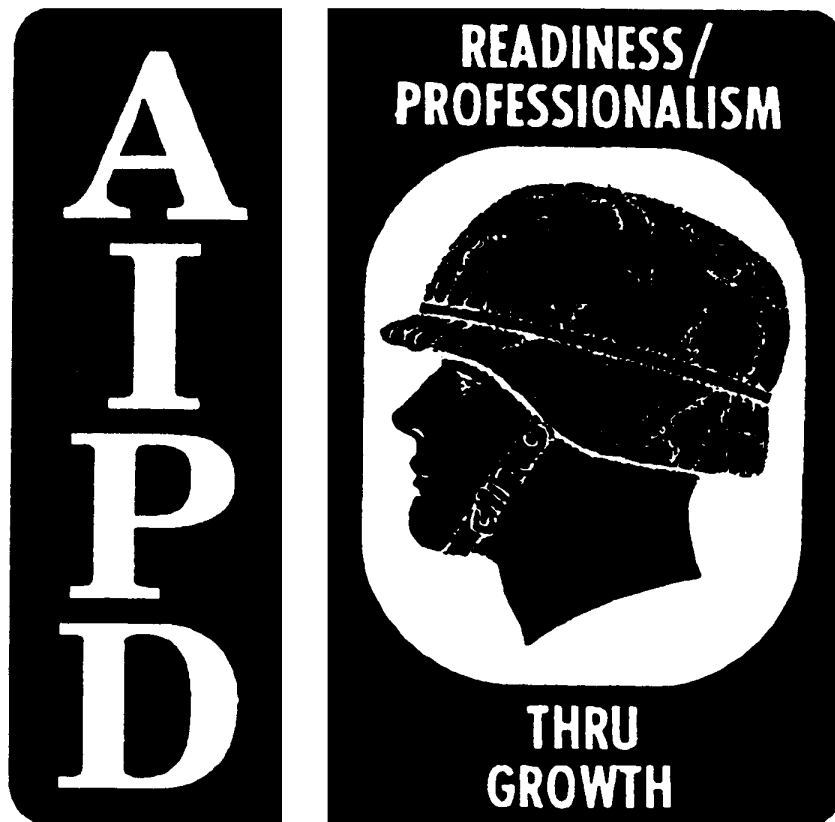
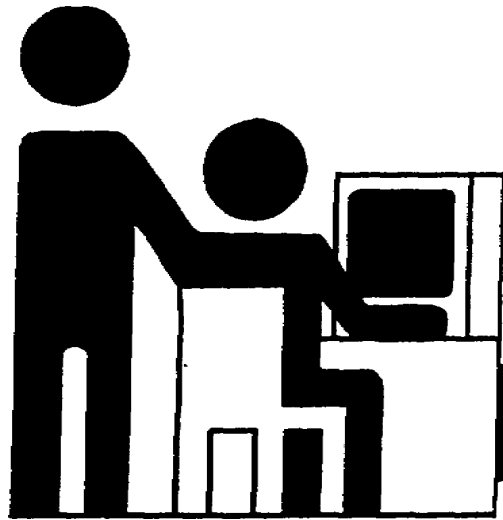


PRINCIPLES OF INTERNAL
COMBUSTION ENGINES



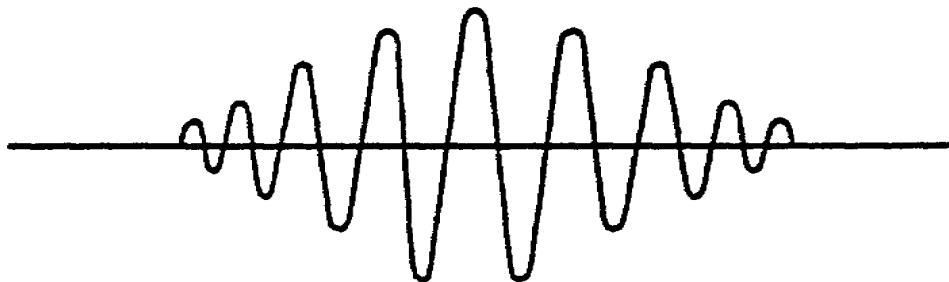
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US ARMY BRADLEY FIGHTING VEHICLE SYSTEMS MECHANIC
CORRESPONDENCE COURSE

MOS/SKILL LEVEL: 63T30

PRINCIPLES OF INTERNAL COMBUSTION ENGINES

SUBCOURSE NO. OD1619

US Army Correspondence
Course Program

7 Credit Hours

GENERAL

The purpose of this subcourse is to increase the mechanic's knowledge of the principles, components, and operation of internal combustion engines.

Seven credit hours are awarded for successful completion of this subcourse.

Lesson 1: INTERNAL COMBUSTION ENGINES

TASK 1: Describe the principles, components, and operation of both the two stroke and four stroke gasoline engines.

TASK 2: Describe the principles, components, and operation of both the two stroke and four stroke diesel engines.

Lesson 2: INTERNAL COMBUSTION ENGINE SUBSYSTEMS

TASK 1: Describe the principles, components, and operation of turbochargers, intake, and exhaust systems.

TASK 2: Describe the principles, components, and operation of the lubrication system.

TASK 3: Describe the principles, components, and operation of the cooling system.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619

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PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/TASK 1

LESSON 1

INTERNAL COMBUSTION ENGINES

TASK 1. Describe the principles, components, and operation of both the two stroke and four stroke gasoline engines.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within two hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Military vehicles incorporate all forms of wheeled and tracked vehicles, including the full range of body types found in commercial vehicles. However, there are also bodies and equipment that are unique to military operations. They include all types of trucks, tractors, truck tractors, personnel carriers, tanks, self-propelled guns, motorized and mechanized special purpose equipment, trailers, vans, and special purpose towed vehicles.

The principal distinction between these vehicles and their commercial counterparts is that military vehicles are specifically designed for military purposes. These include combat operations and the transportation of cargo, personnel, or equipment; towing other vehicles or equipment; and operations, both cross-country and over roads, in close support of combat vehicles and troops. Such vehicles are designed and constructed to endure the rigors of the military environment and to continue to operate at, or above, a prescribed minimum performance

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/TASK 1

level. They have excellent cross-country performance capabilities over all types of terrain where tactical or combat operations can be conducted. This includes snow and ice, rocky terrain, swamps, and desert sands. In order to negotiate water barriers with a minimum of preparation, all sensitive equipment is either permanently water-proofed or designed to function underwater.

The majority of the vehicles described in the paragraphs above have an internal combustion engine. For this reason, a mechanic should know the principles of operation of this engine and its various components. An internal combustion engine is any engine within which the fuel is burned. The four stroke and two stroke cycle gasoline and diesel engines are examples of internal combustion engines because the combustion chamber is located within the engine. In this task, an internal combustion engine, referred to as the piston engine, will be described.

2. Piston Engine Characteristics

a. *Engine Operation.*

(1) *General.* Because the most widely used piston engine is the four stroke cycle type, it will be used as the example for this paragraph and as the basis for comparison in Task 2. The operation of the piston engine can best be understood by comparing it to a simple cannon. In view A of figure 1 on the following page, a cannon barrel, charge of gunpowder, and a cannonball are illustrated. In view B of figure 1, the gunpowder is ignited. The gunpowder burns very rapidly and as it burns there is a rapid expansion of the resulting gases. This rapid expansion causes a tremendous increase in pressure that forces the cannonball from the barrel.

In view A of figure 2 on the following page, the cannon barrel has been replaced by a cylinder and a combustion chamber. The cannonball has been replaced by a piston. A mixture of vaporized fuel and air has replaced the gunpowder. In view B of figure 2, the gasoline is ignited. This time, the resulting force acts to push the piston downward.

FIGURE 1. PISTON ENGINE PRINCIPLES.

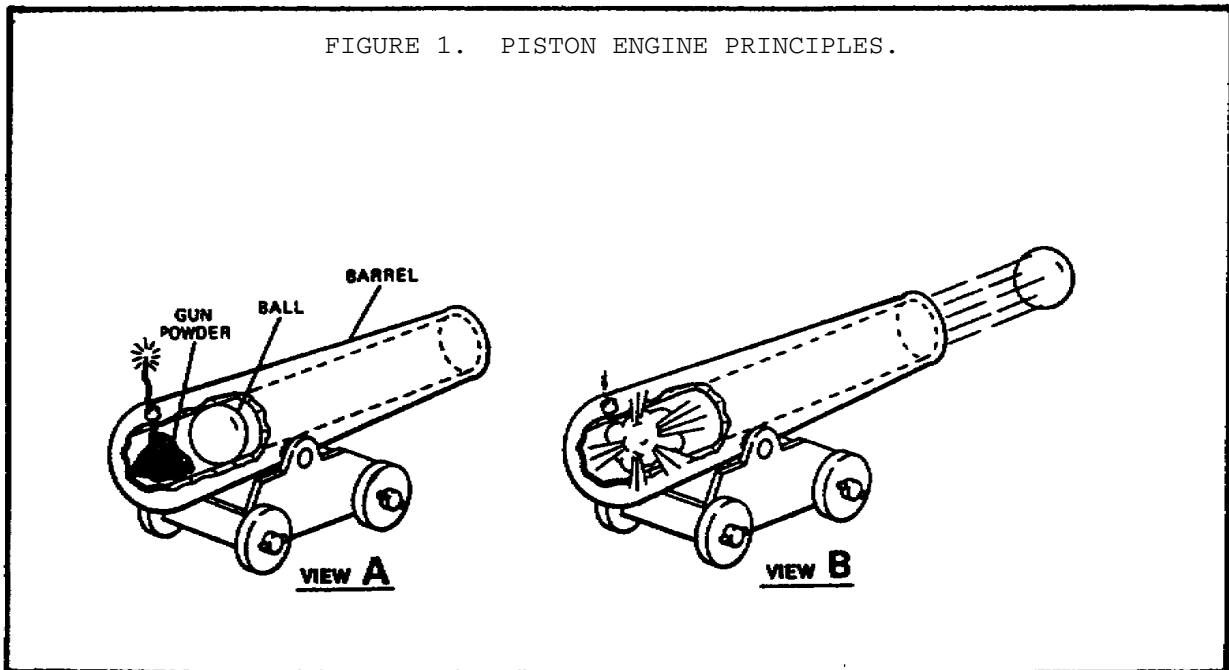
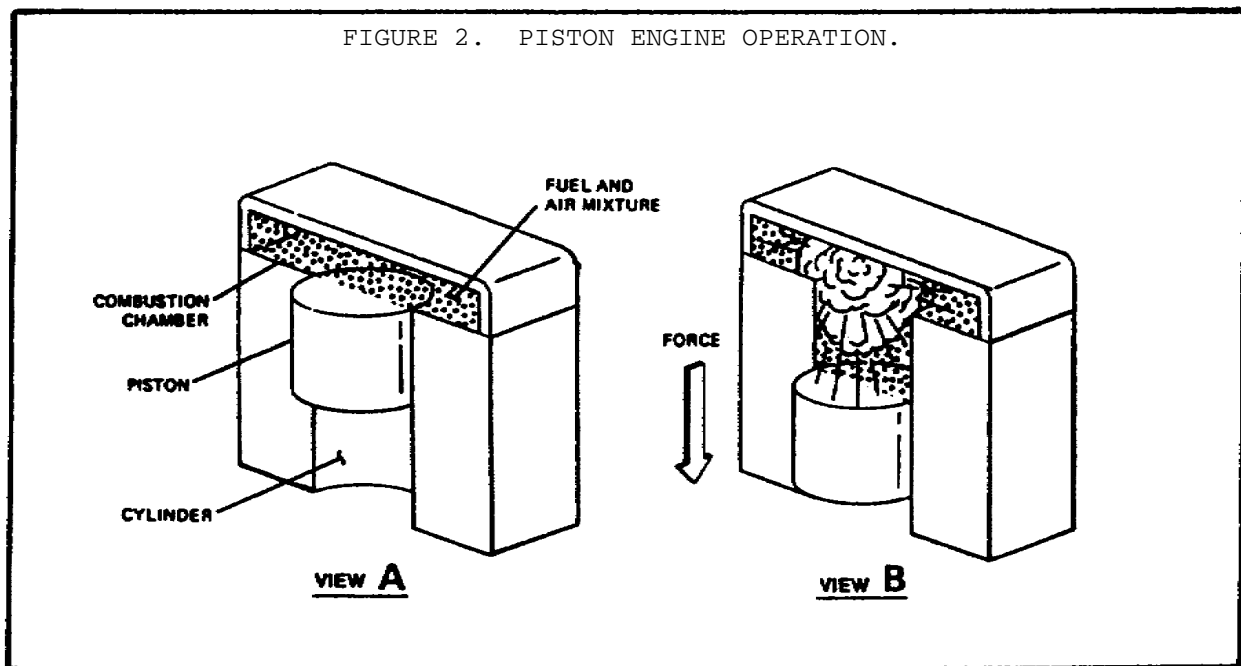
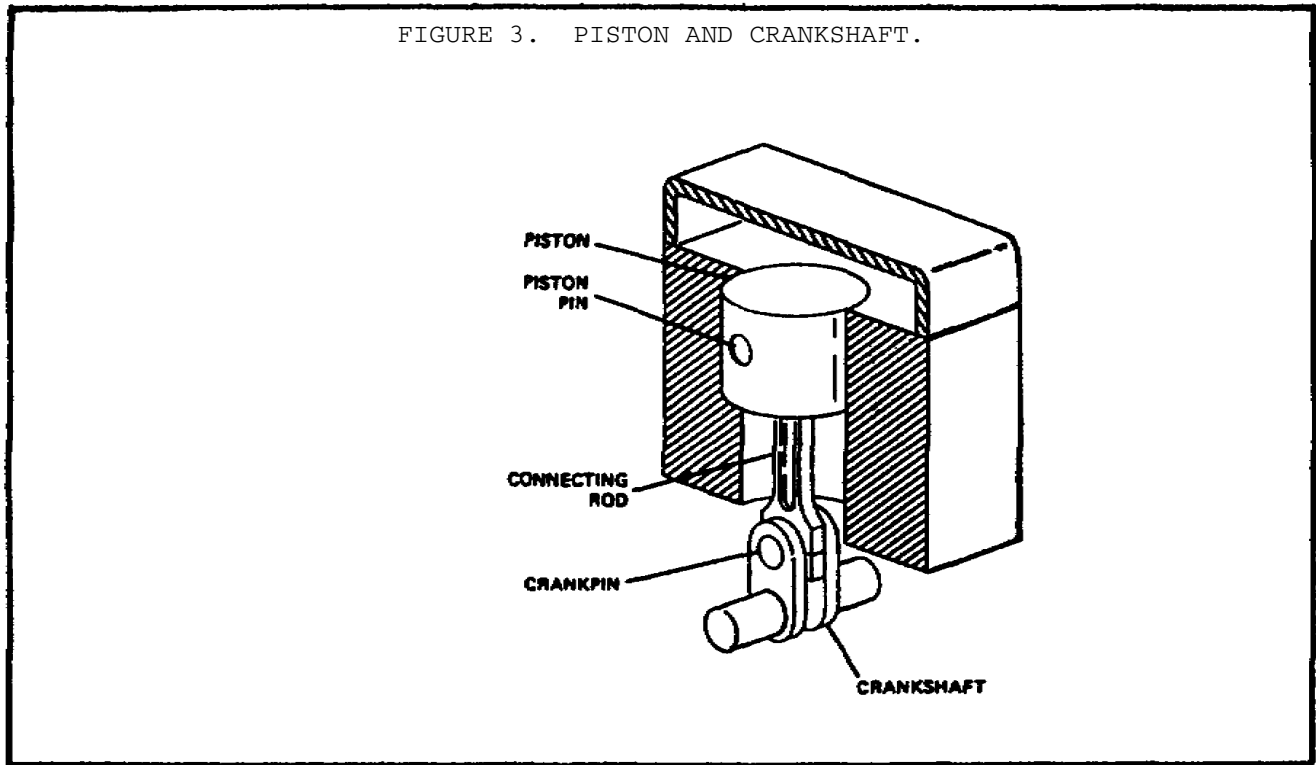


FIGURE 2. PISTON ENGINE OPERATION.



(2) *Reciprocating Motion to Rotary Motion.* The force of the piston acting in a downward motion is of little immediate value if it is to turn the wheels of a vehicle. In order to use this straight line or reciprocating motion, it must be transformed into rotary motion. This is made possible through the use of a crankshaft. The crankshaft is connected to the driving wheels of a vehicle through the drive train on one end. On the other end of the shaft is a crank with a crankpin offset from the shaft's center. Figure 3 on the following page

FIGURE 3. PISTON AND CRANKSHAFT.



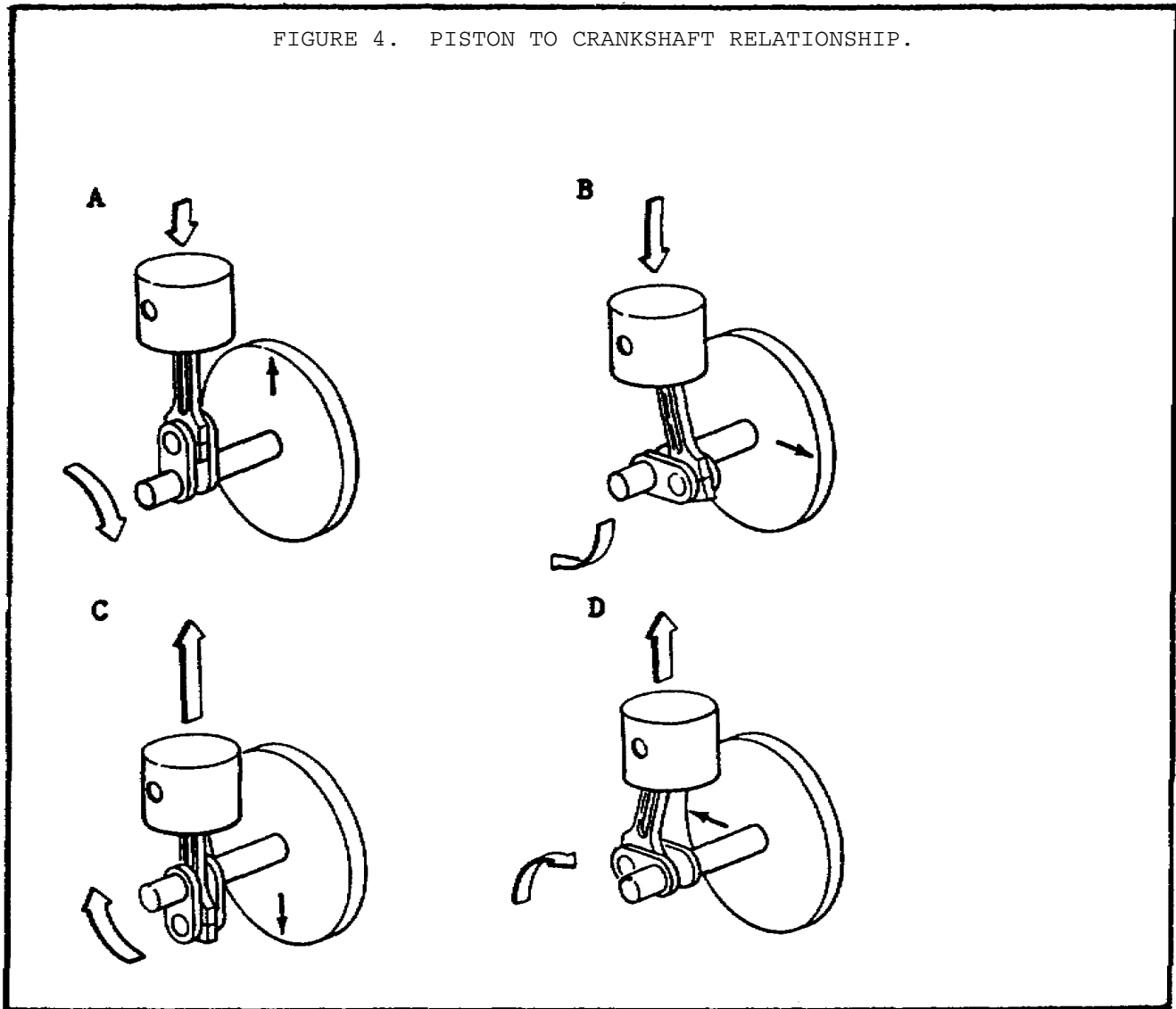
illustrates how the piston and the crankshaft are connected through the connecting rod and the crankpin. Figure 4 on the following page illustrates how reciprocating motion of the piston is changed to rotating motion of the crankshaft.

A more detailed explanation of the parts that perform this reciprocating and rotating motion will be described in paragraph 3 on page 15.

(3) *Intake and Exhaust.* If the engine is going to operate, the fuel and air mixture must be fed into the combustion chamber. The burnt gases also must be exhausted. To accomplish this, there is a passage to the combustion chamber called the intake port, and a passage from the combustion chamber to the exhaust system called the exhaust port. A simplified arrangement is shown in figure 5 on page 6.

By putting openings in the combustion chamber, a problem is created; the force of the burning fuel and air mixture will be lost through the exhaust and intake ports rather than used to push down the piston. To solve this problem, there must be something that opens and closes the intake and exhaust ports to the combustion chambers. To accomplish this, a valve is added to each of these ports; these valves are called the intake and

FIGURE 4. PISTON TO CRANKSHAFT RELATIONSHIP.



exhaust valves. A simplified arrangement is shown in figure 6 on the following page.

The intake and the exhaust valves are opened and closed in a timed sequence by the valve train. The valve train will be discussed in paragraph 2a(5) on page 8.

(4) *Action in the Cylinder.* When the piston is at its highest point in the cylinder, it is in a position called top dead center. When the piston is at its lowest point in the cylinder, it is in a position called bottom dead center. As the piston moves from top dead center to bottom dead center, or vice versa, the crankshaft rotates exactly one-half of a revolution, as shown in figure 6 on the following page.

FIGURE 5. INTAKE AND EXHAUST PORTS AND VALVES.

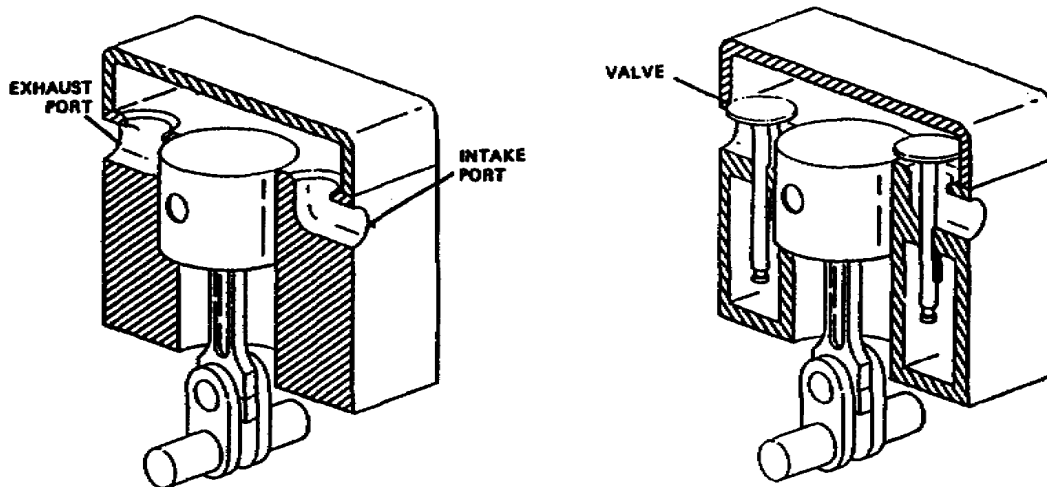
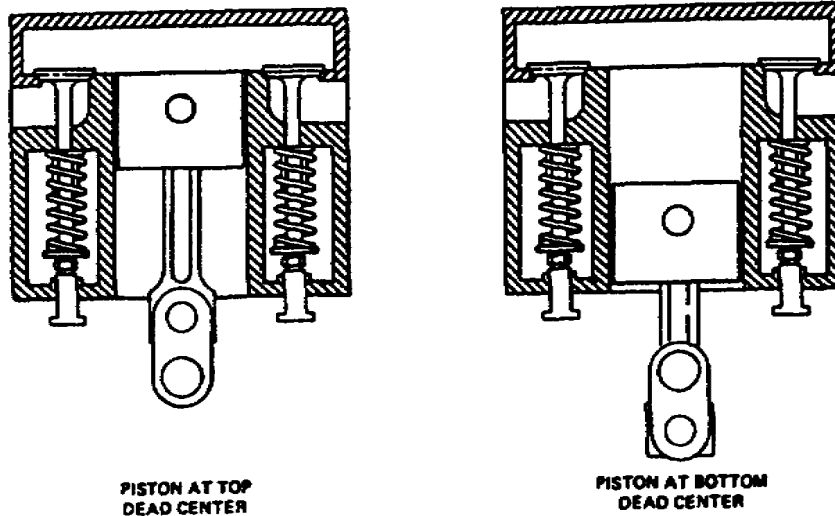


FIGURE 6. PISTON POSITIONS.



Each time the piston moves from top dead center to bottom dead center, or vice versa, it completes a movement called a stroke. Therefore, the piston completes two strokes for every full crankshaft revolution. There are four definite phases of operation that an engine goes through in one

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complete operating cycle. Each one of these operating phases is completed in one piston stroke. Because of this, each operating phase is also referred to as a stroke and, because there are four strokes of operation, the engine is referred to as a four stroke cycle engine. The four strokes are intake, compression, power, and exhaust. Because there are four strokes in one operating cycle, it may be concluded that there are two complete crankshaft revolutions in each operating cycle.

(a) *Intake Stroke* (figure 7 on page 9). The intake stroke begins at top dead center. As the piston moves down, the intake valve opens. The downward movement of the piston with the exhaust valve closed creates a vacuum in the cylinder. The vacuum causes a fuel and air mixture to be drawn through the intake port into the combustion chamber. As the piston reaches bottom dead center, the intake valve closes.

(b) *Compression Stroke*. The compression stroke begins with the piston at bottom dead center. Both the intake and the exhaust valves remain closed. As the piston moves toward top dead center, the amount of space in the upper cylinder gets smaller. The fuel and air mixture is compressed and the potential energy in the fuel is concentrated. The compression stroke ends when the piston reaches top dead center.

(c) *Power Stroke*. As the piston reaches top dead center, ending the power stroke, the spark plug ignites the compressed fuel and air mixture. Because both valves are closed, the force of the resulting explosion pushes the piston down, giving a powerful driving thrust to the crankshaft. The power stroke ends as the piston reaches bottom dead center.

(d) *Exhaust Stroke*. As the piston reaches bottom dead center, ending the power stroke, the exhaust valve opens, beginning the exhaust stroke. As the piston moves upward toward top dead center, it pushes the burnt gases from the fuel and air mixture out of the combustion chamber through the exhaust port. As the piston reaches top dead center, ending the exhaust stroke, the exhaust valve closes. As the exhaust valve closes, the intake valve opens to begin the intake stroke in the next cycle.

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(5) *Valve Train.* It is very important to operate the valves in a timed sequence. Therefore, the engine is fitted with a valve train, which operates the valves. If the exhaust valve were to open in the middle of the intake stroke, the piston would draw burnt gases into the combustion chamber with a fresh mixture of fuel and air. As the piston continued to the power stroke, there would be nothing in the combustion chamber that would burn.

A simplified valve train is illustrated in view A of figure 8 on page 10. A camshaft is made to rotate with the crankshaft through the timing gears. The raised piece on the camshaft is called a cam lobe. As illustrated in view B of figure 8, the valve spring is designed to hold the valve closed.

The cam lobe contacts the bottom of the lifter as it rotates with the camshaft, as shown in view C of figure 8. As the cam lobe pushes up on the lifter it will, in turn, push the valve open against the pressure of the spring. In view D of figure 8, the cam lobe has passed the center of the lifter bottom. As it rotates away from the lifter, the valve spring pulls the valve closed.

By proper position of the cam lobes on the camshaft, a sequence can be established for the intake and exhaust valves. It is described, in subparagraphs 2a(4) (a) through 2a(4) (d) on page 7, how the intake valve and the exhaust valve must each open once for every operating cycle. As explained in subparagraph 2a(4), the crankshaft must make two complete revolutions to complete one operating cycle. Using these two facts, a camshaft speed must be exactly one-half the speed of the crankshaft. To accomplish this, the timing gears are made so that the crankshaft gear has exactly one-half as many teeth as the camshaft gear, as shown in view A of figure 9 on page 11. The timing marks indicated are used to put the camshaft and the crankshaft in the proper position relative to each other.

FIGURE 7. FOUR STROKE CYCLE OPERATIONS.

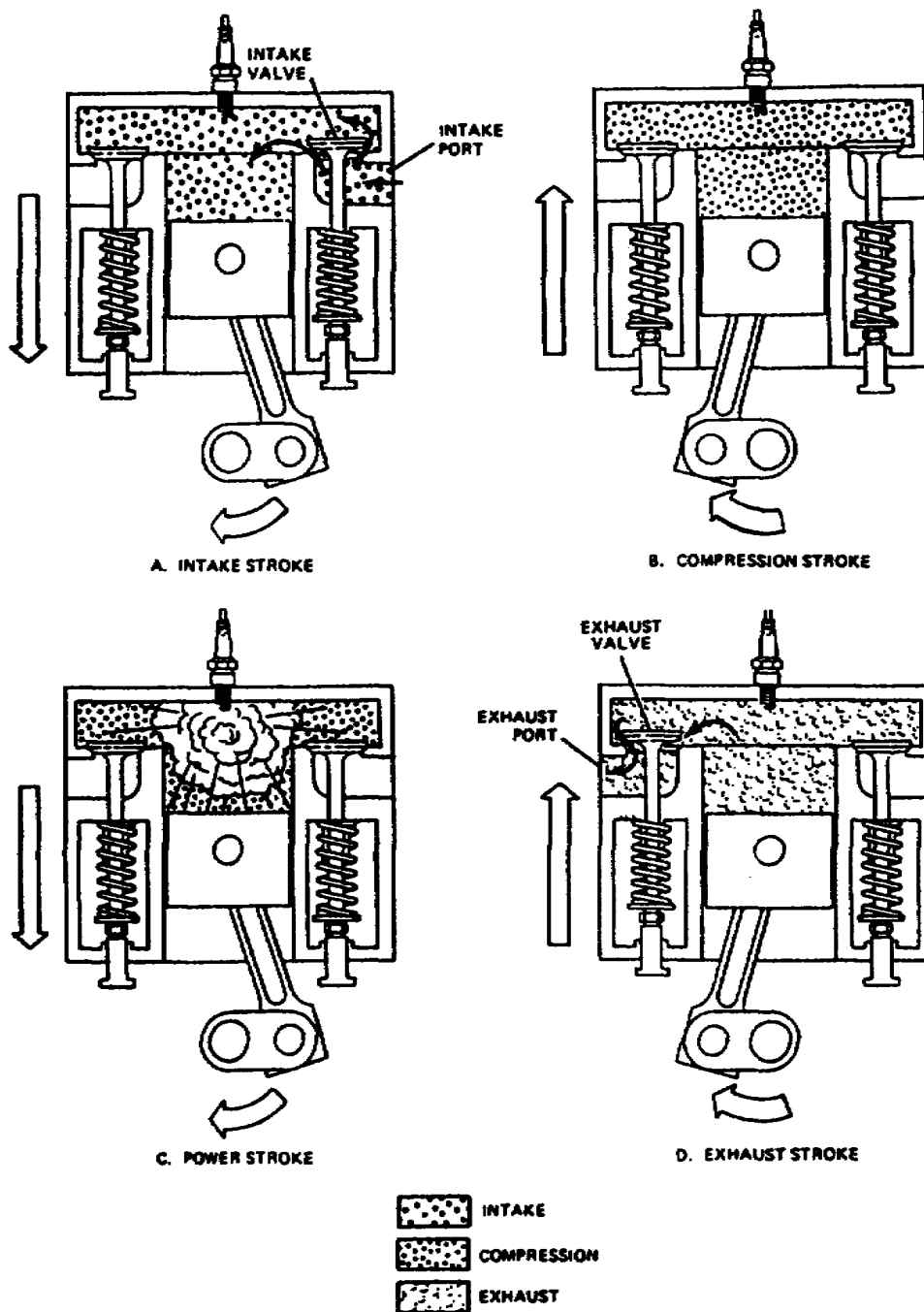
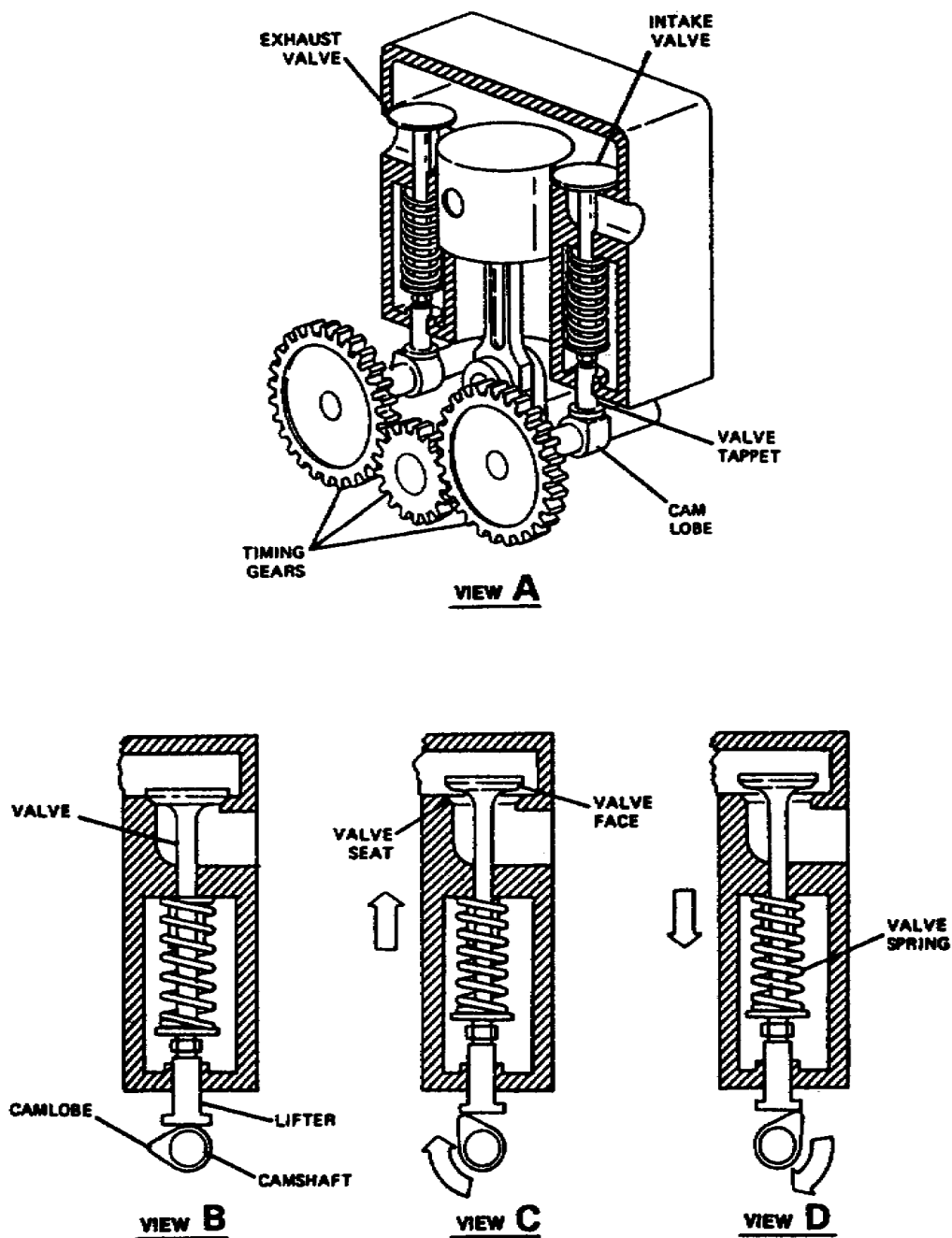


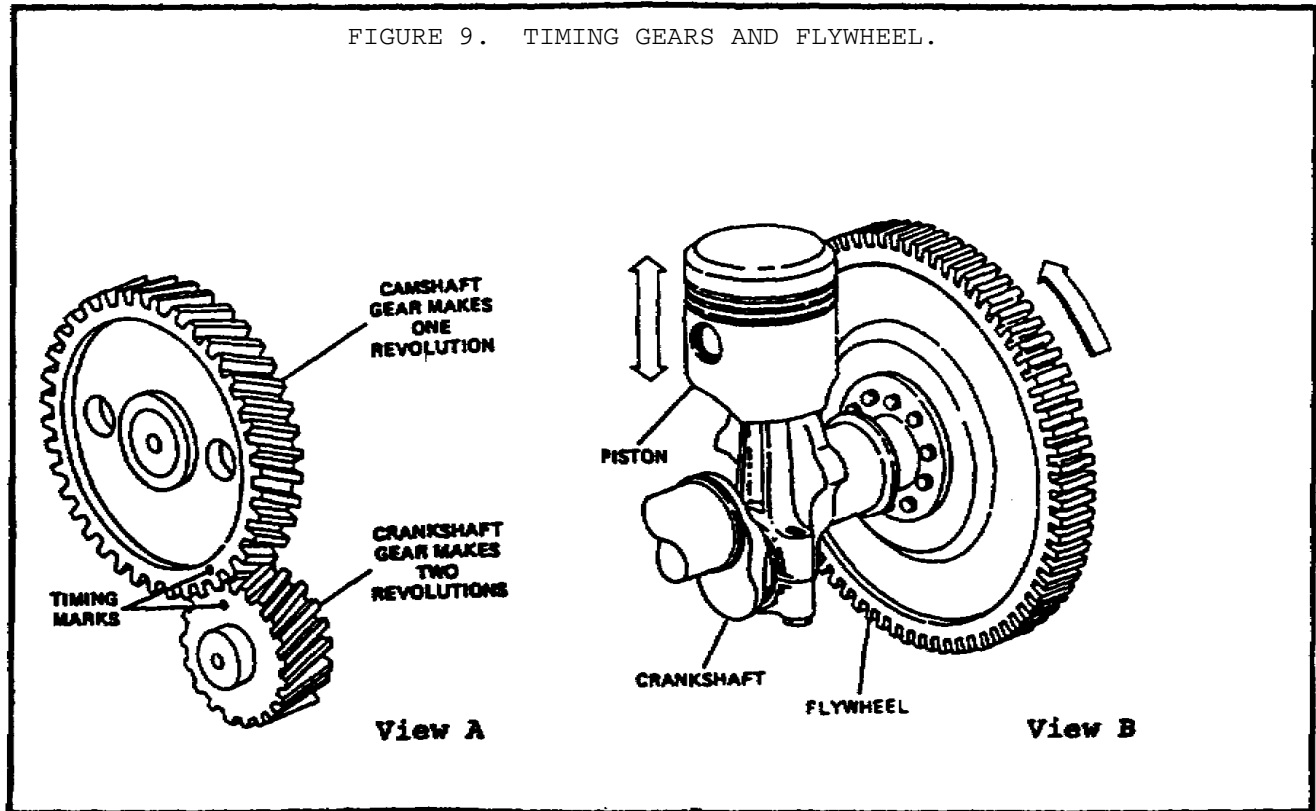
FIGURE 8. VALVE TRAIN OPERATION.



