UNITED STATES MARINE CORPS
ENGINEER EQUIPMENT INSTRUCTION COMPANY
MARINE CORPS DETACHMENT
FORT LEONARD WOOD, MISSOURI 65473-8963

LESSON PLAN

DIESEL ENGINES

NCOM-C01

ENGINEER EQUIPMENT MECHANIC NCO

A16ACU1

REVISED 02/3/2014

APPROVED BY ______________________ **DATE** ______________

INTRODUCTION **(10 MIN)**

(**ON SLIDE #1)**

1. **GAIN ATTENTION**.

INSTRUCTOR NOTE
Computer aided graphic Intro to Diesel Failure Analysis 1.23 minutes.

Who in this class would like to ride a horse to work every day? Better yet who in this class would like to try and move tons of dirt with a horse and wagon? I don't think that would be too much fun or very productive do you?

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(ON SLIDE #2)

2. **OVERVIEW**. Good morning/afternoon class, my name is _______________. The purpose of this period of instruction is to familiarize the student with advanced techniques of isolation, identification, diagnosis, and repair of diesel engine malfunctions.

(ON SLIDE #3)

INSTRUCTOR NOTE
Introduce learning objectives.

3. **LEARNING OBJECTIVES**.

a. TERMINAL LEARNING OBJECTIVE.

(1) Provided a service request, malfunctioning intake/exhaust system, appropriate tools, and references, conduct advanced repair to equipment intake/exhaust system to restore proper function.(1341-MANT-2003)

(2) Provided a service request, malfunctioning fuel system, appropriate tools, and references, conduct advanced repair to equipment fuel system to restore proper function. (1341-MANT-2004)

(3) Provided a service request, malfunctioning coolant system, appropriate tools/test equipment, and references, conduct advanced

repair of coolant system, to restore system to proper function.(1341-MANT-2005)

(4) Provided a service request, a malfunctioning diesel engine, appropriate tools and equipment, and the references, repair a diesel engine to restore engine to proper function. (1341-MANT-2006)

(ON SLIDE #4)

b. **ENABLING LEARNING OBJECTIVES**.

(1) Without the aid of reference, identify the characteristics of a diesel engine per the FOS3007NC. (1341-MANT-2006a)

(2) Without the aid of reference, identify the characteristics of an intake/exhaust system per the FOS3007NC. (1341-MANT-2003a)

(3) Without the aid of reference, identify the characteristics of a fuel system per the FOS3007NC. (1341-MANT-2004a)

(4) Without the aid of reference, identify the characteristics of a cooling system per the FOS3007NC. (1341-MANT-2005a)

(5) With a caterpillar C6.6 engine, tools, TMDE, and references, disassemble the intake/exhaust system per the RENR9722-01 and SENR9968-02. (1341-MANT-2003b)

(6) With a caterpillar C6.6 engine, tools, TMDE, and references, disassemble the cooling system per the RENR9722-01 and SENR9968-02. (1341-MANT-2005b)

(7) With a caterpillar C6.6 engine, tools, TMDE, and references, disassemble the fuel system per the RENR9722-01 and SENR9968-02. (1341-MANT-2004b)

(8) With a caterpillar C6.6 engine, tools, and references, disassemble the engine per the RENR9722-01 and SENR9968-02. (1341-MANT-2006b)

(9) With a disassembled caterpillar C6.6 engine, tools, TMDE, and references, assemble the engine per the RENR9722-01 and SENR9968-02. (1341-MANT-2006c)

(10) With a caterpillar C6.6 engine, tools, TMDE, and references, assemble the fuel system per the RENR9722-01 and SENR9968-02. (1341-MANT-2004c)

(11) With a caterpillar C6.6 engine, tools, TMDE, and references, assemble the cooling system per the RENR9722-01 and SENR9968-02. (1341-MANT-2005c)

(12) With a caterpillar C6.6 engine, tools, TMDE, and references, assemble the intake/exhaust system per the RENR9722-01 and SENR9968-02. (1341-MANT-2003c)

(13) With an assembled caterpillar C6.6 engine, tools, TMDE, and references, test the engine per RENR9722-01 and SENR9968-02. (1341-MANT-2006d)

(ON SLIDE #5)

4. **METHOD/MEDIA** . This period of instruction will be taught using the lecture method with aid of power point presentation, videos, instructor demonstrations, and practical applications.

INSTRUCTOR NOTE
Explain Instructional Rating Forms to the students.

(ON SLIDE #6)

5. **EVALUATION**. There will be a fifty question, multiple choice, closed book examination and a Hands-on evaluation of proper diesel engine trouble shooting procedures. Refer to the training schedule for day and time.

6. **SAFETY/CEASE TRAINING (CT) BRIEF**. In case of fire exit the building and assemble in the parking lot for a head count. There is no safety brief associated with this lecture portion. There will be a safety brief given before certain demonstrations and practical applications.

(ON SLIDE #7)

TRANSITION: Now that you understand the purpose of this presentation, the terminal learning objective, enabling learning objective, how the period of instruction will be taught, and how you'll be evaluated, let's begin with a discussion of some of the recent developments in diesel technology.

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BODY **(76 HRS 40 MIN)**

1. **DIESEL ENGINE CONSTRUCTION** **(2 hrs)**

(ON SLIDE #8)

INSTRUCTOR NOTE
Computer aided graphic Hot Parts 1.37 minutes.

(ON SLIDE #9)

a. **Background**. Because the most widely used piston engine is the four-stroke cycle liquid cooled, it will be used as the focus of discussion.

(1) Attached to diesel engines is a certain mystique that makes owners and mechanics alike call for professional help at the first sign of trouble. There is, in fact, something intimidating about an engine that has no visible means of ignition, the torque characteristics of a bull ox, and fuel-system tolerances expressed as wavelengths of light.

(2) Yet, working on diesels is no more difficult than servicing the current crop of gasoline engines. In some ways, the diesel is an easier nut to crack—symptoms of failure are less ambiguous, specifications are more complete, and the quality of design and materials is generally superior. Nothing in human experience quite compares to the frustration created by an engine that refuses to start. By the same token, no music is sweeter than the sound of an engine that you have just repaired.

(3) Emphasis here is on the uniquely diesel aspects of the technology diagnostics, fuel systems, turbocharging, and the kind of major engine work not often languished on gasoline engines. The emphasis here is on how things work. What is not understood cannot be fixed, except by accident or through an enormous expenditure of time and parts. Combined in this discussion is “how-to” information with theory. The recipes change with engine make and model; however, the theory has currency for all.

(4) The computer revolution has impacted truck, bus, some marine, and many stationary engines. First encounters with computer-controlled engines can send mechanics into culture shock. None of the old rules apply, or that is the way it seems. Actually these “green” engines are still diesels and subject to all the ills that compression ignition is heir to. But the control hardware is electronic, and that is where new skills and new ways of thinking are required.

(ON SLIDE #10)

INSTRUCTOR NOTE
Computer aided graphic Iron and steel 1.18 minutes.

b. **Cylinder Blocks**. The cylinder, or the engine block, is the basic foundation of virtually all engines. The block in most engines is a solid casting made of cast iron that contains the crankcase, cylinders, and coolant passages (air cooled engines will be covered later).

(ON SLIDE #11)

INSTRUCTOR NOTE
Computer aided graphic Casting 0.56 minutes.

(1) Construction. The cylinder block is a one piece casting that is usually an iron alloy containing nickel and molybdenum. This is the best overall material for cylinder blocks. It provides excellent wearing qualities, low material and production costs, and it only changes dimensions minimally when heated.

(ON SLIDE #12)

(2) Cylinders. The cylinders are bored right into the block (Figure4). A good cylinder must be round, not varying in diameter and be uniform for its entire length.

(ON SLIDE #13)

(3) Cylinder Sleeves. Cylinder sleeves or liners commonly are used to provide a wearing surface other than the cylinder block for the pistons to ride against. This is important for the following reasons:

(a) Alloys of steel can be used that will wear longer than the surfaces of the cylinder block. This will increase engine life while keeping production costs down.

(b) Because the cylinders wear more than any other area of the block, the life of the block can be extended greatly by using sleeves. When overhaul time comes, the block then can be renewed by merely replacing the sleeves. For this reason, sleeves are very popular in large diesel engines, for which the blocks are very expensive.

(c) Using a sleeve allows an engine to be made of a material such as aluminum (as is the case for air cooled engines) by providing the wearing qualities necessary for the cylinder that the aluminum cannot.

(d) Whatever method is used to secure the sleeve, it is very important that the sleeve fits tightly. This is important so that the sleeve may transfer its heat effectively to the water jackets. The following are the three basic ways of securing the sleeves in the cylinder block:

(ON SLIDE #14)

1 Different ways to secure the sleeves.

a Pressing in a sleeve that is tight enough to be held in by friction.

b Providing a flange at the top of the block that locks the sleeve in place when the cylinder head is bolted into place. This is more desirable than a friction fit, because it locks the sleeve tightly.

c Casting the sleeve into the cylinder wall. This is a popular means of securing the sleeve in an aluminum block.

(ON SLIDE #15)

c. **Crankcase**. The crankcase is the part of the cylinder block that supports and encloses the crankshaft. It is also where the engine's lubricating oil is stored. The upper part of the crankcase usually is part of the cylinder block, while the lower part is removable (oil pan or oil reservoir).

(ON SLIDE #16)

d. **Cylinder Heads**. The cylinder head is a separate one-piece casting that bolts to the top of the cylinder block.

