certain materials can be a sign of component wear or impending failure of the engine. When you take a sample, note and record the amount of wear metals. If the amount of wear metals increases beyond a normal rate, then the operator can be notified quickly so repair or a recommendation of a specific maintenance procedure or inspection can be ordered.

Oil analysis increases safety by identifying an engine problem before engine failure. It also saves money by finding engine problems before they become large problems or complete engine failure. This procedure can be used for both turbine and reciprocating engines.

Typical Wear Metals & Additives

The following examples of wear metals are associated with areas of the engine that could be lead to their source. Identifying the metal can help identify the engine components that are wearing or failing.

- Iron—wear from rings, shafts, gears, valve train, cylinder walls, and pistons in some engines.
- Chromium—primary sources are chromed parts (such as rings, liners, etc.) and some coolant additives.
- Nickel—secondary indicator of wear from certain types of bearings, shafts, valves, and valve guides.
- Aluminum—indicates wear of pistons, rod bearings, and certain types of bushings.
- Lead—mostly from tetraethyl lead contamination.
- Copper—wear from bearings, rocker arm bushings, wrist pin bushings, thrust washers, and other bronze or brass parts, and oil additive or antiseize compound.
- Tin—wear from bearings.
- Silver—wear of bearings that contain silver and, in some instances, a secondary indicator of oil cooler problems.
- Titanium—alloy in high-quality steel for gears and bearings.
- Molybdenum—gear or ring wear and used as an additive in some oils.
- Phosphorous—antirust agents, spark plugs, and combustion chamber deposits.

Turbine Engine Lubrication Systems

Both wet- and dry-sump lubrication systems are used in gas turbine engines. Wet-sump engines store the lubricating oil in the engine proper, while dry-sump engines utilize an external tank mounted on the engine or somewhere in the aircraft structure near the engine, similar to reciprocating piston engines mentioned earlier.

Turbine engine's oil systems can also be classified as a pressure relief system that maintains a somewhat constant pressure: the full flow type of system, in which the pressure varies with engine speed, and the total loss system, used in engines that are for short duration operation (target drones, missiles, etc.). The most widely used system is the pressure relief system with the full flow used mostly on large fan-type engines. One of the main functions of the oil system in turbine engines is cooling the bearings by carrying the heat away from the bearing by circulating oil around the bearing.

The exhaust turbine bearing is the most critical lubricating point in a gas turbine engine because of the high temperature normally present. In some engines, air cooling is used in addition to oil cooling the bearing, which supports the turbine. Air cooling, referred to as secondary air flow, is cooling air provided by bleed air from the early stages of the compressor.

This internal air flow has many uses on the inside of the engine. It is used to cool turbine disc, vanes, and blades. Also, some turbine wheels may have bleed air flowing over the turbine disc, which reduces heat radiation to the bearing surface. Bearing cavities sometimes use compressor air to aid in cooling the turbine bearing. This bleed air, as it is called, is usually bled off a compressor stage at a point where air has enough pressure but has not yet become too warm (as the air is compressed, it becomes heated).

The use of cooling air substantially reduces the quantity of oil necessary to provide adequate cooling of the bearings. Since cooling is a major function of the oil in turbine engines, the lubricating oil for bearing cooling normally requires an oil cooler. When an oil cooler is required, usually a greater quantity of oil is necessary to provide for circulation between the cooler and engine. To ensure proper temperature, oil is routed through either air-cooled and/or fuel-cooled oil coolers. This system is used to also heat (regulate) the fuel to prevent ice in the fuel.

Turbine Lubrication System Components

The following component descriptions include most found in the various turbine lubrication systems. However, since engine oil systems vary somewhat according to engine model and manufacturer, not all of these components are necessarily found in any one system.

Oil Tank

Although the dry-sump systems use an oil tank that contains most of the oil supply, a small sump is usually included on the engine to hold a small supply of oil. It usually contains the oil pump, the scavenge and pressure inlet strainers, scavenge return connection, pressure outlet ports, an oil filter, and mounting bosses for the oil pressure gauge and temperature bulb connections.

A view of a typical oil tank is shown in *Figure 6-31*. It is designed to furnish a constant supply of oil to the engine during any aircraft attitude. This is done by a swivel outlet assembly mounted inside the tank, a horizontal baffle mounted in the center of the tank, two flapper check valves mounted on the baffle, and a positive vent system.

The swivel outlet fitting is controlled by a weighted end that is free to swing below the baffle. The flapper valves in the baffle are normally open; they close only when the oil in the bottom of the tank tends to rush to the top of the tank during decelerations. This traps the oil in the bottom of the tank where it is picked up by the swivel fitting. A sump drain is located in the bottom of the tank. The vent system inside the tank is so arranged that the airspace is vented at all times even though oil may be forced to the top of the tank by deceleration of the aircraft.

All oil tanks are provided with expansion space. This allows

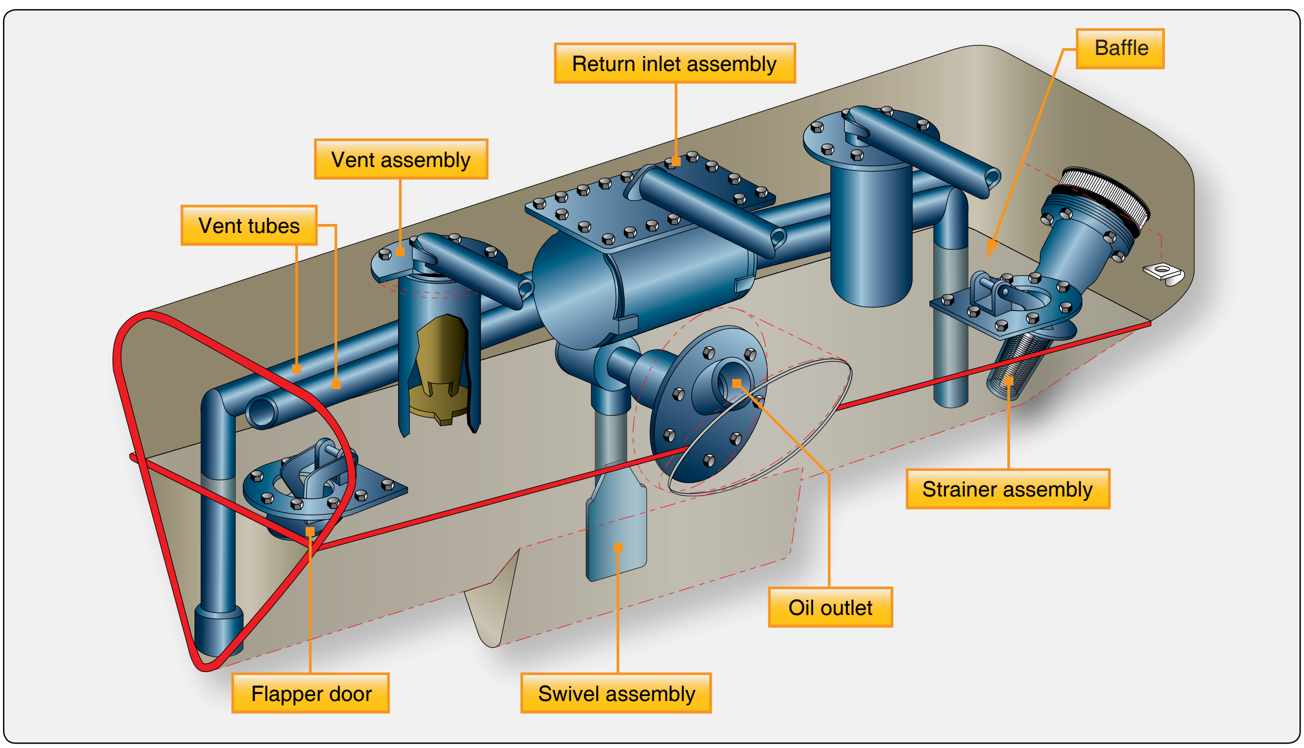

Figure 6-31. *Oil tank.*

expansion of the oil after heat is absorbed from the bearings and gears and after the oil foams as a result of circulating through the system. Some tanks also incorporate a deaerator tray for separating air from the oil returned to the top of the tank by the scavenger system. Usually these deaerators are the can type in which oil enters at a tangent. The air released is carried out through the vent system in the top of the tank. In most oil tanks, a pressure buildup is desired within the tank to ensure a positive flow of oil to the oil pump inlet. This pressure buildup is made possible by running the vent line through an adjustable check relief valve. The check relief valve is usually set to relieve at about 4 psi, keeping positive pressure on the oil pump inlet. If the air temperature is abnormally low, the oil may be changed to a lighter grade. Some engines may provide for the installation of an immersion-type oil heater.

Oil Pump

The oil pump is designed to supply oil under pressure to the parts of the engine that require lubrication, then circulate the oil through coolers as needed, and return the oil to the oil tank. Many oil pumps consist of not only a pressure supply element, but also scavenge elements, such as in a dry-sump system. However, there are some oil pumps that serve a single function; that is, they either supply or scavenge the oil. These pump elements can be located separate from each other and driven by different shafts from the engine. The numbers of pumping elements (two gears that pump oil), pressure and scavenge, depend largely on the type and model of the engine. Several scavenge oil pump elements can be used to accommodate the larger capacity of oil and air mix. The scavenge elements have a greater pumping capacity than the pressure element to prevent oil from collecting in the bearing sumps of the engine.

The pumps may be one of several types, each type having certain advantages and limitations. The two most common oil pumps are the gear and gerotor, with the gear-type being the most commonly used. Each of these pumps has several possible configurations.

The gear-type oil pump has only two elements: one for pressure oil and one for scavenging. *[Figure 6-32]* However, some types of pumps may have several elements: one or more

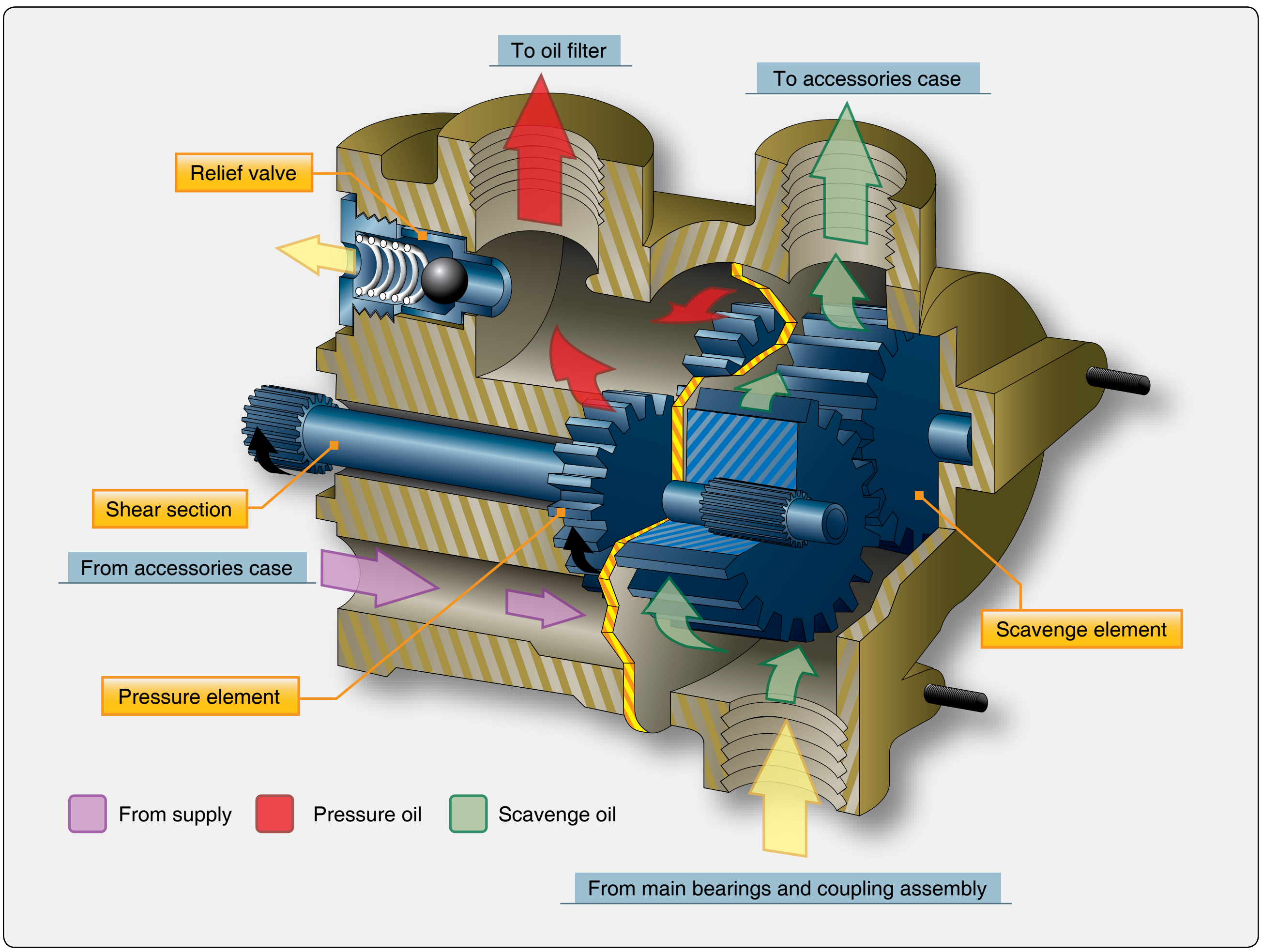

Figure 6-32. *Cutaway view of gear oil pump.*

elements for pressure and two or more for scavenging. The clearances between the gear teeth and the sides of the pump wall and plate are critical to maintain the correct output of the pump.