(6) Engine Accessory Systems.

(a) *Fuel System.* The fuel system supplies the engine with the properly proportioned fuel and air mixture. It also regulates the amount of the mixture supplied to the engine to control engine speed and power output.

FIGURE 9. TIMING GEARS AND FLYWHEEL.



(b) *Ignition System.* The ignition system ignites the fuel and air mixture in the combustion chamber at the precise moment needed to make the engine run.

(c) *Cooling System.* The cooling system removes the excess heat from the engine, generated by combustion.

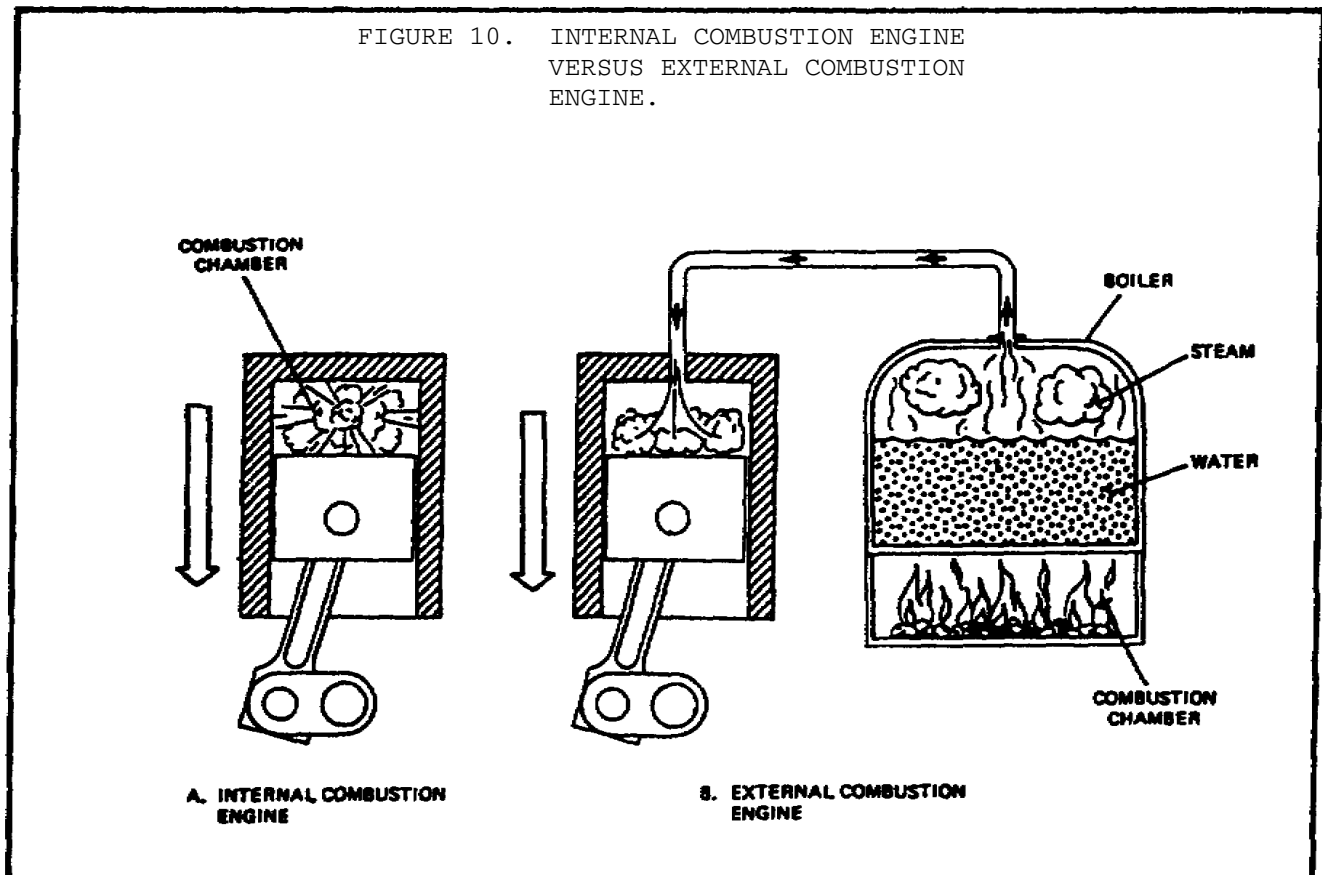
(d) *Lubrication System.* The lubrication system provides a constant supply of oil to the engine to lubricate and cool the moving parts.

(e) *Flywheel* (figure 9, view B). As discussed previously, for every two revolutions the crankshaft makes, it only receives one power stroke which lasts for only one-half of one revolution of the crankshaft. This means that the engine must coast through one and one-half crankshaft revolutions in every operating cycle. This would cause the engine to produce very erratic power output. To solve this problem, a flywheel is added at the end of the crankshaft. The flywheel, which is very heavy, will absorb the violent thrust of the power stroke. It will then release the energy back to the crankshaft so that the engine will run smoothly.

b. *Comparison of Engine Types.*

(1) *Internal Combustion Engine Versus External Combustion Engine.*

(a) *Internal Combustion Engine* (figure 10, view A). An internal combustion engine is any engine in which the fuel is burned from within. A four stroke cycle engine is an internal combustion engine because the combustion chamber is located within the engine.

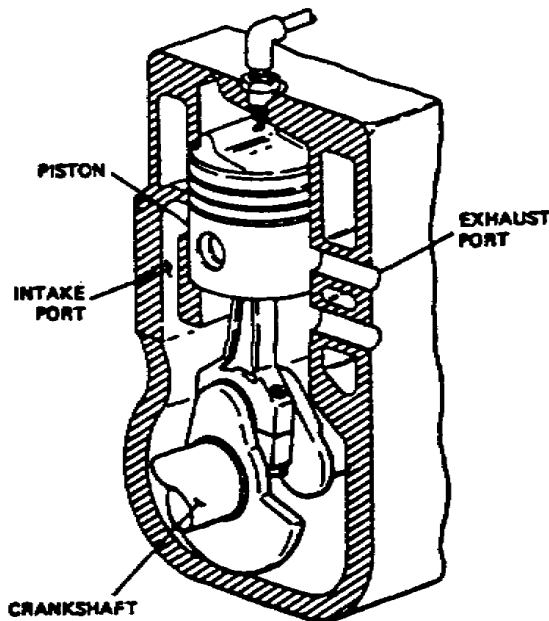


(b) *External Combustion Engine* (figure 10, view B). An external combustion engine is an engine in which the fuel is burned outside of the engine. A steam engine is a perfect example. The fuel is burned in an outside boiler where it makes steam. The steam is piped to the engine to make it run.

(2) *Four Stroke Cycle Versus Two Stroke Cycle.* The engine described until now has been a four stroke cycle engine. There is another form of gasoline piston engine which requires no valve mechanisms and which completes one operating cycle for every revolution of the crankshaft. It is called a two stroke cycle engine and is illustrated

in figure 11. Instead of placing the intake and exhaust ports in the combustion chamber, they are placed in the cylinder wall. In this engine, the piston goes through a power stroke every time it moves from top dead center to bottom dead center. The downward stroke is also an intake and an exhaust stroke. As the piston moves from bottom dead center back to top dead center, it is going through a compression stroke.

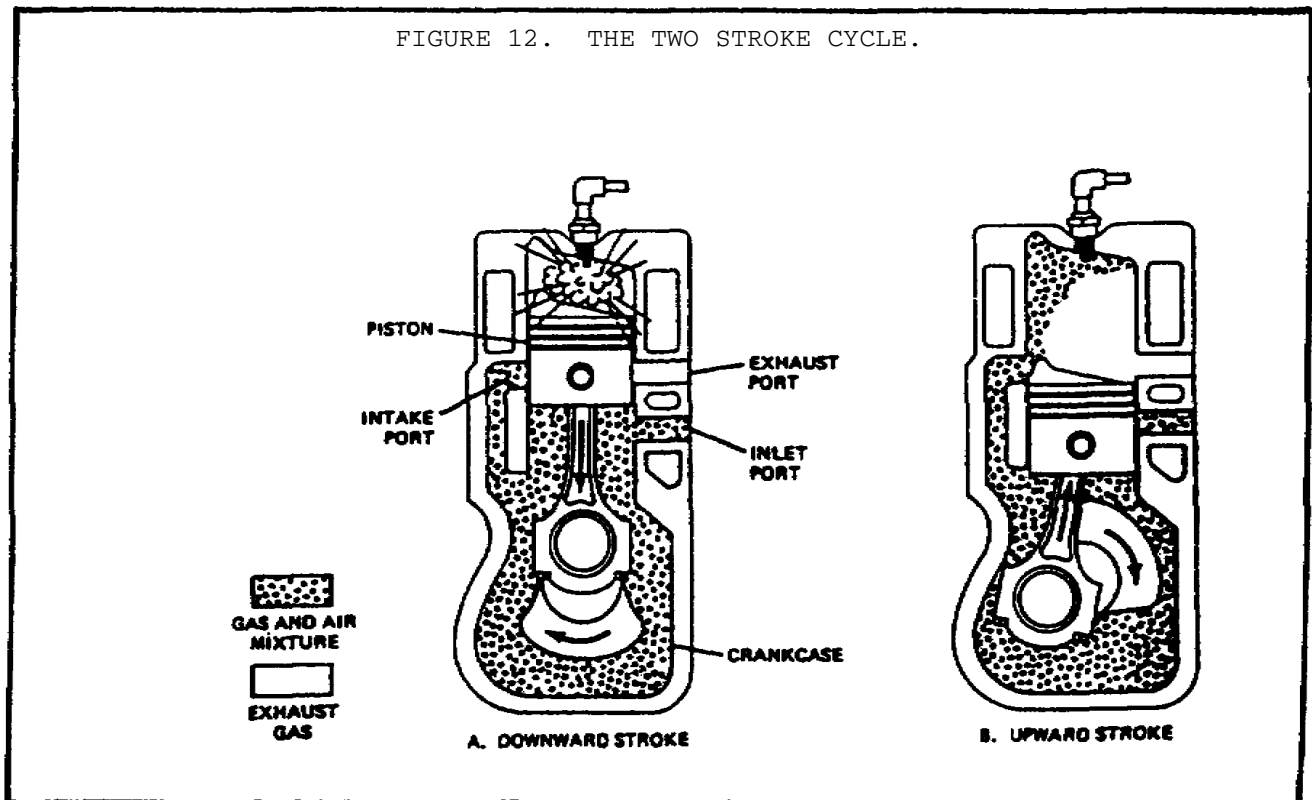
FIGURE 11. TWO STROKE CYCLE ENGINE.



(a) *Downward Stroke* (figure 12, view A, on the following page). The piston begins the power stroke at top dead center. As the exploding fuel and air mixture pushes the piston downward, it first covers the inlet port. This seals the crankcase. As the piston continues downward, it uncovers the intake and the exhaust ports. The pressure built up in the crankcase forces the fuel and air mixture into the cylinder through the intake port. The top of the piston is shaped to divert the mixture upward and away from the exhaust port. As the mixture enters the cylinder, it displaces and pushes the burnt gases out through the exhaust port.

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(b) *Upward Stroke* (figure 12, view B). As the piston moves upward, it covers the intake and exhaust ports. This seals the upper cylinder so that the upward movement of the piston compresses the fuel and air mixture. At the same time, the upward movement of the piston creates a suction in the crankcase so that as the inlet port is uncovered, a mixture of fuel and air is drawn into the crankcase. As the piston reaches top dead center, the spark plug ignites the fuel and air mixture, beginning the downward power stroke again.



(c) *The Fuel and Lubrication System.* The fuel and air mixture must first pass through the crankcase before it gets to the combustion chamber. For this reason, the fuel and air mixture must also provide lubrication for the rotating and reciprocating parts. This is accomplished by mixing a small percentage of oil with the fuel. The oil, mixed with the fuel and air mixture, enters the crankcase in a vapor that constantly coats the moving parts.

(d) *Power Output.* It may seem that a two stroke engine will put out twice as much power as a comparable four stroke cycle engine because there are twice as many power strokes. However, this is not the case. Because the force of the fuel and

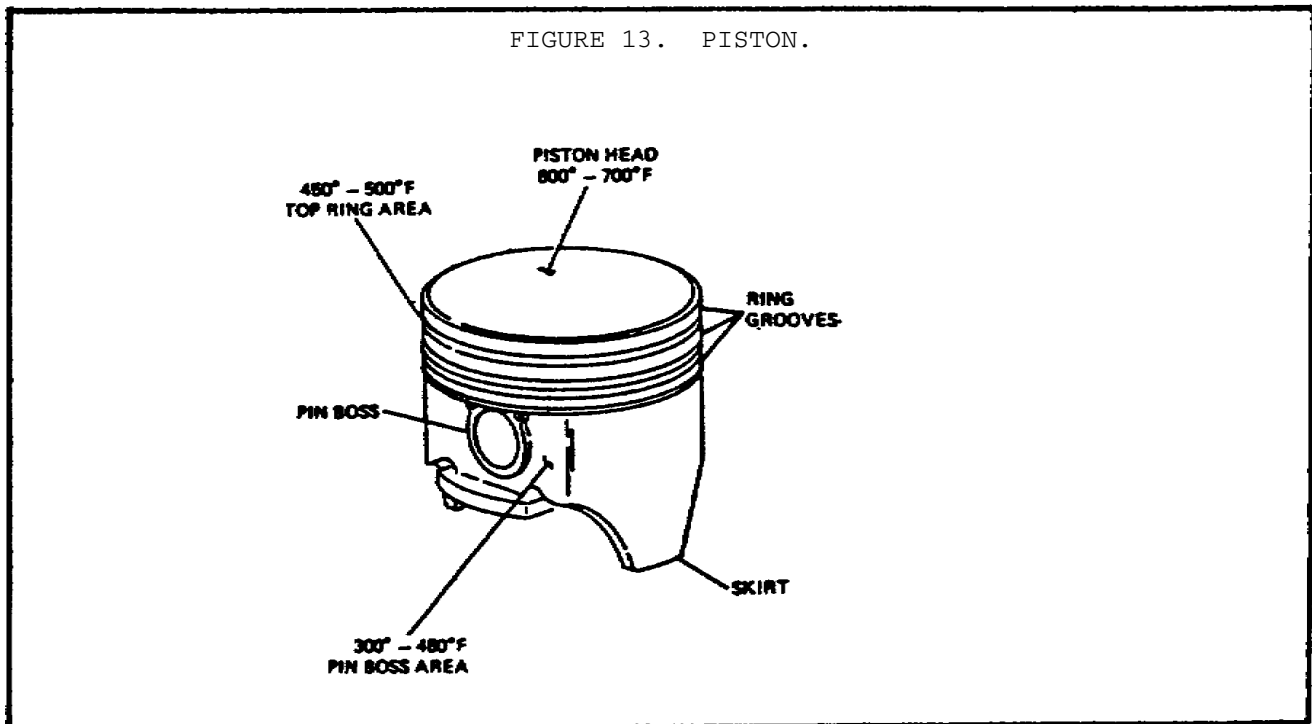
air mixture entering the cylinder must be relied upon to get rid of the burnt gases in the cylinder from the last power stroke, there is some dilution of the mixture. The mixing of the intake mixture with exhaust gases reduces the potential power output. Also, with the inlet and exhaust ports opened together, a certain amount of the fuel and air mixture is lost. There is also a much shorter period in which the inlet port is open. These factors reduce the amount of power from each power stroke.

(e) *Advantage and Usage.* The two stroke cycle engine is used almost exclusively in very small equipment. It is lightweight and able to run at very high speeds due to the absence of a mechanical valve train.

3. Rotating and Reciprocating Parts

a. *Piston.*

(1) *General* (figure 13). The piston is the part of both the two and four stroke engines that receives the energy from the combustion and transmits it to the crankshaft. The piston must withstand heavy stress under severe temperature extremes. The following are examples of conditions that a piston must withstand at normal highway speeds.



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(a) As the piston moves from the top of the cylinder to the bottom (or vice versa), it accelerates from a stop to a speed of approximately 50 miles per hour (mph) (80 kilometers per hour [kph]) at midpoint, and then decelerates to a stop again. It does this approximately 80 times per second.

(b) The head of the piston is subjected to pressures in excess of 1000 pounds per square inch (psi) (6895 kPa).

(c) The piston head is subjected to temperatures well over 600° F (316° C).

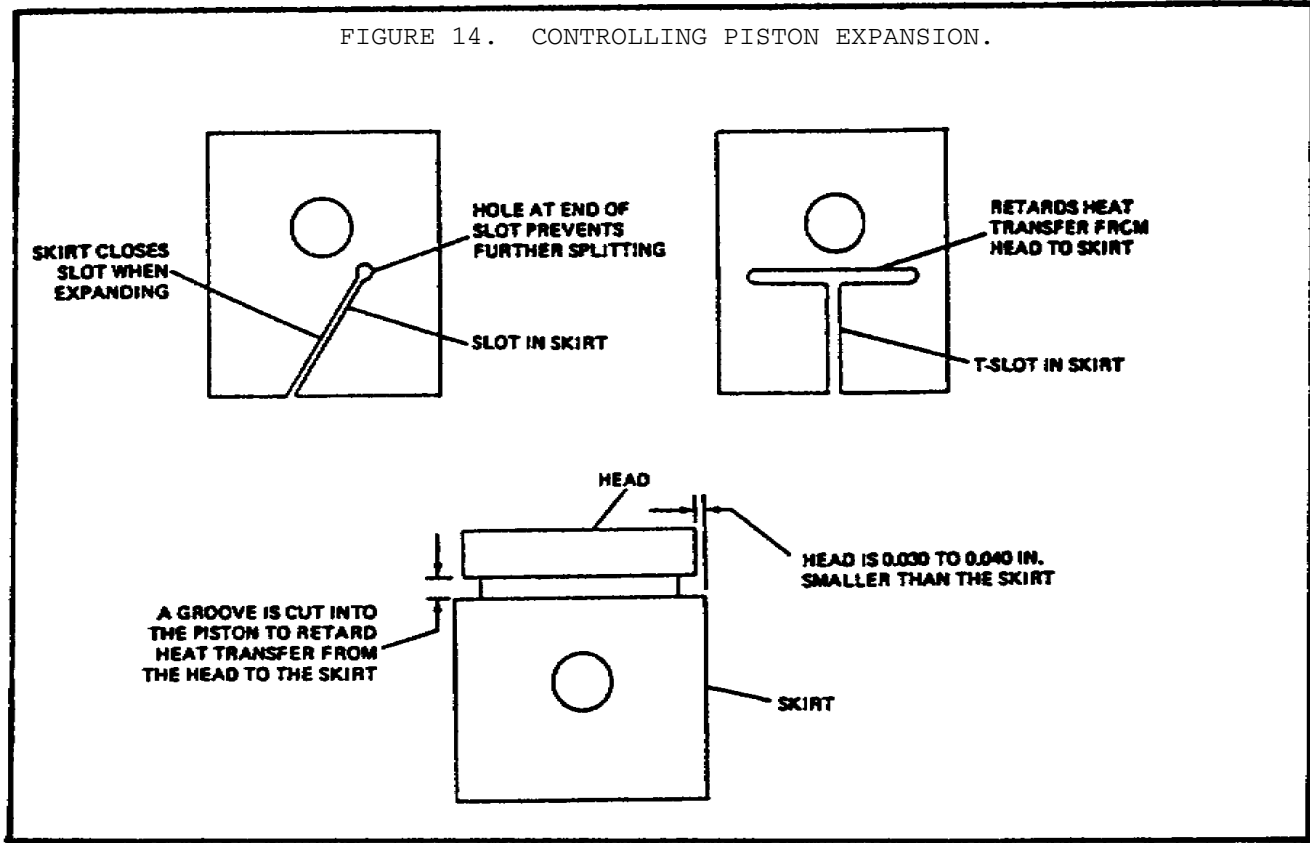
(2) *Construction Materials.* When designing pistons, weight is a major consideration. This is because of the tremendous inertial forces created by the rapid change in piston direction. For this reason, it has been found that aluminum is the best material for piston construction. It has a very high strength-to-weight ratio and, in addition to being lightweight, aluminum is an excellent conductor of heat and is machined easily. Pistons are also manufactured from cast iron. Cast iron is an excellent material for pistons in low-speed engines. It is not suitable for high speeds because it is a very heavy material.

(3) *Controlling Expansion* (figure 14 on the following page). Pistons must have built-in features to help them control expansion. Without these features, pistons would fit loosely in the cylinders when cold, then bind in the cylinders as they warm up. This is a problem with aluminum because it expands so readily. To control expansion, pistons may be designed with the following features:

(a) It is obvious that the crown of the piston will get hotter than the rest of the piston. To prevent it from expanding to a larger size than the rest of the piston, it is machined to a diameter that is approximately 0.03 to 0.04 in. (0.762 to 1.106 mm) smaller than the skirt area.

(b) One of the ways to control expansion in the skirt area is to cut a slot up the side of the skirt. As a split-skirt piston warms up, the split will close up, thereby keeping the skirt from expanding outward and binding the piston in the cylinder.

FIGURE 14. CONTROLLING PISTON EXPANSION.

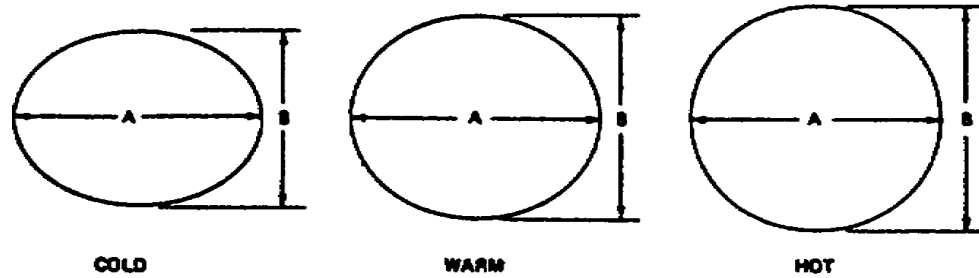


(c) A variation of the split-skirt piston is the T-slot piston. The T-slot piston is similar to the split-skirt piston, with the addition of a horizontal slot that retards heat transfer from the piston head to the piston skirt.

(d) Some aluminum pistons have steel braces cast into them to control expansion.

(4) *Cam Grinding* (figure 15 on the following page). By making the piston egg-shaped, it will be able to fit the cylinder better throughout its operational temperature range. A piston of this configuration is called a cam-ground piston. Cam-ground pistons are machined so that their diameter is smaller parallel to the piston pin axis than it is perpendicular to it. When the piston is cold, it will be big enough across the larger diameter to prevent rocking. As it warms up, it will expand across its smaller diameter at a much higher rate than at its larger diameter. This will tend to make the piston round at operating temperature. Virtually all pistons in automotive applications are cam-ground.

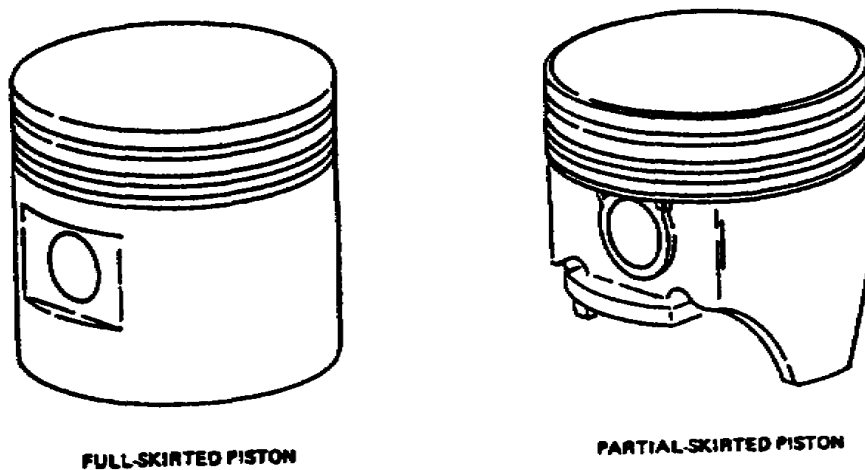
FIGURE 16. CAM-GROUND PISTON.



(5) *Partial-Skirted (Slipper-Skirt) Pistons* (figure 16). The purpose of the piston skirt is to keep the piston from rocking in the cylinder. The slipper-skirt piston has large portions of its skirt removed in the nonthrust areas. Removal of the skirt in these areas serves the following purposes:

(a) Lightens the piston, which, in turn, increases the speed range of the engine.

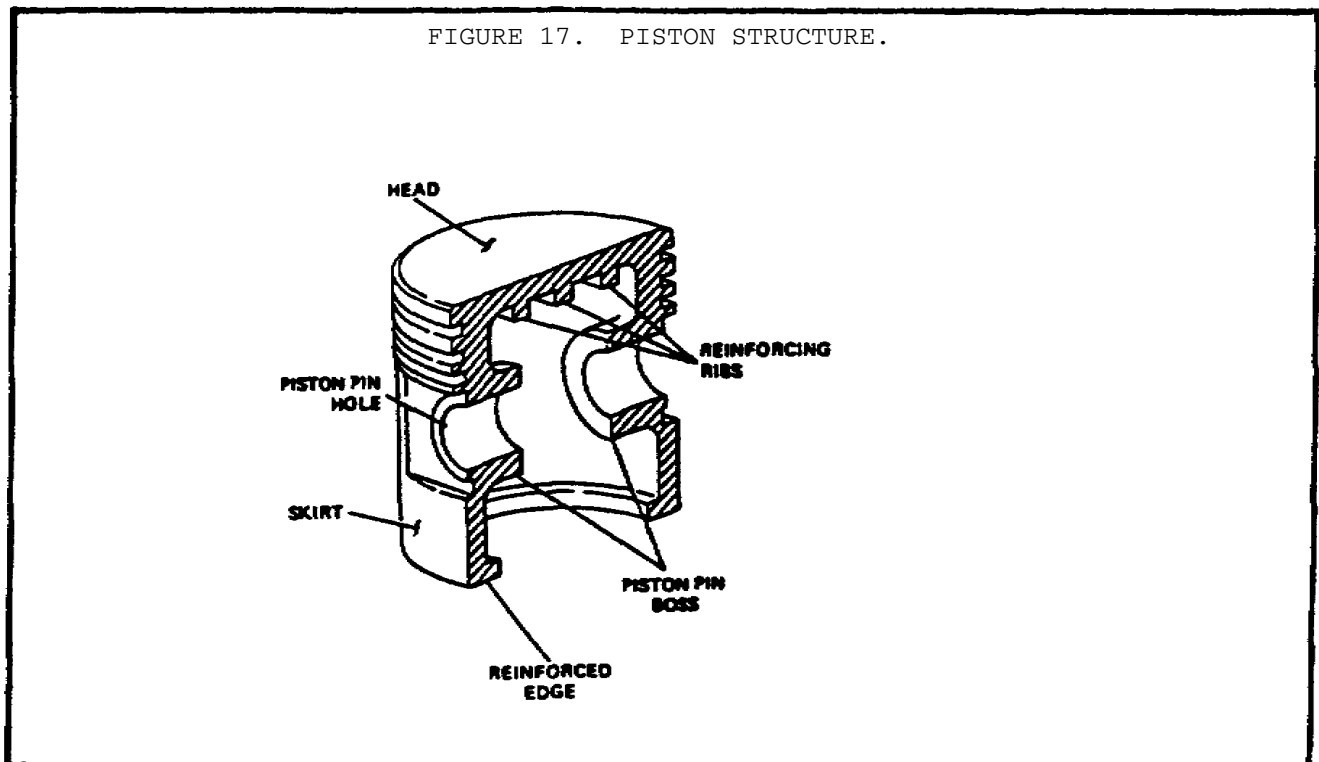
FIGURE 16. FULL AND PARTIAL-SKIRTED PISTONS.



(b) Reduces the contact area with the cylinder wall, which reduces friction.

(c) Allows the piston to be brought down closer to the crankshaft without interference with its counterweights.

(6) *Strength and Structure* (figure 17 on the following page). When designing a piston, weight and strength are critical factors. Two of the ways pistons are made strong and light are as follows:



(a) The head of the piston is made as thin as is practical; to keep it strong enough, ribs are cast into the underside of it.

(b) The areas around the piston pin are reinforced; these areas are called the pin bosses.

(7) *Coatings*. Aluminum pistons are usually treated on their outer surfaces to aid in engine break-in and to increase hardness. The following are the most common processes for treatment of aluminum pistons.

(a) The piston is coated with tin which will work into the cylinder walls as the engine is broken in. This process results in a more perfect

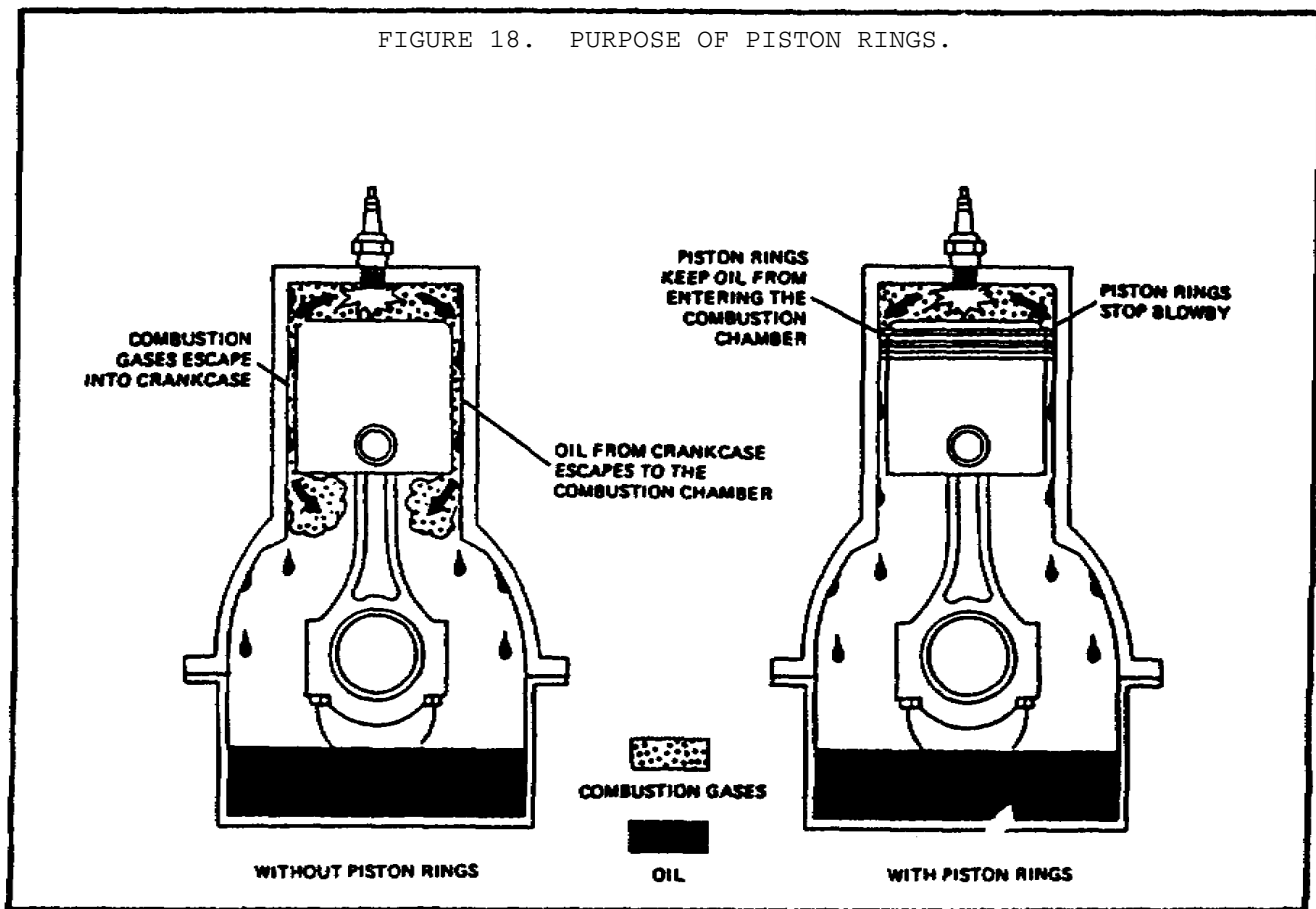
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fit, shortening the break-in period, and an increase in overall engine longevity.

(b) The piston is anodized to produce a harder outside surface. Anodizing is a process that produces a coating on the surface by electrolysis. The process hardens the surface of the piston. This helps it resist picking up particles that may become embedded in the piston, causing cylinder wall damage.

b. Piston Rings.

(1) *General* (figure 18). Piston rings serve three important functions:



(a) They provide a seal between the piston and the cylinder wall to prevent the force of the exploding gases from leaking into the crankcase from the combustion chamber. This leakage is referred to as blowby. Blowby is detrimental to engine performance because the force of the exploding gases will merely bypass the piston rather than push it down. It also contaminates the lubricating oil.