(1) Construction. The cylinder head is made almost exclusively from cast iron on Engineer Equipment. The cylinder head seals the end of the cylinder. This serves to provide a combustion chamber for the ignition of the fuel and to hold the expansive forces of the burning gases so that they may act on the piston. There is an opening to position the fuel injector in the combustion chamber (additional information on combustion chambers will be covered in the air induction portion).

(ON SLIDE #17)

(2) Valves and Ports. The cylinder head on overhead valve configurations supports the valves and has the ports cast into it. (Valves are covered during the Air & Exhaust System).

(ON SLIDE #18)

(3) Sealing. Cylinder heads on liquid-cooled configurations are sealed to the cylinder block by the head gasket. The head gasket usually is made of two sheets of soft steel that sandwich a layer of asbestos. Steel rings are used to line the cylinder openings. They hold the tremendous pressures created on the power stroke. Holes are cut in the gasket to mate the coolant and lubrication feed holes between the cylinder block and the cylinder head.

(ON SLIDE #19)

INSTRUCTOR NOTE
Image of camshaft and tappets.

(ON SLIDE #20)

INSTRUCTOR NOTE
Computer aided graphic camshaft 2.28 minutes.

e. Camshafts and Tappets. The camshaft provides for the opening and closing of the engine valves. The tappets or the lifters are the connecting link between the camshaft and the valve mechanism.

(ON SLIDE #21)

(1) Camshaft Construction. Camshafts usually are made from cast or forged steel. The surfaces of the lobes are hardened for long life.

(ON SLIDE #22)

(2) Camshaft Support. The camshaft is supported, and rotates, in a series of bearings along its length. The bearings usually are pressed into their mountings and made of the same basic construction as crankshaft bearings. The thrust, or the back and forth movement, usually is taken up by the thrust plate, which bolts to the front of the engine block. Any forward thrust loads are then taken up by the front camshaft bearing journal. The drive gear or sprocket then is fitted to the front of the camshaft. Its rear

surface rides against the thrust plate to take up any rearward thrust.

(ON SLIDE #23)

(3) Driving the Camshaft. Camshafts may be driven by gears, belts, or chains. However, Heavy Industrial Diesels rely exclusively on gears. A gear on the crankshaft meshes directly with another gear on the camshaft. The gear on the crankshaft and camshaft are made of steel. The gears are helical in design. Helical gears are used because they are stronger, and they also tend to push the camshaft rearward during operation to help control thrust.

(ON SLIDE #24)

(4) Timing Marks. The camshaft and the crankshaft always must remain in the same relative position to each other. Because the crankshaft must rotate twice as fast as the camshaft, the drive member on the crankshaft must be exactly one-half as large as the driven member on the camshaft. In order for the camshaft and crankshaft to work together, they must be in the proper initial relation to each other. This initial position between the two shafts is designated by marks that are called timing marks. To obtain the correct initial relationship of the components, the corresponding marks are aligned at the time of assembly.

(ON SLIDE #25)

(5) Auxiliary Camshaft Functions. The camshaft, after being driven by the crankshaft, in turn drives other engine components.

(a) The oil pump.

(b) The fuel transfer pump. This is usually accomplished by machining an extra lobe on the camshaft to operate the pump.

(c) On diesel engines, the camshaft often is utilized to operate the fuel injection system.

(ON SLIDE #26)

INSTRUCTOR NOTE
Computer aided graphic Lifters 0.11 minutes.

f. **Tappets**. Tappets (or lifters) are used to link the camshaft to the valve mechanism. The bottom surface is hardened and machined to be compatible with the surface of the camshaft lobe. Tappets may be solid or hydraulic. However, Heavy Industrial Diesel’s rely exclusively on solid tappets.

(ON SLIDE #27)

(1) Mechanical Tappets. Mechanical (or solid) lifters are simply barrel shaped pieces of metal. They have an adjusting screw mechanism to set the clearance between the tappets and the valve stems. Mechanical tappets may also come with a wider bottom surface. These are called mushroom tappets. Another variation is the roller tappet, which has a roller contacting the camshaft. They are used mostly in heavy-duty applications (where tremendous forces are expected) to reduce component wear.

(ON SLIDE #28)

(2) Camshaft-to-Tappet Relationship. The face of the tappet and the lobe of the camshaft are designed so that the tappet will be made to rotate during operation. The cam lobe is machined with a slight taper that mates with a crowned lifter face. The camshaft lobe does not meet the tappet in the center of its face. Using this type of design causes the tappet face to roll and rotate on the cam lobe rather than slide. This greatly increases component life.

(ON SLIDE #29-30)

INSTRUCTOR NOTE
Image of camshaft and tappets

(ON SLIDE #31)

g. **Pistons**.

(1) Piston Requirements. The piston must withstand incredible punishment under severe temperature extremes. These are some examples of conditions that a piston must withstand at normal operating speeds.

(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 mph (80 km/h) at midpoint, and then decelerates to a stop again. It does this approximately 55 times per second.

(b) The piston is subjected to pressures on its head in excess of 1000 psi (6895 kPa).

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

(ON SLIDE #32)

INSTRUCTOR NOTE
Computer aided graphic Pistons 0.59 minutes.

(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 alloys are the best material for piston construction. A very high strength-to-weight ratio, lightweight, excellent conductor of heat, and is machined easily make aluminum alloys very attractive to engine manufacturers. Pistons also are manufactured from cast iron. Cast iron is an excellent material for pistons in very low speed engines, but it is not suitable for higher speeds because it is a very heavy material.

(ON SLIDE #33)

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

(ON SLIDE #34)

(a) It is obvious that the crown (head) 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 smaller than the skirt area.

(ON SLIDE #35)

(b) Cam Grinding. 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 keep from 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.

(ON SLIDE #36)

(2) Skirted Pistons. The purpose of the piston skirt is to keep the piston from rocking in the cylinder.

(ON SLIDE #37)

Some piston skirts have large portions of its skirt removed in the non thrust 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.

(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.

(ON SLIDE #38)

(3) Strength and Structure. When designing a piston, weight and strength are both 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, there are ribs cast into the underside of it.

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

(ON SLIDE #39)

(4) Coatings. Pistons that are made from aluminum are usually treated on their outer surfaces to aid in engine break-in and increase hardness. The following are the most common processes for treatment of aluminum pistons.

(a) The piston is coated with tin so that it will work into the cylinder walls as the engine is broken in. This process results in a more perfect fit, shortening of 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.

(ON SLIDE #40)

(5) Top Ring Groove Insert. The top ring groove is very vulnerable to wear for the following reasons:

(a) It is close to the piston head, subjecting it to intense heat.

(b) The top compression ring is exposed directly to the high pressures of the compression stroke. To remedy the potential problem of premature top ring groove wear, some aluminum pistons are fitted with an insert in the top ring groove. The insert usually is made from nickel iron. Because of the better wear qualities, the ring groove will last longer than if the ring fit directly against the aluminum.

(ON SLIDE #41)

h. **Piston Rings**.

(1) Purpose. There are three main purposes for piston rings.

(a) They provide a seal between the piston and the cylinder wall to keep the force of the expanding combustion 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.

(b) They keep 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.

(ON SLIDE #42)

(2) Description. There are 2 types of piston rings Compression and oil control rings. Piston rings are secured on the pistons by fitting into grooves. There may be two or three compression rings followed by an oil control ring on the bottom. They 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 a solid contact with the cylinder wall around its entire circumference. There are two basic classifications of piston rings.

(ON SLIDE #43)

(3) Top Compression Ring. The compression ring seals the force of the exploding mixture into the combustion chamber. There are many different cross sectional shapes of piston rings available. The various shapes of rings all serve to preload the ring so that its lower edge presses against the cylinder wall.

(a) Functions of the top compression ring.

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

2 As the piston moves downward, the lower edge of the ring scrapes, from the cylinder walls, any oil that manages to work past the oil control rings.

3 On the compression and the exhaust strokes, the ring will glide over the oil, increasing its life.

(4) Second Compression Ring. 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 to the piston with their gaps 60 degrees offset with the first ring gaps.

INSTRUCTOR NOTE
This is a good time to reemphasize that piston construction is significantly different between engine manufactures (Detroit Diesel, Cummins, and Caterpillar) and even among different engine families. Some pistons may have 3, 4, or even 5 compression rings.

(ON SLIDE #44)

INSTRUCTOR NOTE
Computer aided graphic Oil Control Ring 0.16 minutes.

(5) The Oil Control Ring. The oil control ring keeps the engine’s lubricating oil from getting into the combustion chamber by controlling the lubrication of the cylinder walls. They do this by

scraping the excess oil from the cylinder walls on the down stroke. The oil then is forced through slots in the piston ring and the piston ring groove. The oil then drains back into the crankcase. The rings are made in many different configurations that can be one-piece units or multipiece assemblies. Regardless of the configuration, all oil control rings work basically in the same way.

(ON SLIDE #45)

(6) Ring Gap. The split in the piston ring is necessary for:

(a) Installing the ring on the piston.

(b) Allowing for expansion from heating. The gap must be such that there is enough space so that the ends do not come together as the ring heats up. This would cause the ring to break.

(ON SLIDE #46)

(7) Ring Expanders. Expander devices are used in some applications. These devices fit behind the piston ring and force it to fit tighter to the cylinder wall. They are particularly useful in engines where a high degree of cylinder wall wear exists.

(ON SLIDE #47)

(8) Piston Ring Wear-in. When piston rings are new, a period of running is necessary to wear the piston rings a small amount so that they will conform perfectly to the cylinder walls.