A regulating (relief) valve in the discharge side of the pump limits the output pressure of the pump by bypassing oil to the pump inlet when the outlet pressure exceeds a predetermined limit. *[Figure 6-32]* The regulating valve can be adjusted, if needed, to bring the oil pressure within limits. Also shown is the shaft shear section that causes the shaft to shear if the pump gears should seize up and not turn.

The gerotor pump, like the gear pump, usually contains a single element for oil pressure and several elements for scavenging oil. Each of the elements, pressure and scavenge, is almost identical in shape; however, the capacity of the elements can be controlled by varying the size of the gerotor elements. For example, the pressure element may have a pumping capacity of 3.1 gallons per minute (gpm) as compared to 4.25 gpm capacity for the scavenge elements. Consequently, the pressure element is smaller since the elements are all driven by a common shaft. The pressure is determined by engine rpm with a minimum pressure at idling speed and maximum pressure at intermediate and maximum engine speeds.

A typical set of gerotor pumping elements is shown in *Figure 6-33*. Each set of gerotors is separated by a steel plate, making each set an individual pumping unit consisting of an inner and an outer element. The small star-shaped inner element has external lobes that fit within and are matched with the outer element that has internal lobes. The small element fits on and is keyed to the pump shaft and acts as a drive for the outer free-turning element. The outer element fits within a steel plate having an eccentric bore. In one engine model, the oil pump has four elements: one for oil feed and three for scavenge. In some other models, pumps have six elements: one for feed and five for scavenge. In each case, the oil flows as long as the engine shaft is turning.

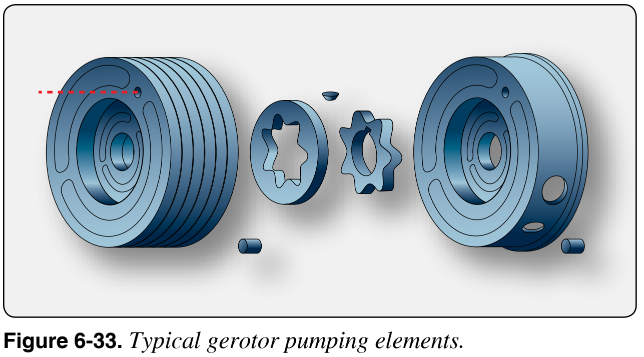

Figure 6-33. *Typical gerotor pumping elements.*

Turbine Oil Filters

Filters are an important part of the lubrication system because they remove foreign particles that may be in the oil. This is particularly important in gas turbines as very high engine speeds are attained; the antifriction types of ball and roller bearings would become damaged quite rapidly if lubricated with contaminated oil. Also, there are usually numerous drilled or core passages leading to various points of lubrication. Since these passages are usually rather small, they are easily clogged.

There are several types and locations of filters used for filtering the turbine lubricating oil. The filtering elements come in a variety of configurations and mesh sizes. Mesh sizes are measured in microns, which is a linear measurement equal to one millionth of a meter (a very small opening).

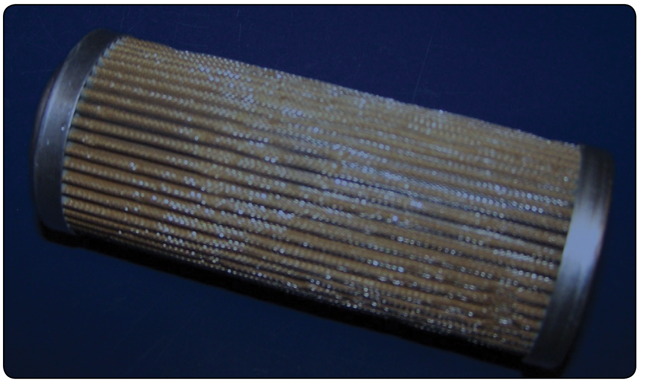

Figure 6-34. *Turbine oil filter element.*

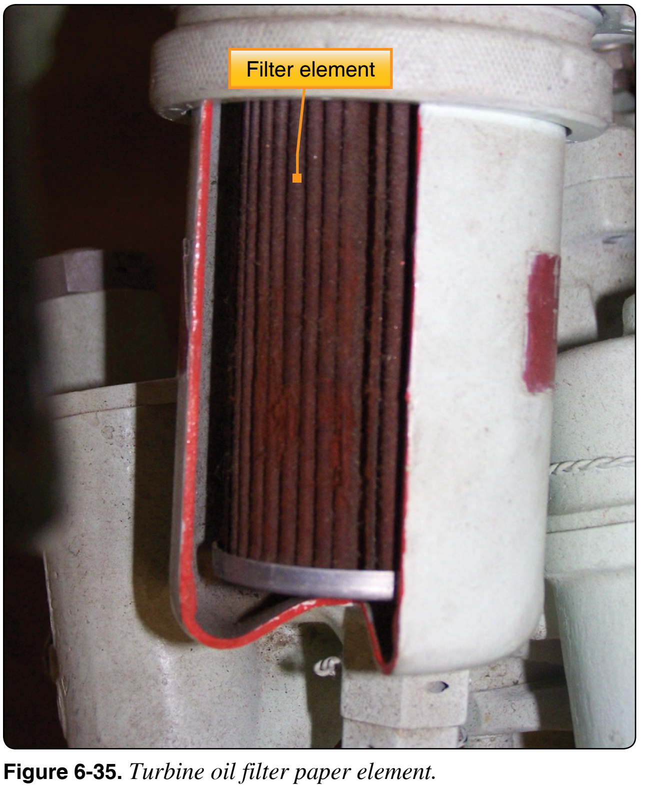

Figure 6-35. *Turbine oil filter paper element.*

A main oil strainer filter element is shown in *Figure 6-34*. The filtering element interior is made of varying materials including paper and metal mesh. *[Figure 6-35]* Oil normally flows through the filter element from the outside into the filter body. One type of oil filter uses a replaceable laminated paper element, while others use a very fine stainless steel metal mesh of about 25–35 microns.

Most filters are located close to the pressure pump and consist of a filter body or housing, filter element, a bypass valve, and a check valve. The filter bypass valve prevents the oil flow from being stopped if the filter element becomes clogged. The bypass valve opens whenever a certain pressure is reached. If this occurs, the filtering action is lost, allowing unfiltered oil to be pumped to the bearings. However, this prevents the bearings from receiving no oil at all. In the bypass mode, many engines have a mechanical indicator that pops out to indicate the filter is in the bypass mode. This indication is visual and can only be seen by inspecting the engine directly. An antidrain check valve is incorporated into the assembly to prevent the oil in the tank from draining down into the engine sumps when the engine is not operating. This check valve is normally spring loaded closed with 4 to 6 psi needed to open it.

The filters generally discussed are used as main oil filters; that is, they strain the oil as it leaves the pump before being piped to the various points of lubrication. In addition to the main oil filters, there are also secondary filters located throughout the system for various purposes. For instance, there may be a finger screen filter that is sometimes used for straining scavenged oil. These screens tend to be large mesh screens that trap larger contaminants. Also, there are fine-mesh screens called last chance filters for straining the oil just before it passes from the spray nozzles onto the bearing surfaces. *[Figure 6-36]* These filters are located at each bearing and help screen out contaminants that could plug the oil spray nozzle.

Figure 6-36. *Last-chance filter before spray nozzle.*

Oil Pressure Regulating Valve

Most turbine engine oil systems are pressure regulating type systems that keep the pressure fairly constant. An oil pressure regulating valve is included in the oil system on the pressure side of the pressure pump. A regulating valve system controls the systems pressure to a limited pressure within the system. It is more of a regulating valve than a relief valve because it keeps the pressure in the system within certain limits other than only opening when the absolute maximum pressure of the system is exceeded.

The regulating valve *Figure 6-37* has a valve held against a seat by a spring. By adjusting the tension (increase) on the spring, you change the pressure at which the valve opens, and you also increase the system pressure. A screw pressing on the spring adjusts the tension on the valve and the system pressure.

Oil Pressure Relief Valve

Some large turbofan oil systems do not have a regulating valve. The system pressure varies with engine rpm and pump speed. There is a wide range of pressure in this system. A relief valve is used to relieve pressure only if it exceeds the maximum limit for the system. *[Figure 6-38]* This true relief valve system is preset to relieve pressure and bypass the oil back to the inlet side of the oil pump whenever the pressure exceeds the maximum preset system limit. This relief valve is especially important when oil coolers are incorporated in the system since the coolers are easily ruptured because of their thin-wall construction. Under normal operation, it should never open.

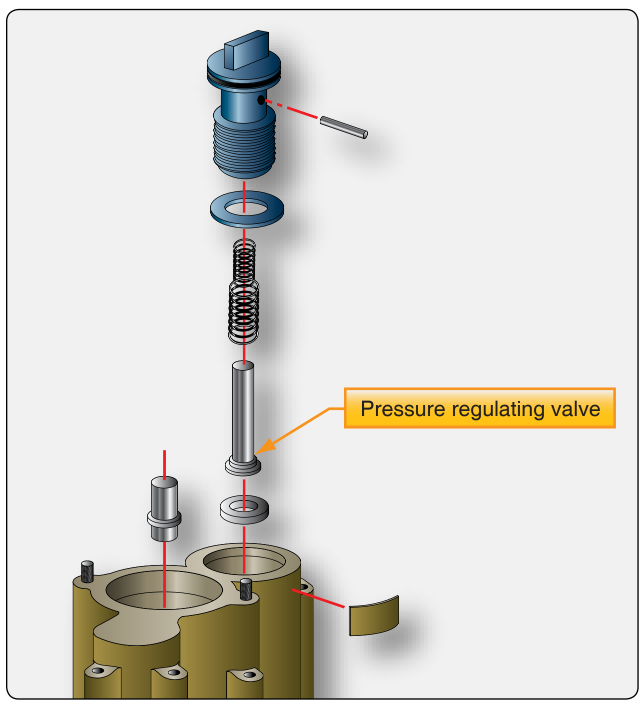

Figure 6-37. *Pressure regulating valve.*

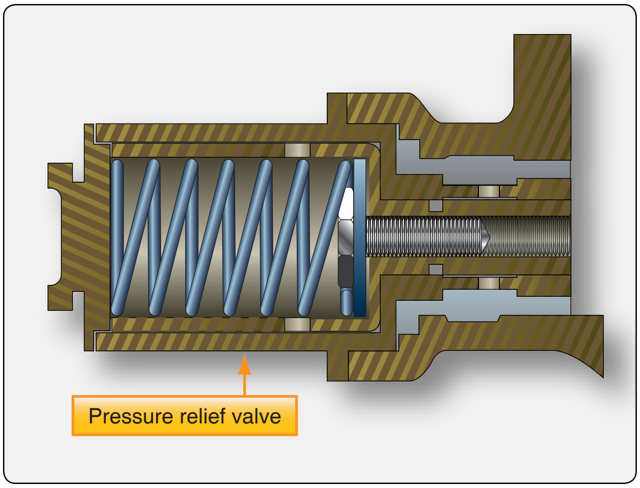

Figure 6-38. *Pressure relief valve.*

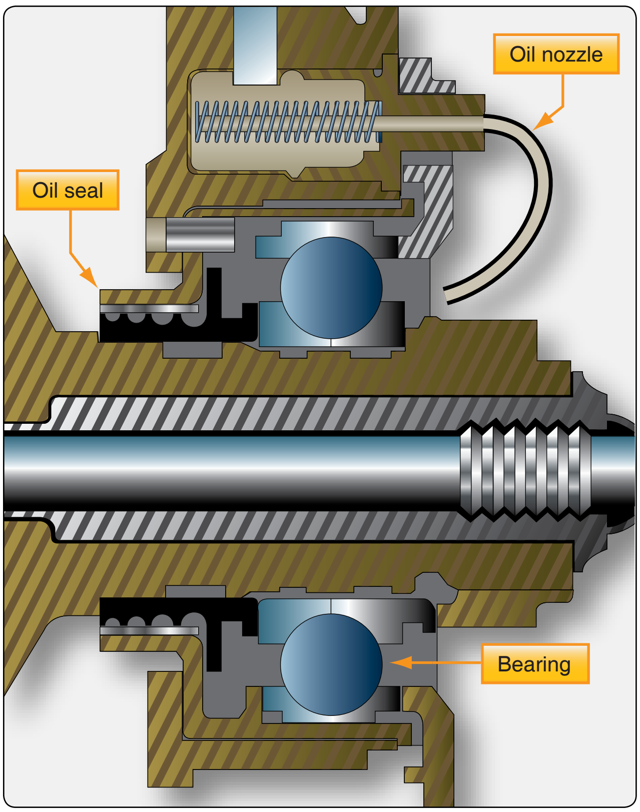

Figure 6-39. *Oil nozzles spray lubricate on bearings.*

Oil Jets

Oil jets (or nozzles) are located in the pressure lines adjacent to, or within, the bearing compartments and rotor shaft couplings. *[Figure 6-39]* The oil from these nozzles is delivered in the form of an atomized spray. Some engines use an air-oil mist spray that is produced by tapping high-pressure bleed air from the compressor to the oil nozzle outlet. This method is considered adequate for ball and roller bearings; however, the solid oil spray method is considered the better of the two methods.