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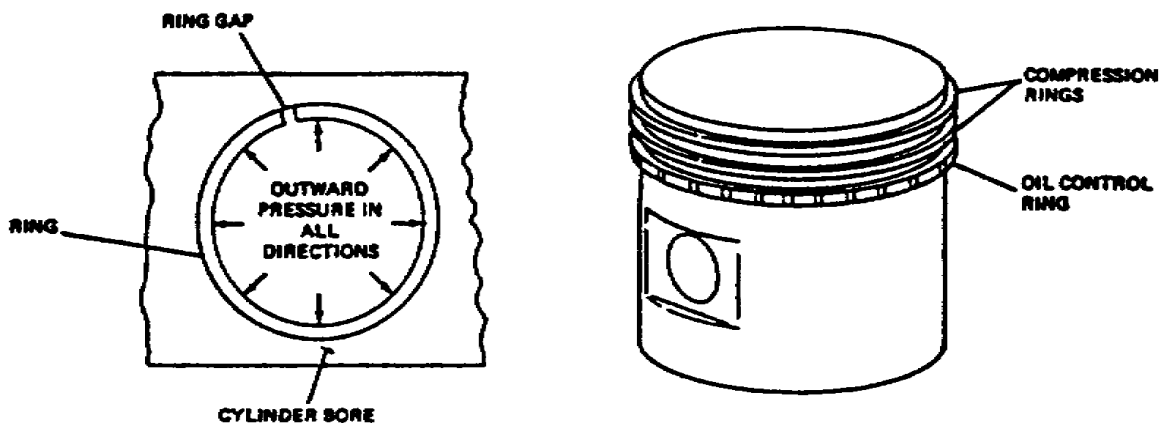
(b) They prevent the lubricating oil from bypassing the piston and getting into the combustion chamber from the crankcase.

(c) They provide a solid bridge to conduct the heat from the piston to the cylinder wall. About one-third of the heat absorbed by the piston passes to the cylinder wall through the piston rings.

(2) *Description* (figure 19). Piston rings are split to allow for installation and expansion, and they exert an outward pressure on the cylinder wall when installed. They fit into grooves that are cut into the piston, and are allowed to float freely in these grooves. A properly formed piston ring, working in a cylinder that is within limits for roundness and size, will exert an even pressure and maintain a solid contact with the cylinder wall around its entire circumference. Although piston rings have been made from many materials, cast iron has proved most satisfactory as it withstands heat, forms a good wearing surface, and retains a greater amount of its original elasticity after considerable use. There are two basic classifications of piston rings.

(a) *The Compression Ring.* The compression ring seals the force of the exploding mixture into the combustion chamber.

FIGURE 19. PISTON RING TYPES AND DESCRIPTION.

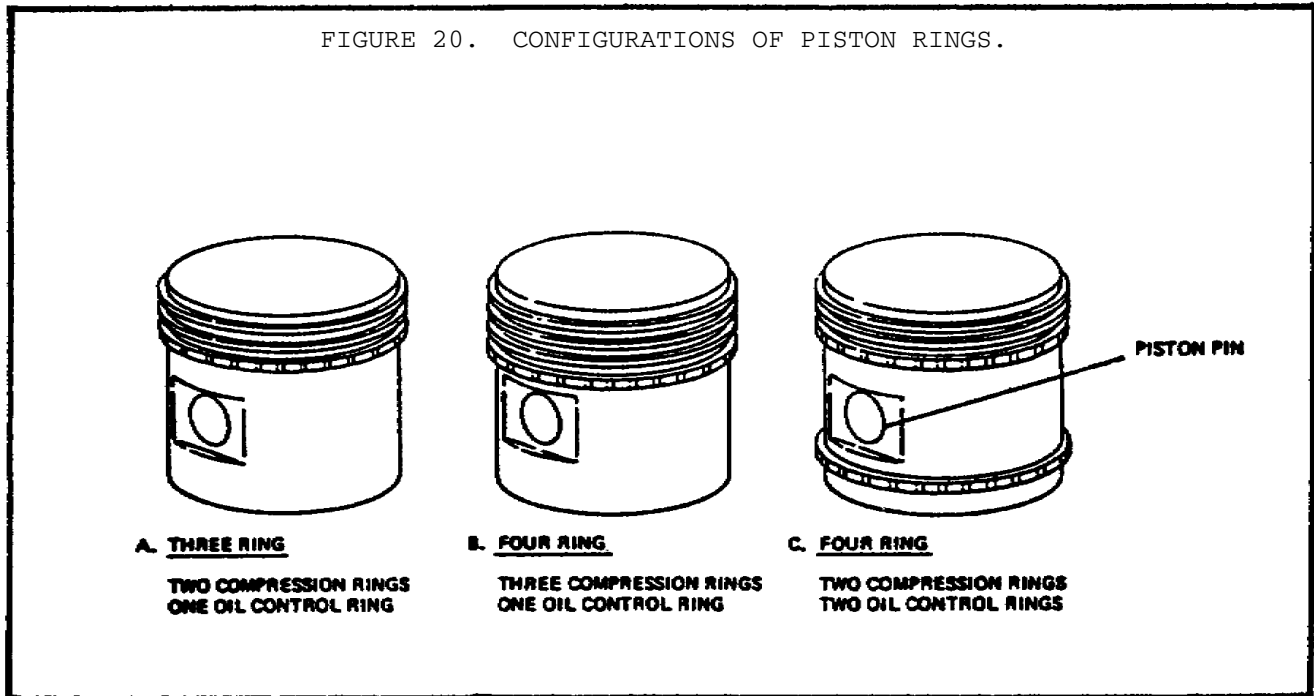


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(b) *The Oil Control Ring.* The oil control ring prevents the engine's lubrication oil from getting into the combustion chamber.

(3) *Configurations.* Piston rings are arranged on the pistons in three basic configurations. They are:

(a) The three-ring piston (figure 20, view A) has two compression rings near the head, followed by one oil control ring. This is the most common piston ring configuration.

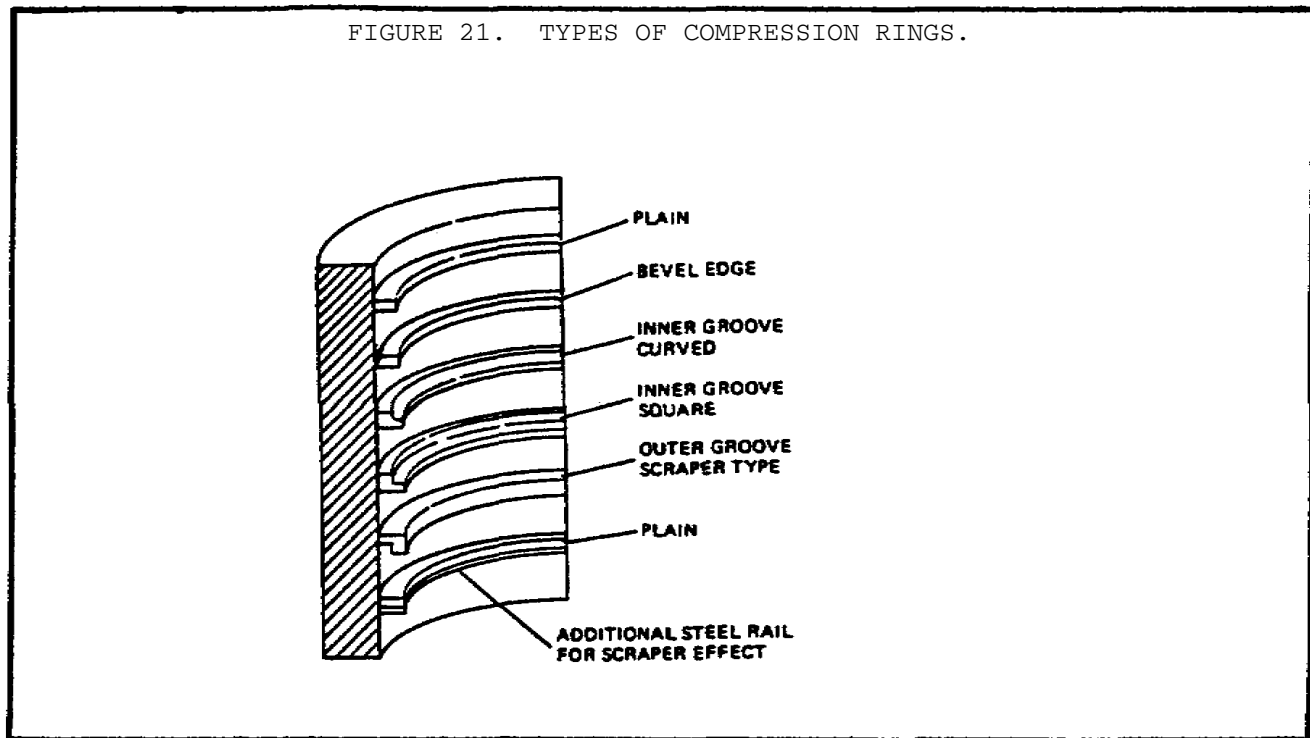


(b) The four-ring piston (figure 20, view B) has three compression rings near the head, followed by one oil control ring. This configuration is common in diesel engines because they are more prone to blowby, due to the much higher pressures generated during the power stroke.

(c) The four-ring piston (figure 20, view C) has two compression rings near the head, followed by two oil control rings. The bottom oil control ring may be located above or below the piston pin.

This is not a very common configuration in current engine design. In addition to the configurations mentioned, there are some diesel engines that use five or more piston rings on each piston to control the higher operating pressures.

(4) *Compression Ring.* As stated in paragraph 3b(2) (a) on page 21, the purpose of the compression ring is to maintain a gastight seal between piston and cylinder, and to hold the pressure from the power stroke in the combustion chamber. There are many different cross sectional shapes of piston rings available (figure 21).



The various shapes of rings all serve to preload the ring so that its lower edge presses against the cylinder wall. As shown in figure 22 on the following page, this serves the following functions:

(a) The pressure from the power stroke will force the upper edge of the ring into contact with the cylinder wall, forming a good seal.

(b) As the piston moves downward, the lower edge of the ring scrapes any oil that works past the oil control rings from the cylinder walls.

(c) On the compression and the exhaust strokes, the ring will glide over the oil, increasing the ring's life.

FIGURE 22. OPERATION OF COMPRESSION RINGS.

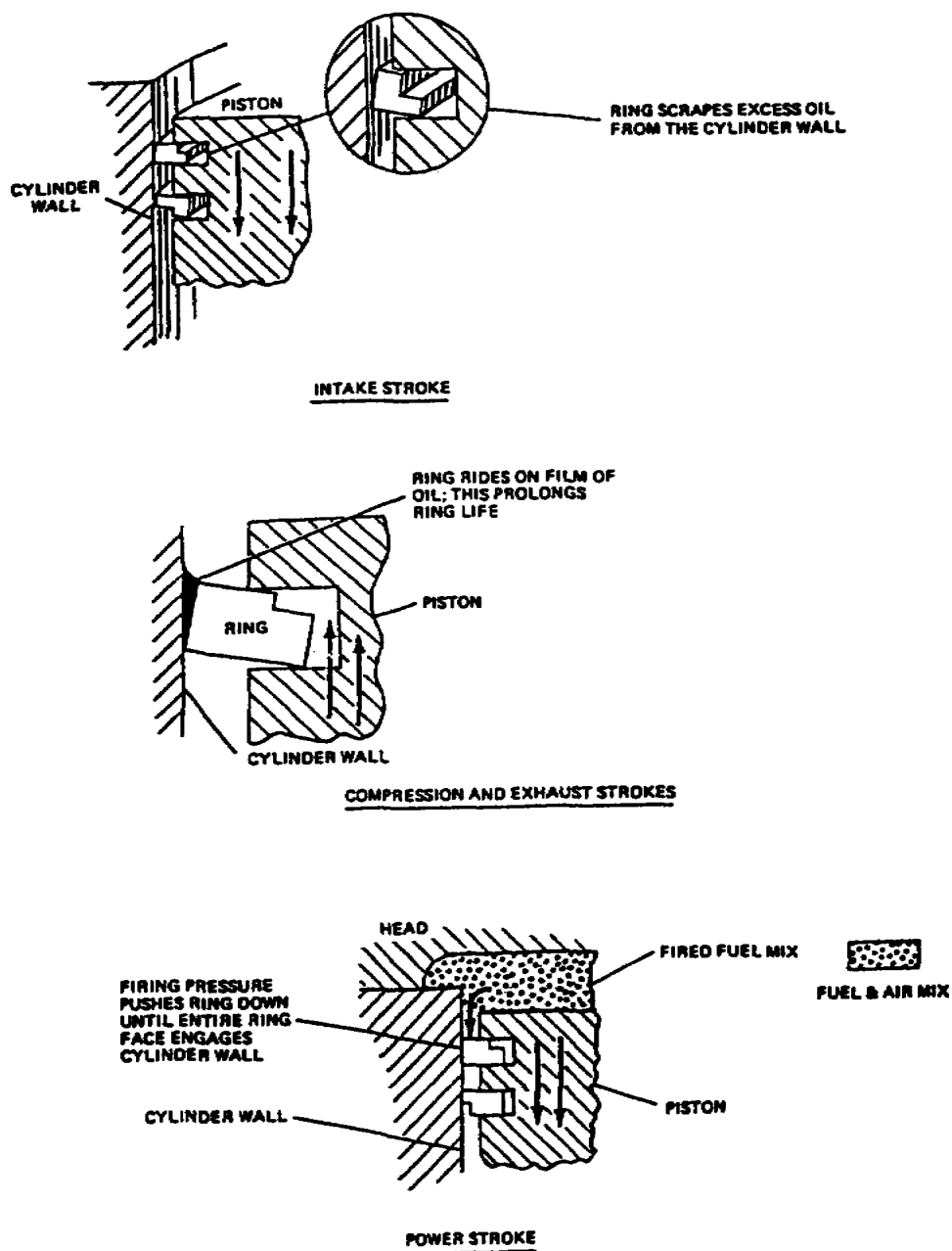
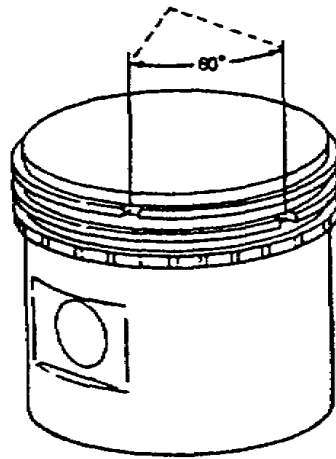


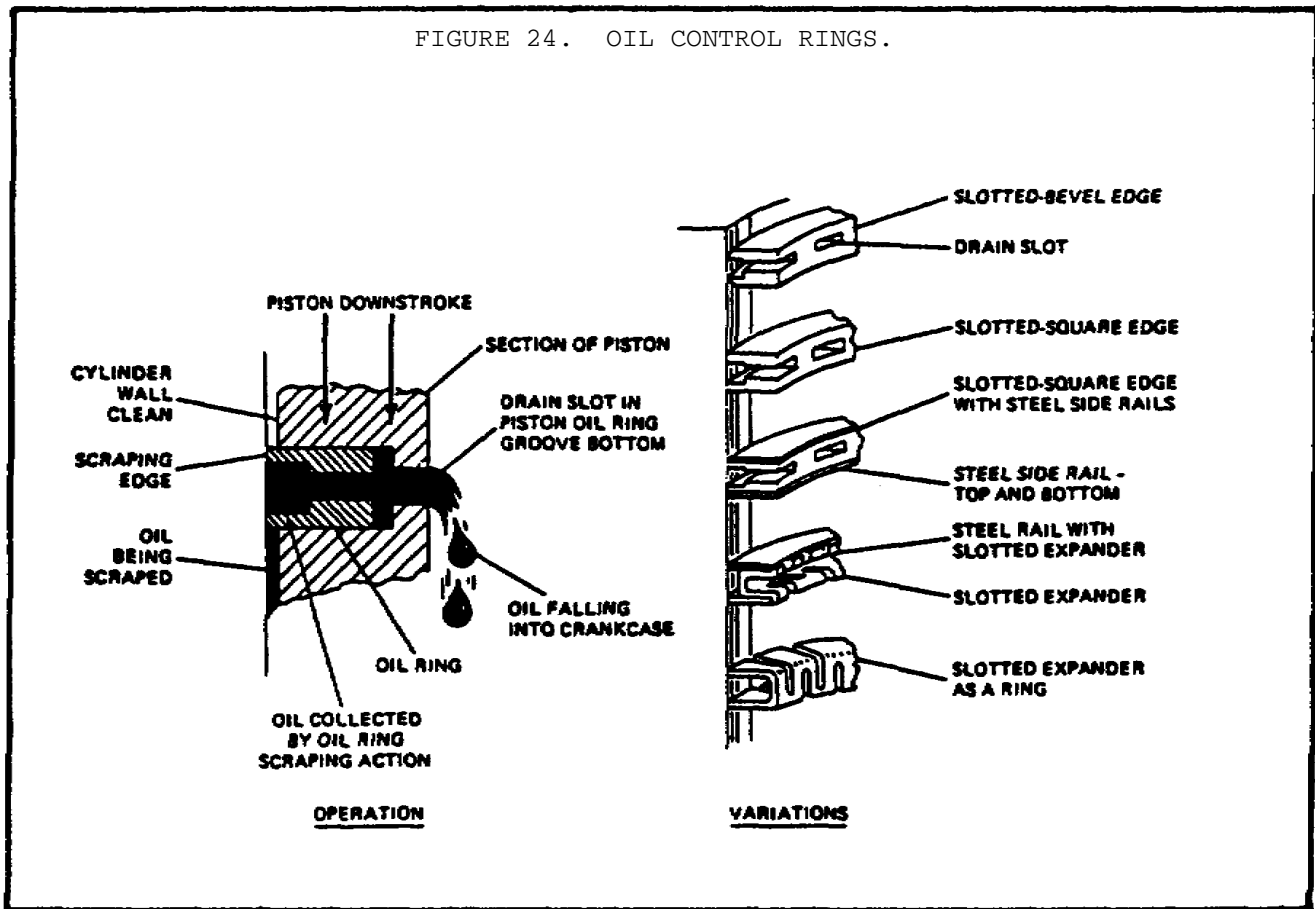
FIGURE 23. STAGGERING RING GAPS.



(5) *Second Compression Ring* (figure 23). The primary reason for using a second compression ring is to hold back any blowby that may have occurred at the top ring. A significant amount of the total blowby at the top ring will be from the ring gap. For this reason, the top and the second compression rings are assembled on the piston with their gaps 60° offset.

(6) *Oil Control Rings* (figure 24 on the following page). The oil control rings serve to control the lubrication of the cylinder walls. They do this by scraping the excess oil from the cylinder walls on the downstroke. The oil is then forced through slots in the piston ring and the piston ring groove draining back into the crankcase. The rings are made in many different configurations, from one-piece units to multipiece assemblies. Regardless of the configuration, all oil control rings work basically in the same way.

FIGURE 24. OIL CONTROL RINGS.



4. Conclusion

This task described the operation of both the two stroke and four stroke gasoline engines. In the next task, the operational information for the diesel engine will be discussed.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/TASK 2

LESSON 1

INTERNAL COMBUSTION ENGINES

TASK 2. Describe the principles, components, and operation of both the two stroke and four stroke diesel engines.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

In task 1, the gasoline piston engine was discussed. In this task, the operation of a four stroke gasoline engine and a four stroke diesel engine will be compared. In addition, information will be provided on the two stroke diesel engine and the combustion chambers.

2. Gasoline Engine Versus Diesel Engine

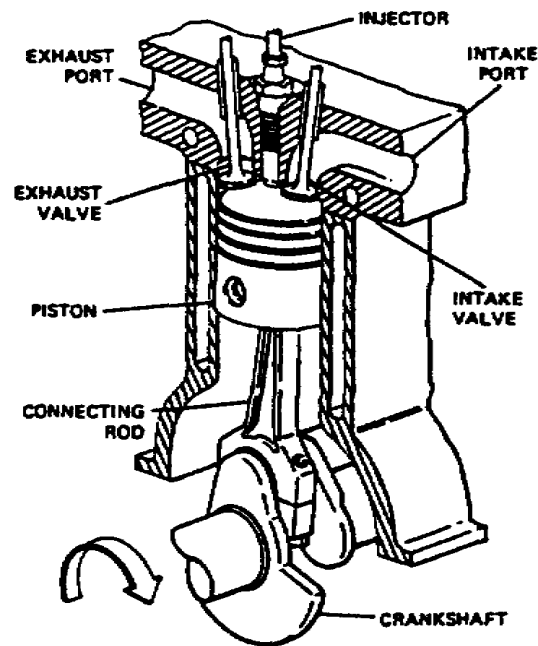
a. *General.* In many respects, the four stroke cycle gasoline engine and the four stroke cycle diesel engine are very similar. They both follow an operating cycle consisting of intake, compression, power, and exhaust strokes. They also share the same system for intake and exhaust valves. The component parts of a diesel engine are shown in (figure 25). The main differences between gasoline engines and diesel engines follow:

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/TASK 2

(1) In a diesel engine the fuel and air mixture is ignited by the heat generated by the compression stroke, versus the use of a spark ignition system in a gasoline engine. The diesel engine therefore needs no ignition system. For this reason, the gasoline engine is referred to as a spark ignition engine and a diesel engine is referred to as a compression ignition engine.

(2) In a diesel engine the fuel and air mixture is compressed to about one-twentieth of its original volume. In contrast, the fuel and air mixture in a gasoline engine is compressed to about one-eighth of its original volume. The diesel engine must compress the mixture this tightly to generate enough heat to ignite the fuel and air mixture. The contrast between the two engines is shown in figure 26 on the following page.

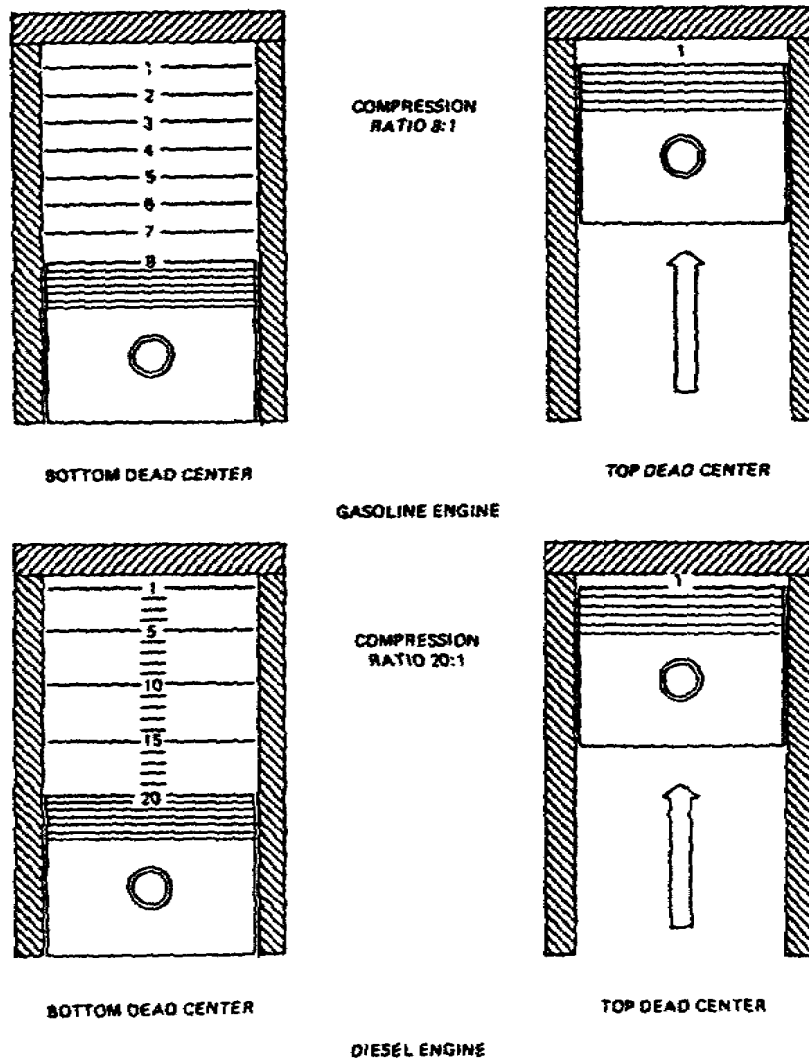
FIGURE 25. THE FOUR STROKE CYCLE DIESEL.



(3) The gasoline engine mixes the fuel and air before it reaches the combustion chamber. A diesel engine takes in only air through the intake port. Fuel is put into the combustion chamber directly through an injection system. The air and fuel then mix in the combustion chamber. This is illustrated in figure 27 on the following page.

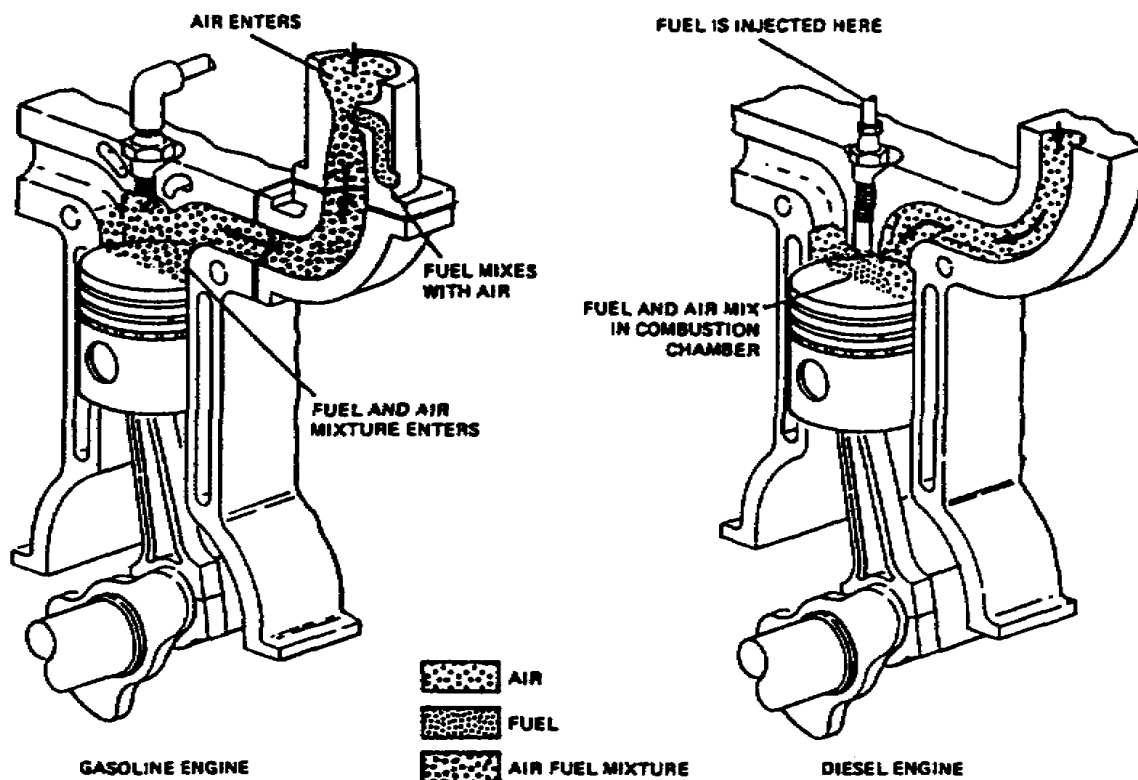
(4) The engine speed and the power output of a diesel engine are controlled by the quantity of fuel admitted to the combustion chamber. The

FIGURE 26. COMPARISON OF DIESEL AND GASOLINE ENGINE COMPRESSION STROKES.



amount of air is constant. This contrasts with the gasoline engine where the speed and power output are regulated by limiting the air entering the engine. This comparison is illustrated in figure 28 on the following page.

FIGURE 27. COMPARISON OF DIESEL AND GASOLINE ENGINE INTAKE STROKES.

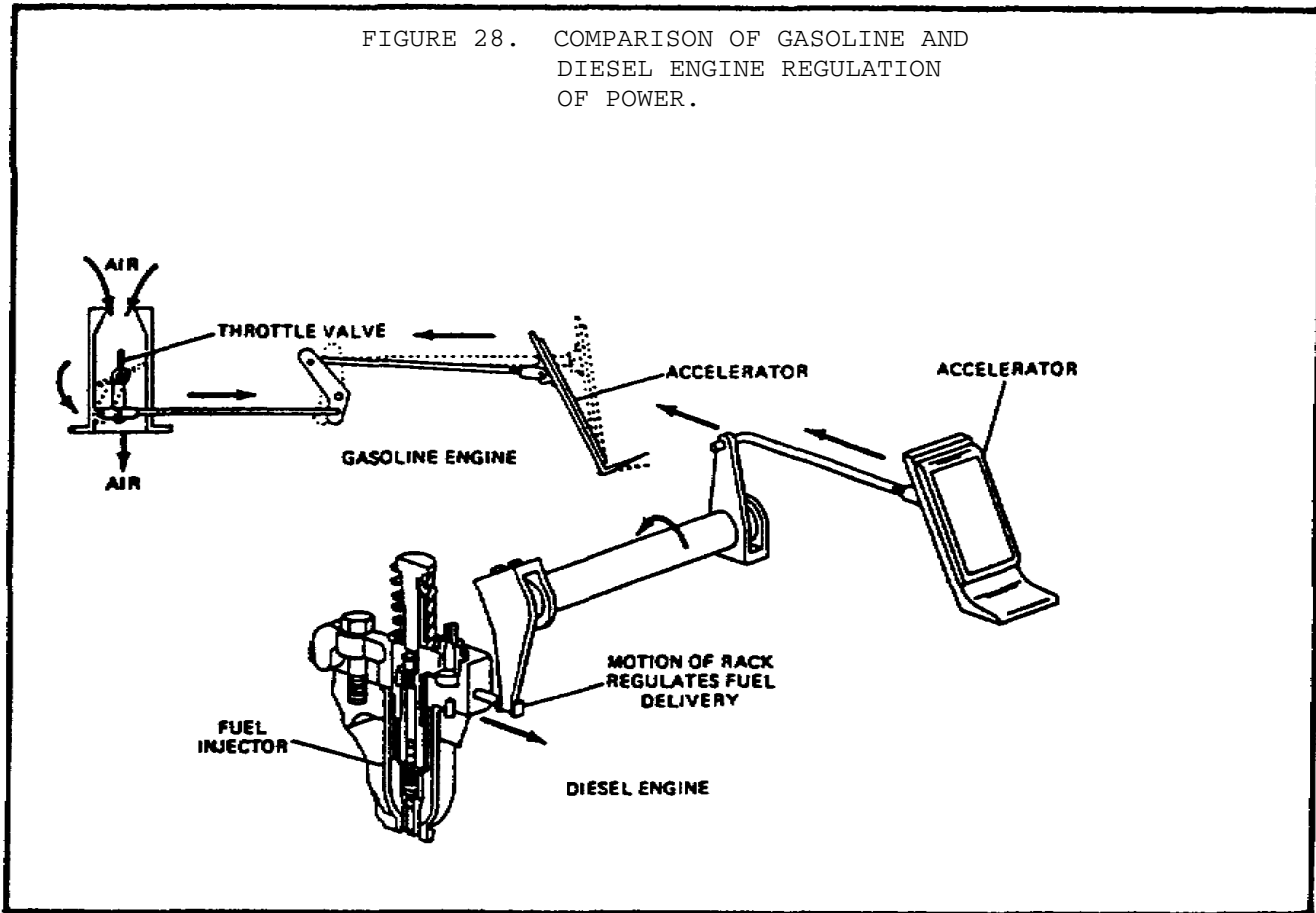


b. Operation.

(1) *Intake* (figure 29, view A, on page 32). The piston is at top dead center at the beginning of the intake stroke. As the piston moves downward, the intake valve opens. The downward movement of the piston draws air into the cylinder. As the piston reaches bottom dead center, the intake valve closes, ending the intake stroke.

(2) *Compression* (figure 29, view B). The piston is at bottom dead center at the beginning of the compression stroke. The piston moves upward,

FIGURE 28. COMPARISON OF GASOLINE AND DIESEL ENGINE REGULATION OF POWER.



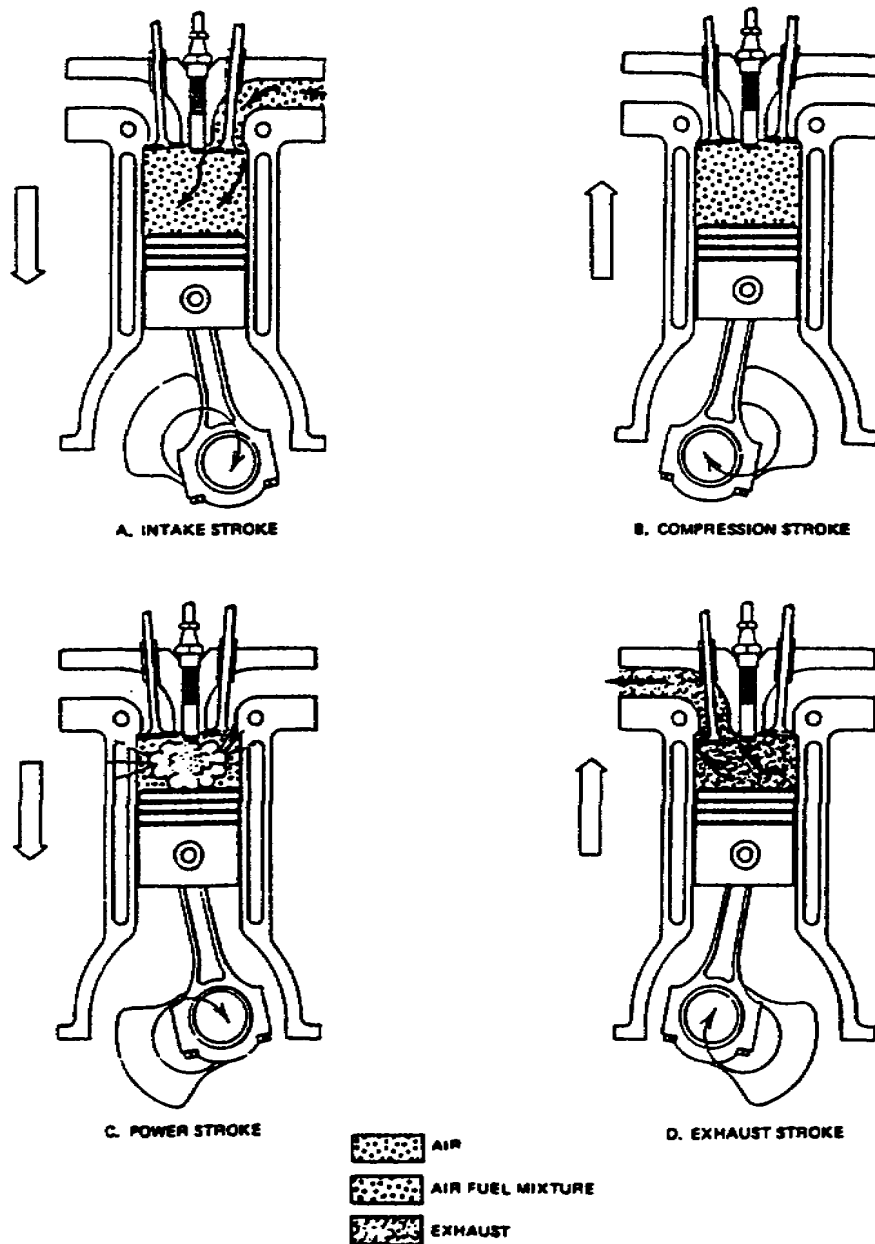
compressing the air. As the piston reaches top dead center, the compression stroke ends.

(3) *Power* (figure 29, view C, on the following page). The piston begins the power stroke at top dead center. At this time, air is compressed in the upper cylinder to as much as 500 psi (3448kPa). The tremendous pressure in the upper cylinder brings the temperature of the compressed air to approximately 1000° F (538° C). The power stroke then begins with the injection of a fuel charge into the engine. The heat of compression ignites the fuel as it is injected. The expanding force of the burning gases pushes the piston downward, providing power to the crankshaft. The power generated in a diesel engine is continuous throughout the power stroke. This contrasts with a gasoline engine, which has a power stroke with rapid combustion in the beginning and little or no combustion at the end.

(4) *Exhaust* (figure 29, view D). As the piston reaches bottom dead center on the power stroke, the power stroke ends and the exhaust stroke begins. The exhaust valve opens and the piston pushes the

burnt gas out through the exhaust port. As the piston reaches top dead center, the exhaust valve closes and the intake valve opens. The engine is then ready to begin another operating cycle.

FIGURE 29. FOUR STROKE CYCLE DIESEL.



c. *Advantages.*

(1) The diesel engine is much more efficient than a gasoline engine due to the much tighter compression of the fuel and air mixture. The diesel engine produces tremendous low-speed power, and gets much greater fuel mileage than its gasoline counterpart. This makes the engine very suitable for large trucks.

(2) The diesel engine requires no ignition tune-ups because there is no ignition system.