(a) The cylinder walls are surfaced with a tool called a hone. The hone leaves fine scratches (called a cross hatch pattern) in the cylinder walls. The piston rings are made with grooves in their faces. The grooved faces of the piston rings rubbing against the roughened cylinder walls serve to accelerate ring wear during the initial stages, and speed wear-in. As the surfaces wear smooth, the rings will be worn in.

(b) Extreme pressure may be applied to high spots on the piston rings during the wear-in period. This can cause the piston rings to overheat at these points and cause damage to the cylinder walls in the form of rough streaks. This condition is called scuffing. New piston rings are coated with a porous material such as graphite, phosphate, or molybdenum. These materials absorb oil and serve to minimize scuffing. As the rings wear in, the coatings wear off.

(c) Some piston rings are chrome plated. Chrome-plated rings generally provide better overall wearing qualities. They also are finished to a greater degree of accuracy, which lets them wear in faster.

(ON SLIDE #48)

INSTRUCTOR NOTE
The Piston Pins are the next component in engine construction we'll cover. It is important to keep in mind that there are two acceptable methods of fitting piston pins into pistons; heating the piston or cooling the pin. **NEVER FORCE A PISTON AND PIN TOGETHER! SEVERE DAMAGE WILL RESULT!**

i. **Piston Pins**.

(1) Purpose. The piston pin serves to connect the piston to the connecting rod. It passes through the pin bosses in the piston and the upper end of the connecting rod. The full-floating piston pins pivot freely in the connecting rod and the piston pin bosses. The outer ends of the piston pins are fitted with lock rings to keep the pin from sliding out and contacting the cylinder walls.

(ON SLIDE #49)

(2) Construction. A piston pin must be hard to provide the desired wearing qualities. At the same time, the piston pin must not be brittle. To satisfy the overall requirements of a piston pin, it was found that a casehardened steel pin is best. Case hardening is a process that hardens the surface of the steel to a desired depth. The pin is also made hollow to reduce the overall weight of the reciprocating mass.

(ON SLIDE #50)

INTERIM TRANSITION: We have just covered components of the combustion chamber, are there any questions? If not go ahead and take a ten minute break.

(BREAK – 10 Min)

INTERIM TRANSITION: Before the break we finished combustion chamber components, are there any questions? If not lets move onto connecting rods.

(ON SLIDE #51)

j. **Connecting Rods**.

(1) Purpose. The connecting rods connect the pistons to the crankshaft. They must be extremely strong to transmit the thrust of the pistons to the crankshaft, and to withstand the inertial forces of the directional changes of the pistons.

(ON SLIDE #52)

(2) Construction. The connecting rods are normally in the form of an I-beam. This design gives the highest overall strength and lowest weight. They usually are made of forged steel, but may be made of aluminum in small engines. The upper end attaches to the piston pin, which connects it to the piston. The lower end is attached to the crankshaft. The lower bearing hole in the connecting rod is split so that it may be clamped to the crankshaft. Because the lower end has much greater movement than the upper, the hole is much larger. This provides much greater bearing surface.

(ON SLIDE #53)

k. **Crankshaft**.

(ON SLIDE #54)

INSTRUCTOR NOTE
Computer aided graphic reciprocating motion to rotary motion 0.29 minutes.

(1) Purpose. The crankshaft is the part of the engine that transforms the reciprocating motion from the pistons to rotating motion.

(ON SLIDE #55)

(2) Construction. Crankshafts are made from forged or cast steel. The forged steel unit is the stronger of the two. It usually is reserved for commercial and military use. The cast unit is used primarily in light and regular duty gasoline engines.

(ON SLIDE #56-58)

INSTRUCTOR NOTE
Computer aided graphic Crankshafts 0.13 minutes.

After the rough forging or casting is produced, it becomes a finished product by going through the following steps:

(a) All surfaces are rough machined.

(b) All holes are located and drilled.

(c) The crankshaft, with the exception of the bearing journals, is plated with a light coating of chrome.

(d) The bearing journals are case-hardened.

(e) The bearing journals are ground to size.

(f) Threads are cut into necessary bolt holes.

(ON SLIDE #59)

(3) Throw Arrangements. The arrangement of the throws on the crankshaft determines the firing order of the engine. The position of the throws for each cylinder arrangement is paramount to the overall smoothness of operation.

(ON SLIDE #60)

(a) In-line cylinder engines have one throw for each cylinder. This is a very common arrangement that is built in four and six cylinder configurations. The four cylinder crankshaft has its throws offset by 180° while the six cylinder design has its throws offset by 120°.

(ON SLIDE #61)

(b) V-type engines have two cylinders operating off of each throw. The two end throws are on one plane offset 180 degrees apart. The two center throws are on another common plane. They are also offset 180 degrees apart. The two planes are offset 90 degrees from each other.

(ON SLIDE #62)

(c) The crankshaft is supported in the crankcase and rotates in the main bearings. The connecting rods are supported on the crankshaft by the rod bearings.

INSTRUCTOR NOTE
BEARINGS ARE COVERED IN GREAT DETAIL DURING THE LUBRICATION SECTION.

(ON SLIDE #63)

(4) Crankshaft Vibration. A crankshaft is very prone to vibration because of its shape, extreme weight, and the tremendous forces acting on it. The following are three basic areas that are of concern when considering vibration in crankshaft design.

(ON SLIDE #64)

(a) Imbalance Vibration. An inherent problem with a crankshaft is that it is made with offset throws. The weight of the throws tends to make the crankshaft rotate elliptically. This is aggravated further by the weight of the piston and the rod. To eliminate the problem, weights are positioned along the crankshaft. One weight is placed 180 degrees away from each throw. They are called counterweights and are usually part of the crankshaft.

(ON SLIDE #65)

INSTRUCTOR NOTE
Computer aided graphic Crankshaft Deflection 0.45 minutes.

(b) Deflection Vibration. The crankshaft will have a tendency to bend slightly when subjected to the tremendous thrust from the piston. This deflection of the rotating member will cause a vibration. This vibration is minimized by heavy crankshaft construction and sufficient support along its length by bearings.

(ON SLIDE #66)

INSTRUCTOR NOTE
Computer aided graphic Crankshaft Torsion 0.37 minutes.

(3) Torsional Vibration. Torsional vibration occurs when the crankshaft twists because of the power stroke thrusts. It is particularly noticeable on engines with long crankshafts, such as in-line engines. It is a major reason why in-line, eight-cylinder engines are no longer produced. The vibration is caused by the cylinders furthest from the crankshaft output. As these cylinders apply thrust to the crankshaft, it twists, and as the thrust decreases, the crankshaft unwinds. The twisting and unwinding of the crankshaft produces a vibration.

(ON SLIDE #67)

1. **Vibration Dampener**.

(1) Purpose. There are a few variations of the vibration dampener, but they all accomplish their task in basically the same manner. The use of a vibration damper at the end of the crankshaft opposite the output end will serve to absorb some torsional vibration.

(ON SLIDE #68)

(2) Construction. The engine damper is usually composed of bonded rubber surrounded by a steel ring. As vibrations hit the engine damper, they cause the bonded rubber to flex and stretch. This process absorbs the vibrations and changes them to heat. Reducing these vibrations also helps extend the life of the main bearings which hold the crankshaft in place.

(ON SLIDE #69)

Whenever a sudden change in crankshaft speed occurs, it causes the friction clutch to slip. This is because the outer section of the damper will tend to continue at the same speed. The slippage of the clutch serves to absorb the torsional vibration. Another type of damper links the two pieces together with rubber.

(ON SLIDE #70)

When the engine is running, the crankshaft vibrates due to the flexing of the crankshaft in response to the impulses created as the connecting rods push on the crankshaft. By absorbing more of the vibrations, engine response becomes smoother.

(ON SLIDE #71)

m. **Flywheel**.

(1) Purpose. The flywheel stores energy from the power strokes, and smoothly delivers it to the drive train of the vehicle. It mounts on the end of the crankshaft, between the engine and the transmission.

(ON SLIDE #72)

(2) Construction. The flywheel on large, low- speed engines usually is made of cast iron. This is desirable due to the heavy weight of the cast Iron, which helps the engine maintain a steady speed.

(a) Manual Transmission. When the vehicle is equipped with a manual transmission, the flywheel serves to mount the clutch.

(b) Automatic Transmission. When the vehicle is equipped with an automatic transmission, the flywheel(flex plate) serves to support the front of the torque converter. On some configurations, the flywheel (flex plate)is combined with the torque converter.

(ON SLIDE #73)

INSTRUCTOR NOTE
Computer aided graphic induction heating 0.51 minutes.

(3) Starter Ring Gear. The outer edge of the flywheel is lined with gear teeth. They are to engage the drive gear on the starter motor.

(4) Operation. For every two revolutions that the crankshaft makes, it only receives one power stroke lasting for only one-half of one revolution of the crankshaft for each cylinder. 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 to 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.

(ON SLIDE #74)

INSTRUCTOR NOTE
Flywheel Pic
A good understanding of Failure Analysis will help the student recognize not only what is broke and why, but also what caused it to break and what can be reused. Each student will take something different from this part of the lecture.
IT SHOULD BE APPROACHED AS AN OPPORTUNITY FOR A GROUP DISCUSSION.

(ON SLIDE #75)

n. **Failure Analysis.** Failure analysis is an advanced method of determining the *"root cause"* of a malfunction or complaint. It is needed when things are broken, deformed, or worn excessively. It is a process of determining the cause of a failure from the type of damage evident in the failed component, in addition to other information surrounding the failure. It is important that all possible information about the failure be gathered and considered in the conclusion. Any failures that significantly caused the sequence of events for the failure should be identified. The material failure should also be described using the standard nomenclature and plain language. A knowledgeable approach to failure analysis and the use of clinical methods during repair will assure the mechanic of success.