The oil jets are easily clogged because of the small orifice in their tips; consequently, the oil must be free of any foreign particles. If the last-chance filters in the oil jets should become clogged, bearing failure usually results since nozzles are not accessible for cleaning except during engine maintenance. To prevent damage from clogged oil jets, main oil filters are checked frequently for contamination.

Lubrication System Instrumentation

Gauge connection provisions are incorporated in the oil system for oil pressure, oil quantity, low oil pressure, oil filter differential pressure switch, and oil temperature. The oil pressure gauge measures the pressure of the lubricant as it leaves the pump and enters the pressure system. The oil pressure transmitter connection is located in the pressure line between the pump and the various points of lubrication. An electronic sensor is placed to send a signal to the Full Authority Digital Engine Control (FADEC) control unit and through the Engine Indicating and Crew Alerting System (EICAS) computers, and on to the displays in the flight deck. *[Figure 6-40]* The tank quantity transmitter information is sent to the EICAS computers. The low oil pressure switch alerts the crew if the oil pressure falls below a certain pressure during engine operation. The differential oil pressure switch alerts the flight crew of an impending oil filter bypass because of a clogged filter. A message is sent to the display in the upper EICAS display in the flight deck as can be seen in *Figure 6-40*. Oil temperature can be sensed at one or more points in the engine's oil flow path. The signal is sent to the FADEC/EICAS computer and is displayed on the lower EICAS display.

Lubrication System Breather Systems (Vents)

Breather subsystems are used to remove excess air from the bearing cavities and return the air to the oil tank where it is separated from any oil mixed in the vapor of air and oil by the deaerator. Then, the air is vented overboard and back to the atmosphere. All engine bearing compartments, oil tanks, and accessory cases are vented together so the pressure in the system remains the same.

The vent in an oil tank keeps the pressure within the tank from rising above or falling below that of the outside atmosphere. However, the vent may be routed through a check relief valve that is preset to maintain a slight (approximately 4 psi) pressure on the oil to assure a positive flow to the oil pump inlet.

In the accessory case, the vent (or breather) is a screen-protected opening that allows accumulated air pressure within the accessory case to escape to the atmosphere. The scavenged oil carries air into the accessory case and this air

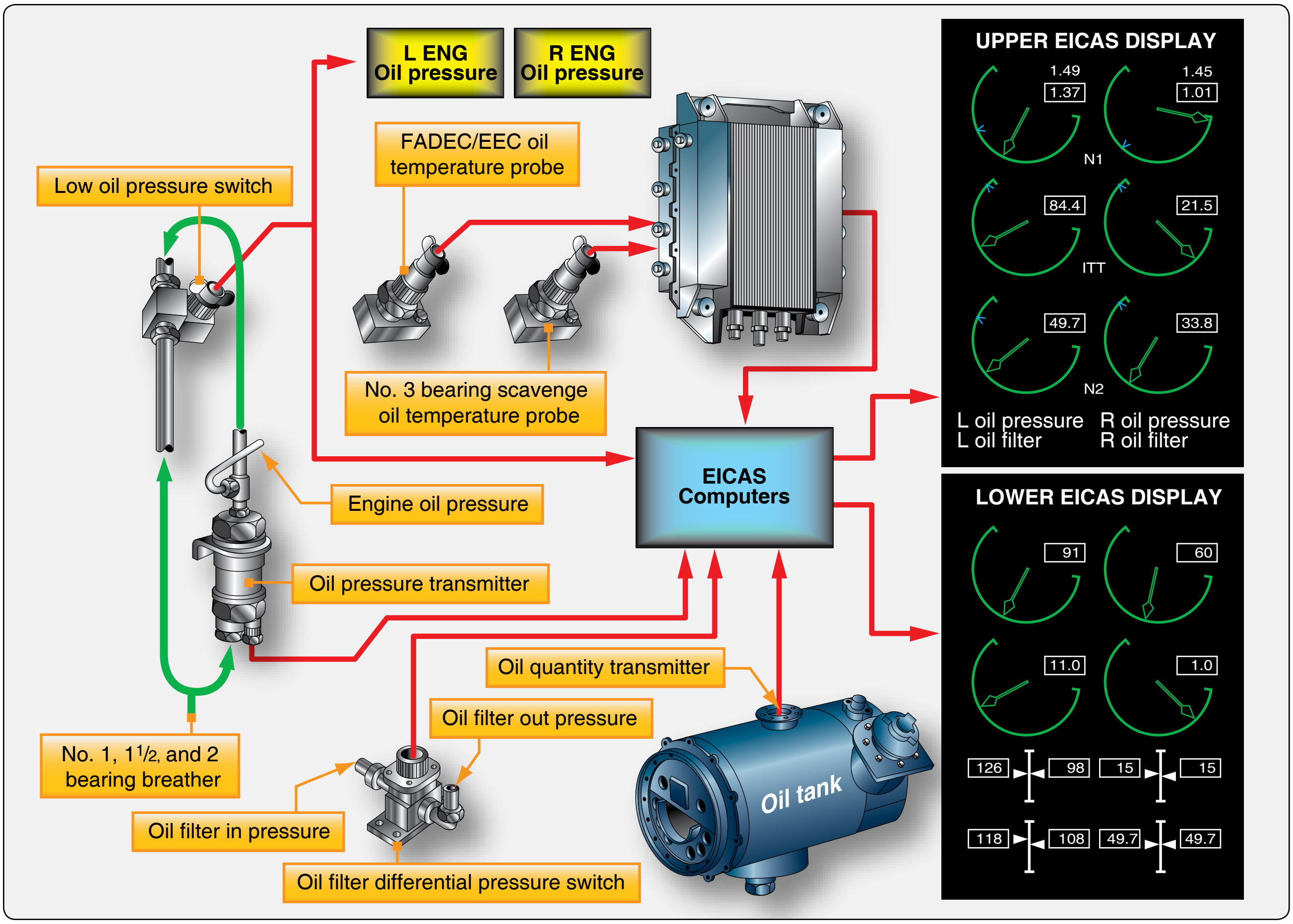

Figure 6-40. *Oil indicating system.*

must be vented. Otherwise, the pressure buildup within the accessory case would stop the flow of oil draining from the bearing, forcing this oil past the bearing oil seals and into the compressor housing. If in enough quantity, oil leakage could cause burning and seal and bearing malfunction. The screened breathers are usually located in the front center of the accessory case to prevent oil leakage through the breather when the aircraft is in unusual flight attitudes. Some breathers may have a baffle to prevent oil leakage during flight maneuvers. A vent that leads directly to the bearing compartment may be used in some engines. This vent equalizes pressure around the bearing surface so that the lower pressure at the first compressor stage does not cause oil to be forced past the bearing rear oil seal into the compressor.

Lubrication System Check Valve

Check valves are sometimes installed in the oil supply lines of dry-sump oil systems to prevent reservoir oil from seeping (by gravity) through the oil pump elements and high-pressure lines into the engine after shutdown. Check valves, by stopping flow in an opposite direction, prevent accumulations of undue amounts of oil in the accessory gearbox, compressor rear housing, and combustion chamber. Such accumulations could cause excessive loading of the accessory drive gears during starts, contamination of the cabin pressurization air, or internal oil fires. The check valves are usually the spring-loaded ball-and-socket type constructed for free flow of pressure oil. The pressure required to open these valves

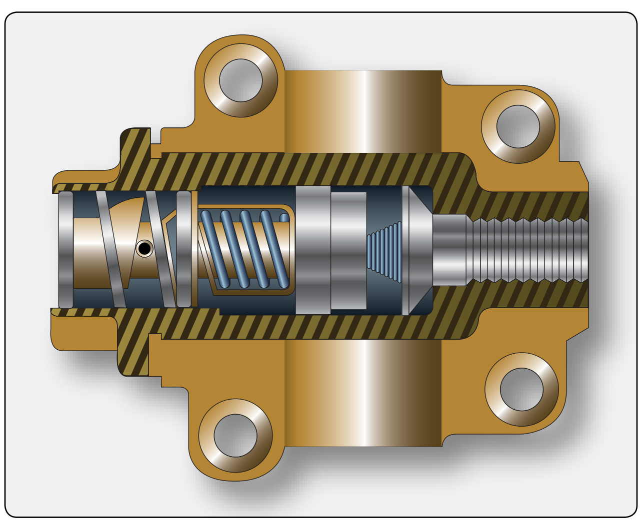

Figure 6-41. *Typical thermostatic bypass valve.*

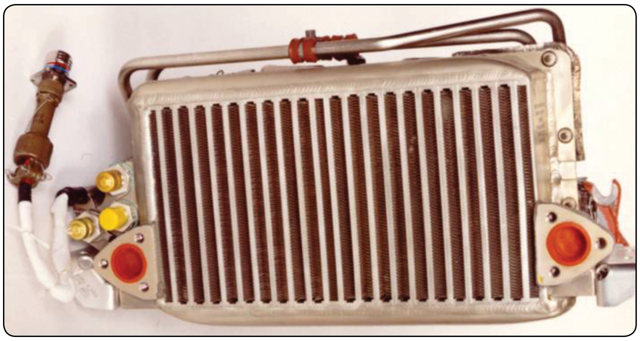

Figure 6-42. *Air oil cooler.*

varies, but the valves generally require from 2 to 5 psi to permit oil to flow to the bearings.

Lubrication System Thermostatic Bypass Valves

Thermostatic bypass valves are included in oil systems using an oil cooler. Although these valves may be called different names, their purpose is always to maintain proper oil temperature by varying the proportion of the total oil flow passing through the oil cooler. A cutaway view of a typical thermostatic bypass valve is shown in *Figure 6-41*. This valve consists of a valve body, having two inlet ports and one outlet port, and a spring-loaded thermostatic element valve. The valve is spring loaded because the pressure drop through the oil cooler could become too great due to denting or clogging of the cooler tubing. In such a case, the valve opens, bypassing the oil around the cooler.

Air-Oil Coolers

Two basic types of oil coolers in general use are the air-cooled and the fuel-cooled. Air-oil coolers are used in the lubricating systems of some turbine engines to reduce the temperature of the oil to a degree suitable for recirculation through the system. The air-cooled oil cooler is normally installed at the forward end of the engine. It is similar in construction and operation to the air-cooled cooler used on reciprocating engines. An air-oil cooler is usually included in a dry-sump oil system. *[Figure 6-42]* This cooler may be air-cooled or fuel-cooled and many engines use both. Dry-sump lubrication systems require coolers for several reasons. First, air cooling of bearings by using compressor bleed-air is not sufficient to cool the turbine bearing cavities because of the heat present in area of the turbine bearings. Second, the large turbofan engines normally require a greater number of bearings, which means that more heat is transferred to the oil. Consequently, the oil coolers are the only means of dissipating the oil heat.

Fuel-Oil Coolers

The fuel-cooled oil cooler acts as a fuel-oil heat exchanger in that the fuel cools the hot oil and the oil heats the fuel for combustion. *[Figure 6-43]* Fuel flowing to the engine must pass through the heat exchanger; however, there is a thermostatic valve that controls the oil flow, and the oil may bypass the cooler if no cooling is needed. The fuel-oil heat

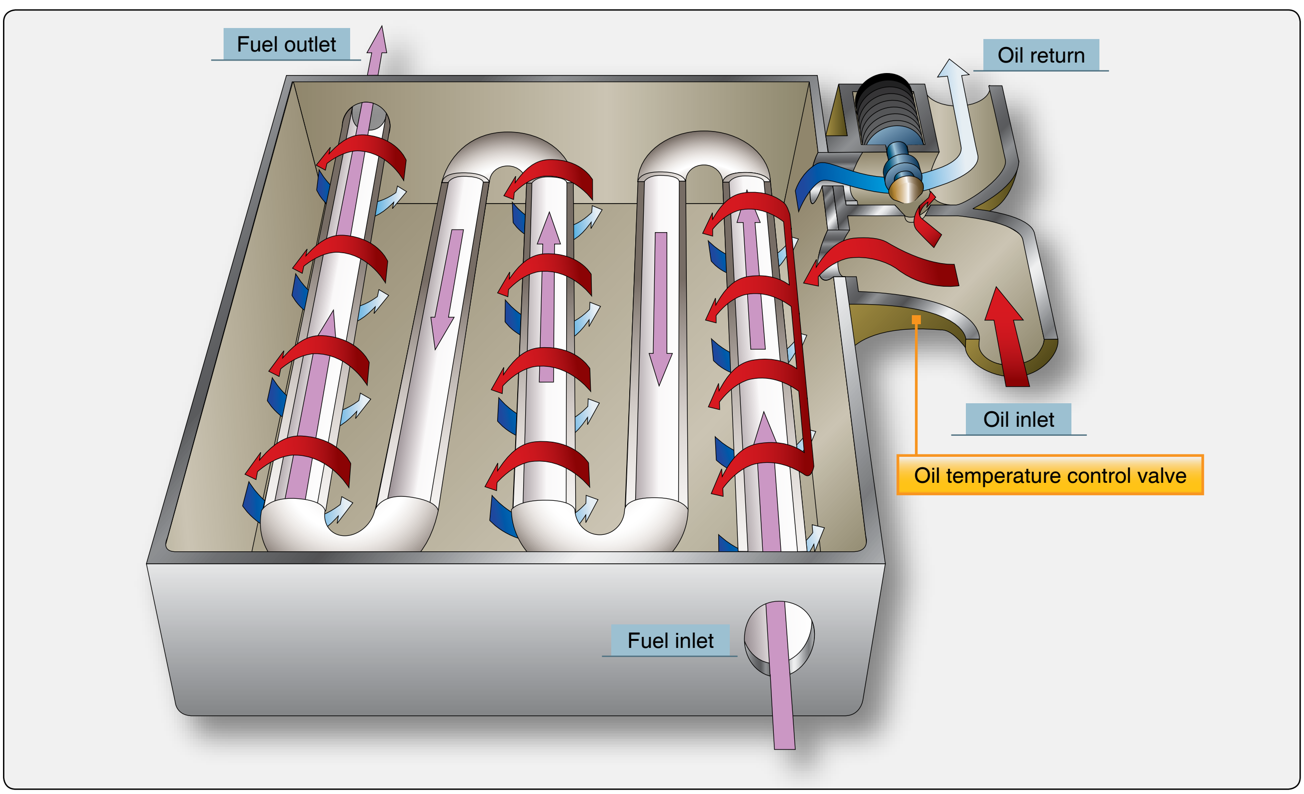

Figure 6-43. *Fuel-oil heat exchanger cooler.*

exchanger consists of a series of joined tubes with an inlet and outlet port. The oil enters the inlet port, moves around the fuel tubes, and goes out the oil outlet port.