(3) Because diesel fuel is of an oily consistency and is less volatile than gasoline, it is not as likely to explode in a collision.

d. *Disadvantages.*

(1) The diesel engine must be made very heavy to have enough strength to withstand the tighter compression of the fuel and air mixture.

(2) The diesel engine is very noisy.

(3) Diesel fuel creates a large amount of fumes.

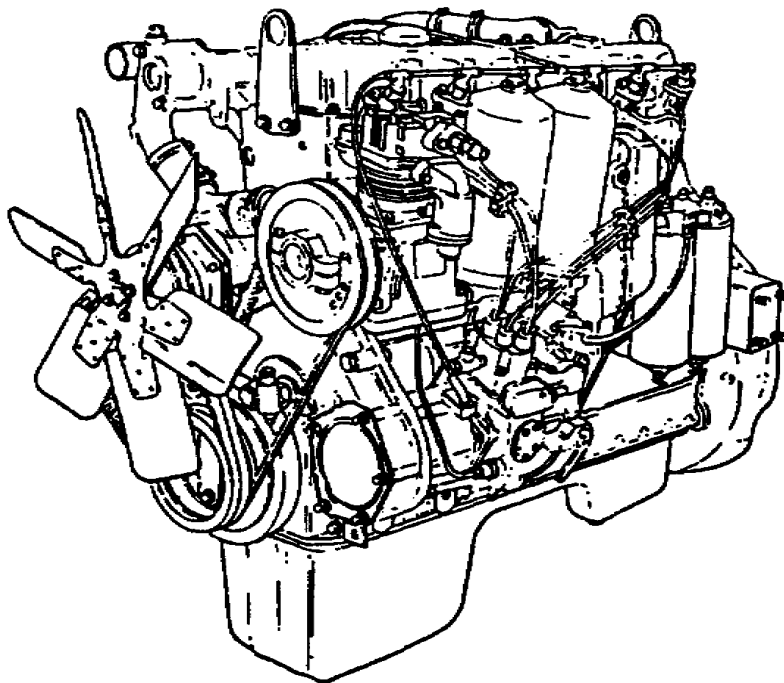
(4) Because diesel fuel is not very volatile, cold weather starting is difficult.

(5) A diesel engine operates well only in low-speed ranges in relation to gasoline engines. This creates problems when using them in passenger cars, which require a wide speed range.

e. *Usage.* Diesel engines are widely used in all types of heavy trucks, trains, and boats. In recent years, more attention has been focused on using diesels in passenger cars.

f. *Multifuel Engine* (figure 30 on the following page). The multifuel engine is basically a four stroke cycle diesel engine with the capability of operating on a wide variety of fuel oils without adjustment or modification. The fuel injection system is equipped with a device called a fuel density compensator. Its job is to vary the amount of fuel, keeping the power output constant regardless of the fuel being used. The multifuel engine uses a spherical combustion chamber to aid in thorough mixing, complete combustion, and minimized knocks.

FIGURE 30. MULTIFUEL ENGINE.



3. Two Stroke Cycle Diesel

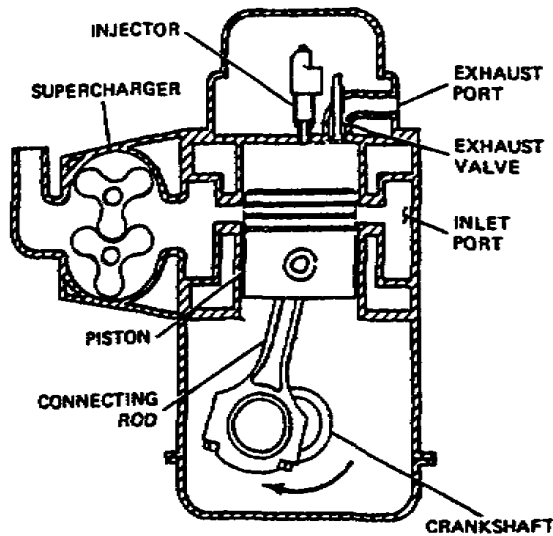
a. *General.* The two stroke cycle diesel (figure 31 on the following page) is a hybrid engine sharing operating principles of both a two stroke cycle gasoline engine and a four stroke cycle diesel engine. The major features of the engine are as follows:

(1) It completes an operating cycle every two piston strokes or every crankshaft revolution. Like a two stroke cycle gasoline engine, it provides a power stroke every time the piston moves downward.

(2) It is a compression ignition engine, making it a true diesel engine.

(3) It uses an exhaust valve on top of the combustion chamber as in a four stroke cycle diesel engine. Intake ports are cut into the cylinder wall as in a two stroke cycle gasoline engine.

FIGURE 31. THE TWO STROKE CYCLE DIESEL ENGINE.



(4) It mixes its fuel and air in the combustion chamber as in a four stroke cycle diesel engine. The air enters through the intake ports and the fuel is injected into the combustion chamber by the fuel injection system.

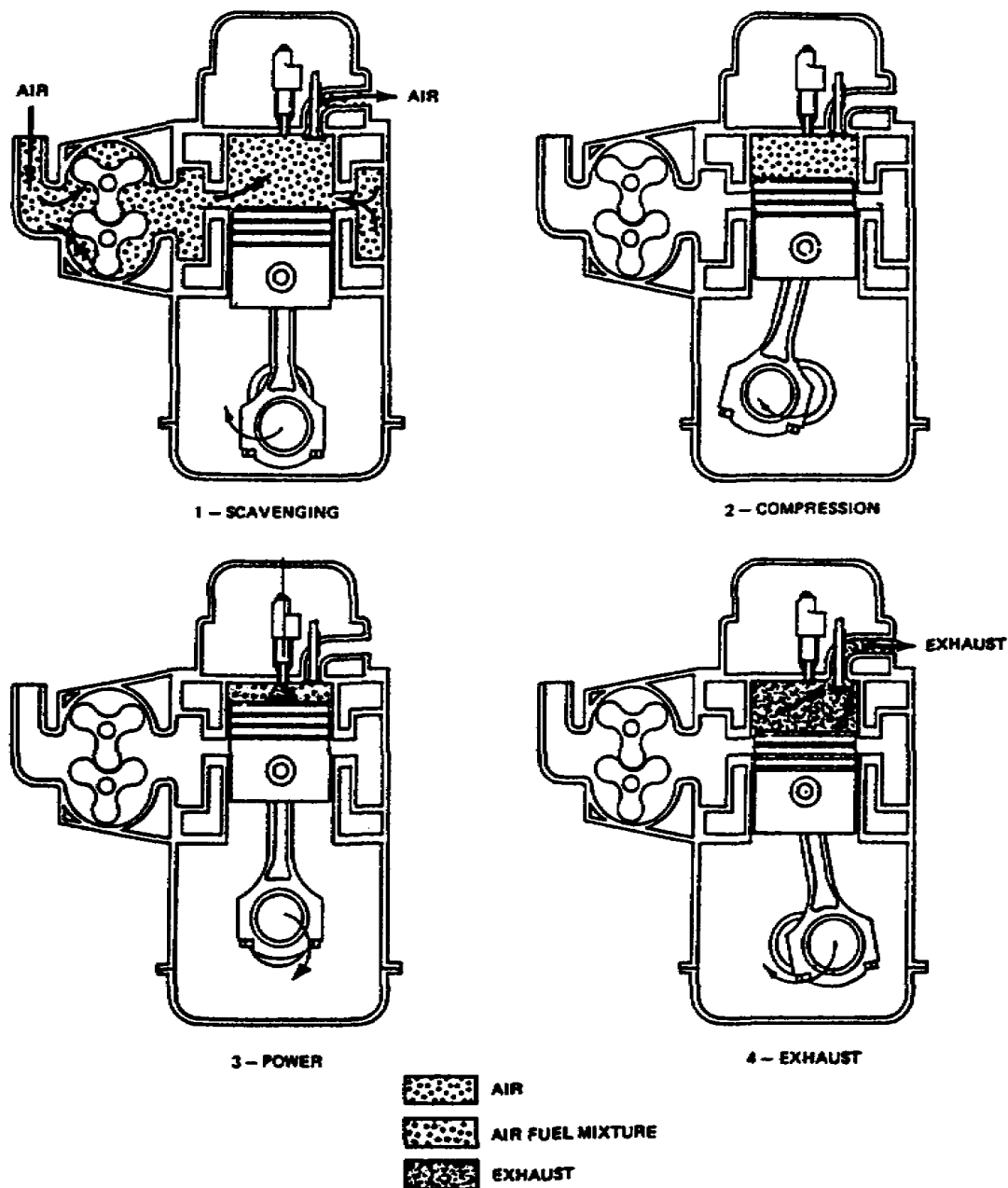
(5) The air supply to the engine is constant while the speed and power output of the engine is regulated by controlling the quantity of fuel injected into the combustion chamber.

(6) Unlike any of the other engine types, the two stroke cycle diesel engine must have a supercharger to force the intake air into the upper cylinder. The most common type used is the Rootes.

b. *Operation* (figure 32 on the following page).

(1) *Scavenging*. Scavenging begins with the piston at bottom dead center. The intake ports are uncovered in the cylinder wall and the exhaust valve opens. Air is forced into the upper cylinder by the supercharger. As the air is forced in, the burnt gases from the previous operating cycle are forced out.

FIGURE 32. THE TWO STROKE DIESEL CYCLE.



(2) *Compression.* As the piston moves toward top dead center, it covers the intake ports. The exhaust valve closes at this point sealing the upper cylinder. As the piston continues upward, the air in the cylinder is tightly compressed. As in the four stroke cycle diesel, a tremendous amount of heat is generated by the compression.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/TASK 2

(3) *Power.* As the piston reaches top dead center, the compression stroke ends. Fuel is injected at this point. The intense heat of compression causes the fuel to ignite. The burning fuel pushes the piston down, giving power to the crankshaft. The power stroke ends when the piston gets down to the point where the intake ports are uncovered. At about this point, the exhaust valve opens and scavenging begins again.

c. *Advantages.* The two stroke cycle diesel engine has all of the advantages that a four stroke cycle engine has over a gasoline engine, plus the following:

(1) Because it is a two stroke cycle engine, it will run smoother than its four stroke cycle counterpart. This is because there is a power stroke generated for every crankshaft revolution.

(2) The two stroke cycle diesel has a less complicated valve train because it does not use intake valves.

d. *Disadvantages.*

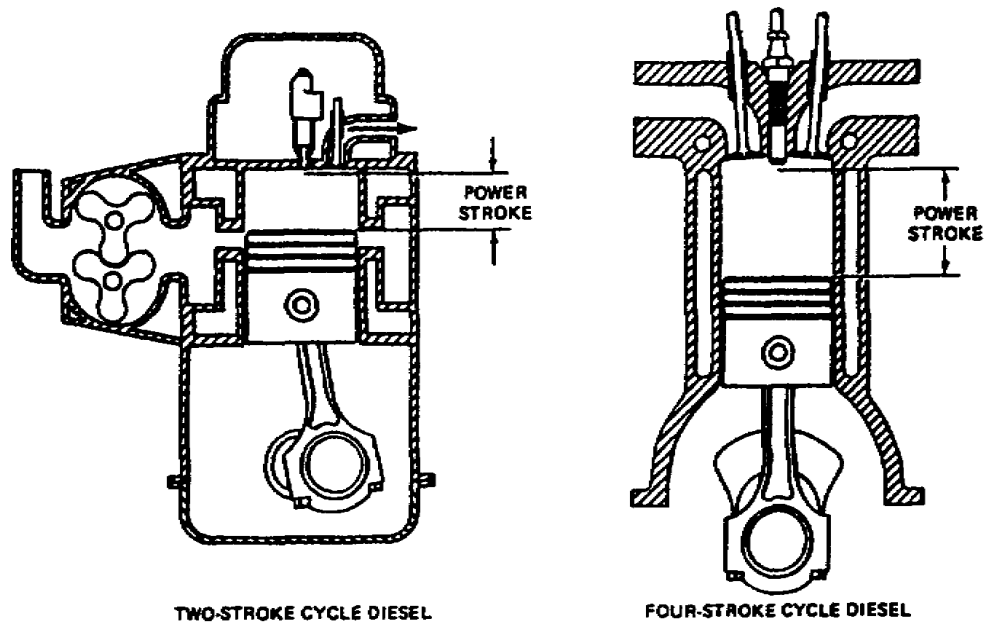
(1) The two stroke cycle engine must use a supercharger to force in the intake air and push out the burnt exhaust gases. This is because the movement of the piston is not such that it will accomplish this naturally. The supercharger uses engine power to operate.

(2) The two stroke cycle diesel uses either two or four exhaust valves per cylinder, which complicates the valve mechanism.

(3) As with the two stroke cycle gasoline engine, the diesel counterpart will not produce twice as much power as a four stroke cycle engine, even though it produces twice as many power strokes. By studying figure 33 on the following page, it can be seen that the power stroke occupies only a portion of the downstroke of the piston in a two stroke cycle diesel. In a four stroke cycle diesel, the power stroke lasts from top dead center to bottom dead center.

e. *Usage.* The two stroke cycle diesel is used in most of the same applications as the four stroke cycle diesel.

FIGURE 33. COMPARISON OF TWO AND FOUR STROKE CYCLE DIESEL POWER STROKE LENGTHS.



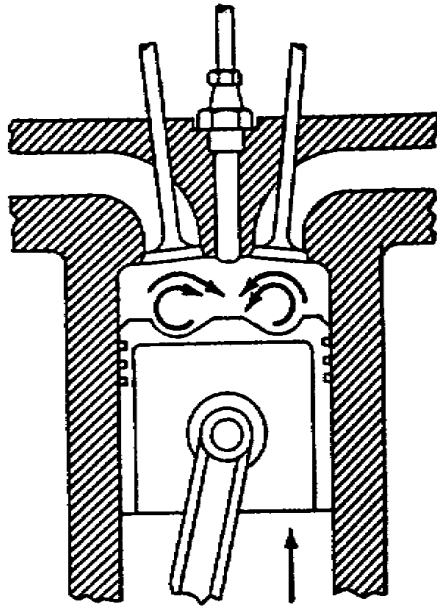
4. Combustion Chamber Design

a. *General.* The fuel injected into the combustion chamber must be mixed thoroughly with the compressed air and be distributed as evenly as possible throughout the chamber if the engine is to function at maximum driveability. The well-designed diesel engine uses a combustion chamber that is designed for the engine's intended usage. The injectors used in the engine should compliment the combustion chamber. The combustion chambers described in the following subparagraphs are the most common and cover virtually all of the designs that are used in current automotive applications.

b. *Open Chamber* (figure 34 on the following page). The open chamber is the simplest form of chamber. It is suitable for slow-speed, four stroke cycle engines, and is used widely in two stroke cycle diesel engines. In the open chamber, the fuel is injected directly into the space at the top of the cylinder. The combustion space, formed by the top of the piston and the cylinder head, is usually shaped to provide a swirling action of the air as the piston comes up on the compression stroke.

There are no special pockets, cells, or passages to aid the mixing of the fuel and air. This type of chamber requires a higher injection pressure and a greater degree of fuel atomization than is required by other combustion chambers to obtain an acceptable level of fuel mixing. This chamber design is very susceptible to ignition lag.

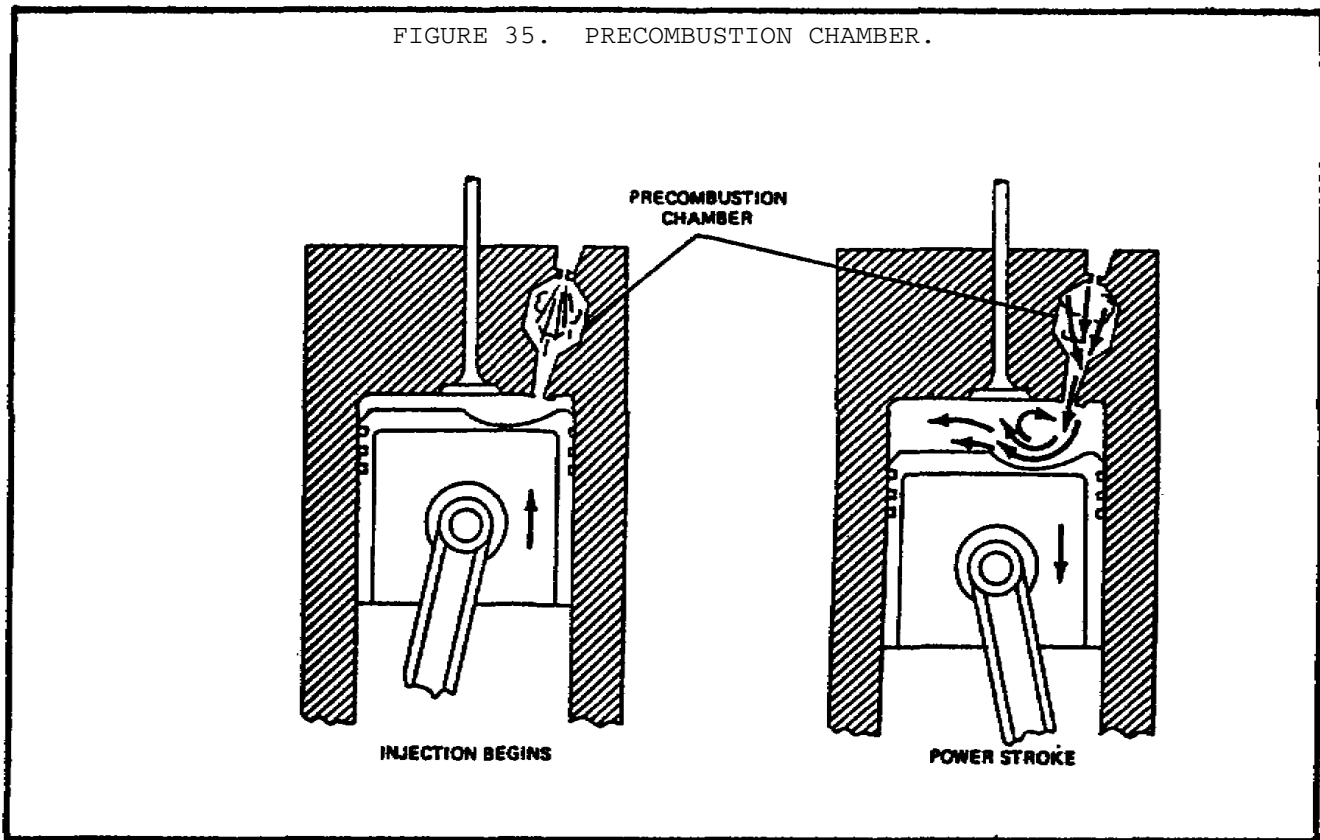
FIGURE 34. OPEN COMBUSTION CHAMBER.



c. *Precombustion Chamber* (figure 35 on the following page). The precombustion chamber is an auxiliary chamber at the top of the cylinder. It is connected to the main combustion chamber by a restricted throat or passage. The precombustion chamber conditions the fuel for final combustion in the cylinder. A hollowed-out portion of the piston top causes turbulence in the main combustion chamber as the fuel enters from the precombustion chamber to aid in mixing with air. The following steps occur during the combustion process:

(1) During the compression stroke of the engine, air is forced into the precompression chamber and, because the air is compressed, it is hot. At the beginning of injection, the precombustion chamber contains a definite volume of air.

FIGURE 35. PRECOMBUSTION CHAMBER.



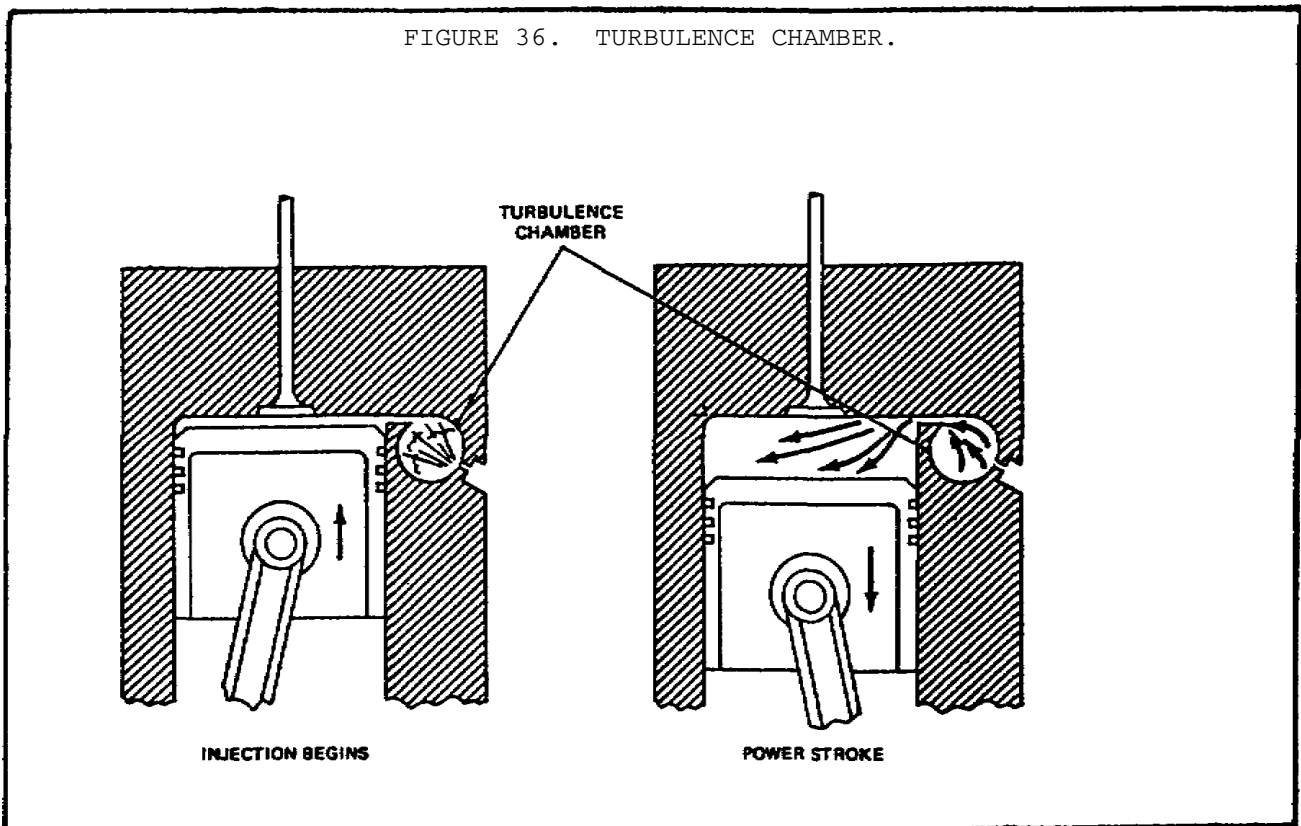
(2) As the injection begins, combustion begins in the precombustion chamber. The burning of the fuel, combined with the restricted passage to the main combustion chamber, creates a tremendous amount of pressure in the chamber. The pressure and the initial combustion cause a superheated fuel charge to enter the main combustion chamber at a tremendous velocity.

(3) The entering mixture hits the hollowed-out piston top, creating turbulence in the chamber to ensure complete mixing of the fuel charge with the air. This mixing ensures even and complete combustion. This chamber design will provide satisfactory performance with low fuel injector pressures and coarse spray patterns, because a large amount of vaporization takes place in the combustion chamber. This chamber also is not very susceptible to ignition lag, making it more suitable for high-speed applications.

d. *Turbulence Chamber* (figure 36 on the following page). The turbulence chamber is similar in appearance to the precombustion chamber, but its function is different. There is very little clearance between the top of the piston and the head, so that a high percentage of the air between the piston and the cylinder head is forced into the

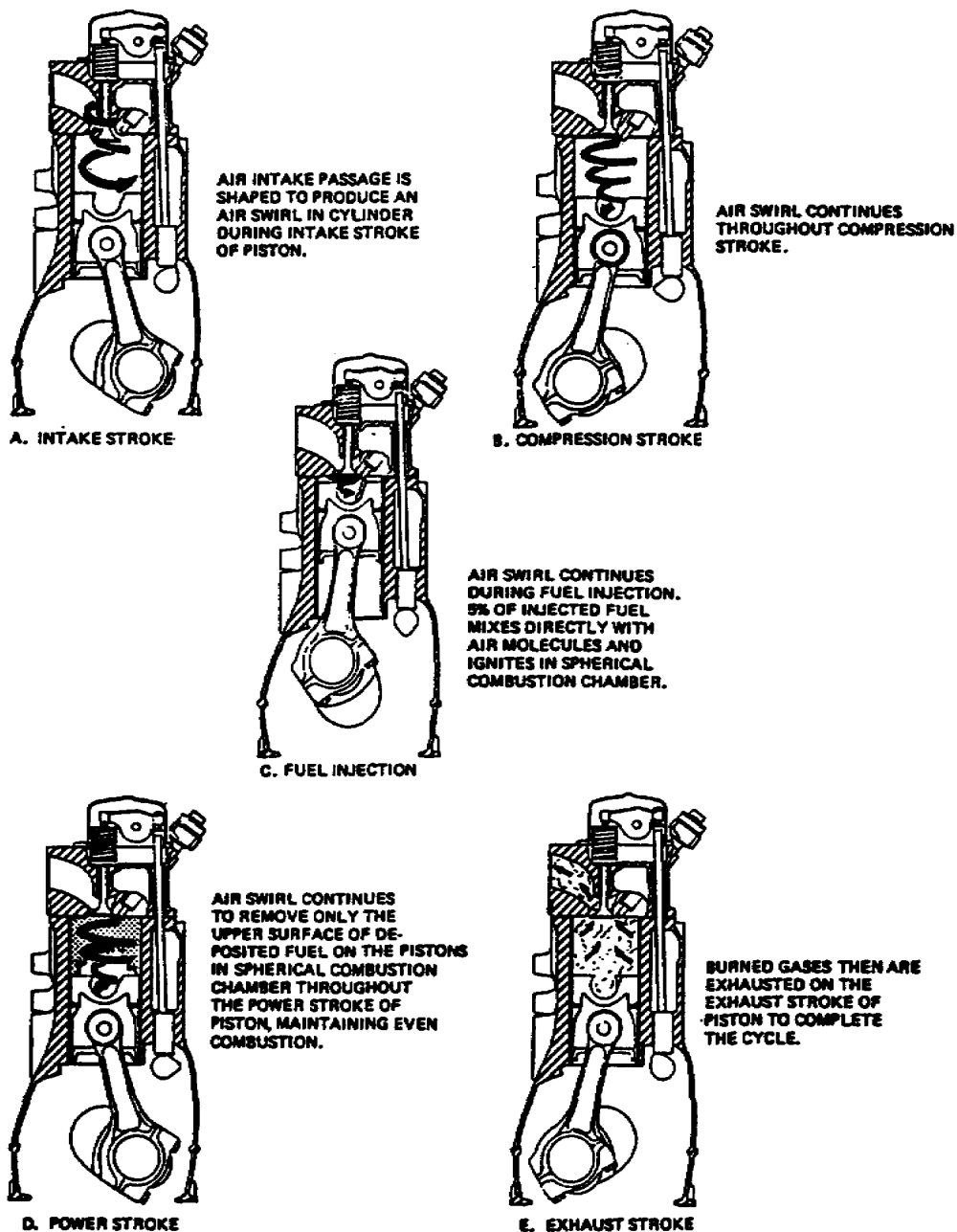
turbulence chamber during the compression stroke. The chamber usually is spherical, and the opening through which the air must pass becomes smaller as the piston reaches the top of the stroke, thereby increasing the velocity of the air in the chamber. This turbulence speed is approximately 60 times crankshaft speed. The fuel injection is timed to occur when the turbulence in the chamber is the greatest. This ensures a thorough mixing of the fuel and the air, with the result that the greater part of combustion takes place in the turbulence chamber itself. The pressure created by the expansion of the burning gases is the force that drives the piston downward on the power stroke.

FIGURE 36. TURBULENCE CHAMBER.



e. *Spherical Combustion Chamber* (figure 37 on the following page). The spherical combustion chamber is principally designed for use in the multifuel engine. The chamber consists of a basic open-type chamber with a spherical-shaped relief in the top of the piston head. The chamber works in conjunction with a strategically positioned injector and an intake port that produces a swirling effect on the intake air as it enters the chamber. Operation of the chamber is as follows:

FIGURE 37. SPHERICAL CHAMBER.



(1) As the air enters the combustion chamber, a swirl effect is introduced to it by the shape of the intake port (figure 37, view A).

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/TASK 2

(2) During the compression stroke, the swirling motion of the air continues as the temperature in the chamber increases (figure 37, view B, on the previous page).

(3) As the fuel is injected, approximately 95 percent of it is deposited on the head of the piston; the remainder mixes with the air in the spherical combustion chamber (figure 37, view C).

(4) As combustion begins, the main portion of the fuel is swept off the piston head by the high-velocity swirl that was created by the intake and the compression strokes. As the fuel is swept off the head, it burns through the power stroke, maintaining even combustion and eliminating detonation (figure 37, view D and E).

6. Conclusion

This concludes the explanation of the gasoline and diesel internal combustion engines. In the next lesson, operational information on the subsystems of internal combustion engines will be discussed.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/PE 1

PRACTICAL EXERCISE 1

1. Instructions

Read the scenario and respond to the requirements that follow the scenario.

2. Scenario

SSG Fredrick has been attending an Army NCO development course for four weeks. This week the subject has been internal combustion engines, which he understands completely. One of his classmates, SSG Olson, is not very sure about this subject and is nervous about the exam which is coming up in two days.

SSG Olson asks SSG Fredrick if he would mind helping him study for the exam. SSG Fredrick agrees to help and decides that the best way to prepare SSG Olson for the exam is to give him a pretest.

3. Requirement

Below is a list of questions that SSG Fredrick feels will give SSG Olson a general understanding of internal combustion engines.

- a. If the engine is going to operate, the fuel and air mixture must be fed into the _____.
- b. What component opens and closes the intake and exhaust valves in a timed sequence?
- c. How many revolutions does the crankshaft rotate when the piston moves from top dead center to bottom dead center?
- d. What are the four strokes of operation in a piston engine?
- e. What system ignites the fuel and air mixture in the combustion chamber at the precise moment needed to make the engine run?
- f. What type of engine is used almost exclusively in very small equipment because it is lightweight and able to run at very high speeds due to the absence of a mechanical valve train?

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- g. What piston ring keeps the engine's lubrication oil from getting into the combustion chamber?
- h. Why is a diesel engine referred to as a compression ignition engine?
- i. Why is the diesel engine much more efficient than the gasoline engine?
- j. The two stroke cycle engine must use a supercharger to force in the intake air and push out the burnt exhaust gases because _____.
- k. What type of combustion chamber is designed principally for use in the multifuel engine?

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 1/PE 1

LESSON 1. PRACTICAL EXERCISE - ANSWERS

1. Requirement
 - a. combustion chamber.
 - b. The valve train.
 - c. Exactly one-half.
 - d. Intake, compression, power, and exhaust.
 - e. The ignition system.
 - f. The two stroke cycle engine.
 - g. The oil control ring.
 - h. The fuel and air mixture is ignited by the heat generated by the compression stroke.
 - i. The diesel engine is much more efficient than the gasoline engine due to the much tighter compression of the fuel and air mixture.
 - j. the movement of the piston is not such that it will accomplish this naturally and the supercharger uses engine power to run it.
 - k. The spherical combustion chamber.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 2/TASK 1

LESSON 2

INTERNAL COMBUSTION ENGINE SUBSYSTEMS

TASK 1. Describe the principles, components, and operation of the turbochargers, intake, and exhaust systems.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

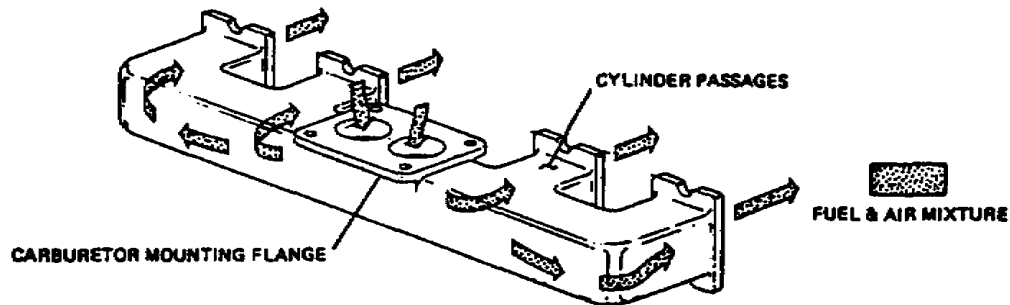
In Lesson one, the principles, components, and operation of diesel and gasoline engines were described. The knowledge obtained from this information can be used to understand the subsystems of the internal combustion engines discussed within this lesson. These subsystems are: intake system; exhaust system; turbochargers; lubrication system; and cooling system.

This task will introduce and describe the intake system, turbochargers, and exhaust system.

2. Intake System

- a. *Purpose.* To draw air from an outside source into the engine cylinder.
- b. *Intake Manifold* (figure 38 on the following page). The intake manifold should:

FIGURE 38. TYPICAL INTAKE MANIFOLD.

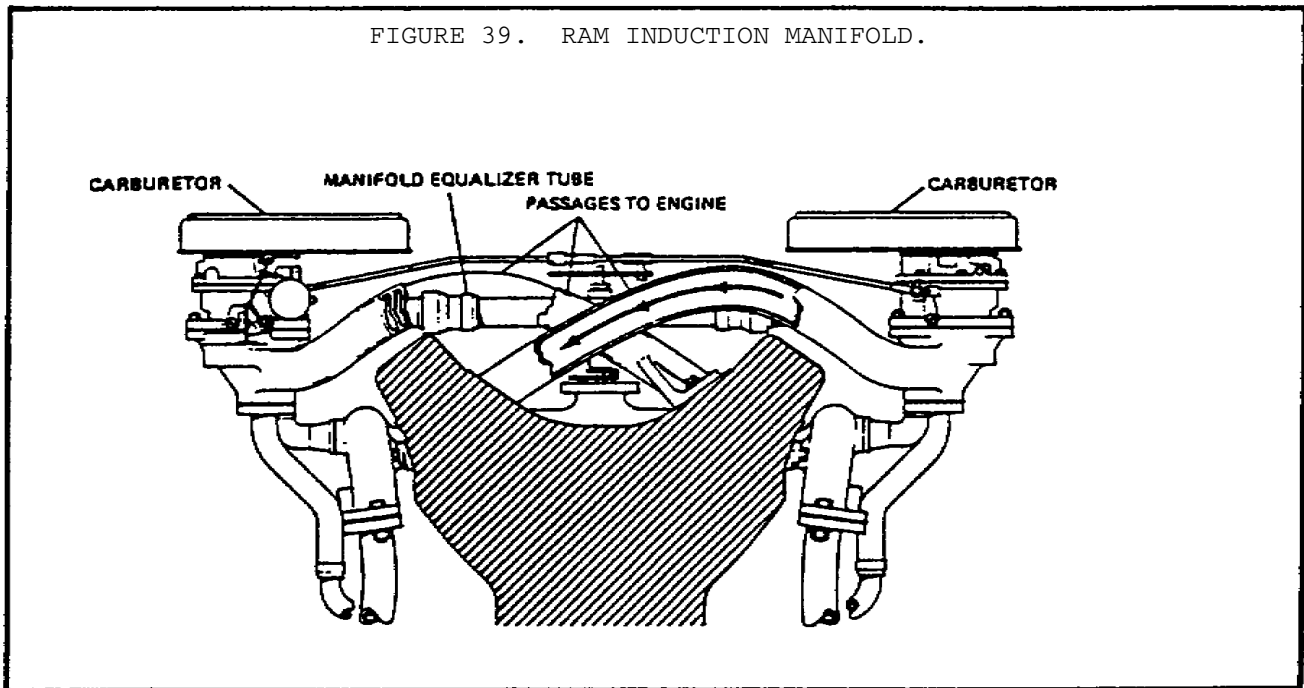


(1) Deliver the mixture to the cylinders in equal quantities and proportions. This is important for smooth engine performance. The lengths of the passages should be as near equal as possible to distribute the mixture equally. In a gasoline engine, there is a series of pipes or passages through which the fuel-air mixture from the carburetor is directed to the engine cylinders on the intake stroke. The diesel engine does not have a carburetor so the air is directed into the cylinder and the fuel is injected to mix with the air.