(1) Depending on the circumstances of the situation, the extent of damage, and the duties assigned will determine how much failure analysis the mechanic can perform. Some typical applications may include:

(2) Product Quality Deficiency Reporting. The provision for including deficiency reporting is important because it frequently identifies the weak link in the chain. It may be possible, for example, to redesign a component with a greater margin of tolerance to correct a specific deficiency.

(3) Defense Reutilization Management. Occasionally an end item will be sent to DRMO because it is less expensive to replace it than it is to repair it. If the mechanic is estimating this cost, he will prepare the inspection paperwork. If components can be salvaged from the equipment, he will be required to make a determination on what to salvage. (This also applies to combat assessment and repair.)

(4) Safety Investigations. There may be no evidence supporting human causes, and a material failure may be the only specific event that can be found with certainty.

(5) Letters of Abuse. When a component has catastrophically failed, and must be rebuilt, a letter listing the causes of failure, corrective action, and command endorsement usually accompanies the component.

(6) Frequent Component Failure. When a specific item of equipment has repeated failure of the same component(s), obviously the mechanic is correcting the symptom not the *"root cause"*. This can be as simple as frequent battery failure to as complex as transmission replacement.

(7) Often insignificant details can provide a major clue in the reconstruction of the failure to determine its cause. When making a failure analysis, review and consider all of the related components. In many situations, a condition causing one part to fail is likely to cause some damage to the other components that will provide a clue to the cause of the failure. Frequently, the evidence of seating patterns, clogging of filters, and other evidence thus found will provide valuable aids in the solution of problems.

(8) Experience in evaluating damage patterns can be most helpful in performing a failure analysis. Capability is needed for

recognizing and distinguishing the different kinds of damage patterns. Associations of these with previous experience of similar patterns, wherein the cause of the failure was known, permit an assignment of the probable cause of the failure.

(9) Considerable judgment is required as different types of damage are frequently superimposed over each other. For example, a set of failed bearings can show severe scratching, with one or more of them showing heavy discoloration and evidence of lack of lubrication. Both conditions could have contributed to the failure; but since lack of lubrication is more likely to cause immediate and total destruction, this is the more logical cause of failure.

(10) In situations where the failed component is totally disintegrated, little evidence is left to indicate the cause of failure. In these situations, a particularly close inspection must be made of the other components for evidence of what damaging condition existed to cause the failure. The principle objective in determining the cause of failure is to direct corrective action toward preventing recurrences.

INSTRUCTOR NOTE
Computer aided graphic getting and inspecting parts 3.04 minutes.

(11) When failure analysis is required a few simple precautions will make the mechanic's job a success.

(a) DO NOT DESTROY EVIDENCE—GO SLOWLY AND OBSERVE ALL CONDITIONS.

(ON SLIDE #76-77)

(b) Inspect the parts and their condition before, during, and after removal.

(c) Remove and arrange all parts as they operate. Observe respective part conditions—amount and condition of lubricant present, burrs, cuts or particles in evidence, condition of journals, fillets, and so forth.

(d) Clean and mark the parts to permanently indicate positions. (Letters and numerals is a good system.)

(e) Inspect all related parts for condition and unusual circumstances.

(ON SLIDE #78)

(f) Use the information in the maintenance record (if available), whatever you can learn of operator, and the condition of the parts you have removed to diagnose the cause of failure.

(g) Correct the cause of the failure before reassembly.

(ON SLIDE #79)

TRANSITION: Over the past 2 hours we have reviewed the function and construction of cylinder blocks, heads, camshafts, tappets, piston assemblies, crankshafts, vibration dampeners, and flywheels moving. Are there any questions? I have some questions for you.

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Opportunity for questions.

1. QUESTIONS FROM THE CLASS:

2. QUESTIONS TO THE CLASS:

Q: Which engine component receives the reciprocating force and transforms it to a rotary motion to drive the power train?
A: Crankshaft
Q: Which engine component stores inertia to transmit mechanical force evenly to the power train during engine operation and reduce engine vibration?
A: Flywheel
Q: What are the three causes of vibration associated with the crankshaft?
A: Its shape, extreme weight, and the tremendous forces acting on it.
Q: What are the features built into the piston to provide for heat expansion.
A: Crown(head) and cam grinding.
Q: What is the purpose of the piston rings?
A: Seals between the cylinder walls and piston containing compression and combustion gases, keeps lubricating oil out of combustion chamber, and provide a means to conduct heat from piston to cylinder walls.
Q: What part of the piston is strengthened to support the piston pin?
A: Piston pin boss
Q: What term is used to describe improper break-in of a new engine that results in rough streaks on the cylinder walls?
A: Scuffing
Q: What is the purpose of the cylinder block?

A: Acts as a connecting point for all other engine components.
Q: What are three reasons for using cylinder sleeves?
A; Extend life of a cylinder block, Block can be renewed by replacing sleeve, allows engine to be made of lighter material like aluminum.
Q: What is the purpose of the cylinder head?
A: Seals the end of the cylinder ensuring an air tight combustion chamber for igniting fuel and focuses on expansive forces to act on pistons.
Q: What is the purpose of the camshaft?
A: Provides opening and closing of the engine valves.

(BREAK – 10 Min)

TRANSITION: Any more questions? If not let's take a quiz.
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INSTRUCTOR NOTE:
Hand out quiz for diesel engine construction.

(ON SLIDE #80)

QUIZ (30min)

Hand out quiz for diesel engine construction. Give the students 20 minutes to complete and review it with the students after.

(BREAK – 10 Min)

TRANSITION: Any questions concerning the quiz? If not let's talk about Diesel engine principles.
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(ON SLIDE #81)

INSTRUCTOR NOTE
Computer aided graphic Clockwork engine 0.19 minutes.

2. **DIESEL ENGINE PRINCIPLES OF OPERATION** (2hrs)

(ON SLIDE #82)

INSTRUCTOR NOTE
Computer aided graphic moving engine (no sound looping).

a. **Internal Combustion Engine versus External Combustion Engine.**

(1) Internal Combustion Engine. An internal combustion engine is any engine in which the fuel is burned within it. A four-stroke-cycle engine is an internal combustion engine because the combustion chamber is located within the engine.

(ON SLIDE #83)

(2) External Combustion Engine. 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.

(ON SLIDE #84)

INSTRUCTOR NOTE
Computer aided graphic 3D combustion chamber (looping graphic no sound).

b. **Reciprocating Motion to Rotary Motion.**

(1) The operation of the piston engine can best be understood by comparing it to a simple cannon. A cannon barrel, charge of gunpowder, and a cannonball, 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. The cannon barrel has been replaced by a cylinder and a combustion chamber. The cannonball has been replaced by a piston.

(ON SLIDE #85)

INSTRUCTOR NOTE
Computer aided graphic 3D 4 stroke.

(2) The force of the piston acting in a downward motion is of little value if it is to turn the wheels of the vehicle. In order to utilize 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, as the name implies, is a shaft 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.

(ON SLIDE #86)

INSTRUCTOR NOTE
In a gasoline engine, ignition is started by the ionization (and heat) of air as electricity jumps from the negative to the positive electrode of the spark plug. In a diesel combustion chamber the ignition of fuel is NEARLY SPONTANEOUS. This means that the leading edge of the fuel spray causes a rise in pressure and heat igniting the rest of the fuel producing the characteristic diesel ***"KNOCK"***.

c. **Action in the Cylinder.**

(1) When the piston is at its highest point in the cylinder, it is in a position called top dead center (**TDC**). When the piston is at its lowest point in the cylinder, it is in a position called bottom dead center (**BDC**). As the piston moves from top dead center to bottom dead center or vice versa, the crankshaft rotates exactly one-half of a revolution. 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 crank-shaft revolution.

(ON SLIDE #87)

There are four definite phases of operation that an engine goes through in one 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. 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 revolutions.

(ON SLIDE #88)

(2) Diesel engine four stroke cycle.

INSTRUCTOR NOTE
Computer aided graphic intake stroke 0.25 minutes.

(a) Intake. 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. The intake stroke ends here.

(ON SLIDE #89)

INSTRUCTOR NOTE
Computer aided graphic compression stroke 0.42 minutes.

(b) Compression. The piston is at bottom dead center at the beginning of the compression stroke. The piston moves upward, compressing the air. As the piston reaches top dead center, the compression stroke ends.

(ON SLIDE #90)

INSTRUCTOR NOTE
Computer aided graphic fuel injection - power stroke 0.29 minutes.

(c) Power. The piston begins the power stroke at top dead center. Air is compressed in the upper cylinder at this time to as much as 500 psi (3448 kPa). The tremendous pressure in the upper cylinder brings the temperature of the compressed air to approximately 1000°F (538°C). The power stroke 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.

(ON SLIDE #91)

INSTRUCTOR NOTE
Computer aided graphic exhaust stroke 0.29 minutes.

(d) Exhaust. 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 gases out through the exhaust port. As the piston reaches top dead center, the exhaust valve closes and the intake valve opens. The engine is now ready to begin another operating cycle.

(ON SLIDE #92)

INSTRUCTOR NOTE
Computer aided graphic air – fuel – heat – combustion 0.38 minutes.