Deoiler

The deoiler removes the oil from the breather air. The breather air goes into an impeller that turns in the deoiler housing. Centrifugal force drives the oil towards the outer wall of the impeller. Then, the oil drains from the deoiler into a sump or oil tank. Because the air is much lighter than the oil, it goes through the center of the impeller and is vented overboard.

Magnetic Chip Detectors

Magnetic chip detectors are used in the oil system to detect and catch ferrous (magnetic) particles present in the oil. *[Figure 6-44]* Scavenge oil generally flows past chip detectors so any magnetic particles are attracted and stick to the chip detector. Chip detectors are placed in several locations but generally are in the scavenge lines for each scavenge pump, oil tank, and in the oil sumps. Some engines have several detectors to one detector. During maintenance, the chip detectors are removed from the engine and inspected for metal; if none is found, the detector is cleaned, replaced, and safety wired. If metal is found on a chip detector, an investigation should be made to find the source of the metal on the chip.

Typical Dry-Sump Pressure Regulated Turbine Lubrication System

The turbine lubrication system is representative of turbine engines using a dry-sump system. *[Figure 6-45]* The lubrication system is a pressure regulated, high-pressure design. It consists of the pressure, scavenge, and breather subsystems.

The pressure system supplies oil to the main engine bearings and to the accessory drives. The scavenger system returns the oil to the engine oil tank that is usually mounted on the compressor case. It is connected to the inlet side of the pressure oil pump and completes the oil flow cycle. A breather system connecting the individual bearing compartments and the oil tank with the breather pressurizing valve completes the engine lubrication system. In a turbine pressure relief dry-sump lubrication system, the oil supply is carried in a tank mounted on the engine. With this type of system, a larger oil supply can be carried, and the temperature of the oil can be readily controlled.

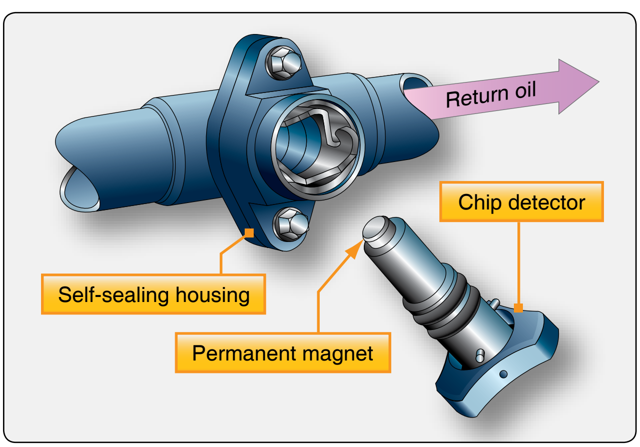

Figure 6-44. *Chip detector.*

Pressure System

The oil pressure branch of the engine lubrication system is pressurized by a gear-type pressure pump located in the oil pump and accessory drive housing. *[Figure 6-45]* The pressure pump receives engine oil at its lower (inlet) side and discharges pressurized oil to an oil filter located on the housing. From the oil filter, which is equipped with a bypass valve for operation in case the filter clogs, the pressurized oil is transmitted to a cored passage running through to the pressure regulating (relief) valve that maintains system pressure. The pressure regulating (relief) valve is located downstream of the pump. It is adjusted to maintain a proper pressure to the oil metering jets in the engine. The pressure regulating (relief) valve is usually easily accessible for adjustment. Then, the oil flows through the fuel-oil cooler and on to the bearing cavities through last-chance filters and out spray nozzles to the bearings. Pressurized oil distributed to the engine main bearings is sprayed on the bearings through fixed orifice nozzles providing a relatively constant oil flow at all engine operating speeds.

Scavenge System

The scavenge system scavenges the main bearing compartments and circulates the scavenged oil back to the tank. The scavenge oil system includes five gear-type pumps. *[Figure 6-45]* The No.1 bearing oil scavenge pump scavenges accumulated oil from the front bearing case. It directs the oil through an external line to a central collecting point in the main accessory gearbox. The oil return from No. 2 and 3 bearings is through internal passages to a central collecting point in the main accessory case. The accessory gearbox oil suction pump, located in the main accessory gearbox, scavenges oil from the gearbox housing to the oil tank. Oil from the No. 4, No. 4½ and No. 5 bearing accumulates in the bearing cavity and is scavenged to the accessory gearbox.

The turbine rear bearing oil suction pump scavenges oil from the No. 6 bearing compartment and directs the scavenged oil through a passage in the turbine case strut. From there, it is directed to the bearing cavity for the 4, 4½, and 5 bearing cavities where it joins the oil and is returned to the oil tank. The scavenge oil passes through the deaerator as it enters the

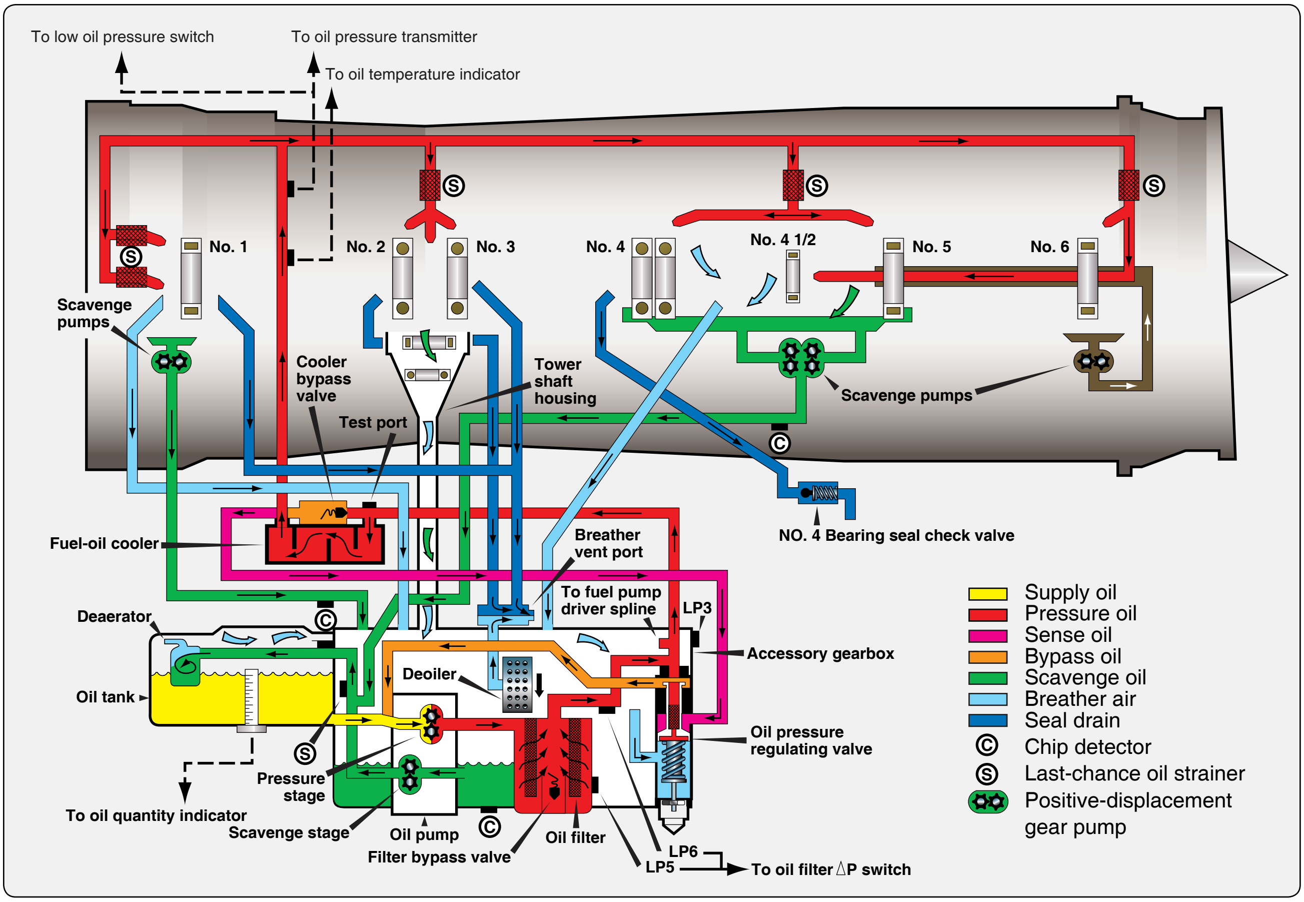

Figure 6-45. *Typical turbine dry-sump pressure regulated lubrication system.*

oil tank, which separates the air mixed in the return oil. The oil stays in the tank while the air flows into the accessory gearbox and enters the deoiler.

Breather Pressurizing System

The breather pressurizing system ensures a proper oil spray pattern from the main bearing oil jets and furnishes a pressure head to the scavenge system. Breather tubes in the compressor inlet case, the oil tank, the diffuser case, and the turbine exhaust case are connected to external tubing at the top of the engine. By means of this tubing, the vapor-laden atmospheres of the various bearing compartments and the oil tank are brought together in the deoiler in the accessory gearbox. The deoiler separates out the oil from the air-oil mist and vents the air back to the atmosphere.

Typical Dry-Sump Variable Pressure Lubrication System

The dry-sump variable-pressure lubrication system uses the same basic subsystems that the regulated systems use (pressure Scavenge breather). *[Figure 6-46]* The main difference is that the pressure in this system is not regulated by a regulating bypass valve. Most large turbofan engine pressure systems are variable-pressure systems in which the pump outlet pressure (oil pressure) depends on the engine rpm. In other words, the pump output pressure is proportional to the engine speed. Since the resistance to flow in the system does not vary much during operation and the pump has only the variable of turning faster or slower, the pressure is a function of engine speed. As an example, oil pressure can vary widely in this type of system, from 100 psi to over 260 psi, with the relief valve opening at about 540 psi.

Pressure Subsystem

The oil flows from the oil tank down to the pressure stage of the oil pump. A slight pressure in the tank assures that the flow of oil into the pressure pump is continuous. After being pressurized, it moves on to the oil filter where it is filtered. If the filter is clogged, the bypass valve sends the oil around the filter. There is no regulating valve but there is a relief valve to prevent the system pressure from exceeding the maximum limits. This valve is usually set to open well above the system's operating pressure. The oil flows from the filter housing to the engine air-oil cooler. The oil either bypasses the cooler (cold) or passes through the cooler (hot) and then on to the fuel-oil cooler. Through the use of the coolers, the fuel temperature is adjusted to meet the requirements needed for the engine. Some of the oil passes through the classified