(2) Help to keep the vaporized mixture from condensing before it reaches the combustion chamber. Because the ideal mixture should be vaporized completely as it enters the combustion chamber, this is very important. To reduce the condensing of the mixture, the manifold passages should be designed with smooth walls and a minimum of bends that collect fuel. Smooth flowing intake manifold passages also increase volumetric efficiency, the method of measuring an engines ability to take in its intake mixture.

(3) Aid in the vaporization of the mixture. To do this, the intake manifold should provide a controlled system of heating, as described in paragraph 3c on page 53. This system must heat the mixture enough to aid in vaporization without heating to the point of significantly reducing volumetric efficiency.

FIGURE 39. RAM INDUCTION MANIFOLD.

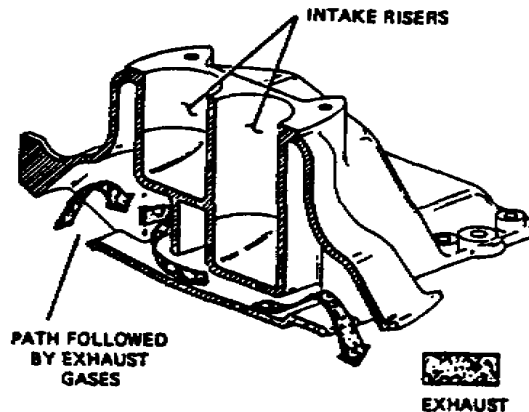


c. *Ram Induction* (figure 39). Intake manifolds can be designed to provide optimum performance for a given engine speed range by varying the length of the passages. The inertia of the moving intake mixture will cause it to bounce back and forth in the manifold passage from the end of one intake stroke to the beginning of the next intake stroke. If the passage is the proper length so that the next intake stroke is just beginning as the mixture is rebounding, the inertia of the mixture will cause it to ram itself into the cylinder. This will increase the volumetric efficiency of the engine in the designated speed range. It should be noted that the ram manifold will serve no useful purpose outside of its designated speed range.

d. *Heating the Mixture*. As stated in paragraph 2b(3) on page 48, providing controlled heat for the incoming mixture is very important for good performance. The heating of the mixture may be accomplished by one or both of the following methods:

(1) Directing a portion of the exhaust through a passage in the intake manifold (figure 40 on the following page). The heat from the exhaust will transfer and heat the mixture. The amount of exhaust that is diverted into the intake manifold heat passage is controlled by the manifold heat control valve.

FIGURE 40. EXHAUST-HEATED INTAKE MANIFOLD.



(2) Directing the engine coolant, which is laden with engine heat, through the intake manifold on its way to the radiator (figure 41 on the following page).

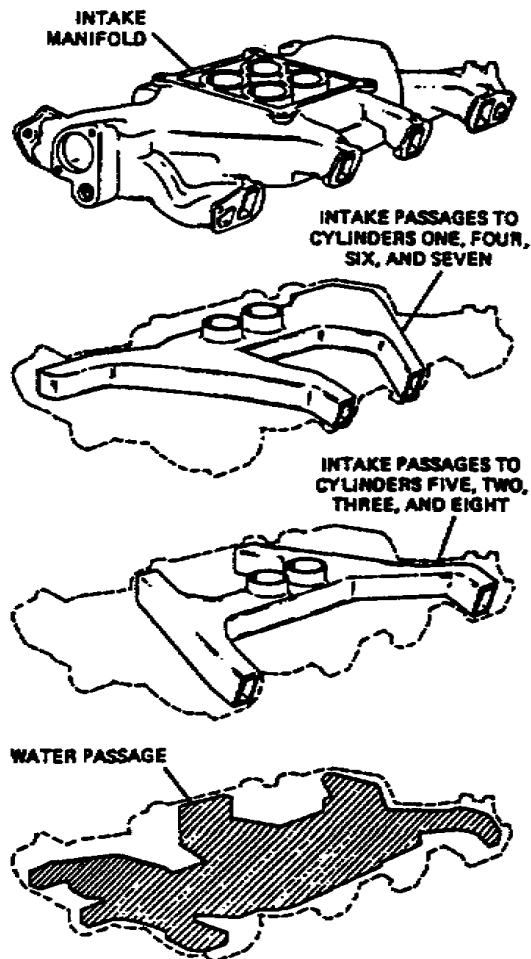
e. *Intake Manifold Flame Heater System* (figure 42 on page 52). Engines are equipped with a flame-type manifold heater for heating the induction air during cold weather starting and warmup operations.

(1) *Operation.* The flame heater assembly is composed of a housing, spark plug, flow control nozzle, and two solenoid control valves. The spark plug is energized by the flame heater ignition unit. The nozzle sprays fuel under pressure into the intake manifold elbow assembly. The fuel vapor is ignited by the spark plug and burns in the intake manifold, heating the air before it enters the combustion chambers.

(2) Because this system uses fuel from the fuel tank of the vehicle, its components must be compatible with all approved fuels when the system is used with a multifuel engine.

(a) The flame fuel pump assembly is a rotary type, driven by an enclosed electric motor. The fuel pump receives fuel from the vehicle fuel tank through the vehicle's supply pump and delivers it to the spray nozzle. The pump is energized by an ON-OFF switch located on the instrument panel.

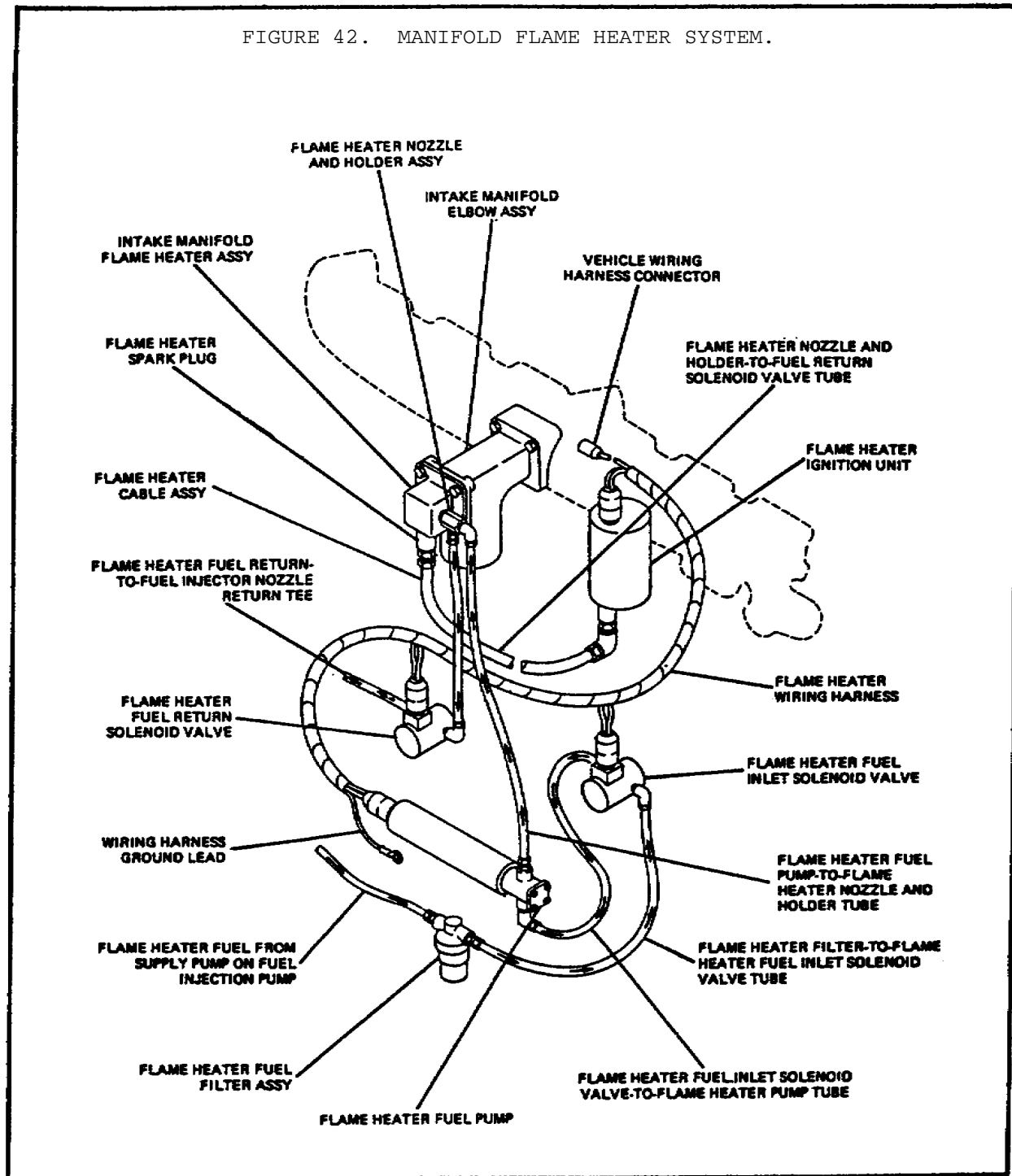
FIGURE 41. WATER-HEATED INTAKE MANIFOLD.



(b) The intake manifold flame heater system has a filter to remove impurities from the fuel before it reaches the nozzle.

(c) Two fuel solenoid valves are used in the flame heater system. The valves are energized (open) whenever the flame heater system is activated. The valves ensure that fuel is delivered only when the system is operating. They stop fuel flow the instant the engine or heater system is shut down.

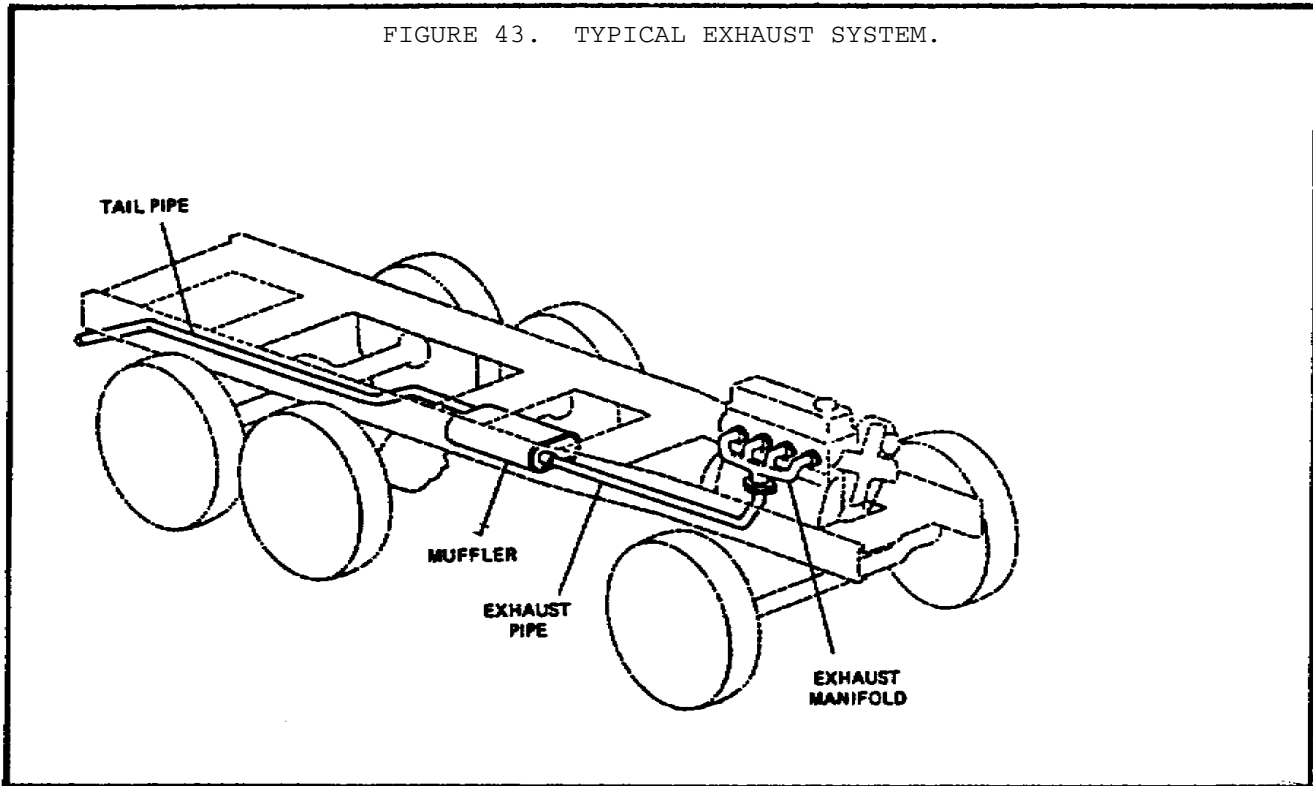
FIGURE 42. MANIFOLD FLAME HEATER SYSTEM.



3. Exhaust System

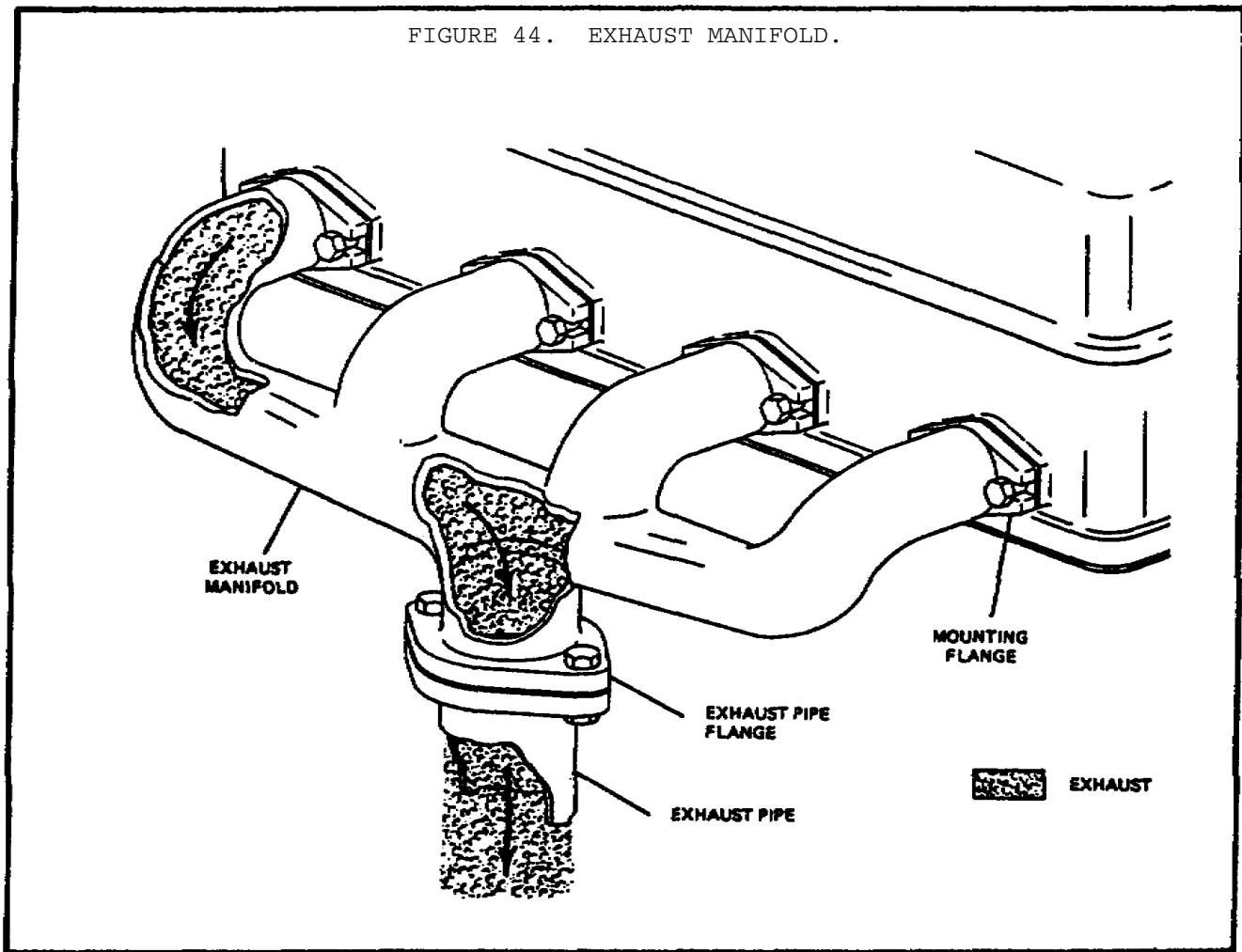
a. *Purpose* (figure 43 on the following page). The waste products of combustion are carried from the engine to the rear of the vehicle by the exhaust system, where they are expelled to the atmosphere. The exhaust system also serves to lessen engine noise.

FIGURE 43. TYPICAL EXHAUST SYSTEM.



b. *Exhaust Manifold* (figure 44 on the following page). The exhaust manifold connects all of the engine cylinders to the exhaust system and is usually made of cast iron. If the exhaust manifold is formed properly, it can create a scavenging action that will cause all of the cylinders to help each other get rid of exhaust gases. Back pressure (the force that the pistons must exert to push out the exhaust gases) can be reduced by making the manifold with smooth walls and without sharp bends. All of these factors are taken into consideration when the exhaust manifold is designed, and the best possible manifold is manufactured to fit into the confines of the engine compartment.

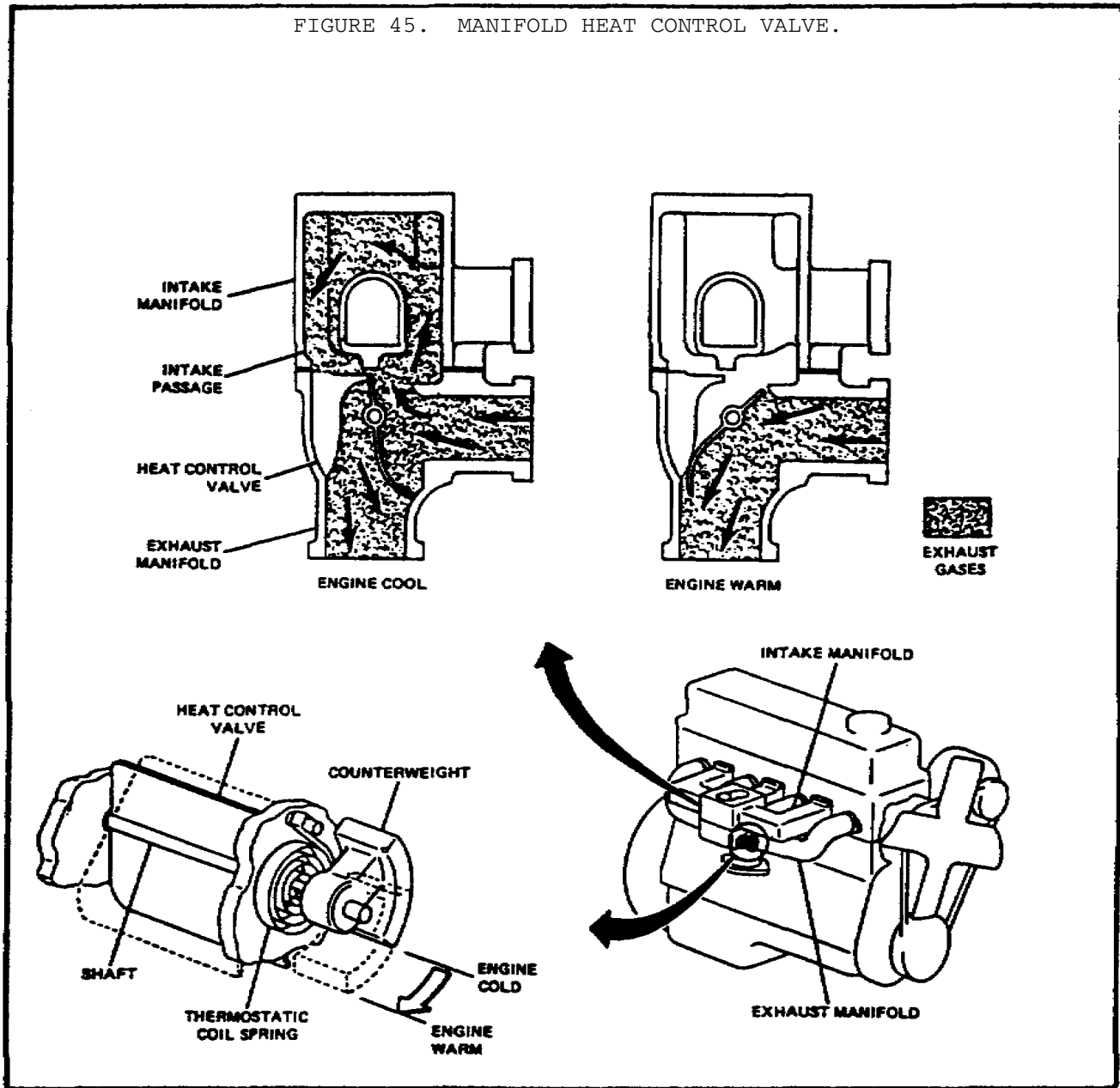
c. *Manifold Heat Control Valve* (figure 45 on page 55). A valve is placed in the exhaust manifold on some gasoline engines to deflect exhaust gases toward a hot spot in the intake manifold until the engine reaches operating temperature. This valve is a flat metal plate that is the same shape as the opening it controls. It pivots on a shaft and is operated by a thermostatic coil spring. The spring pulls the valve closed against a counterweight before warmup. The spring expands as the engine warms up and the counterweight pulls the valve open.



d. *Muffler* (figure 46 on page 56). The muffler reduces the acoustic pressure of exhaust gases to discharge them to the atmosphere with a minimum of noise. The muffler is usually located at a point about midway in the vehicle, with the exhaust pipe between it and the exhaust manifold, and the tailpipe leading from it to the rear of the vehicle. The inlet and the outlet of the muffler are usually slightly larger than their connecting pipes so that it may be hooked up by slipping over them. The muffler is then secured to the exhaust pipe and the tailpipe by clamps. A typical muffler has several concentric chambers with openings between them. The gas enters the inner chamber and expands as it works its way through a series of holes in the other chambers and finally to the atmosphere. Mufflers must be designed to quiet exhaust noise while creating a minimum of back pressure. Excessive back pressure could cause loss of engine power, economy, and also cause overheating. Exhaust system components are usually made of steel. They are usually coated with aluminum or zinc to retard corrosion.

Stainless steel is also used in exhaust systems, in limited quantities due to its high cost. A stainless steel exhaust system will last indefinitely.

FIGURE 45. MANIFOLD HEAT CONTROL VALVE.



4. Turbochargers

Turbocharging is a method of increasing engine volumetric efficiency by forcing the air-fuel mixture into the intake rather than merely allowing the pistons to draw it in naturally. A turbocharger (figure 47 on page 57) uses the force of the engine exhaust stream to force the air-fuel mixture into the engine. It consists of a housing

containing two chambers. One chamber contains a turbine that is spun as hot exhaust gases are directed against it. The turbine shaft drives an impeller that is located in the other chamber. The spinning impeller draws an air-fuel mixture from the carburetor and forces it into the engine. Because the volume of exhaust gases increases with engine load and speed, the turbocharger speed will increase proportionally, keeping the manifold pressure fairly uniform. A device known as a waste gate is installed on turbocharged engines to control manifold pressure. It is a valve which, when open, allows engine exhaust to bypass the turbocharger turbine, effectively reducing intake pressure. The waste-gate valve is operated by a diaphragm that is operated by manifold pressure. The diaphragm will open the waste-gate valve whenever manifold pressure reaches the desired maximum.

FIGURE 46. MUFFLER.

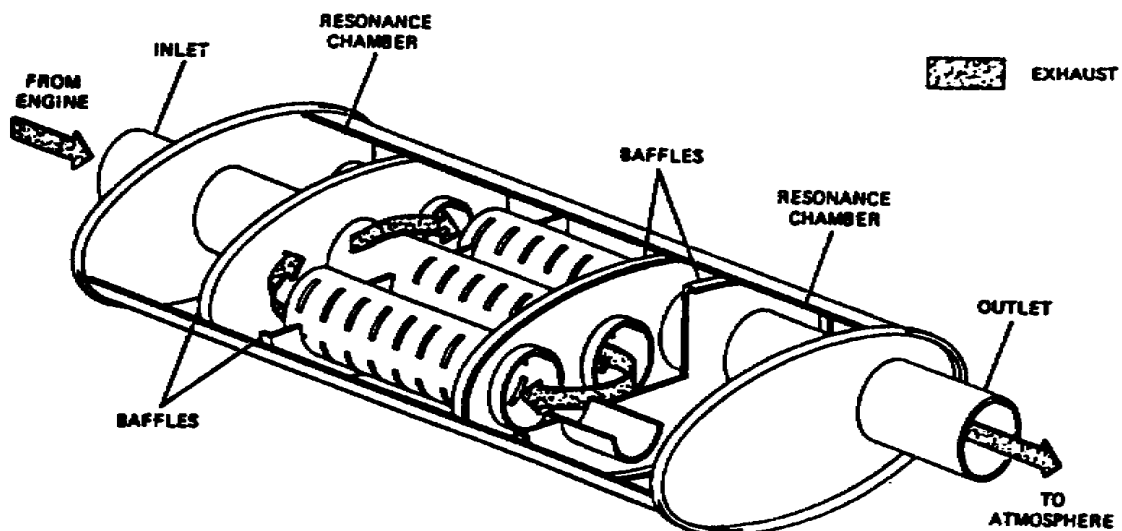
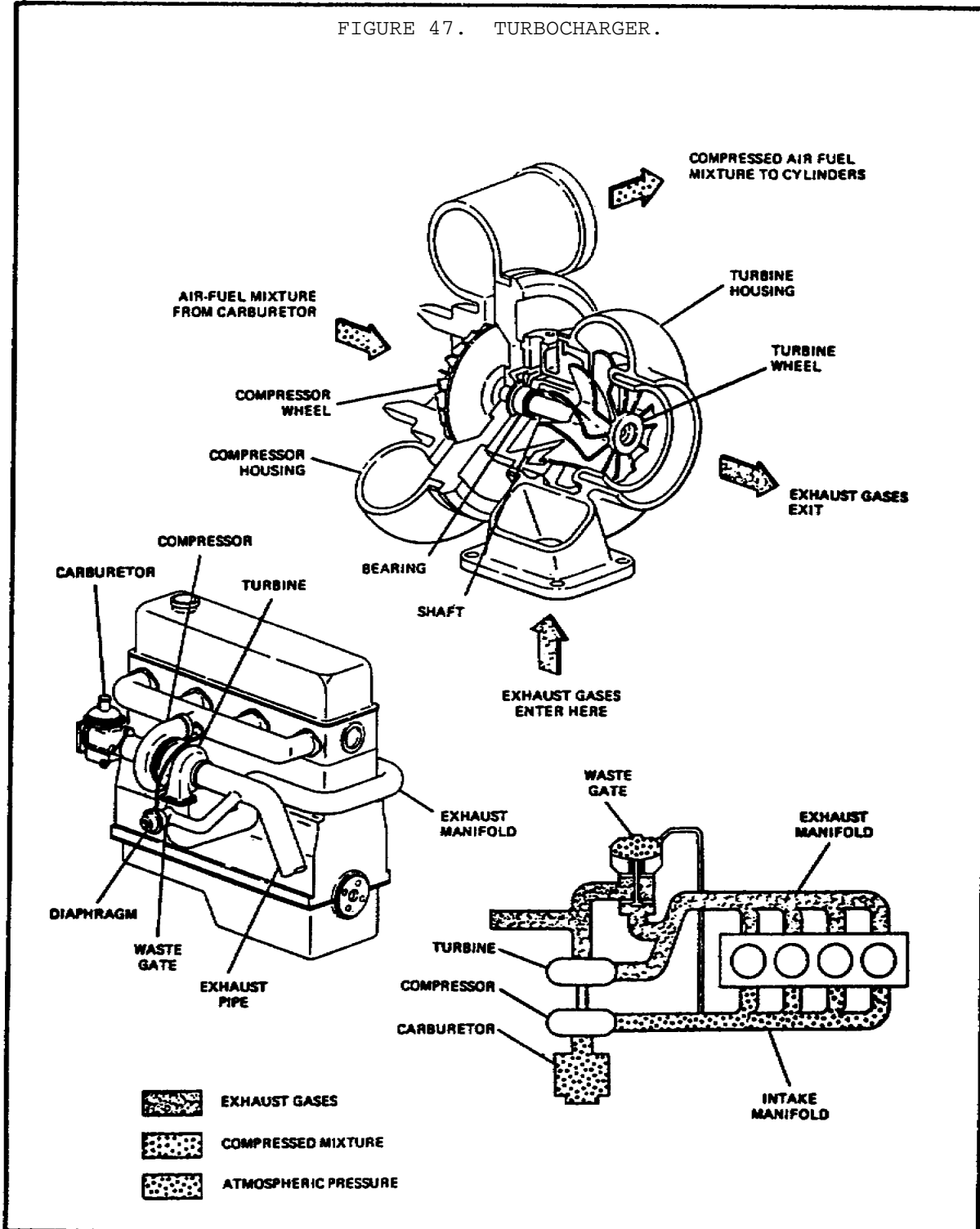


FIGURE 47. TURBOCHARGER.



5. Conclusion

This task described three subsystems of an internal combustion engine. The next task will define the lubrication system.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 2/TASK 2

LESSON 2

INTERNAL COMBUSTION ENGINE SUBSYSTEMS

TASK 2. Describe the principles, components, and operation of the lubrication system.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

The lubrication system (figure 48 on the following page) in an automotive engine supplies a constant supply of oil to all moving parts. This constant supply of fresh oil is important to minimize wear, flush bearing surfaces clean, and remove the localized heat that develops between moving parts as a result of friction. In addition, the oil that is supplied to the cylinder walls helps the piston rings make a good seal to reduce blowby.

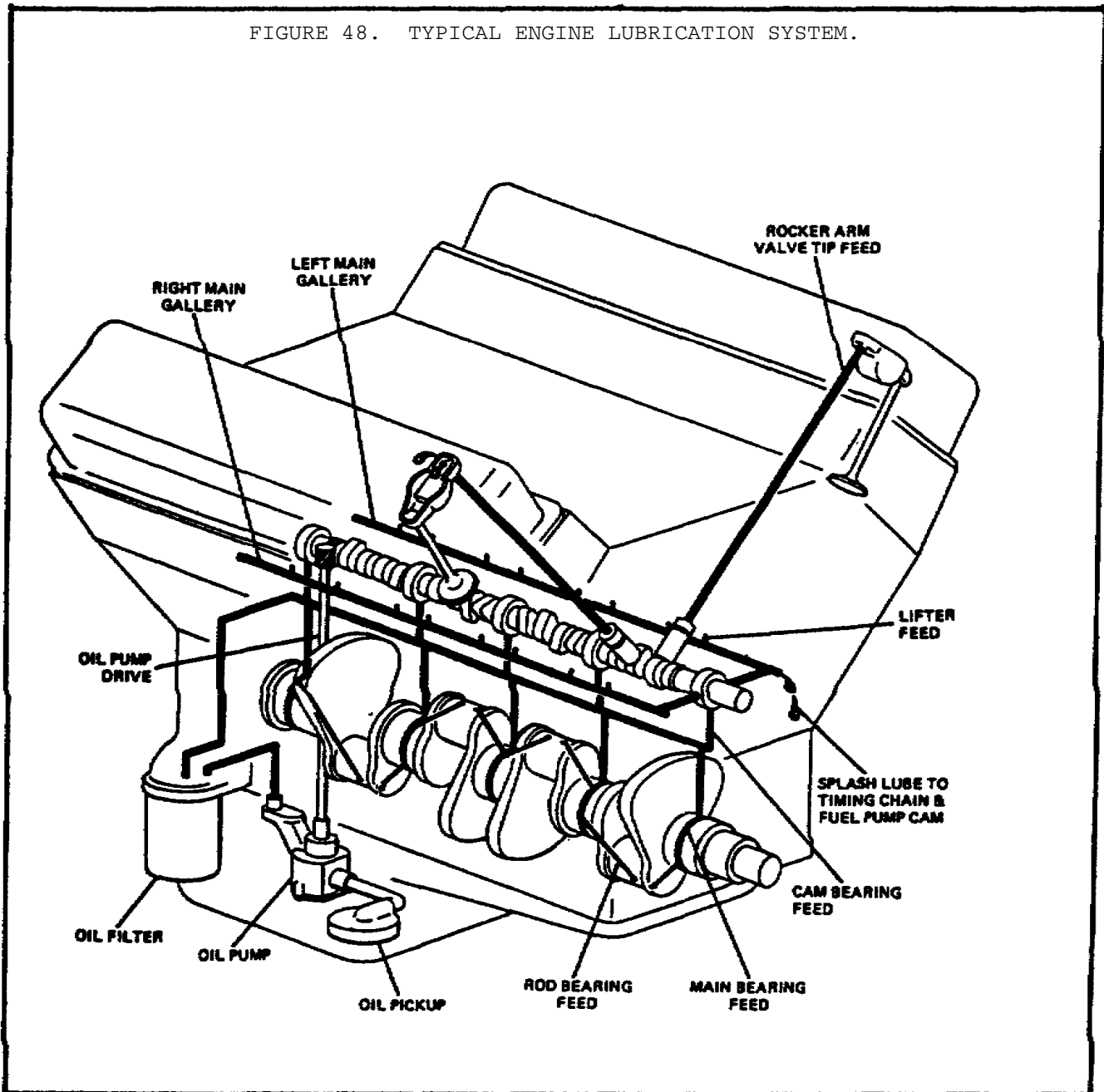
This task will describe the characteristics, components, and function of an internal combustion engine lubrication system.

2. Purpose of Lubrication

a. *Oil as a Lubricant.* The primary function of engine oil is to reduce friction between moving parts (lubricate). Friction, in addition to wasting engine power, creates destructive heat and rapid wear of parts. The greater the friction present between moving parts, the greater the energy required to overcome that friction. The

increase in energy adds to the amount of heat generated, causing moving parts that are deprived of oil to melt, fuse, and seize after a very short period of engine operation. The effectiveness of a modern lubrication system makes possible the use of friction-type bearings in an engine. Friction between the pistons and the cylinder walls is severe, making effective lubrication of this area imperative. Lubrication of the connecting rod and main bearings is crucial because of the heavy loads that are placed on them. There are many other less critical engine parts that also need a constant supply of oil, such as the camshaft, valve stems, rocker arms, and timing chains.

FIGURE 48. TYPICAL ENGINE LUBRICATION SYSTEM.



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b. *Oil as a Coolant.* Engine oil circulated throughout the engine also serves to remove heat from the friction points. The oil circulates through the engine and drains to the sump. The heat picked up by the oil while it is circulated is reduced by an airflow around the outside of the sump. In some instances, where the sump is not exposed to a flow of air, it is necessary to add an oil cooling unit that transfers the heat from the oil to the engine cooling system.

3. Engine Oils

a. *General.* Mineral oil is used in most internal combustion engines. Engine oils generally are classified according to their performance qualities and their thickness.

(1) *How Oil Lubricates* (figure 49 on the following page).

(a) Every moving part of the engine is designed to have a specific clearance from its adjacent surface. As oil is fed to the surface it forms a film, preventing the moving part from actually touching the surface.