(e) The fuel Injected into the combustion chamber must be mixed thoroughly with the compressed air and distributed as evenly as possible throughout the chamber if the engine is to function at maximum efficiency. 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 complement the combustion chamber. The combustion chambers described in the following paragraphs are the most common and cover virtually all of the designs that are used in current automotive designs.

(ON SLIDE #93)

INSTRUCTOR NOTE

Combustion chamber design is significant. All Marine Corps equipment employs an open combustion chamber design. This subject should be approached with the student gaining a more thorough understanding of how diesel ignites and how the shape of the combustion chamber influences ignition lag. Emphasis MUST be placed on these factors that affect power from the engine:

Compression ratio and speed (covered here).
Fuel type, quality, temperature, timing, and spray (covered during the fuel class).
Intake air density, temperature, and removal of inert (burnt) exhaust gasses (covered during the air and exhaust class).

d. **Combustion chamber design.** There are three distinct combustion chamber designs used in diesel engines: Pre-combustion chamber, Turbulence Chamber, and Open combustion chamber. Open combustion chamber will be our main focus.

(ON SLIDE #94)

(1) The open chamber is the simplest form of chamber. It is only suitable for slow-speed, four-stroke cycle engines, but is used widely in two-stroke cycle diesel engines.

(ON SLIDE #95)

(2) In the open chamber, the fuel is injected directly into the space at the top of the cylinder.

(ON SLIDE #96)

(3) 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.

(ON SLIDE #97)

(4) 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.

(ON SLIDE #98)

(5) This chamber design is very susceptible to ignition lag. Ignition lag is the time between fuel injection and combustion in a diesel engine

(ON SLIDE #99)

INSTRUCTOR NOTE
Computer aided graphic diesel ignition 0.11 minutes.

e. **Diesel Engine Characteristics.**

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

(ON SLIDE #100)

INSTRUCTOR NOTE
Computer aided graphic compressing air 0.11 minutes.

(2) The air is compressed to as high as one-twentieth of its original volume in a diesel engine. The diesel engine must compress the mixture this tightly to generate enough heat to ignite the fuel or fuel oil as it is injected.

(ON SLIDE #101)

INSTRUCTOR NOTE
Computer aided graphic fuel injection 1.19 minutes.

(3) 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.

(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 amount of air is constant. This is only for naturally aspirated.

(ON SLIDE #102)

INSTRUCTOR NOTE
Computer aided graphic End of the Cycle 0.38 minutes

f. **Advantages**.

(1) The diesel engine is much more efficient than most other engine types. This is due to the much tighter compression of the fuel and air. The diesel engine produces tremendous low-speed power. 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 less volatile than fuel sources, it is not as likely to explode in a collision.

(ON SLIDE #103)

g. **Disadvantages**.

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

(2) The diesel engine is very noisy.

(3) Combustion of diesel fuel creates a large amount of fumes mainly due to the presence of sulfur and benzene in the fuel. (This topic will be covered in more detail in the Air and Exhaust system class and the Fuel system class.)

(4) Because diesel fuel is not very volatile, it is difficult to start a diesel engine in cold weather.

(5) A diesel engine operates well only in low speed ranges in relation to other engines. This creates problems when using them in applications that require a wide speed range.

(ON SLIDE #104 & #105)

h. **Multi-cylinder Engine Vs. Single-Cylinder Engine**.

(1) The rotation of a crankshaft is measured by breaking up one revolution into 360 equal parts. Each part is called a degree. The standard starting point is with the piston at top dead center. This is expressed as 180 degrees of crankshaft rotation. We also can recall that there are two complete crankshaft revolutions for every four-stroke operating cycle. This is expressed as 720 degrees of crankshaft rotation.

(ON SLIDE #106)

(2) Power Overlap. In a simple four-stroke cycle engine, the power stroke produces a driving force that rotates the crankshaft. This means that out of a 720-degree operating cycle, there are only 180 degrees when the crankshaft actually receives any driving force. In reality, the power stroke is actually even shorter. This is due to the fact that engineers have found that an engine will run better if the exhaust valve is set to begin opening approximately four-fifths of the way through the power stroke. This reduces the power stroke still further, to approximately 145 degrees. When the engine runs, it has to rely on power that is stored in the flywheel from the power stroke to push it through the 575 degrees remaining in the operating cycle. A much smoother running engine can be made by making it a multi cylinder engine.

(ON SLIDE #107)

(3) A multi cylinder engine is actually more than one engine, all operating a common crankshaft. Engines are usually built using four, six, or eight-cylinders. Whenever engines are built with more than one cylinder, it is important that the cylinders give their power strokes in equal increments of crankshaft rotation.

(4) The equally spaced power strokes in a four-cylinder engine reduce the periods when the flywheel is carrying the engine. With four power strokes for every 720 degrees of rotation, one can be made to begin every 180 degrees. This leaves the engine with four equally spaced periods of 35 degrees each that the flywheel must carry the crankshaft.

(ON SLIDE #108)

(5) If the engine has more than four cylinders, the power strokes overlap, meaning that before one power stroke is finished, another one begins. A six-cylinder engine has a 25-degree power overlap between cylinders. An eight-cylinder engine has an even larger 55-degree power overlap. It becomes very obvious that the more cylinders that an engine has, the smoother the power delivery will be.

(6) It also is obvious that the most practical way to increase the power output of an engine is to make a lot of small cylinders instead of one big one. A multi cylinder engine is not only smoother but more reliable also. This is because each piston weighs less than a comparable size single-cylinder engine. The constant changing of direction of the piston causes more bearing wear if the piston is excessively heavy Also, the single-cylinder engine is not as smooth, which will decrease not only the life of the engine, but also the equipment that it is operating.

(ON SLIDE #109)

INTERIM TRANSITION: Over the past 45 minutes we have reviewed everything that creates the right conditions in the combustion chamber favorable for harnessing mechanical power from diesel fuel. At this time are there any questions? Take a ten minute break.

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(BREAK – 10 Min)

INTERIM TRANSITION: Did anyone think of any more questions while on break? Let’s talk about engine measurement

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(ON SLIDE #110)

i. **Engine Measurement**.

(1) Bore. The bore is the diameter of the cylinder.

(2) Stroke. The stroke is the distance that the piston travels as it moves from top dead center to bottom dead center.

(3) Piston Displacement. Piston displacement is the volume of space that the piston displaces as it moves from top dead center to bottom dead center. The piston displacement is used to express engine size.

(ON SLIDE #111)

(4) Compression Ratio. The compression ratio is the method that is universally used to measure how tightly the mixture is squeezed during the compression stroke. Diesel engines commonly use a compression ratio of 13:1 or as high as 23:1.

(5) Measuring Compression Ratio. The compression ratio is found by measuring the volume that the mixture occupies when the piston is at bottom dead center and dividing it by the volume that the mixture occupies when the piston is at top dead center. For a given engine cylinder, the volume of the space occupied by the mixture is 480 cubic centimeters (cc) when the piston is at bottom dead center. As the piston moves to top dead center, the mixture is squeezed into an area with a volume of 60 cc. Example 480cc divided by 60 cc gives you 8cc. Compression ratio= 8 to 1.

(ON SLIDE #112)

(6) Effect of Compression Ratio. As the compression ratio is increased, the mixture is squeezed into a tighter space. This means that there is a higher initial pressure at the start of the power stroke and that the burning gases have further to expand. For these reasons, any increase in compression ratio will cause an increase in engine power output.

(ON SLIDE #113)

(7) Factors Limiting Compression Ratio. Diesel engines employ high compression ratios to generate the heat necessary for ignition. In theory, diesel compression ratios could be higher to

increase in power output. However, ratios higher than 23: 1 would take a tremendous amount cranking force, and once started the terrific pressures inside the combustion chamber would push the metallurgy of cylinder liners to the extreme.

INSTRUCTOR NOTE
"Why can't gasoline engines have higher compression ratios?" should prompt a class discussion. The appropriate answer is "Because a gasoline engine will have pre-ignition and could very easily develop a '*Dieseling*' condition."

(ON SLIDE #114)

INSTRUCTOR NOTE
Computer aided graphic force 0.16 minutes.

j. **Work.** Work is the transfer of energy or movement of a body against an opposing force. Work is measured in units of foot pounds (Newton meters). One foot pound of work is the equivalent of lifting a 1-lb. weight 1 ft. When sliding something horizontally, work is measured by the force required to move the object multiplied by the distance that it is moved. Note that work is always the force exerted over a distance. Also note that if there is no movement of the object, then there is no work accomplished, no matter how much force is applied.

(ON SLIDE #115)

k. **Energy.** Energy is the ability to do work. Energy takes many forms, such as heat, light, sound, stored energy (potential), or an object in motion (kinetic energy). Energy performs work by changing from one form into another. To illustrate this, consider the operation of a dozer. From start to finish, it will do the following.

(1). When it is sitting still and not running, it has potential energy stored in the fuel.

(2). To set it into motion, the diesel is burned, changing its potential energy into heat energy. The dozer engine then transforms the heat energy from the burning fuel into kinetic energy by forcing the dozer into motion.

(3). The action of stopping the dozer is accomplished by the brakes. By the action of friction, the brakes will transform the kinetic energy of the dozer back into heat energy. When all of this kinetic energy is transformed into heat energy, the dozer will be stopped. The heat energy will then dissipate into the air. It is very easy to see that work was accomplished when the dozer was set into motion. It may not be as easy to see that work was also accomplished to stop the dozer. Because stopping requires applying a force over a distance, it also fits the definition of work.