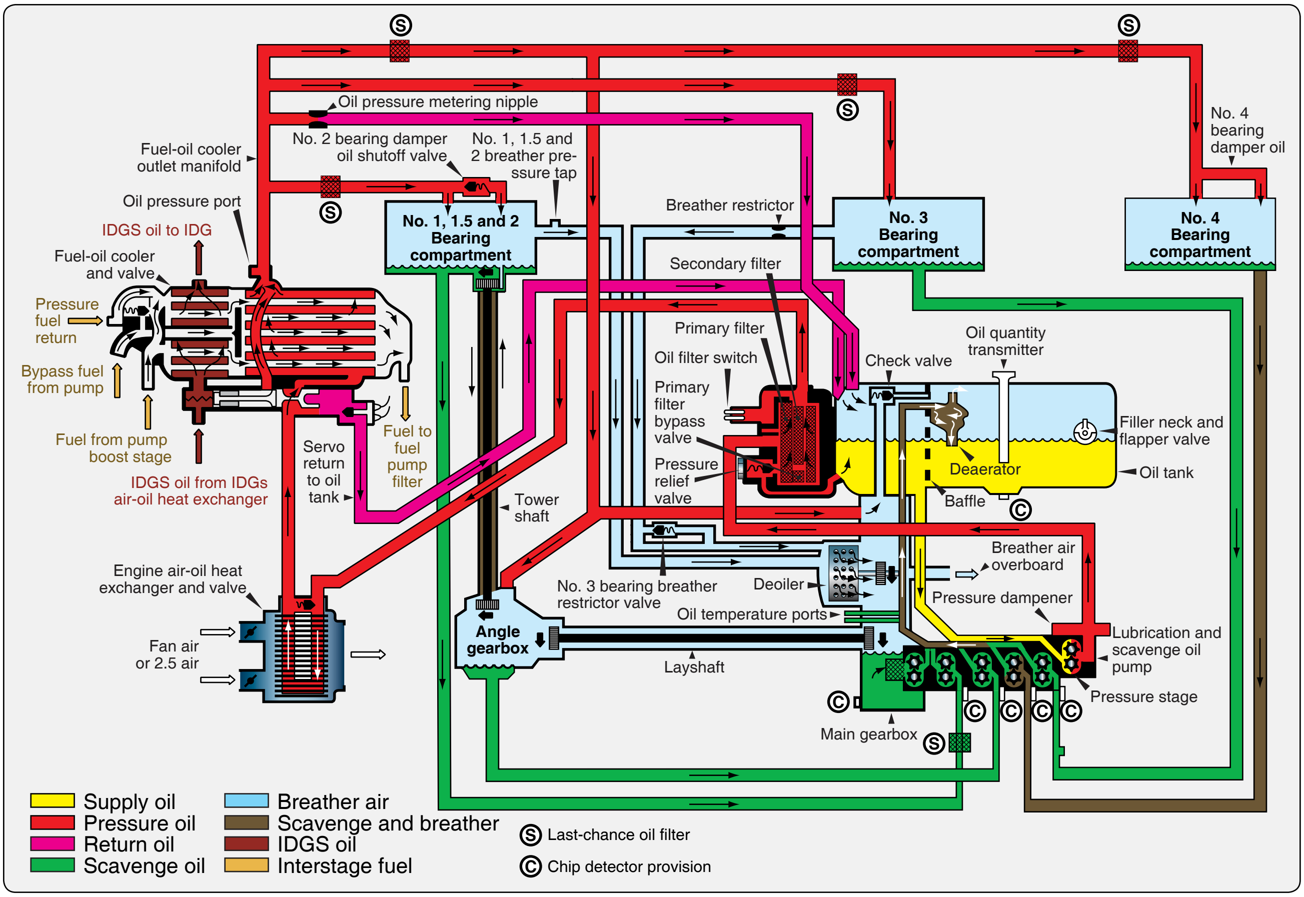

Figure 6-46. *Typical turbine dry-sump variable pressure lubrication system.*

oil pressure trim orifice that helps adjust oil pressure at low speeds. The oil now flows through the last-chance oil filters (strainers) that remove particles from the oil if the oil filter has been bypassed. The engine oil passes through the nozzles to lubricate the bearings, gearboxes, seals, and accessory drive splines. After performing its functions of lubricating, cleaning, and cooling the bearings, the oil needs to be returned to the old tank by the scavenge system.

Scavenger Subsystem

The scavenger oil pump has several stages that pull oil from the bearing compartments and gearboxes and sends the oil to the tank. At the tank, the oil enters the deaerator, which separates the air from the scavenge oil. The oil returns to the tank and the air is vented through a check valve overboard. Each stage of the scavenge pump has a magnetic chip detector that can be removed for inspection.

Breather Subsystem

The purpose of the breather system is to remove air from the bearing compartments, separate breather air from oil, and vent the air overboard. The breather air from the bearing compartments is drawn to the gearbox by the deoiler. The deoiler is turned at high speed and causes the oil to separate from the air. The air is then vented with air from the deaerator overboard. By referring to *Figure 6-46*, notice that the deaerator is in the oil tank and the deoiler is in the main gearbox.

Turbine Engine Wet-Sump Lubrication System

In some engines, the lubrication system is the wet-sump type. There are relatively few engines using a wet-sump type of oil system. The components of a wet-sump system are similar to those of a dry-sump system. The major difference between the two systems is the location of the oil reservoir. The reservoir for the wet-sump oil system may be the accessory gear case or it may be a sump mounted on the bottom of the accessory case. Regardless of configuration, reservoirs for wet-sump systems are an integral part of the engine and contain the bulk of the engine oil supply. *[Figure 6-47]*

Included in the wet-sump reservoir are the following components:

1. A sight gauge indicates the oil level in the sump.
2. A vent or breather equalizes pressure within the accessory casing.

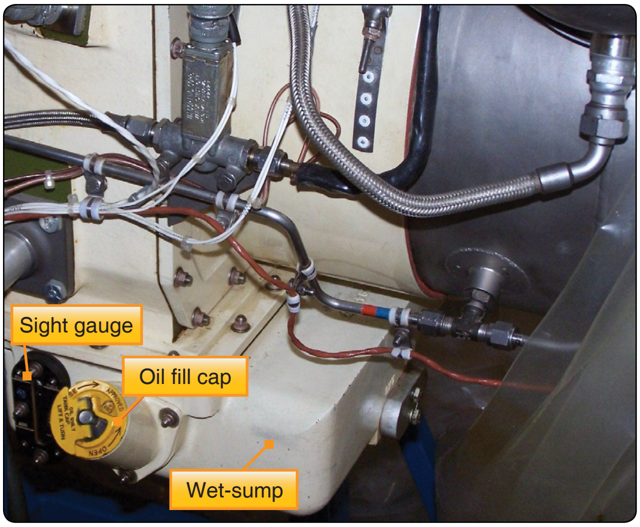

Figure 6-47. *Typical turbine wet-sump system.*

3. A magnetic drain plug may be provided to drain the oil and also to trap any ferrous metal particles in the oil. This plug should always be examined closely during inspections. The presence of metal particles may indicate gear or bearing failure.
4. Provision may also be made for a temperature bulb and an oil pressure fitting.

This system is typical of all engines using a wet-sump lubrication system. The bearing and drive gears in the accessory drive casing are lubricated by a splash system. The oil for the remaining points of lubrication leaves the pump under pressure and passes through a filter to jet nozzles that direct the oil into the rotor bearings and couplings. The oil is returned to the reservoir (sump) by gravity. Oil from the compressor bearing and the accessories drive coupling shaft drains directly into the reservoir. Turbine oil drains into a sump where the oil was originally pumped.

Turbine Engine Oil System Maintenance

Maintenance of gas turbine lubrication systems consists mainly of adjusting, removing, cleaning, and replacing various components. Oil filter maintenance and oil change intervals for turbine engines vary widely from model to model, depending on the severity of the oil temperature conditions imposed by the specific airframe installation and engine configuration. The applicable manufacturer's instructions should be followed. The oil filter should be removed at every regular inspection. It should be disassembled, cleaned, and any worn or damaged filter elements replaced. The following steps illustrate typical oil filter removal cleaning and replacement procedures:

1. Provide a suitable container for collecting the drained oil, if needed.

Figure 6-48. *Oil filter housing.*

2. Remove the filter housing and withdraw the filter assembly. *[Figure 6-48]* Discard the old seals.
3. Immerse the screen or filter in an approved carbon remover at room temperature for a few minutes. Rinse them in a degreaser fluid or cleaning solvent. Then, blow them dry with an air jet.
4. Then, install the filter in the filter housing assembly. Place a new seal and tighten it to the torque prescribed in the manufacturer's instructions.
5. Secure with lock wire.

To adjust the oil pressure, first remove the adjusting screw acorn cap on the oil pressure relief valve. Then, loosen the locknut and turn the adjusting screw clockwise to increase, or counterclockwise to decrease, the oil pressure. In a typical turbojet lubrication system, the adjusting screw is adjusted to provide an oil pressure of 45, ±5 psi, at approximately 75 percent of normal rated thrust. The adjustment should be made while the engine is idling; it may be necessary to perform several adjustments before the desired pressure is obtained. When the proper pressure setting is achieved, tighten the adjusting screw locknut, and install the acorn cap with a new gasket, then tighten and secure with lock wire.

Checking or servicing aircraft engine oil is an important maintenance function. Before servicing any aircraft engine, consult the specific aircraft maintenance manual to determine the proper type of servicing equipment and procedures. In general, aircraft engine oil is checked with a dipstick or a sight gauge. There are markings on the stick or around the sight gauge to determine the correct level. Turbine engines must be checked just after shutdown.

Maintenance of scavenge and breather systems at regular inspections includes checks for oil leaks and security of mounting of system components. Also, check chip detectors for particles of ferrous material and clean last-chance filters; install and safety.

Engine Cooling Systems

Excessive heat is always undesirable in both reciprocating and turbine aircraft engines. If means were not available for its control or elimination, major damage or complete engine failure would occur. Although the vast majority of reciprocating engines are air cooled, some diesel liquid-cooled engines are being made available for light aircraft. *[Figure 6-49]* In a liquid-cooled engine, around the cylinder are water jackets, in which liquid coolant is circulated and the coolant takes away the excess heat. The excess heat is then dissipated by a heat exchanger or radiator using air flow. Turbine engines use secondary airflow to cool the inside components and many of the exterior components.

Reciprocating Engine Cooling Systems

An internal-combustion engine is a heat machine that converts chemical energy in the fuel into mechanical energy at the crankshaft. It does not do this without some loss of energy, however, and even the most efficient aircraft engines may waste 60 to 70 percent of the original energy in the fuel. Unless most of this waste heat is rapidly removed, the cylinders may become hot enough to cause complete engine failure. Excessive heat is undesirable in any internal-combustion engine for three principal reasons:

1. It affects the behavior of the combustion of the air-fuel charge.
2. It weakens and shortens the life of engine parts.
3. It impairs lubrication.

If the temperature inside the engine cylinder is too great, the air-fuel mixture is preheated, and combustion occurs before the desired time. Since premature combustion causes detonation, knocking, and other undesirable conditions, there must be a way to eliminate heat before it causes damage.

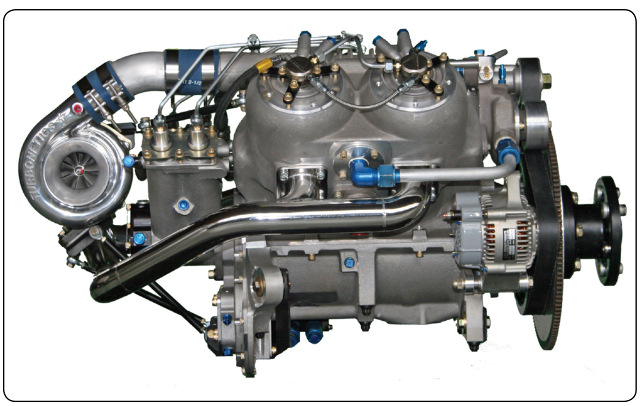

Figure 6-49. *Diesel liquid-cooled aircraft engine.*

One gallon of aviation gasoline has enough heat value to boil 75 gallons of water; thus, it is easy to see that an engine that burns 4 gallons of fuel per minute releases a tremendous amount of heat. About one-fourth of the heat released is changed into useful power. The remainder of the heat must be dissipated so that it is not destructive to the engine. In a typical aircraft powerplant, half of the heat goes out with the exhaust and the other is absorbed by the engine. Circulating oil picks up part of this soaked-in heat and transfers it to the airstream through the oil cooler. The engine cooling system takes care of the rest. Cooling is a matter of transferring the excess heat from the cylinders to the air, but there is more to such a job than just placing the cylinders in the airstream. A cylinder on a large engine is roughly the size of a gallon jug. Its outer surface, however, is increased by the use of cooling fins so that it presents a barrel-sized exterior to the cooling air. Such an arrangement increases the heat transfer by convection. If too much of the cooling fin area is broken off, the cylinder cannot cool properly, and a hotspot develops. Therefore, cylinders are normally replaced if a specified number of square inches of fins are missing.

Cowling and baffles are designed to force air over the cylinder cooling fins. *[Figure 6-50]* The baffles direct the air close around the cylinders and prevent it from forming hot pools of stagnant air while the main streams rush by unused. Blast tubes are built into the baffles to direct jets of cooling air onto the rear spark plug elbows of each cylinder to prevent overheating of ignition leads. Blast tubes also provide cooling to engine accessories such as alternators, generators, and starters.

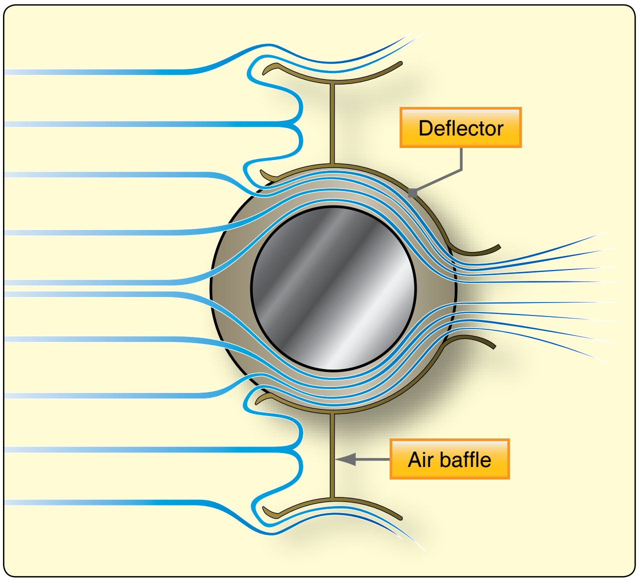

Figure 6-50. *Cylinder baffle and deflector system.*

An engine can have an operating temperature that is too low. For the same reasons that an engine is warmed up before takeoff, it is kept warm during flight. Fuel evaporation and distribution and oil circulation depend on an engine being kept at its optimum operating temperature. The aircraft engine has temperature controls that regulate air circulation over the engine. Unless some controls are provided, the engine could overheat on takeoff and get too cold in high altitude, high-speed and low-power letdowns.