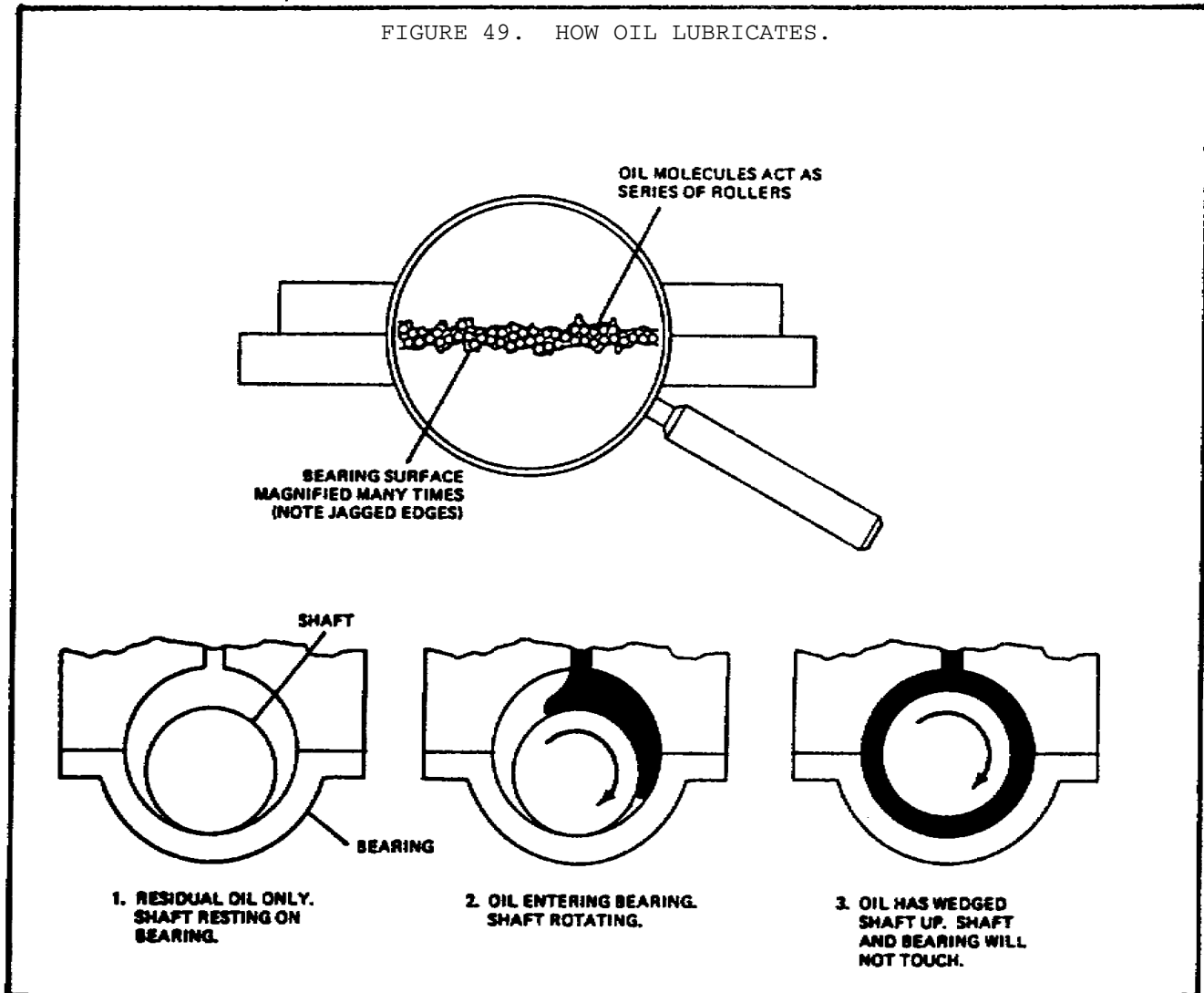
(b) As a part rotates, the film of oil acts as a series of rollers. Because the moving parts do not actually touch each other, friction is reduced greatly.

(c) It is important that sufficient clearance be allowed between the part and the bearing; otherwise the film might be too thin. This would allow contact between the parts, causing the bearing to wear or burn up.

(d) It also is important that the clearance not be too large between rotating parts and their bearings. This is true particularly with heavily loaded bearings like those found on the connecting rods. The heavy loads could then cause the oil film to be squeezed out, resulting in bearing failure.

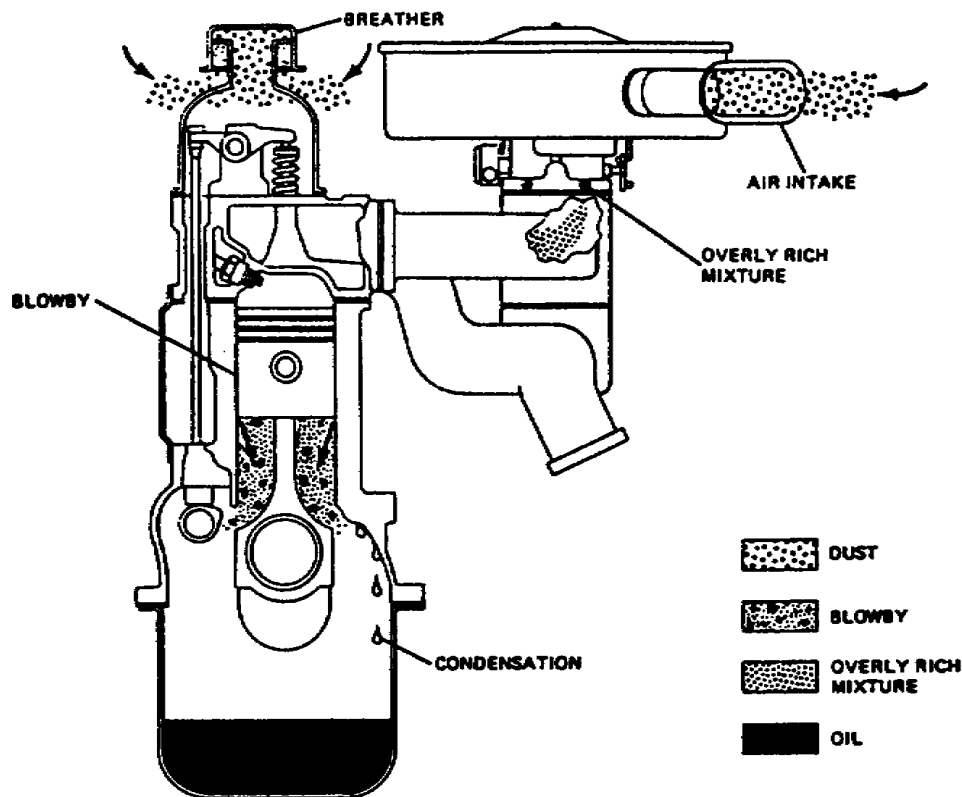
(2) *Oil Contamination* (figure 50 on page 62). Oil does not wear out, but it does become contaminated. When foreign matter enters through the air intake, some of it will pass by the piston rings and enter the crankcase. This dirt, combined with foreign matter entering through the crankcase

breather pipe, mixes with the oil, and when forced into the bearings, greatly accelerates wear. Water, one of the products of combustion, will seep by the piston rings as steam and condense in the crankcase. The water in the crankcase then will emulsify with the oil to form a thick sludge. Products of fuel combustion will mix with the oil as they enter the crankcase through blowby. The oil, when mixed with the contaminants, loses its lubricating qualities and becomes acidic. Engine oil must be changed periodically to prevent contaminated oil from allowing excessive wear and causing etching of bearings. Oil contamination is controlled in the following ways:



(a) Control engine temperature; a hotter running engine burns its fuel more completely and evaporates the water produced within it before any appreciable oil contamination occurs.

FIGURE 50. SOURCES OF OIL CONTAMINATION.



(b) The use of oil filters removes dirt particles from the oil before it reaches the bearings, minimizing wear.

(c) An adequate crankcase ventilation system will purge the crankcase of blowby fumes effectively before a large amount of contaminants can mix with the oil.

(d) The use of air intake filters trap foreign material and keep it from entering the engine.

(3) *Oil Dilution* (refer to figure 50). Engine oil thins out when mixed with gasoline, causing a dramatic drop in its lubricating qualities. Some of the causes of oil dilution are the following:

(a) Excessive use of a hand choke causes an overrich mixture and an abundance of unburned fuel to leak past the piston rings into the crankcase. The same condition can occur on vehicles equipped

with an improperly adjusted or malfunctioning automatic choke system.

(b) A vehicle with a defective ignition system can cause oil dilution due to misfiring spark plugs. Whenever a spark plug misfires, most of the unburned fuel will be forced into the exhaust system but a small portion of it will also pass the rings and enter the crankcase.

(c) An engine with a malfunctioning thermostat, or an engine that is operated for short durations only, will never reach a sufficient temperature to burn the fuel completely. A small amount of oil dilution occurs in all engines from initial startup through warmup. When, however, the engine reaches its operational range (180° F [82.2° C] to 200° F [93.3° C]), this condition is corrected as the excess gasoline vaporizes in the crankcase and is carried off by the crankcase ventilation system.

b. American Petroleum Institute (API) Rating System.

(1) *General.* The API system for rating oil classifies oil according to its performance characteristics. The higher rated oils contain additives that provide maximum protection against rust, corrosion, wear, oil oxidation, and thickening at high temperatures. There are currently six oil classifications for gasoline engines (SA, SB, SC, SD, SE, and SF) and four classifications for diesel engines (CA, CB, CC, and CD). The higher the alpha designation, the higher is the quality of the oil.

(2) *API Designations.*

(a) *SA (Utility Gasoline Engines).* Adequate for utility engines subjected to light loads, moderate speeds, and clean conditions. SA-rated oils generally contain no additives.

(b) *SB (Minimum Duty Gas -Automotive).* Adequate for automotive use under favorable conditions (light loads, low speeds, and moderate temperatures) with relatively short oil change intervals. SB-rated oils generally offer minimal protection to the engine against bearing scuffing, corrosion, and oil oxidation.

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(c) *SC.* Meets all automotive manufacturers' requirements for vehicles manufactured from 1964 to 1967.

(d) *SD.* Meets all automotive manufacturers' requirements for vehicles manufactured from 1968 to 1970. SD oil offers additional protection over SC oils, necessary with the introduction of emission controls.

(e) *SE.* Meets all automotive manufacturers' requirements for vehicles manufactured from 1971 to 1979. Stricter emission requirements during these years created the need for this oil to provide protection.

(f) *SF.* Meets all automotive manufacturers' requirements for vehicles manufactured after 1980. SF oil is designed to meet the demands of the small, high-revving engines made necessary by the trend toward smaller vehicles. An SF oil can be used in all automotive vehicles. API service ratings have related military specification designations.

c. Viscosity and Viscosity Measurement.

(1) *General.* The viscosity of an oil refers to its resistance to flow. When oil is hot, it will flow more rapidly than when it is cold. In cold weather, therefore, oil should be thin (low viscosity) to permit easy flow. In hot weather, oil should be heavy (high viscosity) to permit it to retain its film strength. The ambient temperature in which a vehicle operates determines whether an engine oil of high or low viscosity should be used. If, for example, too thin an oil were used in hot weather, consumption would be high because it would leak past the piston rings easily. The lubricating film would not be heavy enough to take up bearing clearances or prevent bearing scuffing. In cold weather, heavy oil would not give adequate lubrication because its flow would be sluggish; some parts might not receive oil at all.

(2) *Viscosity Measurement.* Oils are graded according to their viscosity by a series of Society of Automotive Engineers (SAE) numbers. The viscosity of the oil will increase progressively with the SAE number. An SAE 5 oil would be very light (low viscosity) and an SAE 90 oil would be

very heavy (high viscosity). The viscosity of the oil used in gasoline engines generally ranges from SAE 5 (arctic use) to SAE 60 (desert use). It should be noted that the SAE number of the oil has nothing to do with the quality of the oil. The viscosity number of the oil is determined by heating the oil to a predetermined temperature and allowing it to flow through a precisely sized orifice while measuring the rate of flow. The faster an oil flows, the lower the viscosity. The testing device is called a viscosimeter. Any oil that meets SAE low temperature requirements will be followed by the letter W. An example would be SAE 10W.

(3) *Multiweight Oils.* Multiweight oils are manufactured to be used in most climates because they meet the requirements of a light oil in cold temperatures and a heavy oil in hot temperatures. Their viscosity rating will contain two numbers.

An example of this would be 10W-30. An oil with a viscosity rating of 10W-30 would be as thin as a 10W-weight oil at 0° F (-17.7° C) and as thick as a 30-weight oil at 210° F (99° C).

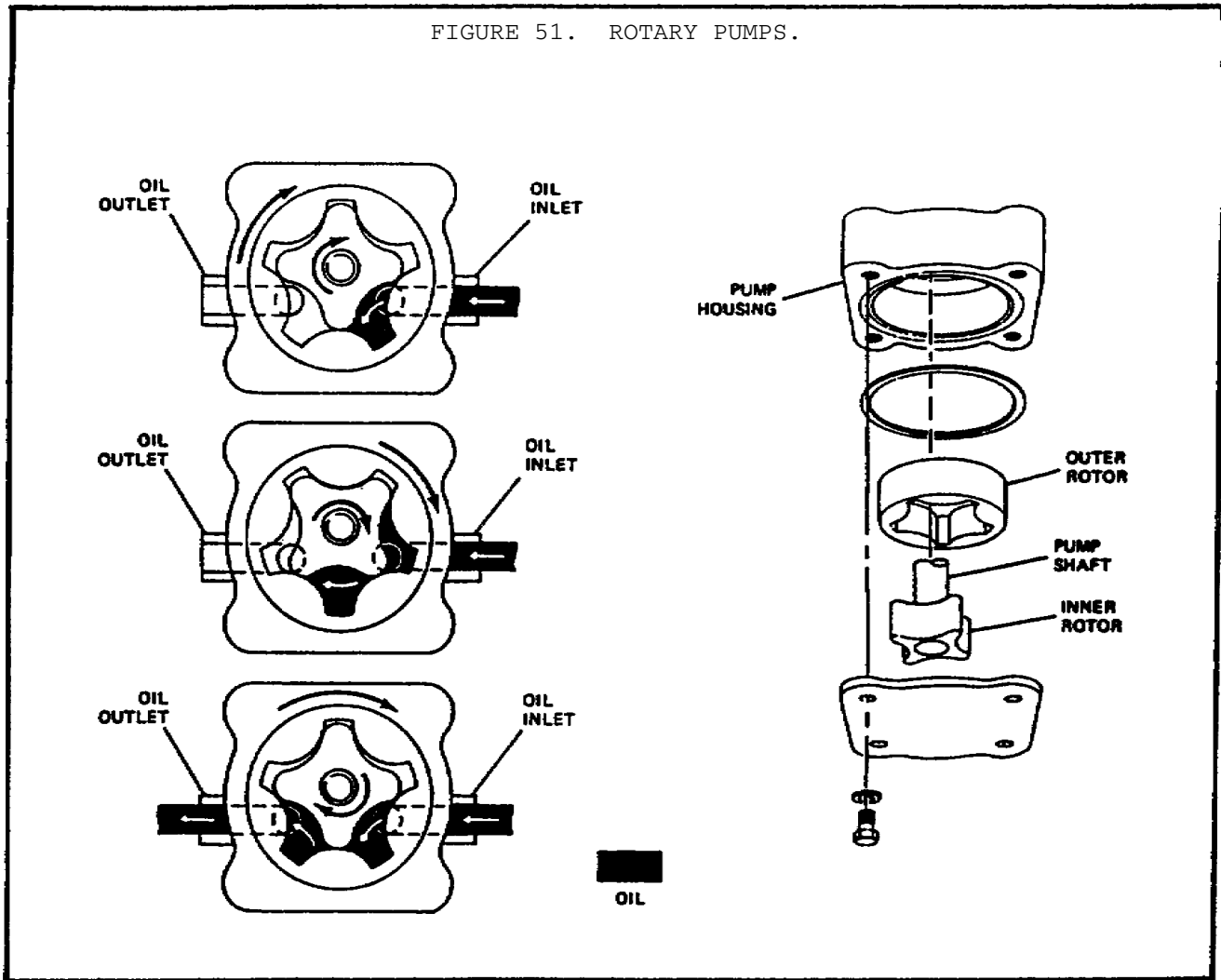
(4) *Detergent Oils.* Detergent oils contain additives that help keep the engine clean by preventing the formation of sludge and gum. All SE and SF oils are detergent oils.

4. *Oil Pumps.*

a. *General.* Oil pumps are mounted either inside or outside of the crankcase, depending on the design of the engine. They are usually mounted so that they can be driven by a worm or spiral gear directly from the camshaft. Oil pumps generally are of the gear or the rotor type.

b. *Rotor-Type Oil Pump* (figure 51 on the following page). The rotor oil pump makes use of an inner rotor with lobes that match similarly shaped depressions in the outer rotor. Figure 51 shows the manner in which the two rotors fit together. The inner rotor is off center from the outer rotor. The inner rotor is driven and, as it rotates, it carries the outer rotor around with it. The outer rotor floats freely in the pump body. As the two rotors turn, the openings between them are filled with oil. This oil is then forced out from between the rotors as the inner-rotor lobes enter the

FIGURE 51. ROTARY PUMPS.



openings in the outer lobes. This action is much like that in the gear-type pump.

c. *Gear-Type Oil Pump* (figure 52 on the following page). Gear-type oil pumps have a primary gear that is driven by an external member, and which drives a companion gear. Oil is forced into the pump cavity, around each gear, and out the other side into the oil passages. The pressure is derived from the action of the meshed gear teeth, which prevents oil from passing between the gears, forcing it around the outside of each gear instead. The oil pump incorporates a pressure relief valve, a spring-loaded ball that rises when the desired pressure is reached, allowing the excess oil to be delivered to the inlet side of the pump.

FIGURE 52. GEAR-TYPE PUMPS.

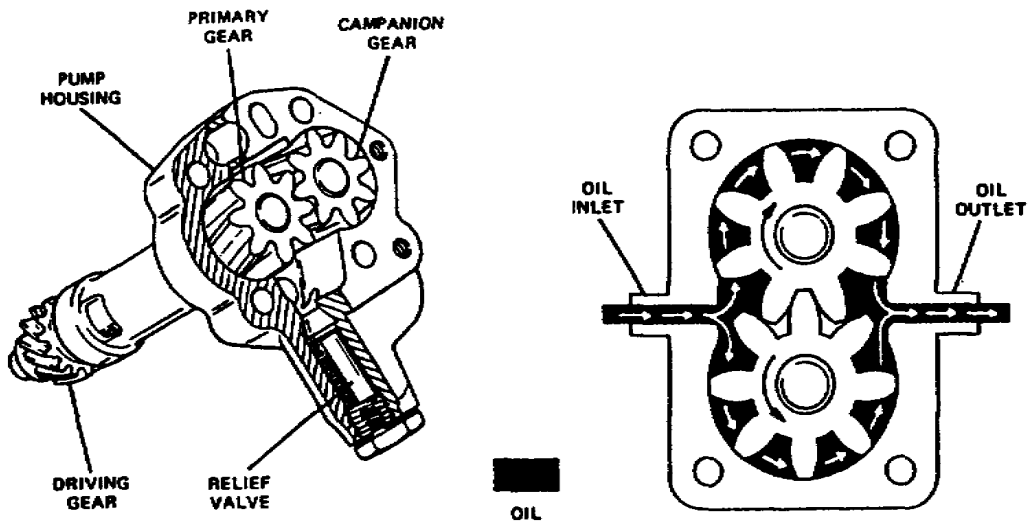
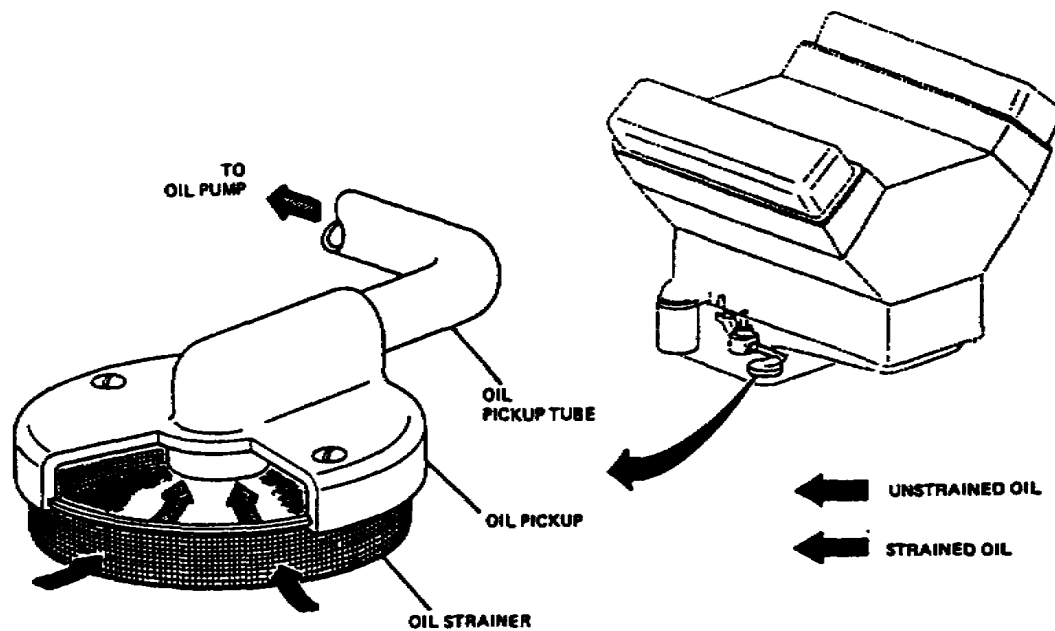


FIGURE 53. OIL PICKUP AND STRAINER.



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d. *Oil Strainer and Pickup* (figure 53 on the previous page). Most manufacturers of in-line and V-type engines place at least one oil strainer or screen in the lubrication system. The screen is usually a fine mesh bronze screen, located in the oil sump on the end of the oil pickup tube. The oil pickup tube is then threaded directly into the pump inlet or may attach to the pump by a bolted flange. A fixed-type strainer, like the one described, is located so that a constant supply of oil will be assured. Some automotive engines use a pickup that is hinged from the oil pump. The pickup is designed to float on top of the oil, thus preventing sediment from being drawn into the oiling system.

e. *Oil Filters.*

(1) *General* (figure 54 on the following page). The oil filter removes most of the impurities that have been picked up by the oil as it is circulated through the engine. The filter is mounted outside the engine and is designed to be readily replaceable.

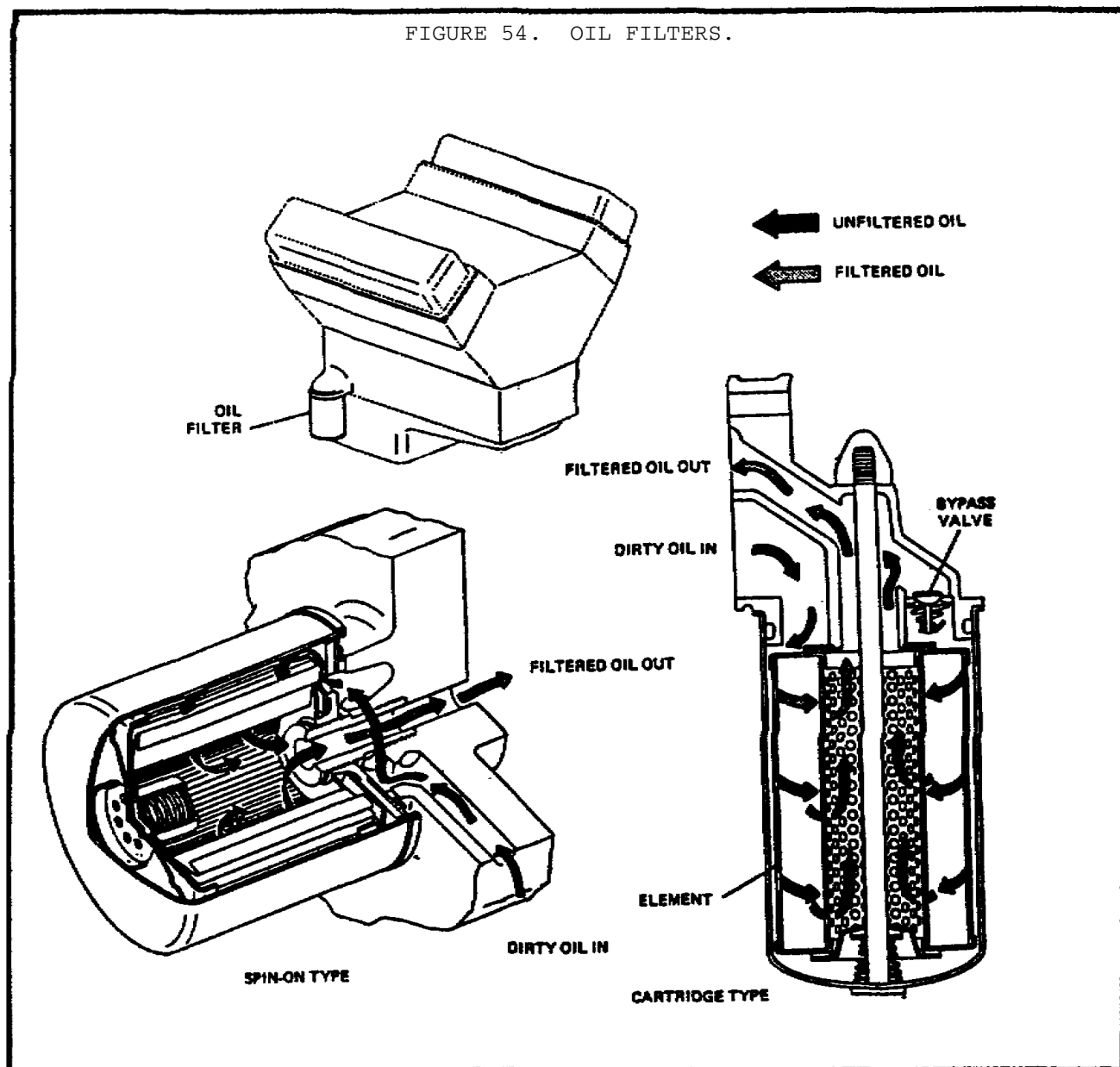
(2) *Filter Configurations* (figure 54). There are two basic filter element configurations: the cartridge-type and the sealed can-type.

(a) The cartridge-type filter element fits into a permanent metal container. Oil is pumped under pressure into the container where it passes from the outside of the filter element to the center. From here the oil exits the container. The element is changed easily by removing the cover from the container when this type of filter is used.

(b) The sealed can-type filter element is completely self-contained, consisting of an integral metal container and filter element. Oil is pumped into the container on the outside of the filter element. The oil then passes through the filter medium to the center of the element where it exits the container. This type of filter is screwed onto its base and is removed by spinning it off.

(3) *Filter Medium Materials* (figure 55 on page 70).

FIGURE 54. OIL FILTERS.

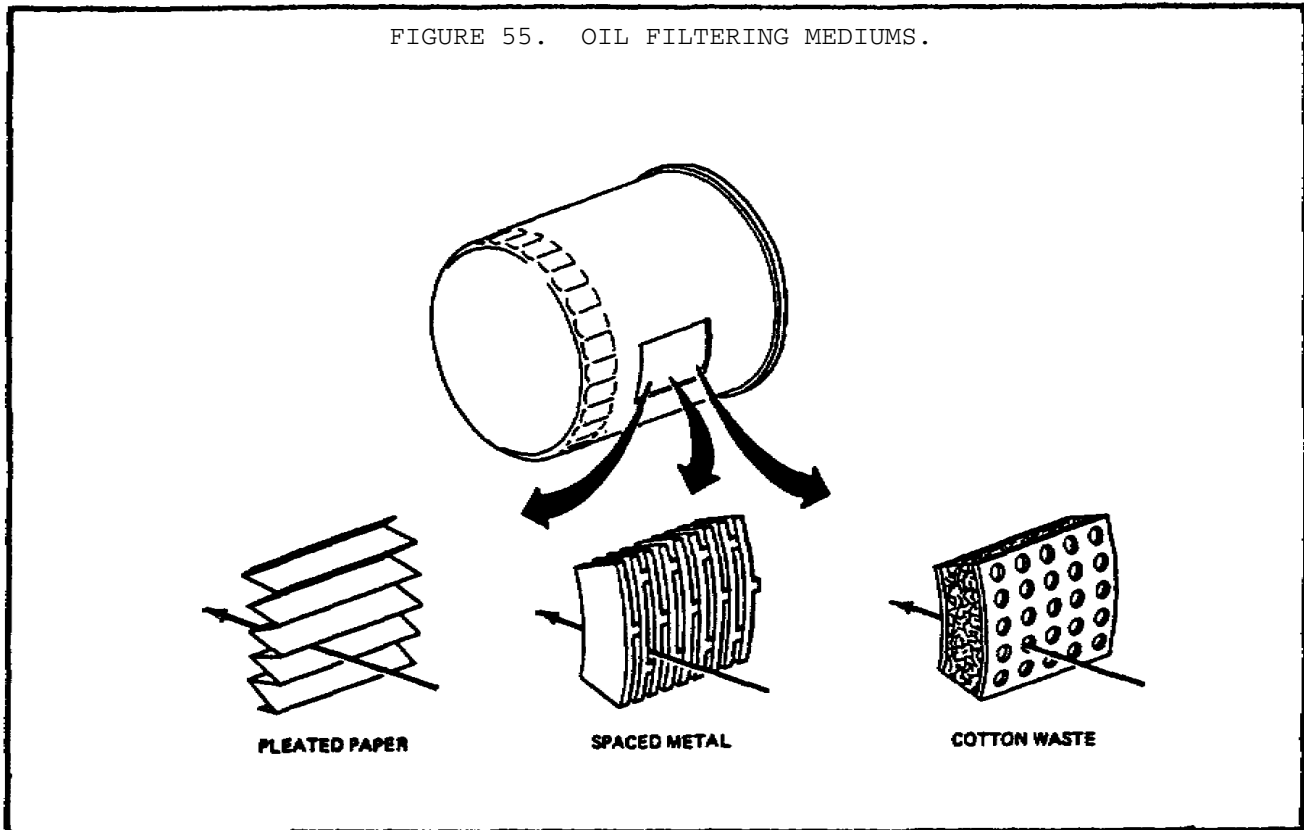


(a) Cotton waste or resin-treated paper are the two most popular automotive filter mediums. They are held in place by sandwiching them between two perforated metal sheets.

(b) Some heavy-duty applications use layers of metal that are thinly spaced apart. Foreign matter is strained out as the oil passes between the metal layers.

(4) *Filter System Configurations.* There are two-filter system configurations, the full-flow system and the bypass system. Operation of each system is as follows:

FIGURE 55. OIL FILTERING MEDIUMS.



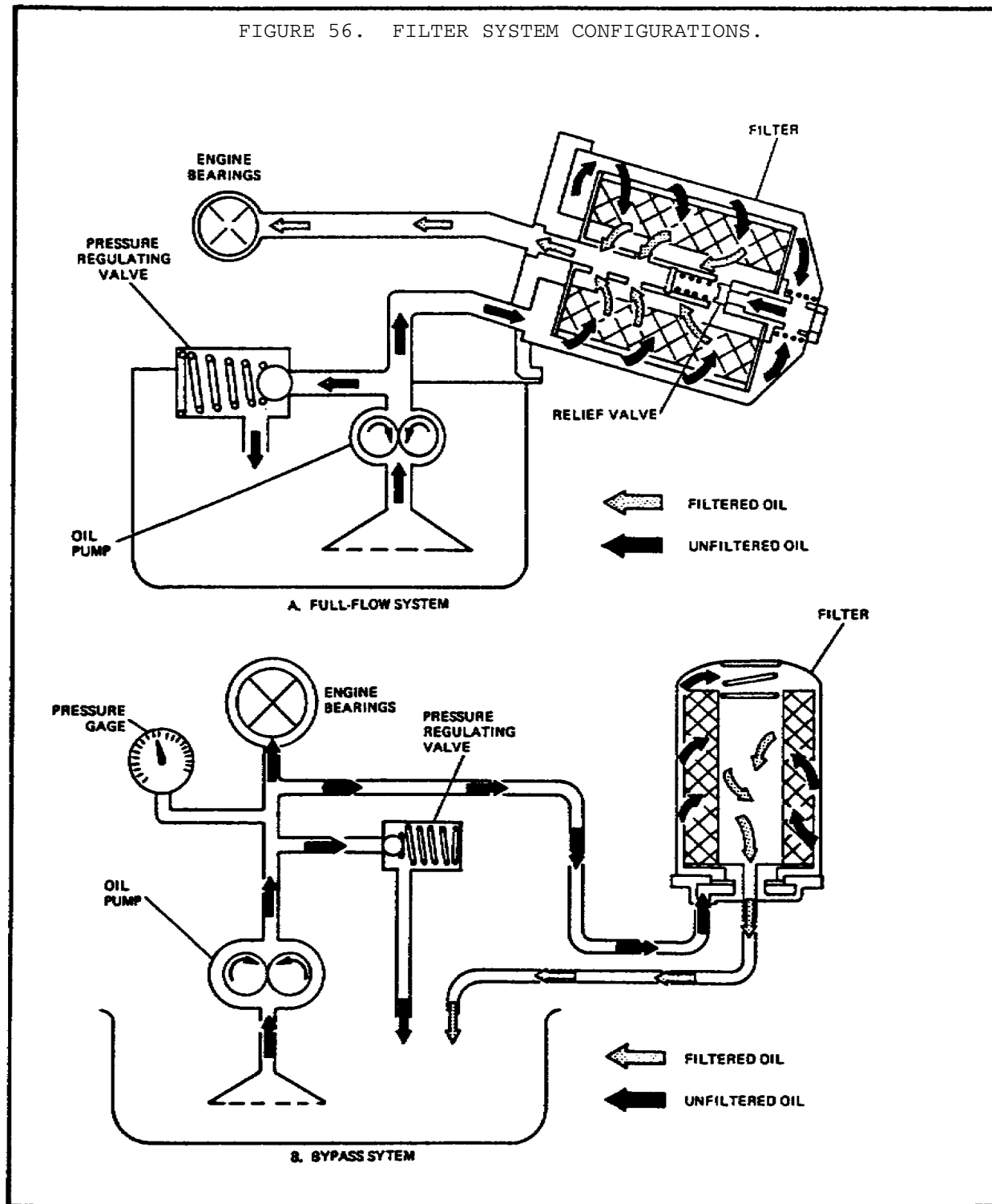
(a) The full-flow (figure 56, view A, on the following page) is the most popular in current automotive design. All oil in a full-flow system is circulated through the filter before it reaches the engine. When a full-flow system is used, it is necessary to incorporate a bypass valve in the oil filter to allow the oil to pass through the element in the event it becomes clogged. This will prevent the oil supply from being cut off to the engine.

(b) The bypass system (figure 56, view B) diverts only a small quantity of the oil each time it is circulated and returns it directly to the oil pan after it is filtered. This type of system does not filter the oil before it is sent to the engine.

f. Oil Coolers.

(1) *Purpose.* Some automotive configurations do not allow sufficient airflow around the crankcase to allow the oil to dissipate heat. Engines in heavy duty and desert use must be able to dissipate more heat from their oil than normal airflow can accomplish. An oil cooler is installed in all of these cases.

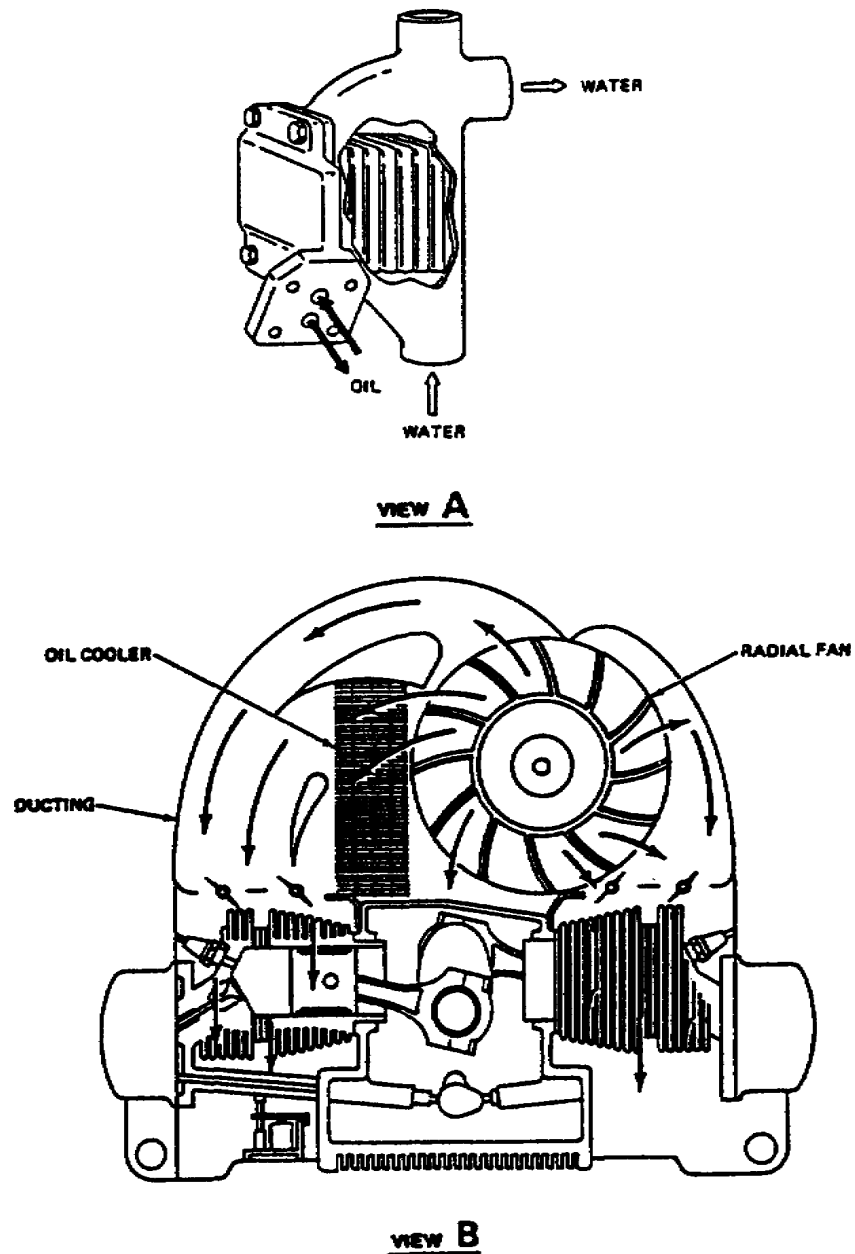
FIGURE 56. FILTER SYSTEM CONFIGURATIONS.