(ON SLIDE #116)

l. **Power.** Power is the rate of work. Engines are rated by the amount of work that they can do in 1 minute. The unit of measure for rating engines is called horsepower. The horsepower unit was developed about the time that steam engines were being developed. Through testing, it was found that the average horse could lift a 200-lb. weight to a height of 165 ft in 1 minute. The equivalent of one horsepower can be reached by multiplying 165 ft by 200 lb. (work formula) for a total of 33,000 ft lb. per minute or multiplying 550 lb by 60 seconds.

(ON SLIDE #117)

(1) Indicated Horsepower. Indicated horsepower is the power developed inside of the engine based on the pressure developed in the cylinders. It is always much higher than the brake horsepower because it does not consider friction or the inertia of the reciprocating masses within the engine.

(2) Friction Horsepower. Efficiency is the relationship between results obtained and the effort required to obtain those results. For example, if a 90-lb. box was lifted with a rope and pulley, it would require a force of 100 lb. Therefore: output / input 90 lb. 100 lb. The above results simply mean that only 90 percent of the total effort used for lifting the box actually went to that task. The remainder, or 10% of the effort, was lost to frictional forces within the pulley system.

(ON SLIDE #118)

(3) Mechanical Efficiency. Mechanical efficiency within the engine is the relationship between the actual power produced in the engine (indicated horsepower) and the actual power delivered at the crankshaft (brake horsepower). The actual power at the crankshaft is always less than the power produced within the engine. Mechanical efficiency is calculated by dividing the brake horsepower by the indicated horsepower. This is due to frictional losses between the many moving parts. Also in four-stroke cycle engines, a great deal of horsepower is used to drive the valve train.

(ON SLIDE #119)

INSTRUCTOR NOTE
Computer aided graphic Torque 0.12 minutes.

m. **Torque Effect.** Torque is a force that, when applied, tends to result in the twisting of the object rather than its physical movement. When measuring torque, the force that is applied must be multiplied by the distance from the axis of the object. Because the force in pounds (Newtons) is multiplied by distance in feet (meters), torque is expressed in terms of pound feet (Newton meters). When applying torque to an object, the force and the distance from the axis will be dependent on each other. Work can only be produce when torque is greater than the resistance. For example, if a 100-ft lb. torque is applied to a nut, a 100-lb. Force would be applied if the wrench were 1-ft long. If a 2-ft-long wrench were used, a 50-lb. force is all that would be necessary.

(ON SLIDE #120)

n. **Torque-Horsepower-Speed (RPM) Relationship.** As illustrated in the example horsepower will continue to increase with speed even after torque begins to fall off. The reason that this happens is because horsepower is dependent on speed and torque. The horsepower will continue to increase due to the speed increase offsetting the torque decrease. At a point, however, the torque begins to fall off so sharply that the increase in speed cannot offset it and horsepower also falls off. The brake-horsepower can clearly show that horsepower, speed, and torque are all dependent on each other.

(ON SLIDE #121-122)

INSTRUCTOR NOTE
Image of Cummins engine

(ON SLIDE #123)

INTERIM TRANSITION: Thus far, we have discussed diesel engine construction and principles of operation. Are there any questions? Take a ten minute break.

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(BREAK - 10 MIN)

(ON SLIDE #124)

INTERM TRANSITION: Before the break we discussed diesel engine construction and principles of operation. Are there any other questions? If not let's move on to a demonstration of how to start and run your engines.

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INSTRUCTOR NOTE

Perform the Following demonstration. Have students take breaks as required or as Instructed.

DEMONSTRATION. (3 HRS) Introduce the students in groups of no more than 5 to the engine that they will be using during the disassembly and reassembly process. The engine starter and 2 12 volt batteries will be required. Will demonstrate with one group at a time. All other groups will be in the classroom with study material.

STUDENT ROLE: The students will become familiar with and see how to start their engine. They should also ask any questions at this time.

INSTRUCTOR ROLE: Demonstrate how to correctly run the engines for the students.

1. 1st step- Have students get two 12v batteries, fuel can with fuel from hazmat and the starting switch from the tool room.
2. 2nd step- Have students ensure that all engine radiators are full prior to starting the engine.
3. 3rd step- Hook batteries and start switch to engine. Start engine.
1. Safety Brief: Make sure students know how to hook up the batteries correctly. At all times proper PPE will be worn. Make sure to stay clear of the fan and all hot components. Exhaust fan should be on at all times that the engine is running.
2. Supervision and Guidance: The instructor will hook up the engine start switch to the starter and hook up the two 12 volt batteries to the starter also. Start engine and show the students that it runs prior to their disassembly.
3. Debrief: (If applicable) (Allow students the opportunity to comment on what they experienced and/or observed. Provide overall feedback, guidance on any misconceptions, and review the learning points of the demonstration.

QUESTIONS FROM THE CLASS:

QUESTIONS TO THE CLASS:

Q: Describe three characteristics unique to a Diesel Engine.
A: Uses compression to generate heat used to ignite fuel air mixture, has high compression ratio and is built out of heavy materials to withstand the high compression.
Q: In which type of combustion chamber design has the combustion chamber formed in the piston head?
A: Open Chamber
Q: Describe four ADVANTAGES of a Diesel Engine.
A: More efficient than most other engines, requires no-ignition tune up, diesel fuel is less volatile, and they produce tremendous low-speed power.
Q: Define the term Power Overlap.
A: Before one power stroke ends, another one begins.
Q: Define the term mechanical efficiency.
A: The relationship between the power produced in the engine and the actual power delivered at the crankshaft.
Q: The force that tends to result in the twisting of the object rather than its physical movement.
A: Torque
Q: What is method that is used to measure how tightly the mixture is squeezed during the compression stroke?
A: Compression Ratio

TRANSITION: Any more questions? If not let's take a quiz.
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QUIZ (30min)
Hand out quiz for diesel engine principles of operation. Give the students 20 minutes to complete and review it with the students after.

(BREAK - 10 MIN)

TRANSITION: Any more questions? If not let's talk about the intake/exhaust system.
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(ON SLIDE #125)

3. **DIESEL ENGINE INTAKE AND EXHAUST SYSTEM OPERATION AND TROUBLESHOOTING** **(2hrs)**

(ON SLIDE #126)

INSTRUCTOR NOTE: **Hello Kitty**

(ON SLIDE #127)

a. **Vacuum in Cylinder on the Intake Stroke.**

(1) The Atmosphere. The earth is surrounded by an ocean of air that is known as the atmosphere. Because it is colorless and odorless, people are not always aware of it. However, the atmosphere does have weight.

(2) Atmospheric Pressure. Elevation is always referred to in relation to the level of the ocean. This is known as sea level. Because the atmosphere extends for many miles above the earth, the weight of all of this air creates a large force on the earth's surface. In fact, the weight of the air creates a pressure of approximately 14.7 PSI or 1 Bar on all things at sea level. As the elevation increases, this atmospheric pressure progressively decreases.

(ON SLIDE #128)

(3) Vacuum in the Cylinder. When the piston moves downward on the intake stroke, it may appear that it is sucking the mixture into the cylinder. Actually, what is really happening is that by the piston moving downward, it is making a larger space in the cylinder that contains nothing (a vacuum). The atmospheric pressure outside the cylinder will then push its way in through the intake port, filling the cylinder.

(ON SLIDE #129)

(4) Volumetric Efficiency.

(a) General. Volumetric efficiency is a way of measuring an engine's ability to take in, or aspirate, its intake. As the piston moves down on the intake stroke, atmospheric pressure will push the intake into the cylinder. Theoretically, the volume of air that enters the engine for each intake stroke would be exactly equal to the displacement of the cylinder engine type directly affects how well this actually occurs.

(ON SLIDE #130)

Diesel engines breathe well because they are un-throttled. The speed of the engine is proportional to the amount of fuel injected unlike the gasoline engine in which the speed of the engine is proportional to the fuel – air mixture that enters the cylinder. Diesel engines always take in more air than what is required for combustion. Since all that is needed is more fuel, it is easy to understand how a diesel can *"runaway".*

(ON SLIDE #131)

(b) Measuring Volumetric Efficiency. Volumetric efficiency is expressed as a ratio of the amount of air that enters the cylinders on the intake stroke to the amount of mixture that the cylinders could actually hold.

(ON SLIDE #132)

The following factors will decrease volumetric efficiency:

(1) The shorter the duration of the intake stroke (higher RPM) the lower the efficiency.

(2) As the air passes through the engine on its way to the cylinder, it picks up heat. As the air heats up, it becomes less dense. This means that less air actually enters the cylinder.

(3) Sharp bends, obstructions, rough surfaces on the walls of the intake ports, or improper valve lash settings will slow down the intake air, decreasing volumetric efficiency.

(4) Elevation also affects volumetric efficiency. An increase in elevation will decrease the density of air.

(ON SLIDE #133)

(5) Increasing Volumetric Efficiency. Any increase in volumetric efficiency will increase engine performance. Volumetric efficiency may be increased by doing the following.

(a) Keep the intake air cool. By ducting intake air from outside of the engine compartment, the intake air can be kept cooler. The cooler the air is, the higher the volumetric efficiency will be. This is because a cool air is denser or more tightly packed.

(b) Modify the intake passages. Any changes to the intake passages that make it easier for the air to flow through will cause an increase in volumetric efficiency. Other changes include reshaping ports to smooth out bends, reshaping the back of the valve heads, or polishing the inside of the ports.

(c) Altering the time that the valves open or how far they open, volumetric efficiency can be improved.

(d) Turbocharging, the volumetric efficiency figure can be brought to over 100 percent.