The most common means of controlling cooling is the use of cowl flaps. *[Figure 6-51]* These flaps are opened and closed by electric motor-driven jackscrews, by hydraulic actuators, or manually in some light aircraft. When extended for increased cooling, the cowl flaps produce drag and sacrifice streamlining for the added cooling. On takeoff, the cowl flaps are opened only enough to keep the engine below the red-line temperature. Heating above the normal range is allowed so that drag is as low as possible. During ground operations, the cowl flaps should be opened wide since drag does not matter and cooling needs to be set at maximum. Cowl flaps are used mostly with older aircraft and radial engine installations.

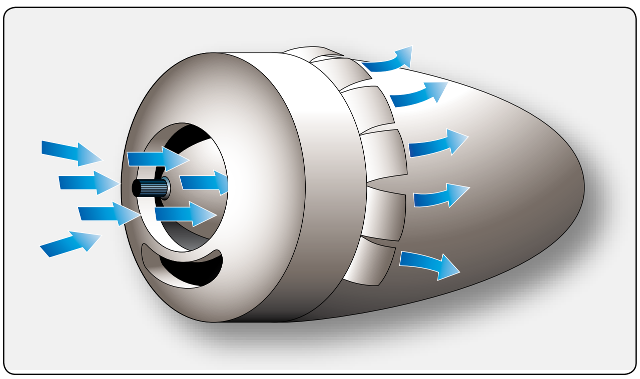

Figure 6-51. *Regulating the cooling airflow.*

Some aircraft use augmentors to provide additional cooling airflow. *[Figure 6-52]* Each nacelle has two pairs of tubes running from the engine compartment to the rear of the nacelle. The exhaust collectors feed exhaust gas into the inner augmentor tubes. The exhaust gas mixes with air that has passed over the engine and heats it to form a high-temperature, low-pressure, jet-like exhaust. This low-pressure area in the augmentors draws additional cooling air over the engine. Air entering the outer shells of the augmentors is heated through contact with the augmentor tubes but is not contaminated with exhaust gases. The heated air from the shell goes to the cabin heating, defrosting, and anti-icing system.

Augmentors use exhaust gas velocity to cause airflow over the engine so that cooling is not entirely dependent on the prop wash. Vanes installed in the augmentors control the volume of air. These vanes are usually left in the trail position to permit maximum flow. They can be closed to increase the heat for cabin or anti-icing use or to prevent the engine from cooling too much during descent from altitude. In addition to augmentors, some aircraft have residual heat doors or nacelle flaps that are used mainly to let the retained heat escape after engine shutdown. The nacelle flaps can be opened for more cooling than that provided by the augmentors. A modified form of the previously described augmentor cooling system is used on some light aircraft. *[Figure 6-53]* Augmentor systems are not used much on modern aircraft.

As shown in *Figure 6-53*, the engine is pressure cooled by air taken in through two openings in the nose cowling, one on each side of the propeller spinner. A pressure chamber is sealed off on the top side of the engine with baffles properly directing the flow of cooling air to all parts of the engine compartment. Warm air is drawn from the lower part of the engine compartment by the pumping action of the exhaust

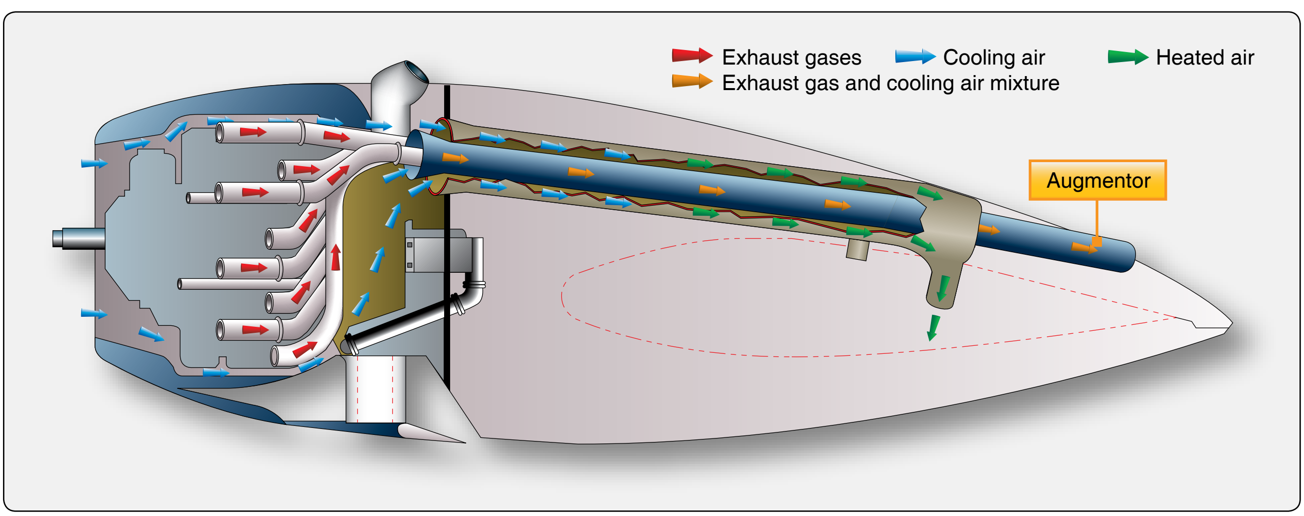

Figure 6-52. *Augmentor.*

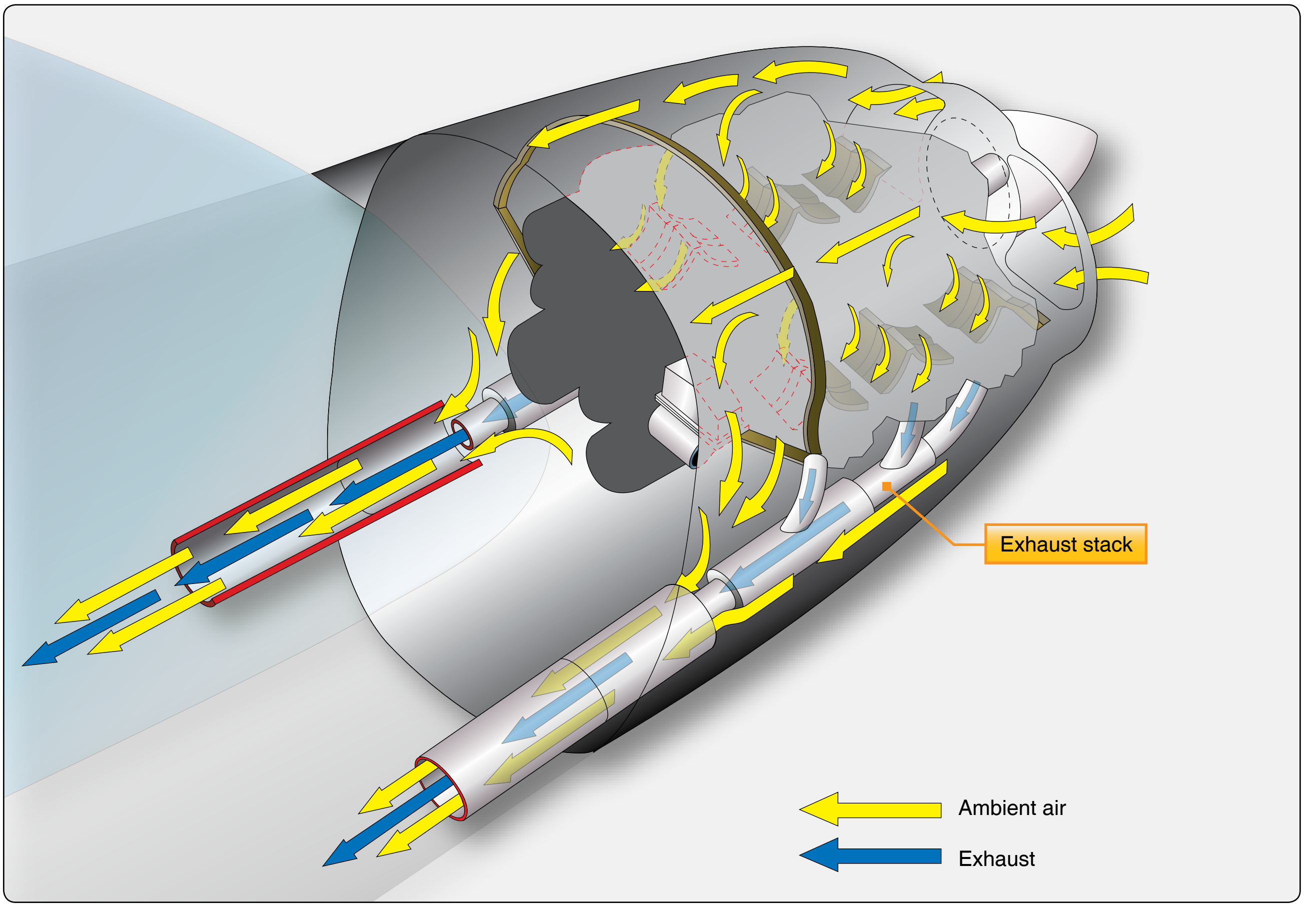

Figure 6-53. *Engine cooling and exhaust system.*

gases through the exhaust ejectors. This type of cooling system eliminates the use of controllable cowl flaps and assures adequate engine cooling at all operating speeds.

Reciprocating Engine Cooling System Maintenance

The engine cooling system of most reciprocating engines usually consists of the engine cowling, cylinder baffles, cylinder fins, and some use a type of cowl flaps. In addition to these major units, there are also some temperature-indicating systems, such as cylinder head temperature, oil temperature, and exhaust gas temperature.

The cowling performs two functions:

1. It streamlines the bulky engine to reduce drag.
2. It forms an envelope around the engine that forces air to pass around and between the cylinders, absorbing the heat dissipated by the cylinder fins.

The cylinder bases are metal shields, designed and arranged to direct the flow of air evenly around all cylinders. This even distribution of air aids in preventing one or more cylinders from being excessively hotter than the others. The cylinder fins radiate heat from the cylinder walls and heads. As the air passes over the fins, it absorbs this heat, carries it away from the cylinder, and is exhausted overboard through the bottom rear of the cowl.

The controllable cowl flaps provide a means of decreasing or increasing the exit area at the rear of the engine cowling. *[Figure 6-54]* Closing the cowl flaps decreases the exit area, which effectively decreases the amount of air that can circulate over the cylinder fins. The decreased airflow cannot carry away as much heat; therefore, it has a tendency for the engine temperature to increase. Opening the cowl flaps makes the exit area larger. The flow of cooling air over the cylinders increases, absorbing more heat and the engine temperature tends to decrease. Good inspection and maintenance in the care of the engine cooling system aids in overall efficient and economical engine operation.

Maintenance of Engine Cowling

Of the total ram airflow approaching the airborne engine nacelle, only about 15 to 30 percent enters the cowling to provide engine cooling. The remaining air flows over the outside of the cowling. Therefore, the external shape of the cowl must be faired in a manner that permits the air to flow smoothly over the cowl with a minimum loss of energy.