(2) *Oil Temperature Regulator* (figure 57, view A, on the following page). The oil temperature regulator is used to prevent the oil temperature from rising too high in hot weather, and to assist in raising the temperature during cold starts in winter weather. The regulator makes use of the

liquid in the cooling system. It provides a more positive means of controlling oil temperature than does cooling by radiation of heat from the oil pan wells.

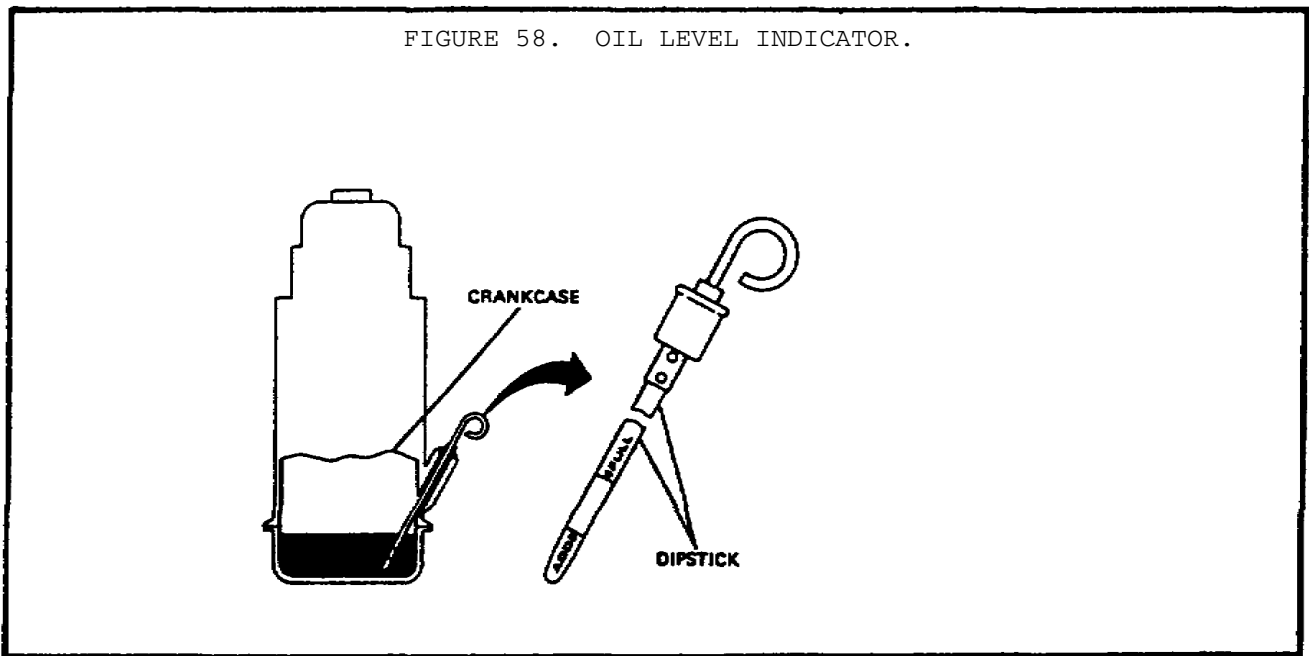
FIGURE 57. OIL TEMPERATURE REGULATOR AND OIL COOLER.



The regulator unit is made up of a core and a housing. The core through which the oil circulates is of cellular or bellows construction, built to expose as much oil as possible to the coolant that circulates through the housing. The regulator is attached to the engine so that the oil will flow through the regulator after passing through the pump. The oil leaves the regulator either heated or cooled, depending on the temperature of the coolant, and is then circulated through the engine.

(3) *Oil Cooler* (figure 57, view B, on the previous page). The types of oil coolers used with combat vehicles consist of a radiator through which air is circulated by movement of the vehicle, or by a cooling fan. Oil from the engine is circulated through this radiator and back to the sump or supply tank. In this system, the radiator will act only to cool the oil. It will not heat oil in a cold engine.

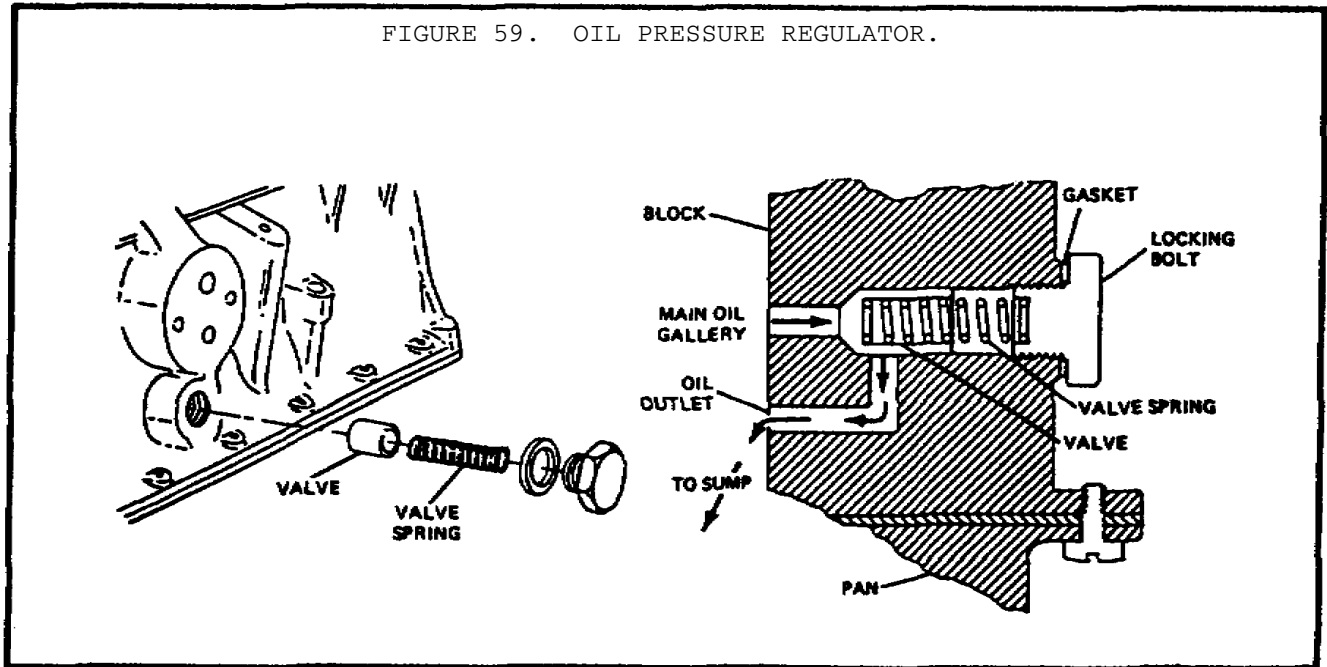
FIGURE 58. OIL LEVEL INDICATOR.



g. *Oil Level Indicator* (figure 58). The oil level indicator is usually of a bayonet type. It consists of a small rod, known as a dipstick, that extends through a tube into the crankcase. It is marked to show when the crankcase is full or, if it is low, how much oil is needed. Readings are taken by pulling the dipstick out and noting the oil level which it indicates.

h. *Pressure Regulator* (figure 59). The oil pump will produce pressures in great excess to those necessary. This excess pressure, if uncontrolled, would cause excess oil consumption due to flooded cylinder walls and leakage through oil seals. A spring-loaded regulator valve is installed in the lubrication system to control pump pressure. The valve will open as the pressure reaches the value that is determined by the spring, causing excess oil to be diverted back to the crankcase.

FIGURE 59. OIL PRESSURE REGULATOR.



5. Types of Lubrication Systems

a. *Splash System* (figure 60 on the following page). The splash lubrication system is no longer used in automotive engines, though it is used in small equipment engines. In a splash lubrication system, dippers on the connecting rods enter the oil in the crankcase with each crankshaft revolution, thus splashing the oil. As the oil is thrown upward, it finds its way into the various engine parts. A passage is drilled from the dipper to the bearing in each connecting rod to ensure lubrication. This system is too uncertain for modern automotive applications. One reason is that the level of oil in the crankcase will greatly vary the amount of lubrication received by the engine; a high level results in excess lubrication and oil consumption and even a slightly low level results in inadequate lubrication.

FIGURE 60. SPLASH-TYPE LUBRICATION SYSTEM.

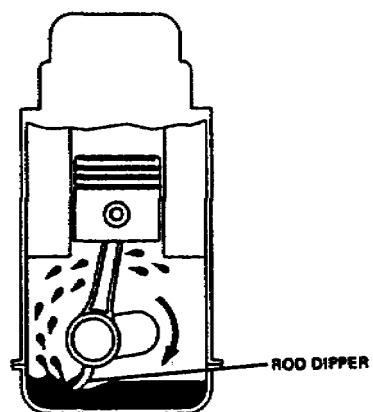
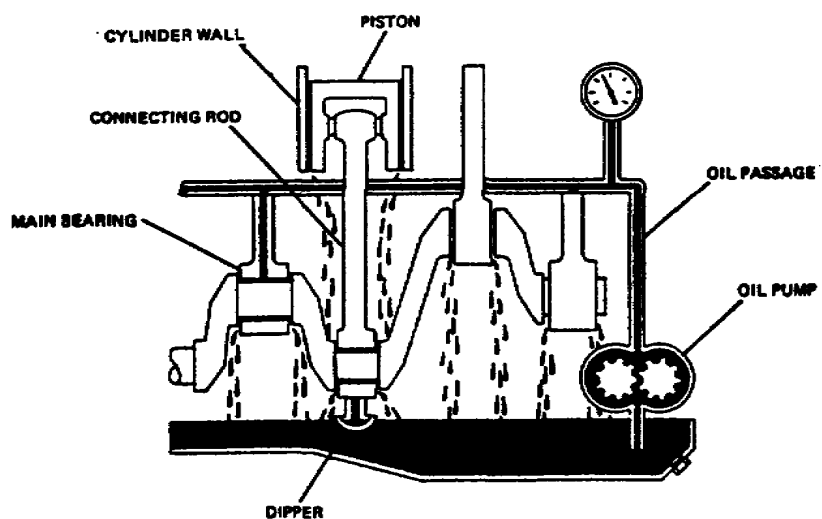
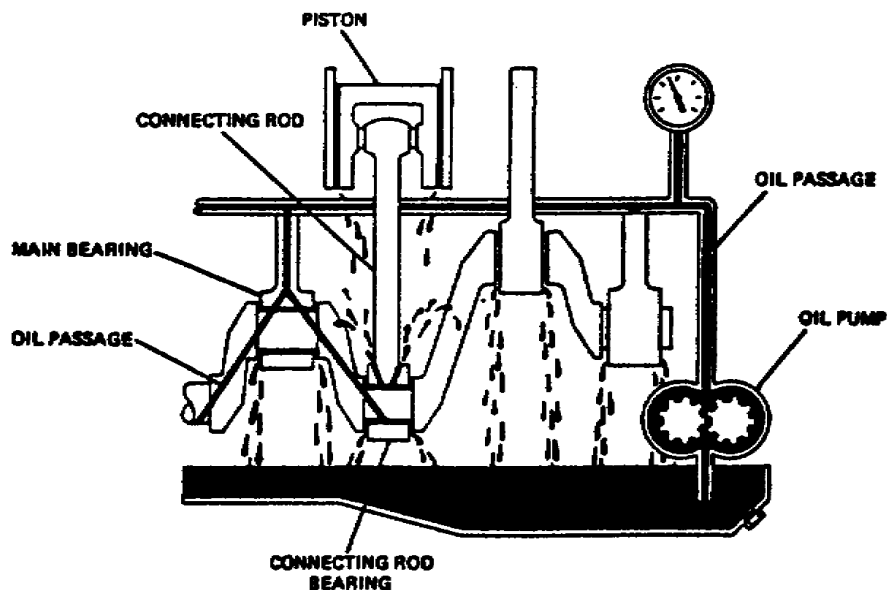


FIGURE 61. COMBINATION SPLASH AND FORCE-FEED LUBRICATION SYSTEM.



b. *Combination Splash and Force-Feed System* (figure 61 on the previous page). In the combination system, oil is delivered to some parts by means of splash and to other parts through oil passages, under pressure from a pump in the crankcase. The main and the camshaft bearings are usually the items that are force fed while the connecting rods are fitted with dippers that supply oil to the rest of the engine by splash. Some configurations use small troughs under each connecting rod, kept full by small nozzles that deliver oil under pressure from the oil pump. These oil nozzles deliver an increasingly heavy stream as speed increases. At very high speeds, these oil streams are powerful enough to strike the dippers directly. This causes a much heavier splash so that adequate lubrication of the pistons and the connecting rod bearings is provided at higher speeds. If a combination system is used on an overhead valve engine, the upper valve train is lubricated by pressure from the oil pump.

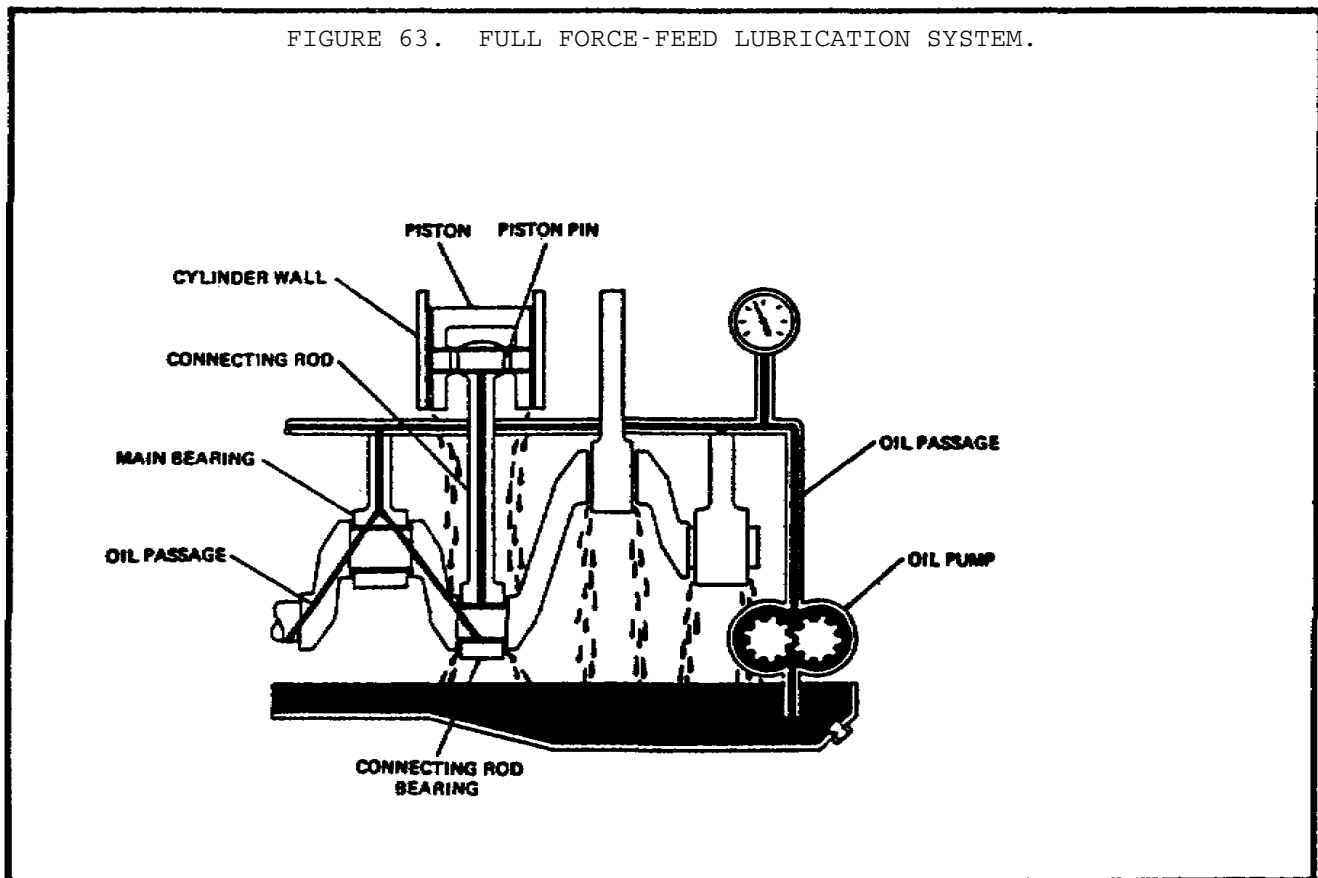
FIGURE 62. FORCE-FEED LUBRICATION SYSTEM.



c. *Force-Feed Lubrication System* (figure 62). A somewhat more complete pressurization of lubrication is achieved in the force-feed lubrication system. Oil is forced by the oil pump from the crankcase to the main bearings and the

camshaft bearings. Unlike the combination system, the connecting rod bearings are also fed oil under pressure from the pump. Oil passages are drilled in the crankshaft in order to lead oil to the connecting rod bearings. The passages deliver oil from the main bearing journals to the rod bearing journals. In some engines, these openings are holes that index (line up) once for every crankshaft revolution. In other engines, there are annular grooves in the main bearings through which oil can feed constantly into the hole in the crankshaft. The pressurized oil that lubricates the connecting rod bearings goes on to lubricate the pistons and walls by squirting out through strategically drilled holes. This lubrication system is used in virtually all engines that are equipped with semifloating piston pins.

FIGURE 63. FULL FORCE-FEED LUBRICATION SYSTEM.



d. *Full Force-Feed Lubrication System* (figure 63). In the full force-feed lubrication system, all of the bearings mentioned in paragraph 5b on page 76 are lubricated by oil under pressure. This includes main bearings, rod bearings, camshaft bearings, and the complete valve mechanism. In addition, the full force-feed lubrication system provides lubrication under pressure to the pistons

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and the piston pins. This is accomplished by holes drilled the length of the connecting rod, creating an oil passage from the connecting rod bearing to the piston pin bearing. This passage not only feeds the piston pin bearings, but also provides lubrication for the pistons and cylinder walls. A full force-feed lubrication system is used in virtually all current automotive engines that are equipped with full-floating piston pins.

6. Conclusion

The lubrication system plays an important role in keeping an internal combustion engine operational. The cooling system, described in the next task, is another subsystem essential for proper operation of an internal combustion engine.

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - LESSON 2/TASK 3

LESSON 2

INTERNAL COMBUSTION ENGINE SUBSYSTEMS

TASK 3. Describe the principles, components, and operation of the cooling system.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

All internal combustion engines are equipped with some type of cooling system because of the high temperatures generated during operation. High temperatures are necessary to produce the high gas pressures that act on the head of the piston. Power cannot be produced efficiently without high temperatures. However, it is not possible to use all of the heat of combustion without harmful results. The temperature in the combustion chamber during the burning of the fuel is well above the melting point of iron. Therefore, if nothing is done to cool the engine during operation, valves will burn and warp, lubricating oil will break down, and bearings and pistons will overheat, resulting in engine seizure.

This task will describe the principles, components, and operation of the cooling system.

2. Cooling Essentials

a. *Cooling Mediums.*

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(1) *Liquid.* Liquid is the most popular coolant in automotive use. A liquid cooling system provides the most positive cooling and is best for maintaining an even engine temperature.

(2) *Air.* Air cooling is most practical for small vehicles and equipment because no radiator or hoses are required. Air cooling generally will not be used wherever water cooling is practical. This is because air-cooled engines do not run at even temperatures and require extensive use of aluminum to dissipate heat.

b. *Other Sources of Engine Cooling.* There are other sources of heat dissipation for the engine in addition to the cooling system.

(1) The exhaust system dissipates as much, if not more, heat than the cooling system, although that is not its purpose.

(2) The engine oil, as stated in paragraph 1 on page 58, removes heat from the engine and dissipates it to the air from the sump.

(3) The fuel provides some engine cooling through vaporization.

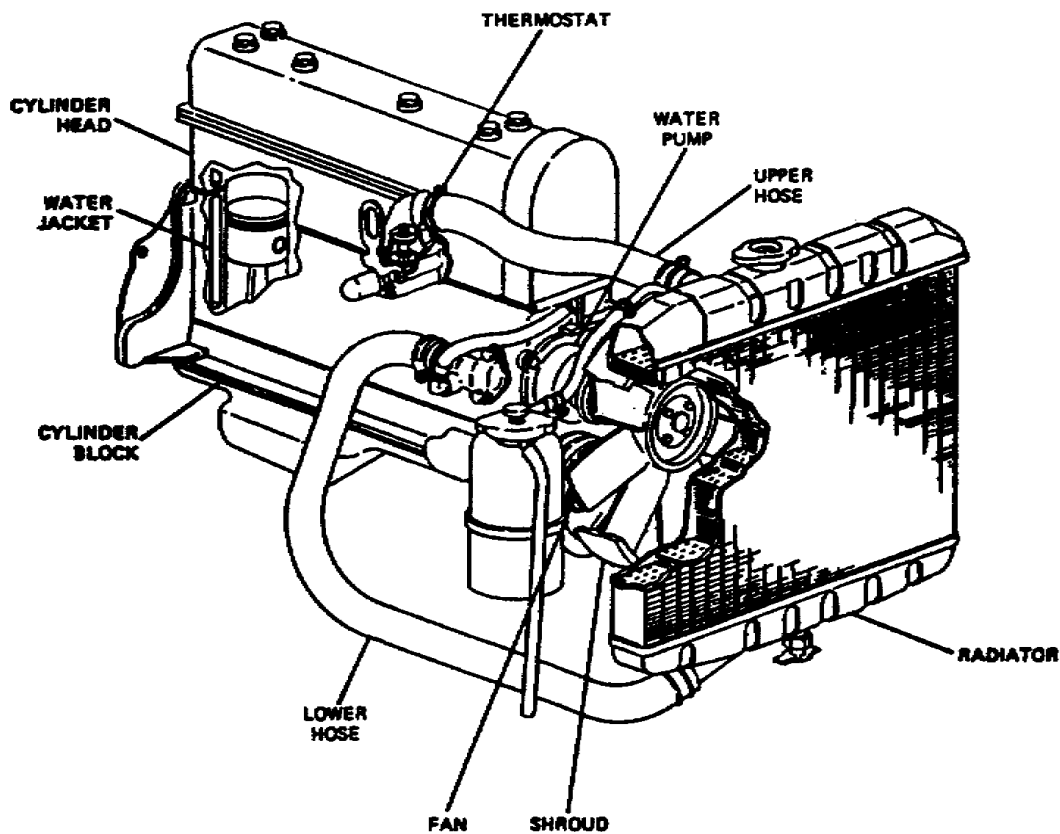
(4) A measurable amount of heat is dissipated to the air through radiation from the engine.

3. Liquid Cooling Systems

a. *Flow of Coolant* (figure 64 on the following page). A simple liquid-cooled cooling system consists of a radiator, coolant pump, piping, fan, thermostat, and a system of jackets and passages in the cylinder head and cylinder block through which the coolant circulates. Some engines are equipped with a water distribution tube inside the cooling passages; these direct additional coolant to the points where the temperatures are highest. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled. The pump draws the coolant from the bottom of the radiator, forces it through the jackets and passages, and ejects it into the upper tank on the top of the radiator. The coolant then passes through a set of tubes to the bottom of the radiator from which the cooling cycle begins again. The radiator is situated in front of a fan driven either by the water pump or by an electric

motor. The fan ensures an airflow through the radiator at times when there is no vehicle motion. It should be noted that the downward flow of coolant through the radiator creates what is known as a thermosiphon action. This simply means that as the coolant is heated in the jackets of the engine, it expands. As it expands, it becomes less dense and therefore lighter. This causes it to flow out of the top outlet of the engine and into the top tank of the radiator. As the coolant is cooled in the radiator, it again becomes more dense and heavier. This causes the coolant to settle to the bottom tank of the radiator. The heating in the engine and the cooling in the radiator, therefore, creates a natural circulation that aids the water pump. The earliest automotive vehicles relied on thermosiphon action and used no water pump.

FIGURE 64. LIQUID-COOLED SYSTEM.



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b. *Engine Water Jackets* (figure 64 on the previous page). The water passages in the cylinder block and cylinder head form the engine water jacket. In the majority of cylinder blocks, the water jacket completely surrounds all cylinders along their full length. Within the jacket, narrow passages are provided between cylinders for coolant circulation. In some engine configurations, however, the cylinder bores are attached to each other and a coolant passageway is not provided between bores. An engine of this design often is referred to as having siamese cylinders. This type of engine tends to operate with cylinder temperatures slightly higher between the bores, and slightly cooler where water jackets come in contact with the bores. In addition, all engines are provided with water passages around the exhaust valve seat. This provides cooling for the valve when it comes in contact with the seat.

In the cylinder head, the water jacket covers the combustion chambers at the top of the cylinders and contains water passages around the valve seats when these are located in the head. The coolant flows from the cylinder block up into the cylinder head through passages called water transfer ports. A tight seal at the ports between the cylinder head and block is very important. The watertight seal at the ports, as well as the gastight seal at the combustion-chamber openings, is obtained with one large gasket called the cylinder-head gasket.

c. *Coolants*. Water is by far the most popular coolant for liquid-cooled engines. It is plentiful, inexpensive, and its boiling point is within the efficient operational temperature range of the engine.

(1) *Antifreeze Protection*. When a vehicle is operated in areas where the temperature falls below 32° F (0° C), an antifreeze solution must be added if water is used as the coolant. The most common antifreeze is ethylene glycol. Other antifreezes that are little used are glycerin, methyl alcohol, and ethyl alcohol. Ethyl and methyl alcohol provide adequate protection as an antifreeze when used in sufficient quantities. The main objection to these liquids, however, is that they evaporate below the operating temperature of modern automotive engines, making them impractical. Glycerin offers the same degree of protection as alcohol, but does not evaporate in use, has a high

boiling point, is noncorrosive, has no odor, and gives complete protection against freezing in normal use. Ethylene glycol gives a maximum protection against freezing to -65° F (-53.8° C) when it is mixed to a solution of 60 percent with 40 percent water.

If the proportions of ethylene glycol are raised in the solution, it will result in a higher freezing point for the solution, consequently having less protection. If a 100-percent solution of ethylene glycol were used, its freezing point would be much below that of water. Other antifreeze solutions, however, do not show this increase of freezing point with increasing concentration. Two good examples are methyl alcohol which freezes at -144° F (-97.8° C), and ethyl alcohol which freezes at -174° F (-114.3° C).

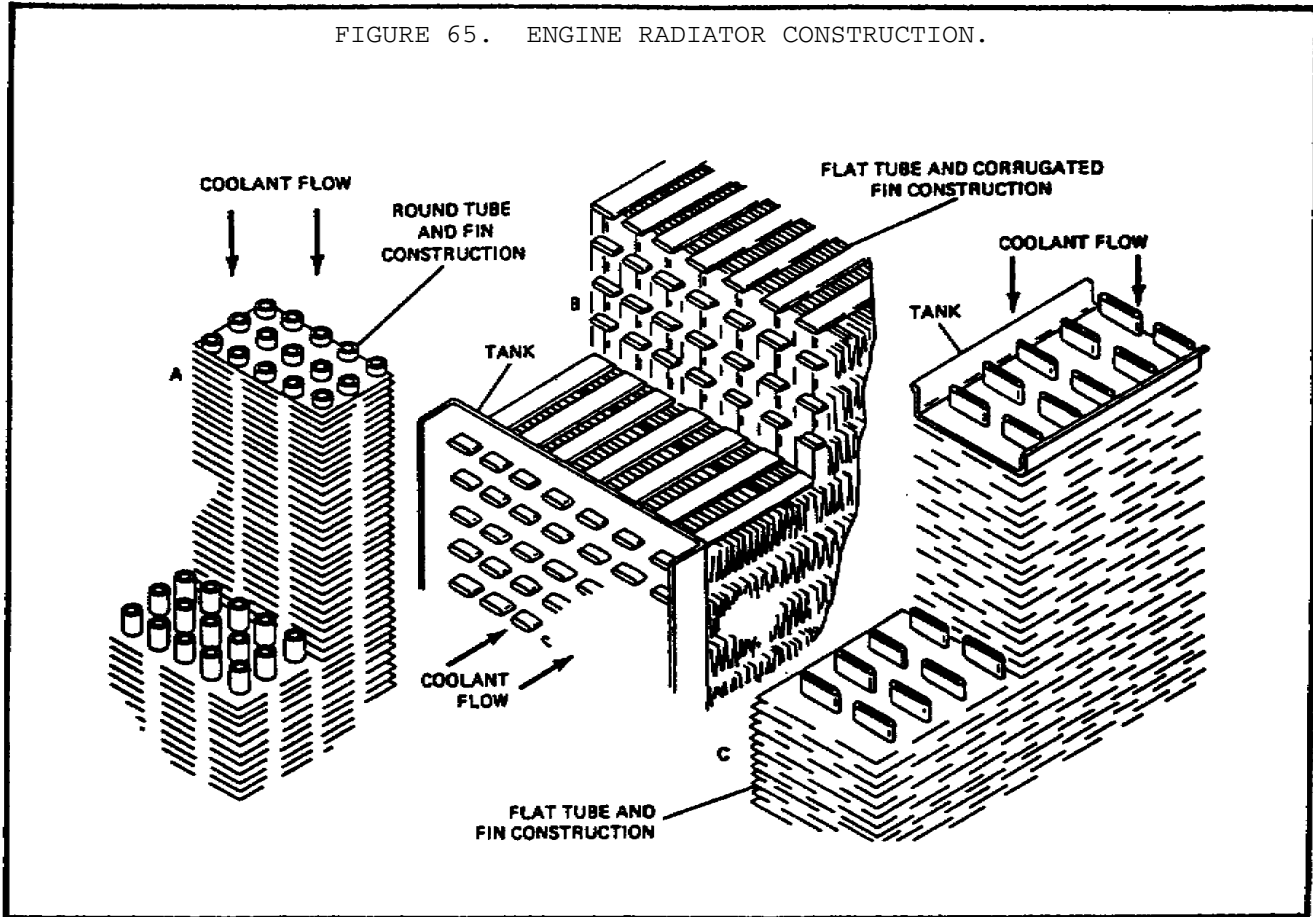
(2) *Corrosion Resistance.* The cooling system must be free of rust and scale in order to maintain its efficiency. The use of inhibitors or rust preventatives will reduce or prevent corrosion and the formation of scale. Inhibitors are not cleaners and, therefore, will not remove rust and scale that have already accumulated. Most commercially available antifreeze solutions contain inhibitors. If water alone is used as a coolant, an inhibitor should be added.

d. *Radiators* (figure 65 on the following page). Radiators for automotive vehicles using liquid cooling systems consist of two tanks with a heat exchanging core between them. The upper tank contains an outside pipe called an inlet. The filler neck generally is placed on the top of the upper tank; attached to this filler neck is an outlet to the overflow pipe. The lower tank also contains an outside pipe that serves as the radiator's outlet. Operation of the radiator is as follows:

(1) The upper tank collects incoming coolant and, through the use of an internal baffle, distributes it across the top of the core.

(2) The core is made of numerous rows of small vertical tubes that connect the upper and lower radiator tanks. Sandwiched between the rows of tubes are thin sheet-metal fins. As the coolant passes through the tubes to the lower tank, the fins conduct the heat away from it and dissipate it

FIGURE 65. ENGINE RADIATOR CONSTRUCTION.



into the atmosphere. The dissipation of the heat from the fins is aided by directing a constant airflow between the tubes and over the fins.

(3) The lower tank collects the coolant from the core and discharges it to the engine through the outlet pipe.

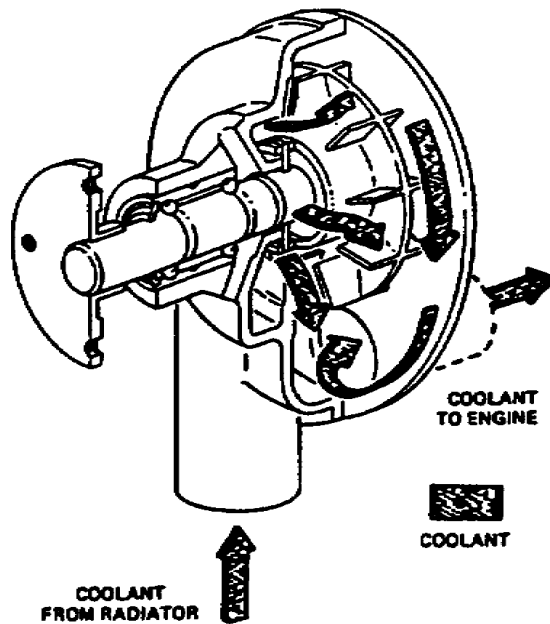
(4) The overflow pipe provides an opening from the radiator for escape of coolant or steam if pressure in the system exceeds the regulated maximum. This prevents rupture of cooling system components.

Some radiators are designed with their tanks on the sides in a vertical position. They are connected by a core that contains horizontal tubes. This radiator configuration is called a crossflow radiator and operates in the same manner as the conventional vertical flow radiator, though it should be noted that there is no thermosiphon effect with a crossflow radiator.

e. *Water Pump* (figure 66 on the following page). All modern cooling systems have water pumps to

circulate the coolant. The pump, usually located on the front side of the engine block, receives coolant from the lower tank and forces it through the water jacket into the upper radiator tank. The pump is of a centrifugal type and has an impeller with blades that force coolant outward as the impeller rotates. It is usually driven by the engine crankshaft through a V-belt. Advantages of a centrifugal pump as a water pump are that it is inexpensive, circulates great quantities of coolant for its size, and is not clogged by small amounts of foreign matter. Another advantage is that a centrifugal pump permits a limited amount of thermosiphon action after the engine is shut down to help prevent boilover. The pump housing usually is cast from iron or aluminum. The impeller can be made of iron, aluminum, or plastic. It rides on a shaft that is supported in the housing on a sealed double-row ball bearing. The pump shaft also has a spring-loaded seal to prevent coolant leakage.

FIGURE 66. WATER PUMP CONSTRUCTION.



f. *Fan and Shrouding* (refer back to figure 64 on page 81). The fan pulls a large volume of air through the radiator core so that engine heat can be dissipated effectively. In most cases, the fan

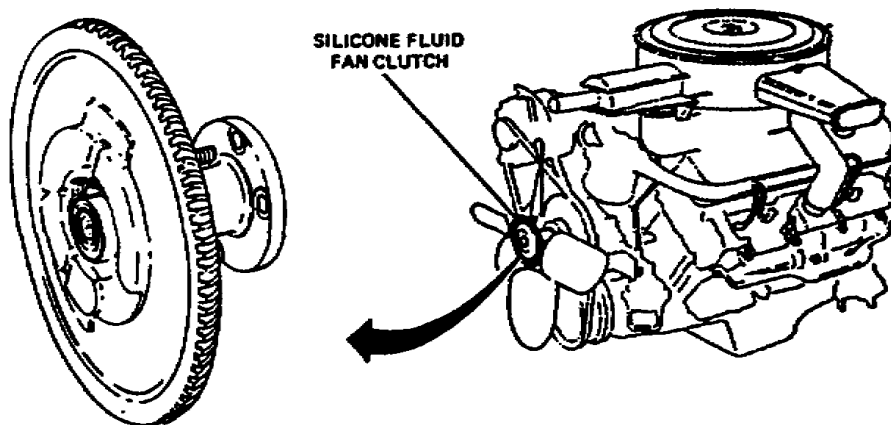
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works in an enclosure called a shroud to ensure maximum efficiency of the fan. There are two methods of driving a fan. One method is to attach it to the end of the water pump shaft. The other method, becoming increasingly popular, is to use an electric motor.