(ON SLIDE #134)

b. **Valves.** The I-head configuration is the most popular for current diesel engines and gets its name from the letter formed by the piston and the valve. These engines have their camshafts located in their cylinder blocks. These engines are also known as the overhead valve (ohv) engines. A typical ohv cylinder head is shown. The camshaft operates the valves through the lifter, push rod, and rocker arm.

(ON SLIDE #135)

(1) Purpose. Each cylinder in a four-stroke cycle engine must have one intake and one exhaust valve to allow fresh (oxygen rich) air into each cylinder, and allow burnt (inert) gasses to escape. The valves are commonly of the poppet design. The word poppet is derived from the popping action of the valve. The valve shape that is used in a given engine design is dependent upon the requirements and combustion chamber shape.

(ON SLIDE #136)

(2) Construction. Construction and design considerations are very different between intake and exhaust valves. The difference is based on their temperature operating angles. Intake valves are kept cool by the incoming intake air. Exhaust valves are subject to intense heat from the burnt gases that pass by it. The temperature of the exhaust valve can be in excess of 1,300 °F (704.4 °C). Intake valves are made of a nickel chromium alloy. Exhaust valves are made of a silichrome alloy. Some exhaust valves use a special hard facing process that keeps the face of the valve from taking on the shape of the valve seat at high temperatures. Stems may be hollow and filled with sodium to improve heat transport and transfer.

(ON SLIDE #137)

Older air cooled engines used exhaust valves were hollowed out and partially filled with metallic sodium. The sodium, which liquefied at operating temperatures, splashed between the valve head, where it picked up heat, and the valve stem, where the heat is transferred to the valve guide.

(ON SLIDE #138)

(3) Valve Seats. The valve seats are very important, as they must match the face of the valve head to form a perfect seal. The seats are made so that they are concentric with the valve guides; that is, the surface of the seat is an equal distance from the center of the guide all around.

(ON SLIDE #139)

There are three common angles that are used when machining the valve seat; they are 15, 30, and 45 degrees (dependent on manufacturer specs.). The face of the valve is usually ground with a ½° to a 1° difference to help the parts seat quickly.

(ON SLIDE #140)

By reducing the contact area, the pressure between the mating parts is increased, thereby forming a better seal. The valve seats can be either part of the cylinder head or separate inserts. Valve seat inserts generally are held into the head by an interference (squeeze) fit. The head is heated in an oven to a uniform high temperature and the seat insert is shrunk by cooling it in dry ice. While the two parts are at opposite temperature extremes, the seat insert is pressed into place.

(ON SLIDE #141)

(4) Valve Guides. The valve guides are the parts that support the valves in the head and are machined to a fit with a few thousandths of an inch clearance from the valve stem. Valve guides may be cast integrally with the head, or they may be removable. Removable valve guides are usually press fitted into the head. This close clearance is important for the following reasons:

(a) It keeps the lubricating oil from getting into the combustion chamber.

(b) It keeps exhaust gases from getting into the crankcase area past the exhaust valve stems during the exhaust stroke.

(c) It keeps the valve face in perfect alignment with the valve seat.

(ON SLIDE #142)

(5) Valve Springs, Retainers, and Seals. The valve assembly is completed by the spring, retainer, and seal. Before the spring and the retainer fit into place, a seal is placed over the valve stem.

The seal acts like an umbrella to keep the valve operating mechanism oil from running down the valve stem and into the combustion chamber.

(ON SLIDE #143)

The spring, which keeps the valve in a normally closed position, is held in place by the retainer. The retainer locks onto the valve stem with two wedged-shaped parts that are called valve keepers.

(ON SLIDE #144)

INSTRUCTOR NOTE
Computer aided graphic valve keeper 0.10 minutes.

(ON SLIDE #145)

(6) <u>Valve Rotators.</u>

(a) <u>Purpose.</u> It is common in heavy-duty applications to use mechanisms that make the exhaust valves rotate. They keep carbon from building up between the valve face and seat, which could hold the valve partially open, causing it to burn.

(ON SLIDE #146)

(b) <u>Types.</u>

(1) The release-type rotator releases the spring tension from the valve while open. The valve then will rotate from engine vibration.

(2) The positive rotator is a two-piece valve retainer with a flexible washer between the two pieces. A series of balls between the retainer pieces roll on machined ramps as pressure is applied and released from the opening and the closing of the valve. The movement of the balls up and down the ramps translates into rotation of the valve.

(ON SLIDE #147)

(7) <u>Valve Train.</u> It is obvious that it is very important to operate the valves in a timed sequence. If the exhaust valve opened in the middle of the intake stroke, the piston would draw burnt gases into the combustion chamber with a fresh air. As the piston continued to the power stroke, there would be nothing in the combustion chamber that would burn. The valves in overhead valve engines use additional

components to link the camshaft to the valves. Overhead valve engines use push rods and rocker arms.

(ON SLIDE #148)

INSTRUCTOR NOTE
Computer aided graphic pushrods 0.11 minutes.

(a) Push Rods. Push rods usually are constructed of hollow steel. Most air-cooled engines use the push rods to supply lubricant to the upper valve mechanism.

(ON SLIDE #149)

INSTRUCTOR NOTE
Computer aided graphic rocker arms 0.35 minutes.

(b) Rocker Arms. Rocker arms are manufactured of steel, aluminum, or cast iron. The most common for current use are cast iron rockers. They are used in larger, low-speed engines. They almost always pivot on a common shaft.

(ON SLIDE #150)

INSTRUCTOR NOTE
Computer aided graphic valve adjustment 2.35 minutes.

(c) Adjusting Clearance. The provision for adjusting valve clearance on solid tappet, valve-in-head engines is usually in the form of a screw on the rocker arm. On overhead valve (or push rod engines), there is usually a screw-type adjustment where the push rod actuates it. The adjusting screw can either be of the self-locking type, or have a jam nut to lock it.

(ON SLIDE #151)

INSTRUCTOR NOTE
Computer aided graphic gear train timing 0.08 minutes.

(d) 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. The timing marks are used to put the camshaft and the crankshaft in the proper position to each other.

(ON SLIDE #152)

(8) Valve Timing.

(a) General. Valve timing is a system developed for measuring in relation to the crankshaft position (in degrees), the points when the valves open, how long they stay open, and when they close. Valve timing is probably the single most important factor in tailoring an engine for specific needs. By altering valve timing, an engine can be made to produce its maximum power in a variety of, speed ranges. The following factors together make up a valve operating sequence.

1 Opening and Closing Point. The opening and closing points are the positions of the crankshaft (in degrees) when the valve just begins opening and just finishes closing.

2 Duration. Duration is the amount of crankshaft rotation (in degrees) that a given valve will remain open. It can be modified to change power output. (EX Larger Cam)

3 Valve Overlap. Valve overlap is a period in the four-stroke cycle when the intake valve opens before the exhaust valve closes.

(ON SLIDE #153)

(9) Valve Timing Considerations. Throughout the crankshaft revolution, the speed of the piston changes. From a stop at the bottom of the stroke, the piston will reach its maximum speed halfway through the stroke and gradually slow to a stop as it reaches the end of the stroke. The piston will behave exactly the same on the down stroke. There are two periods of crankshaft rotation in which there is almost no perceptible movement of the piston. One of these periods begins at approximately 15° to 20° before top dead center and ends at approximately 15° to 20° after top dead center. The other period begins at approximately 15° to 20° before bottom dead center and ends at approximately 15° to 20° after bottom dead center. These two periods of crankshaft rotation are utilized when establishing a valve timing sequence as follows.

(a) During the period that occurs at top dead center, valve overlap is introduced to increase volumetric efficiency. By opening the intake valve before the exhaust valve is closed, the intake is pulled in by the momentum of the exiting exhaust gas. The intake coming in also helps to sweep or scavenge the cylinder of exhaust gases. Because the overlap occurs during one of the periods of little piston movement, there is no problem with exhaust being pushed into the intake port or exhaust gas being pulled into the cylinder through the exhaust port by the piston.

(b) During the period that occurs at bottom dead center, the pressure remaining in the cylinder at the end of the power stroke is utilized by opening the exhaust valve early. When the exhaust valve opens, the pressure in the cylinder starts pushing the exhaust gas out of the cylinder. Because the final 15° to 20° of the power stroke have almost no piston movement, there is no problem with exhaust being drawn in by the piston. As stated earlier, engines can be designed to produce power in a specific speed range by altering valve timing. By increasing the valve duration and overlap, an engine can be made to produce more power in the higher speed ranges. This is because the exiting exhaust gas will have more inertia, making its scavenging effect last longer. This same engine will run poorly at low speed due to the piston having a tendency to pull exhaust back into the cylinder and blow it back up into the intake port.

(ON SLIDE #154)

INSTRUCTOR NOTE

The Marine Corps current stock of construction equipment has only two examples of naturally aspirated diesel engines the 7½ Ton Crane (Cummins B 3.9 L) and the ACE (Cummins 903).

(ON SLIDE #155)

INTERIM TRANSITION: Are there any questions? If not take a break.
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(BREAK 10min)

INTERIM TRANSITION: Any more questions before we move on.
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(ON SLIDE #156)

c. **Turbocharging/Supercharging.**

(ON SLIDE #157)

INSTRUCTOR NOTE
Computer aided graphic air intake1 0.18 minutes.

(1) Turbocharging is a method of increasing engine volumetric efficiency by forcing the air into the intake rather than merely allowing the pistons to draw it in naturally. Turbocharging in some cases will push volumetric efficiencies over 100 percent. Engines must be modified to operate properly in some cases, because the extra air will cause higher compression pressures.