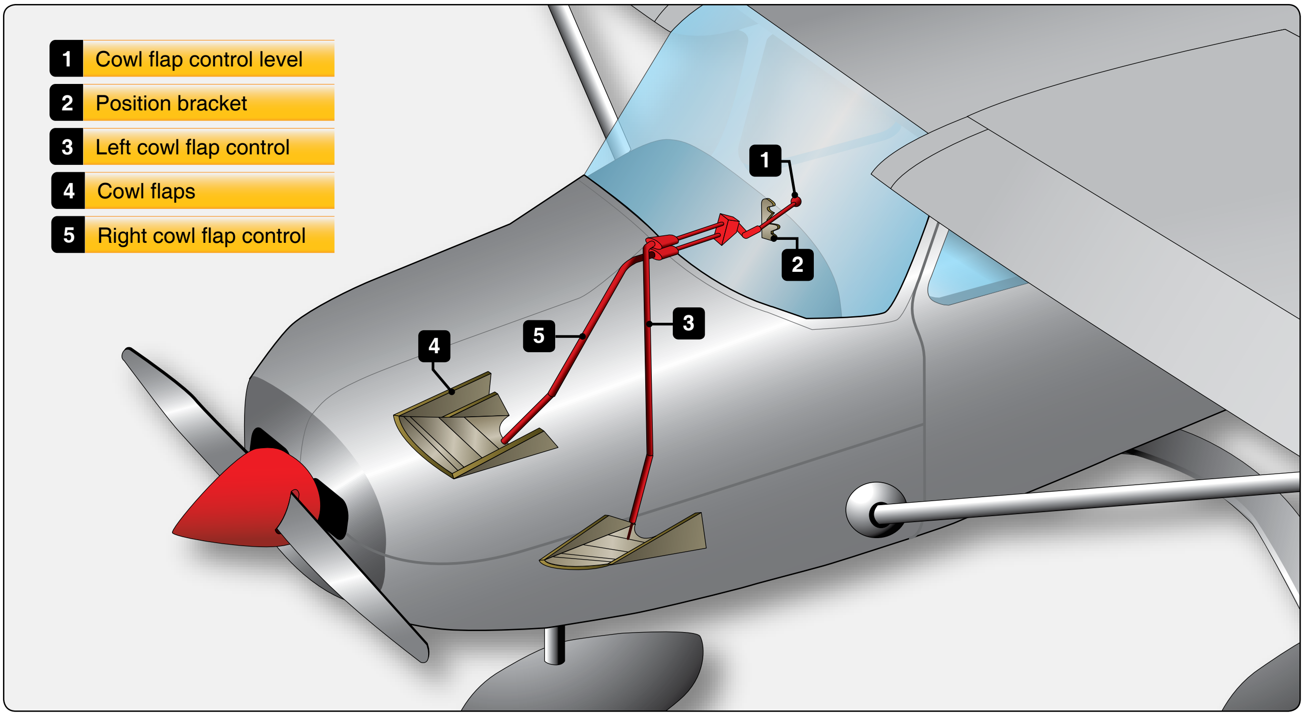

Figure 6-54. *Small aircraft cowl flaps.*

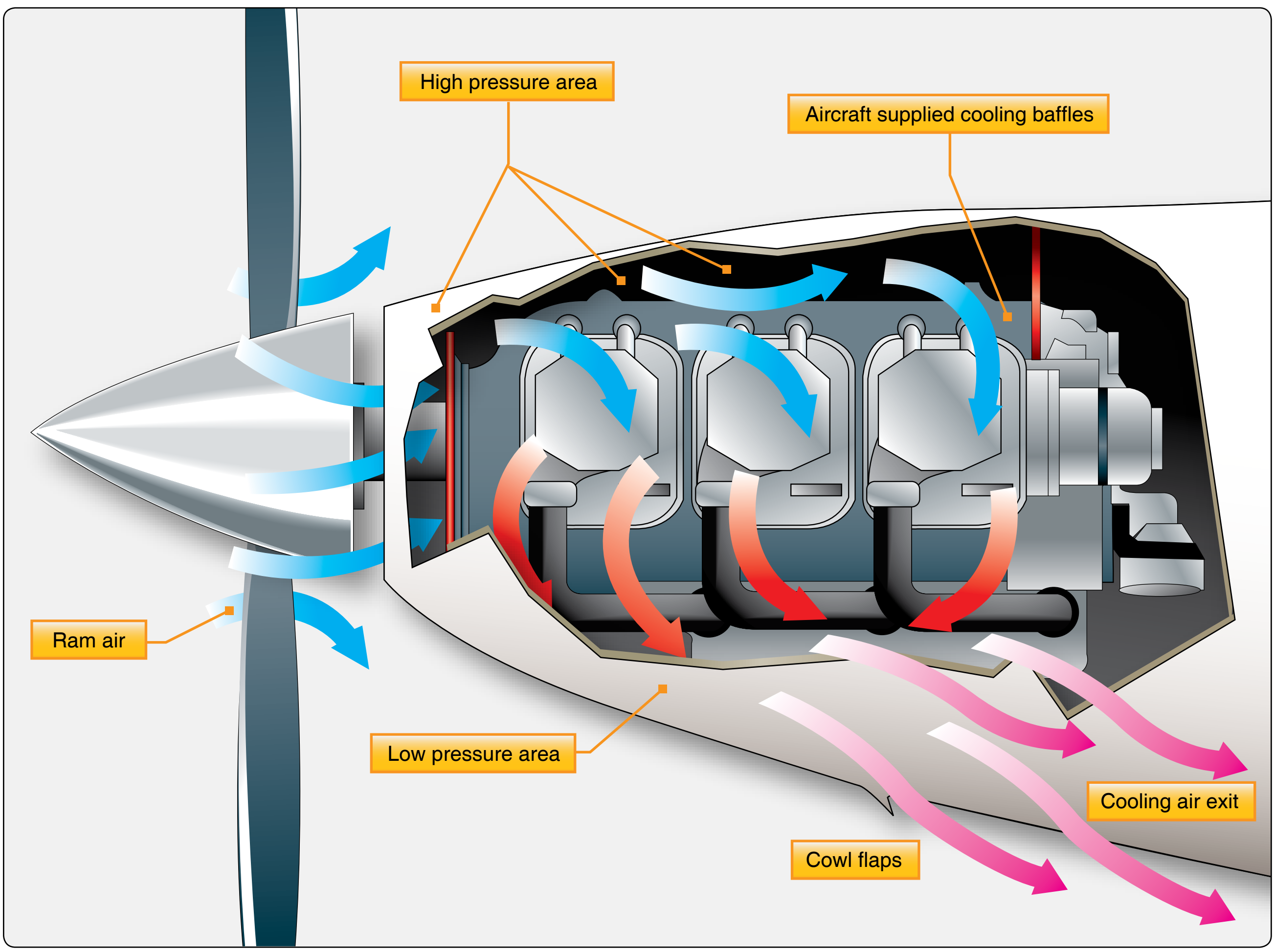

Figure 6-55. *Differential air cooling.*

The engine cowling discussed in this section is typical of that used on many radial or horizontally opposed engines. All cooling systems function in the same manner, with minor engineering changes designed for specific installations.

The cowl is manufactured in removable sections, the number varies with the aircraft make and model. The installation shown in *Figure 6-55* contains two sections that are locked together when installed.

The cowl panels, made from sheet aluminum or composite material, have a smooth external surface to permit undisturbed airflow over the cowl. The internal construction is designed to give strength to the panel and, in addition, to provide receptacles for the toggle latches, cowl support, and engine air seal.

An air seal is constructed of rubber material, bolted to a metal rib riveted to the cowl panel. *[Figure 6-55]* This seal, as the name implies, seals the air in the engine section, preventing the air from escaping along the inner surface of the panel without circulating around the cylinders. The engine air seal must be used on engines that have a complete cylinder baffling system that covers the cylinder heads. Its purpose is to force the air to circulate around and through the baffle system. Inspect the cowl panels during each regular engine and aircraft inspection. Removing the cowling for maintenance provides an opportunity for a more detailed inspection of the cowling.

Inspect the cowling panels for scratches, dents, and tears in the panels. This type of damage causes weakness of the panel structure, increases drag by disrupting airflow, and contributes to the starting of corrosion. The cowling panel latches should be inspected for pulled rivets and loose or damaged handles. The internal construction of the panel should be examined to see that the reinforcing ribs are not cracked and that the air seal is not damaged. The cowl flap hinges, if equipped, and cowl flap hinge bondings should be checked for security of mounting and for breaks or cracks. These inspections are visual checks and should be performed frequently to ensure that the cowling is serviceable and is contributing to efficient engine cooling.

Engine Cylinder Cooling Fin Inspection

The cooling fins are of the utmost importance to the cooling system, since they provide a means of transferring the cylinder heat to the air. Their condition can mean the difference between adequate or inadequate cylinder cooling. The fins are inspected at each regular inspection. Fin area is the total area (both sides of the fin) exposed to the air. During the inspection, the fins should be examined for cracks and breaks. *[Figure 6-56]* Small cracks are not a reason for cylinder removal. These cracks can be filled or even sometimes stop-drilled to prevent any further cracking. Rough or sharp corners on fins can be smoothed out by filing, and this action eliminates a possible source of new cracks. However, before reprofiling cylinder cooling fins, consult the manufacturer's service or overhaul manual for the allowable limits.

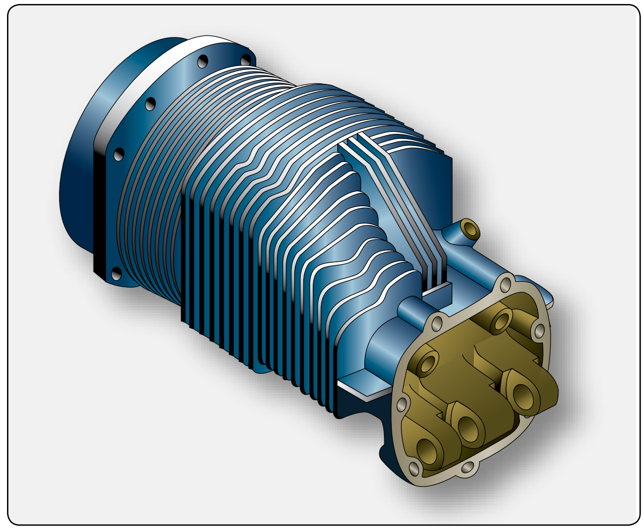

Figure 6-56. *A cylinder head and fins.*

The definition of fin area becomes important in the examination of fins for broken areas. It is a determining factor for cylinder acceptance or removal. For example, on a certain engine, if more than 12 inches in length of any one fin, as measured at its base, is completely broken off, or if the total fins broken on any one cylinder head exceed 83 square inches of area, the cylinder is removed and replaced. The reason for removal in this case is that an area of that size would cause a hot spot on the cylinder; since very little heat transfer could occur.

Where adjacent fins are broken in the same area, the total length of breakage permissible is six inches on any two adjacent fins, four inches on any three adjacent fins, two inches on any four adjacent fins, and one inch on any five adjacent fins. If the breakage length in adjacent fins exceeds this prescribed amount, the cylinder should be removed and replaced. These breakage specifications are applicable only to the engine used in this discussion as a typical example. In each specific case, applicable manufacturer's instructions should be consulted.

Cylinder Baffle & Deflector System Inspection

Reciprocating engines use some type of intercylinder and cylinder head baffles to force the cooling air into close contact with all parts of the cylinders. *Figure 6-50* shows a baffle and deflector system around a cylinder. The air baffle

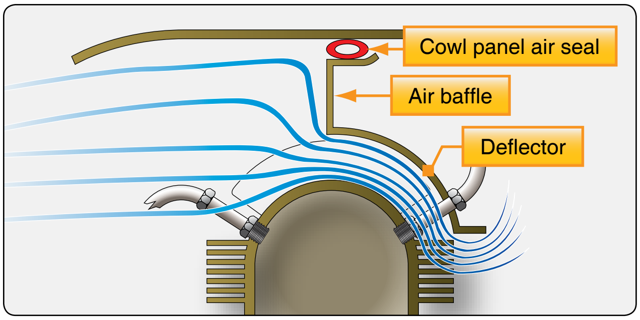

Figure 6-57. *Cylinder head baffle and deflector system.*

blocks the flow of air and forces it to circulate between the cylinder and the deflectors. *Figure 6-57* illustrates a baffle and deflector arrangement designed to cool the cylinder head. The air baffle prevents the air from passing away from the cylinder head and forces it to go between the head and deflector. Although the resistance offered by baffles to the passage of the cooling air demands that an appreciable pressure differential be maintained across the engine to obtain the necessary airflow, the volume of cooling air required is greatly reduced by employing properly designed and located cylinder deflectors.

As shown in *Figure 6-55*, the airflow approaches the nacelle and piles up at the top of the engine, creating a high pressure in the top of the cylinders. This piling up of the air reduces the air velocity. The outlet at the bottom rear of the cowling produces a low-pressure area. As the air nears the cowl exit, it is speeded up again and merges smoothly with the airstream. The pressure differential between the top and the bottom of the engine forces the air past the cylinders through the passages formed by the deflectors. The baffles and deflectors normally are inspected during the regular engine inspection, but they should be checked whenever the cowling is removed for any purpose. Checks should be made for cracks, dents, or loose hold down studs. Cracks or dents, if severe enough, would necessitate repair or removal and replacement of these units. However, a crack that has just started can be stop-drilled, and dents can be straightened, permitting further service from these baffles and deflectors.

Cylinder Temperature Indicating Systems

This system usually consists of an indicator, electrical wiring, and a thermocouple. The wiring is between the instrument and the nacelle firewall. At the firewall, one end of the thermocouple leads connects to the electrical wiring, and the other end of the thermocouple leads connects to the cylinder. The thermocouple consists of two dissimilar metals, generally constantan and iron, connected by wiring to an indicating system. If the temperature of the junction is different from the temperature where the dissimilar metals are connected to wires, a voltage is produced. This voltage sends a current through wires to the indicator, a current-measuring instrument

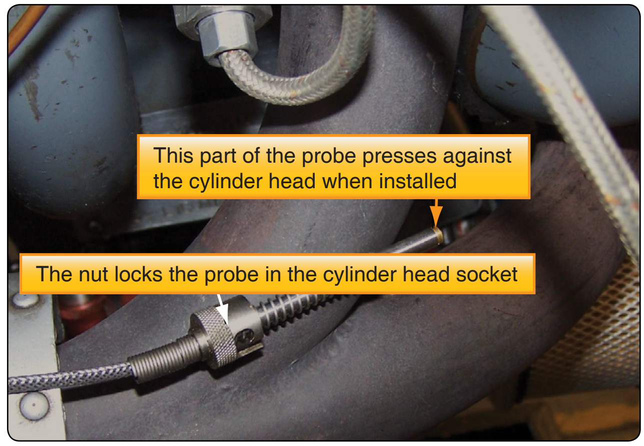

Figure 6-58. *Bayonet type CHT probe.*

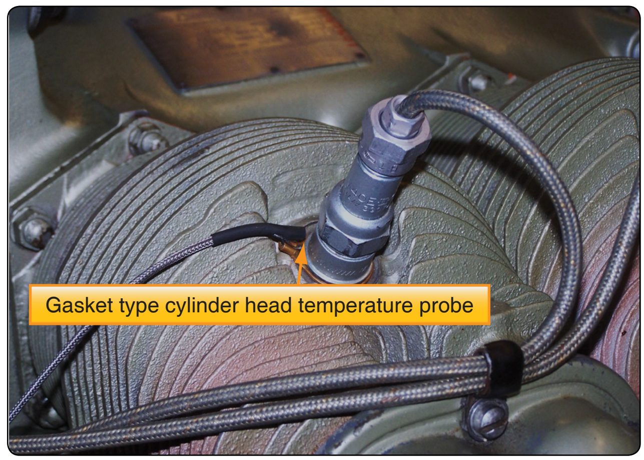

Figure 6-59. *Gasket type CHT probe.*

graduated in degrees.