(1) *Thermostatically Controlled Engine-Driven Fan.* Some vehicles are equipped with a seven-blade fan, particularly those for heavy-duty use or those with air conditioning. This fan configuration will move tremendous amounts of air through the radiator to provide extra cooling capacity. The problem with a high-capacity fan is that it can cause the radiator core to freeze in cold weather. Other problems associated with a high output fan are excessive power consumption and noise at highway speeds. Most seven-blade fans are driven by the water pump through a viscous (fluid) clutch (figure 67) to correct these conditions. The fan clutch is designed to limit the fan speed based on the temperature of the air drawn through the radiator. The clutch will provide controlled slippage if the temperature of this air is below a preset minimum. A fan clutch also will control the noise and the power consumption of the fan by limiting its speed to a preset maximum.

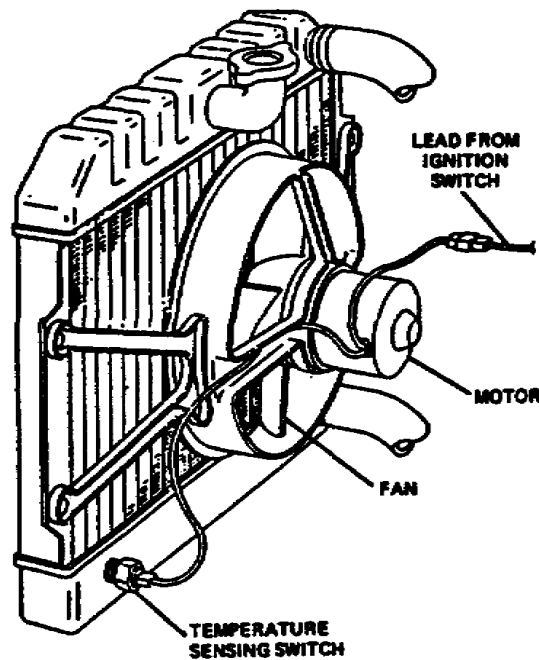
(2) *Electrically Motorized Fan* (figure 68 on the following page). The electrically motorized fan is gaining popularity in automotive use. In the newer

FIGURE 67. VISCOUS FAN CLUTCH.



configurations of front-wheel drive vehicles with transversely mounted engines, the electric fan is a necessity because the end of the engine is not located directly behind the radiator. Description and operation of the fan is as follows:

FIGURE 68. ELECTRICALLY MOTORIZED FAN.



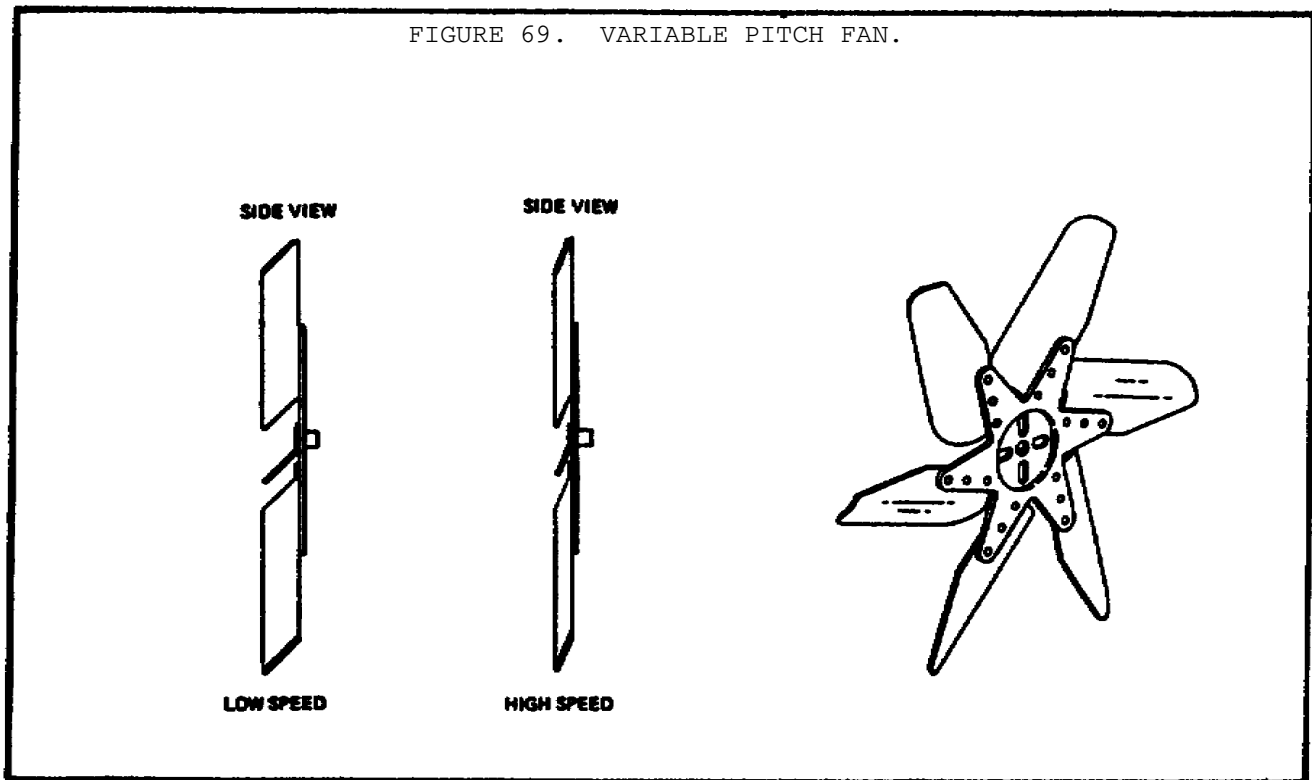
(a) The fan blade is mounted on the motor shaft. The motor and fan blade assembly is then mounted directly behind the radiator core.

(b) The fan receives electric current through the ignition switch and a temperature sensitive switch located at the bottom of the radiator. The purpose of this radiator thermal switch is to turn on the fan to provide cooling whenever the temperature of the coolant reaches approximately 210° F (98.8° C). This serves to allow the fan to run only when needed.

(c) Some models incorporate a timed relay that allows the fan to run for a short time after engine shutdown. This, in conjunction with thermosiphon action in the cooling system, helps to prevent boilover after engine shutdown.

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(3) *Variable Pitch* (Flexible) Fan Blades (figure 69). Some vehicles are equipped with blades that are made of flexible aluminum or fiberglass. These fan blades are made to change pitch as the speed of the fan increases so that the fan will not create excessive noise or draw excessive engine power at highway speeds.

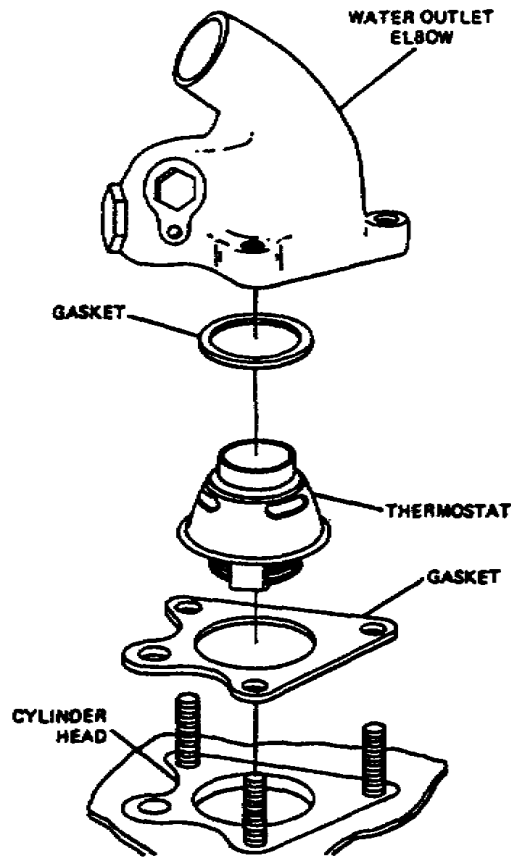


g. Thermostats.

(1) *Purpose.* The water pump starts the coolant circulating through the system as the engine is started, no matter how low the temperature. Therefore, it is necessary to install a thermostat to ensure quick warmup and prevent overcooling in cold weather. A thermostat regulates engine temperature by automatically controlling the amount of coolant flowing from the engine block to the radiator core.

(2) *Operation.* The thermostat is merely a heat-operated unit that controls a valve between the engine block and the radiator. It is usually located in series with the engine coolant outlet in a casing called the thermostat housing. The thermostat, by design, is made that if it fails, it will be in the opened position allowing the free circulation of coolant through the engine.

FIGURE 70. BELLOWS-TYPE THERMOSTAT.

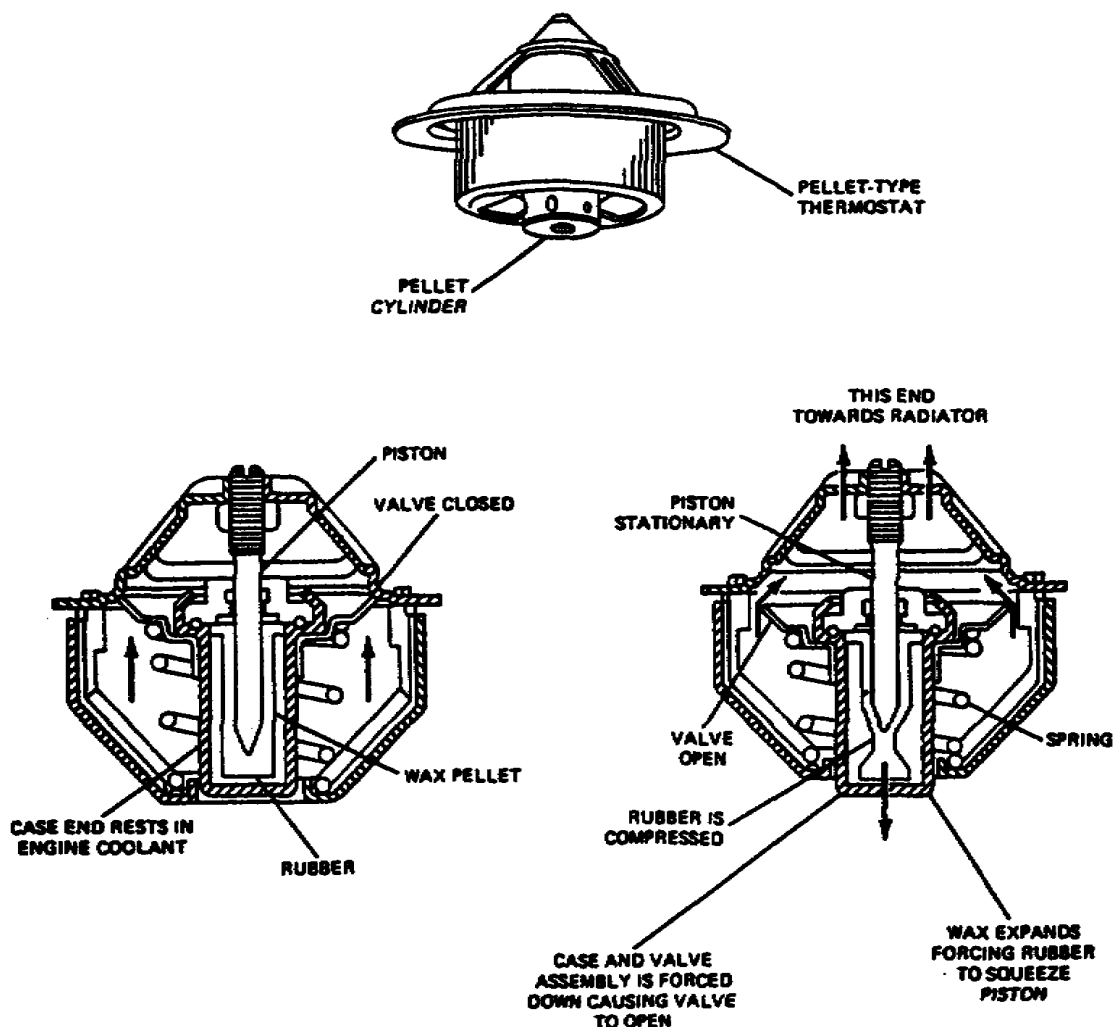


(3) *Configurations.* The two configurations of the thermostat are:

(a) The bellows type (figure 70 on the following page), which consists of a flexible metal bellows attached to a valve. The bellows, which is sealed and expandable, is filled with a highly volatile liquid such as ether. The bellows chamber is contracted when the coolant is cold, holding the valve closed. The liquid in the bellows vaporizes as the coolant is heated, causing the bellows to expand. The bellows pull the valve open as they expand, allowing coolant to circulate. The bellows-type thermostat is little used in modern equipment because its great sensitivity to the pressure around it makes it inaccurate in modern pressurized cooling systems.

(b) The pellet type thermostat (figure 71), is currently used because its accuracy is unaffected by modern pressurized cooling systems. The thermostat consists of a valve operated by a piston, a steel pin that fits into a small case containing a copper impregnated wax pellet. When the engine is cold, the wax pellet is contracted and the spring pushes the valve closed. The wax pellet expands as the engine heats up, pushing the valve open against the force of the spring. The pellet-type thermostat will maintain a constant temperature by varying the size of the valve opening.

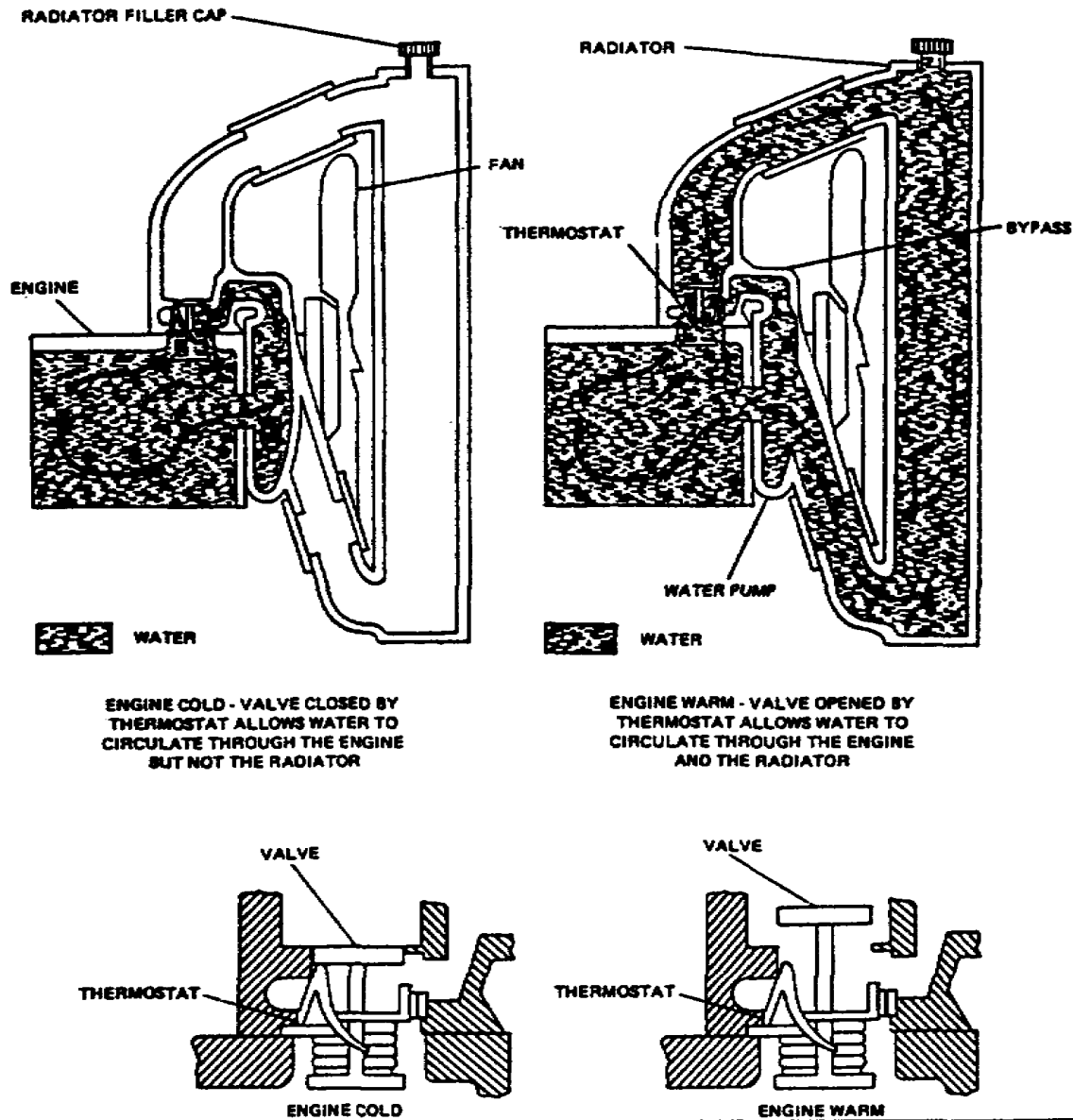
FIGURE 71. PELLETYPE THERMOSTAT.



(4) Thermostat Beat Ranges. A variety of thermostats are available to allow the coolant to operate at different temperatures. The standard heat ranges available are from 160° F (71° C) to 210° F (99.8° C).

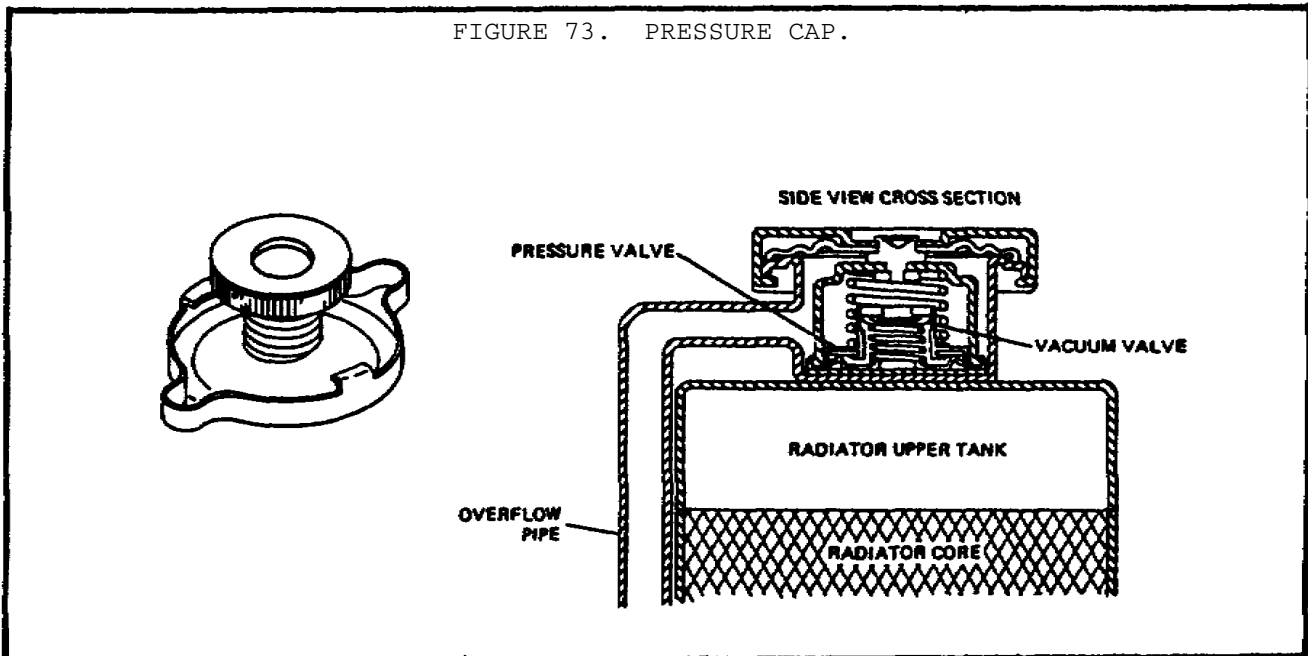
(5) Coolant Bypass (figure 72 on the following page). The engine is designed so that the water pump will circulate coolant within the water jackets whenever the thermostat is closed. This is important to keep pistons and valves from overheating even though the engine is below operating temperature.

FIGURE 72. COOLANT BYPASS.



h. *Radiator Pressure Cap.*

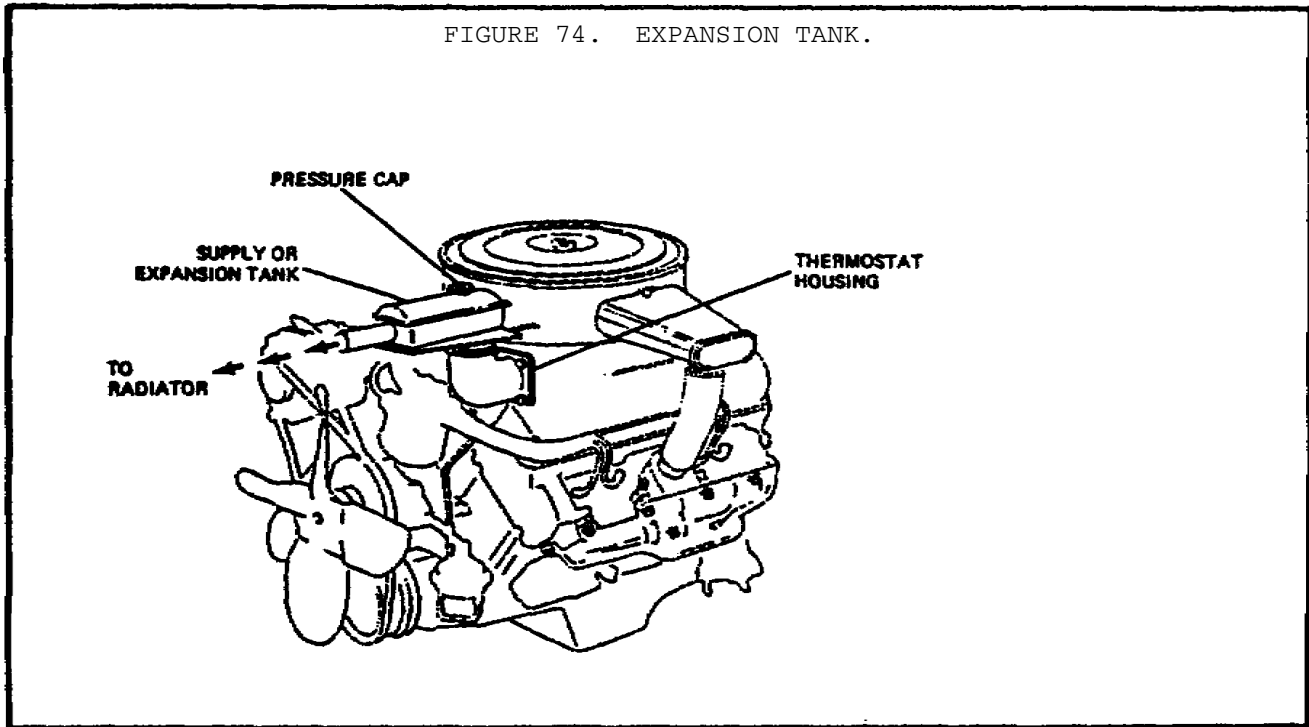
(1) *Purpose.* Modern automotive vehicles use pressurized cooling systems that allow a certain amount of pressure to develop within the system as its temperature goes up. The increase in pressure will raise the boiling point of the coolant proportionally, helping to prevent boilover.



(2) *Operation* (figure 73). The cap contains two spring-loaded valves that are normally closed, sealing the system. The larger of these two valves is the pressure valve, the smaller is the vacuum valve. The pressure valve acts as a safety valve that will vent any pressure over the rated maximum through the overflow pipe. The vacuum valve allows air to enter the system as the engine cools down. This is to prevent atmospheric pressure from collapsing the hoses.

i. *Expansion Tank* (figure 74 on the following page). Some vehicles use an expansion tank in their cooling systems. The expansion tank is mounted in series with the upper radiator hose. It is used to supply extra room for coolant expansion and generally takes the place of the upper radiator tank. The radiator pressure cap and the overflow line are also mounted on the expansion tank.

FIGURE 74. EXPANSION TANK.

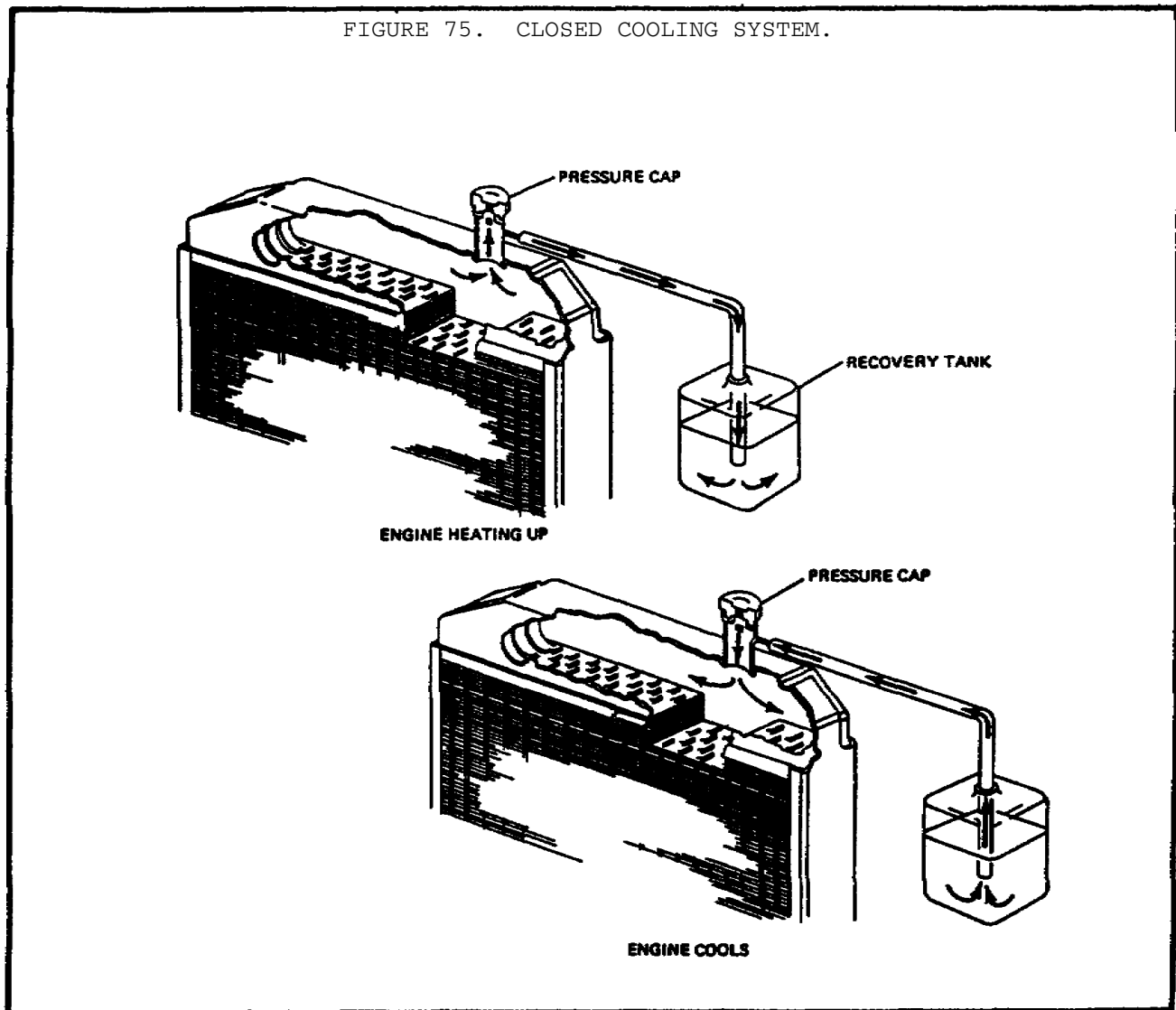


j. *Closed Cooling System* (figure 75 on the following page).

(1) *Purpose.* The purpose of a closed cooling system is twofold. First, the system is designed to maintain a completely full radiator at all times. This will increase the efficiency of the system by allowing a maximum amount of coolant in the system during all operating conditions. Second, during an overheating condition, the closed cooling system prevents coolant loss through the overflow line by collecting it in the recovery tank.

(2) *Operation.* As the temperature of the cooling system rises, the pressure also will rise. This will open the pressure valve in the pressure cap, causing coolant to exit through the overflow tube, thus venting excess pressure. An open-type cooling system will empty coolant onto the road, causing a low coolant level after the temperature returns to normal. When a closed cooling system is used, the overflow line is connected to the bottom of a coolant recovery tank to catch and hold any expelled coolant. As the temperature of the coolant drops, the corresponding drop in pressure causes atmospheric pressure to push the coolant in the recovery tank back into the cooling system through the open vacuum valve in the pressure cap.

FIGURE 75. CLOSED COOLING SYSTEM.

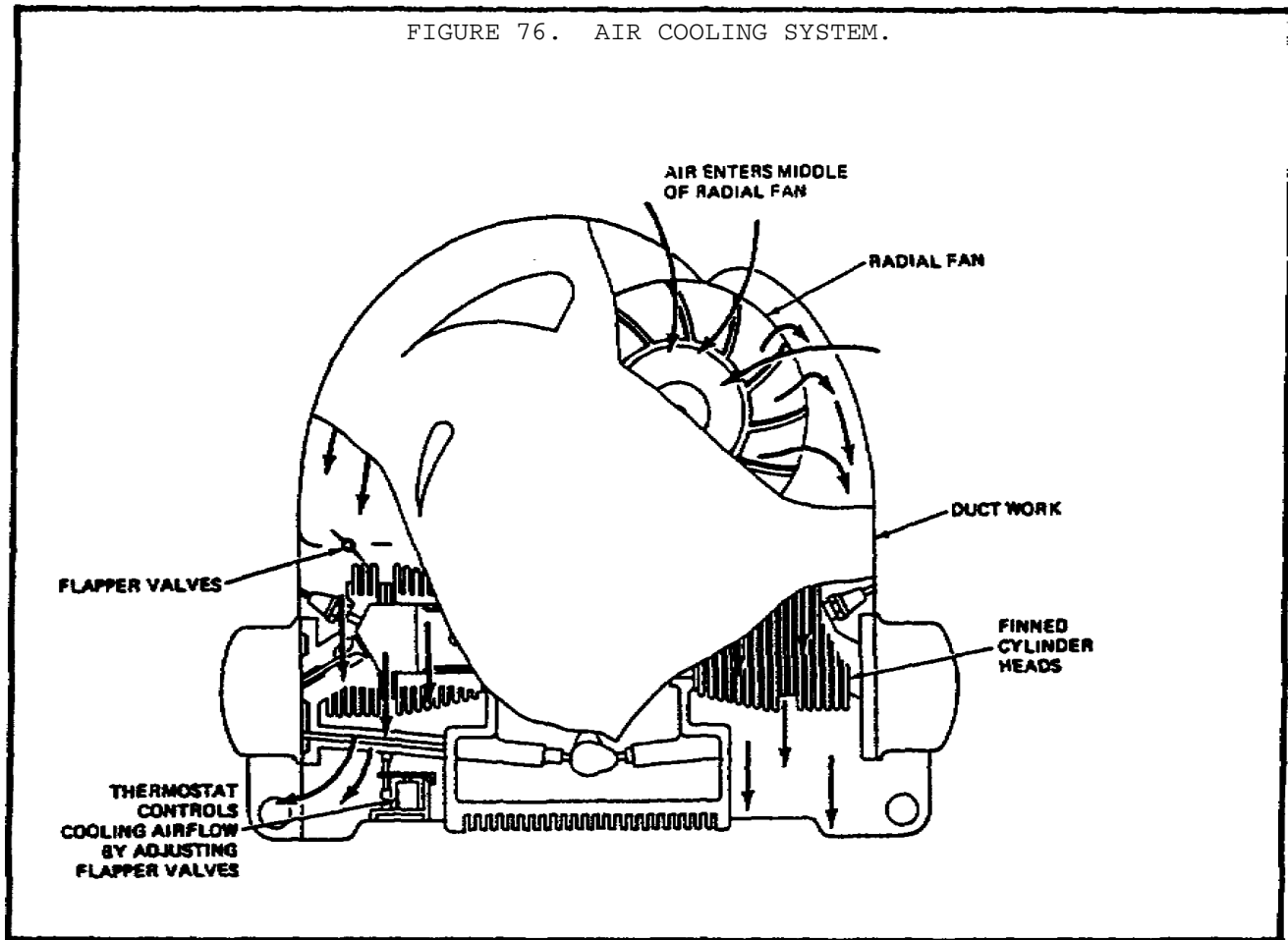


4. Air Cooling Systems

a. An air-cooled engine uses air as the principal cooling medium (figure 76 on the following page). Air-cooled engines are very easily identified by separate finned cylinders, finned cylinder heads and, in most cases, large cooling fans and extensive duct work.

b. The primary means of removing heat from an air-cooled engine is by dissipation to the air. The duct work and the cooling fans cause a constant flow of air over and around the cylinders and cylinder heads. The finned design of these components add a tremendous amount of surface area to them so they are able to dissipate an adequate amount of heat.

FIGURE 76. AIR COOLING SYSTEM.



c. An air cooling system, like a liquid cooling system, must be controlled to prevent overcooling of the engine. To accomplish this, a system of thermostatically controlled doors are usually incorporated into the ducting. The thermostat is usually a bellows filled with butyl alcohol. As the thermostat heats up, it opens the temperature control doors through linkage. When the doors are open, all of the cooling air is diverted through the engine cooling fins. When the doors are closed, all cooling air bypasses the engine and no cooling takes place. To maintain uniform engine temperature, the thermostat, in most cases, will position the doors so that part of the cooling air bypasses and part of it cools. The thermostat, in the event of failure, is designed to open the doors fully to prevent overheating.

d. Because an air cooling system does not employ a liquid coolant, it is often assumed that air alone acts as the cooling medium. However, this is not true because, as was pointed out in paragraph 2a on page 80, the fuel and the lubrication systems also help in cooling the engine. The lubrication system of an air-cooled

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engine always uses an air cooling system. There is also a certain amount of cooling as the fuel vaporizes in the intake manifolds and combustion chambers.

e. Virtually all air-cooled engines use an oil cooler to help in the cooling process. The oil cooler unit is usually located in the ducting so that it is exposed to the forced air from the cooling fan. Its operation is the same as that described in paragraph 3f of Lesson 2 Task 2 on page 73.

4. Conclusion

This concludes the discussion of the cooling system and the subsystems of the internal combustion engine. The information provided in this subcourse should give the mechanic a general idea of the principles and operation of an internal combustion engine and its subsystems. For a more complete understanding of internal combustion engines, their operations, and components, the mechanic should refer to TM 9-8000.

PRACTICAL EXERCISE 2

On a plain sheet of paper, write down the answers to the following questions. When you have answered them, turn the page and check your answers.

1. When will a ram manifold serve no useful purpose?
2. Along with dampening noise, what other function does the exhaust system have?
3. Which component connects all of the engine cylinders to the exhaust system?
4. A component that uses the force of the engine exhaust stream to force the air-fuel mixture into the engine is called a _____.
5. What is the primary function of engine oil?
6. What oil is used in most internal combustion engines?
7. What are the four oil classifications for diesel engines?
8. The viscosity of an oil refers to _____.
9. What are the two basic filter element configurations?
10. Name the four types of lubrication systems.
11. What is the most popular coolant for liquid-cooled engines?
12. The two configurations of the thermostat are the _____.

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LESSON 2. PRACTICAL EXERCISE - ANSWERS

1. When it is outside its designated speed range.
2. The waste products of combustion are carried from the engine to the rear of the vehicle by the exhaust system.
3. Exhaust manifold
4. Turbocharger
5. To reduce friction between the moving parts inside the engine and lubricate.
6. Mineral oil
7. CA, CB, CC, and CD
8. Its resistance to flow
9. The cartridge type and the sealed can type.
10. Splash system, combination splash and force-feed system, force-feed lubrication system, and full force-feed lubrication system.
11. Water
12. Bellows type and pellet type

REFERENCES

PRIN. OF INTERNAL COMBUSTION ENGINES - OD1619 - REFERENCES

REFERENCES

The following documents were used as resource materials in developing this subcourse:

TM 9-8000