The thermocouple end that connects to the cylinder is either the bayonet or gasket type. To install the bayonet type, the knurled nut is pushed down and turned clockwise until it is snug. *[Figure 6-58]* In removing this type, the nut is pushed down and turned counterclockwise until released. The gasket type fits under the spark plug and replaces the normal spark plug gasket. *[Figure 6-59]* When installing a thermocouple lead, remember not to cut off the lead because it is too long, but coil and tie up the excess length. The thermocouple is designed to produce a given amount of resistance. If the length of the lead is reduced, an incorrect temperature reading results. The bayonet or gasket of the thermocouple is inserted or installed on the hottest cylinder of the engine, as determined in the block test. When the thermocouple is installed and the wiring connected to the instrument, the indicated reading is the cylinder temperature. Prior to operating the engine, provided it is at ambient temperature, the cylinder head temperature indicator indicates the free outside air temperature; that is one test for determining that the instrument is working correctly. The cover glass of the cylinder head temperature indicator should be checked regularly to see that it has not slipped or cracked. The cover glass should be checked for indications of missing or damaged decals that indicate temperature limitations. If the thermocouple leads were excessive in length and had to be coiled and tied down, the tie should be inspected for security or chafing of the wire. The bayonet or gasket should be inspected for cleanness and security of mounting. When operating the engine, all of the electrical connections should be checked if the cylinder head temperature pointer fluctuates.

Exhaust Gas Temperature Indicating Systems

The exhaust gas temperature indicator consists of a thermocouple placed in the exhaust stream just after the cylinder port. *[Figure 6-60]* It is then connected to the instrument in the instrument panel. This allows for the adjustment of the mixture, which has a large effect on engine temperature. By using this instrument to set the mixture, the engine temperature can be controlled and monitored.

Turbine Engine Cooling

The intense heat generated when fuel and air are burned necessitates that some means of cooling be provided for all internal combustion engines. Reciprocating engines are cooled either by passing air over fins attached to the cylinders or by passing a liquid coolant through jackets that surround the cylinders. The cooling problem is made easier because combustion occurs only during every fourth stroke of a four-stroke-cycle engine.

The burning process in a gas turbine engine is continuous, and nearly all of the cooling air must be passed through the inside of the engine. If only enough air were admitted to the engine to provide an ideal air-fuel ratio of 15:1, internal temperatures would increase to more than 4,000 °F. In practice, a large amount of air in excess of the ideal ratio is admitted to the engine. The large surplus of air cools the hot sections of the engine to acceptable temperatures ranging from 1,500° to 2,100 °F. Because of the effect of cooling, the temperatures of the outside of the case are considerably less than those encountered within the engine. The hottest area occurs in and around the turbines. Although the gases have begun to cool a little at this point, the conductivity of the metal in the case carries the heat directly to the outside skin.

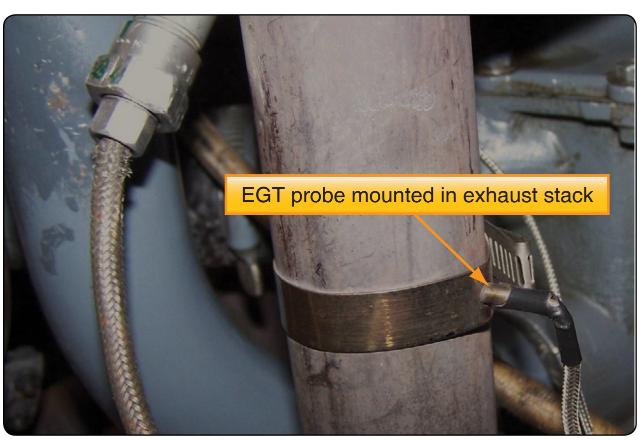

Figure 6-60. *EGT probe in exhaust stack.*

The secondary air passing through the engine cools the combustion-chamber liners. The liners are constructed to induce a thin, fast-moving film of air over both the inner and outer surfaces of the liner. Can-annular-type burners frequently are provided with a center tube to lead cooling air into the center of the burner to promote high combustion-efficiency and rapid dilution of the hot combustion gases while minimizing pressure losses. In all types of gas turbines, large amounts of relatively cool air join and mix with the burned gases aft of the burners to cool the hot gases just before they enter the turbines.

Cooling-air inlets are frequently provided around the exterior of the engine to permit the entrance of air to cool the turbine case, the bearings, and the turbine nozzle. Internal air is bled from the engine compressor section and is vented to the bearings and other parts of the engine. Air vented into or from the engine is ejected into the exhaust stream. When located on the side of the engine, the case is cooled by outside air flowing around it. The engine exterior and the engine nacelle are cooled by passing fan air around the engine and the nacelle. The engine compartment frequently is divided into two sections. The forward section is referred to as the cold section and the aft section (turbine) is referred to as the hot section. Case drains drain potential leaks overboard to prevent fluids from building up in the nacelle.

Accessory Zone Cooling

Turbine powerplants can be divided into primary zones that are isolated from each other by fireproof bulkheads and seals. The zones are the fan case compartment, intermediate compressor case compartment, and the core engine compartment. *[Figure 6-61]* Calibrated airflows are supplied to the zones to keep the temperatures around the engine at levels that are acceptable. The airflow provides for proper ventilation to prevent a buildup of any harmful vapors. Zone 1, for example, is around the fan case that contains the accessory case and the electronic engine control (EEC). This area is vented by using ram air through an inlet in the nose cowl and is exhausted through a louvered vent in the right fan cowling.

If the pressure exceeds a certain limit, a pressure relief door opens and relieves the pressure. Zone 2 is cooled by fan air from the upper part of the fan duct and is exhausted at the lower end back into the fan air stream. This area has both

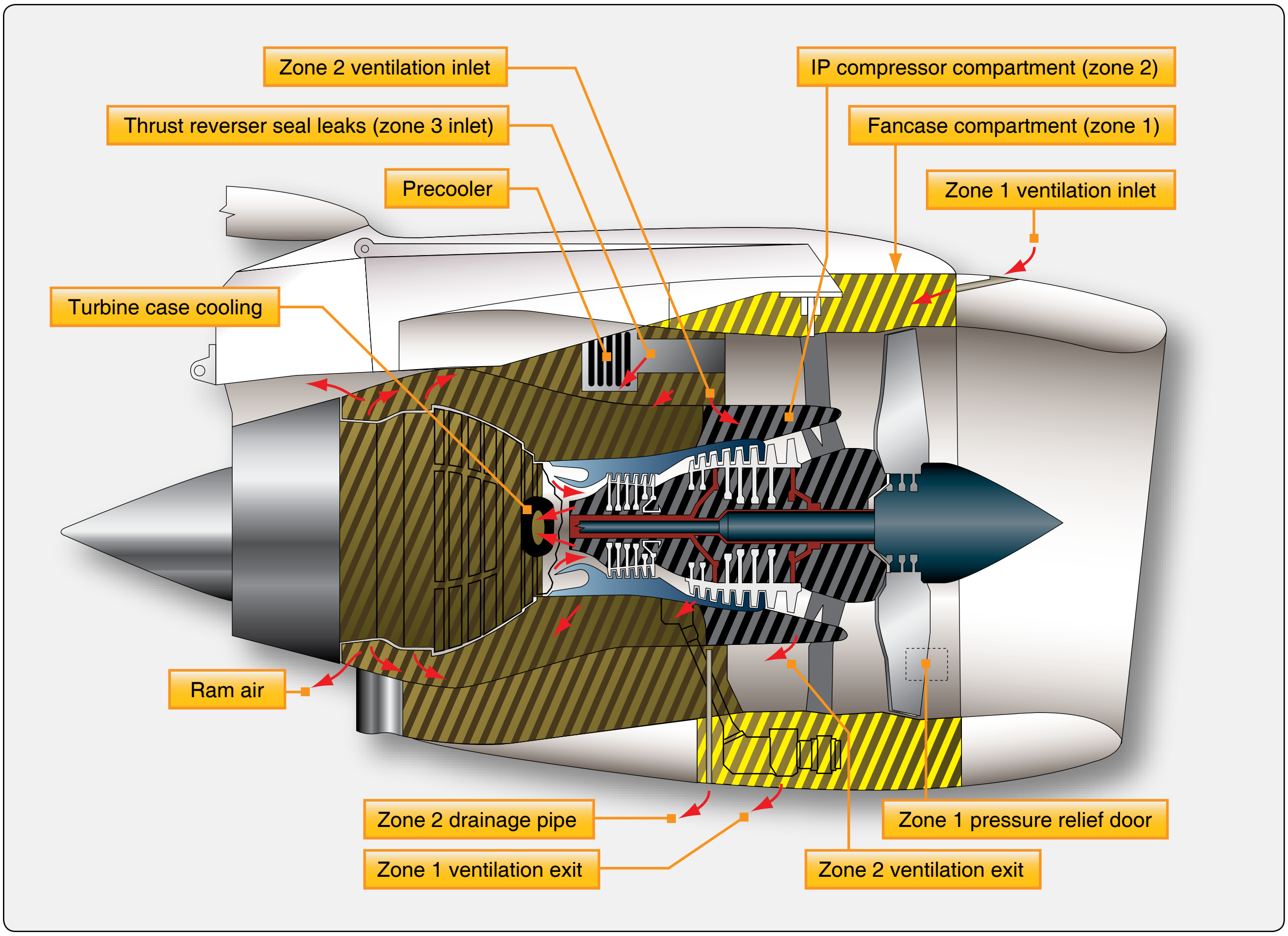

Figure 6-61. *Accessory zone cooling.*

fuel and oil lines, so removing any unwanted vapors would be important.

Zone 3 is the area around the high-pressure compressor to the turbine cases. This zone also contains fuel and oil lines and other accessories. Air enters from the exhaust of the pre-cooler and other areas and is exhausted from the zone through the aft edge of the thrust reverser inner wall and the turbine exhaust sleeve.

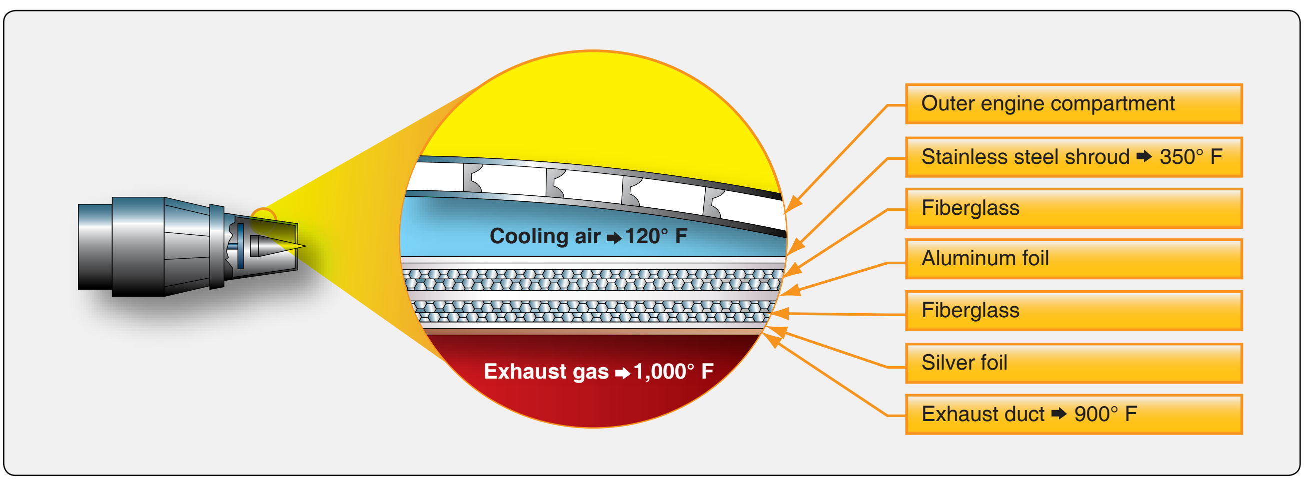

Figure 6-62. *Typical engine insulation blanket.*

Turbine Engine Insulation Blankets

To reduce the temperature of the structure in the vicinity of the exhaust duct or thrust augmentor (afterburner) and to eliminate the possibility of fuel or oil coming in contact with the hot parts of the engine, it is sometimes necessary to provide insulation on the exhaust duct of gas turbine engines. The exhaust duct surface temperature runs quite high. A typical insulation blanket and the temperatures obtained at various locations are shown in *Figure 6-62*. This blanket contains fiberglass as the low conductance material and aluminum foil as the radiation shield. The blanket is suitably covered so that it does not become oil soaked. Insulation blankets have been used rather extensively on many installations in which long exhaust is needed. Some auxiliary power units (APU) mounted in the tail cone of transport aircraft have air that surrounds the exhaust tail pipe that provides cooling and protects the surrounding structure.