(ON SLIDE #158)

INSTRUCTOR NOTE
Computer aided graphic turbochargers 0.20 minutes.

(2) A turbocharger uses the force of the engine exhaust stream to force the air 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 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 boost fairly uniform.

(ON SLIDE #159)

INSTRUCTOR NOTE
Computer aided graphic wastegates 0.15 minutes.

(3) A device known as a waste gate is installed on turbocharged engines to control manifold pressure. It is a valve that, 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.

(ON SLIDE #160)

INSTRUCTOR NOTE

Computer aided graphic after coolers 0.27 minutes.

(4) Many late model engines which are turbocharged employ an after cooler to further improve the engine efficiency. After coolers (also called inter coolers or heat exchangers) are small radiators positioned between the compressor housing of the turbocharger and the inlet manifold of the engine.

(a) Water cooled intercoolers are the design common to industrial diesel engines. Coolant enters the intercooler and passes through the core tubes and back into the cylinder block or cylinder head. Air from the turbocharger (compressor) flows around the tubes and is cooled before it enters the inlet manifold. This increases the power output by about 10% to 20% because the incoming air is cooled to within 40° F of the engine coolant temperature and, therefore, more air enters the cylinders.

(b) The result is lower cylinder pressure, more effective cooling of the cylinder components, and a lower exhaust gas temperature. Without the intercooler, the air temperature entering the intake manifold would increase sharply because of the compression of the air and because of heat from the turbocharger. This would result in a loss in air density and power, and elevated cylinder and exhaust gas temperatures.(approximately 1° increase in air intake temperature will increase the exhaust temperature increases by 3° F).

(ON SLIDE #161)

INSTRUCTOR NOTE

Until very recently off highway trucks and construction equipment diesel engines have been immune to emission controls, however Tier II (and Tier III in 2006) EPA engine emission controls have impacted the design and diagnostics of our equipment.

(5) Exhaust emissions. When the fuel is burned in the combustion chamber, the ideal situation would be to have the fuel combine completely with the oxygen from the intake air. The carbon would then combine to form carbon dioxide (CO_2), the hydrogen would combine to form water (H_20), and the nitrogen that is present in the intake air would stand alone. The only other product present in the exhaust would be any oxygen from the intake air that was not used in the burning of the fuel.

(ON SLIDE #162)

In a real life situation however, this is not what happens. The fuel never combines completely with the oxygen and undesirable exhaust emissions are created as a result. Normally a diesel engine has more air available than what is used and the fuel delivery system is precisely timed to be injected when combustion chamber pressure and temperature is optimal for complete burning of the fuel. Major pollutants include:

(a) Carbon Monoxide (CO). Carbon monoxide is formed as a result of combustion chamber pressures (temperatures) that are too low. A cold engine will produce more Carbon Monoxide until it reaches operating temperature when emissions will become extremely low. Carbon monoxide is a colorless, odorless gas that is poisonous.

(b) Nitrogen oxides (NOx). Oxides of nitrogen are formed when the nitrogen and oxygen in the intake air combine due to the high temperatures of combustion. Oxides of nitrogen are harmful to all living things.

(c) Sulfur dioxide (SO2) is generated from the sulfur present in diesel fuel. The concentration of SO**2** in the exhaust gas depends on the sulfur content of the fuel. Sulfur dioxide is a colorless toxic gas with a characteristic, irritating odor. Oxidation of sulfur dioxide produces sulfur trioxide which is the precursor of sulfuric acid. Sulfur oxides have a profound impact on environment being the major cause of acid rain.

(ON SLIDE #163)

(d) Hydrocarbons (HC). Hydrocarbons are unburned fuel. They are particulate in form (solid) and, like carbon monoxide, they are manufactured by combustion chamber pressures (temperatures) that are too low. Hydrocarbons are harmful to all living things. In any urban area where vehicular traffic is heavy, hydrocarbons in heavy concentrations react with sunlight to produce a brown fog known as photochemical smog.

(ON SLIDE #164)

1 Diesel particulate matter (DPM), is defined by the EPA regulations as a complex aggregate of solid and liquid material. Diesel particulates are very fine. The carbon particles may have a diameter of 0.01 - 1 micron range. As such, diesel particulate matter is almost totally inhalable and has a significant health impact on humans. It has been classified by several government agencies as either "human carcinogen" or "probable human carcinogen". It is also known to increase the risk of heart and respiratory diseases.

(ON SLIDE #165)

2 Polynuclear Aromatic Hydrocarbons (PAH) are hydrocarbons containing two or more benzene rings. Many compounds in this class are known human carcinogens. PAH's in the exhaust gas are split between gas and particulate phase. The most harmful compounds of four and five rings are present in the organic fraction of DPM (SOF).

(ON SLIDE #166)

(6) Controlling of Exhaust Emissions. The control of exhaust emissions is a very difficult job. To eliminate carbon monoxide and hydrocarbon emissions, the temperatures of the combustion chamber would have to be raised to a point that would melt pistons and valves. This is compounded with the fact that oxides of nitrogen emissions go up with any increases in combustion chamber temperatures. Knowing these facts, it can be seen that auxiliary emission control devices are necessary.

(a) Draft Tube System. Older engines used a very simple system that vented blowby to the atmosphere through a draft tube. The draft tube extends from an area of the crankcase that is above oil level to a point of exit that project straight downward under the equipment. The outlet of the tube is cut on a slant upward toward the rear of the equipment. With this shape outlet, suction is created by the forward movement of the equipment. Circulation of fresh air will occur in the crankcase with the addition of a breather cap also located at a point on the crankcase above oil level.

(b) The negative pressure created at the end of the draft tube will cause air to be drawn In through the crankcase breather. A wire mesh filter is built into the breather to keep dirt out of the crankcase.

(c) The draft tube contains a sediment chamber and a wire mesh filter at the point where it attaches to the crankcase. Its purpose is to trap any oil that tries to leave through the draft tube and return it to the crankcase.

(d) By strategic location of the breather cap and draft tube and the use of baffles, a complete purging of crankcase blowby fumes is ensured. The draft tube system is obsolete now because it discharged excessive hydrocarbon emissions directly into the atmosphere. It also did not keep the crankcase as clean as the positive crankcase ventilation system. This is because it relied on the movement of the vehicle to activate it. As a result of this, draft tube-equipped engines were very prone to sludge buildup.

(7) Positive Crankcase Ventilation (PCV) System. The positive crankcase ventilation system utilizes turbocharger vacuum to purge the crankcase of blowby fumes. The fumes are then aspirated back into the engine where they are reburned.

(a) A hose is tapped into the crankcase at a point that is well above the engine oil level. The other end of the hose is tapped into the piping before the turbocharger.

(b) An inlet breather is installed on the crankcase in a location that is well above the level of the engine oil. The inlet breather also is located strategically to ensure complete purging of the crankcase by fresh air.

(c) The areas of the crankcase where the hose and the inlet breather are tapped have baffles to keep the motor oil from leaving the crankcase.

(d) A flow control valve (called a PCV valve) is installed in the line that connects the crankcase to vacuum. It is and serves to avoid the air mixture by doing the following:

(ON SLIDE #167)

(8) Waste Gate Solenoid. The waste gate solenoid allows the ECM to control the speed of the Turbocharger, therefore, controlling the amount of air going into the intake manifold.

(ON SLIDE #168)

(9) Exhaust Smoke Diagnosis. Good mechanics go into action quickly, making simple observations and tests that set limits to the problem. A strong familiarization with how the components work together will help the mechanic to limit tests to the most likely cause. Diaphragm

(ON SLIDE #169)

NEVER ASS-U-ME corrective action based on this initial indication, only which tests should be performed first before making a diagnosis.

(a) Distinguishing between conditions that affect all cylinders and those that affect one or two is a simple first step.

1 General malfunctions discolor the whole exhaust stream such as too much advance on pump timing will send all cylinders into detonation.

2 Single cylinder malfunctions can generate puffs of smoke such as the clatter caused by a faulty injector will be limited to the associated cylinder.

(b) After determining whether it's one or all cylinders, the next step is to determine why. White smoke means one or more fueled, but misfiring cylinders, and usually accompanies cold starts (in a warm engine it may indicate low compression). Black smoke is the sooty residue of partially burned (high HC's) fuel, normally present during hard acceleration. Blue, blue-white, or gray-white results from lube-oil combustion.

(ON SLIDE #170)

BLACK or DARK GRAY SMOKE		
Symptom	**Probable cause**	**Remedial action**
Smokes under load, especially at high and medium speed. Engine quieter than normal.	Injector pump timing retarded.	Set timing.
Smokes under load, especially at low and medium speed. Engine noisier than normal.	Injector pump timing advanced.	Set timing.
Smokes under load at all speeds, but most apparent at low and medium speeds. Engine may be difficult to start.	Weak cylinder compression.	Repair engine.
Smokes under load, especially at high speed.	Restricted air cleaner.	Clean / replace air filter element.
Smokes under load, noticeable loss of power.	Turbocharger malfunction.	Check boost pressure.
Smokes under load, especially at high and medium speeds. Power may be down.	Dirty injector, nozzle (s).	Clean/replace injectors.
Smokes under load, especially at low and medium speeds. Power may be down.	Clogged / restricted fuel lines.	Clean/replace fuel lines.
Puffs of black smoke, sometimes with blue or white component. Engine may knock.	Sticking injectors.	Repair/replace injectors.

(ON SLIDE #171)

BLUE, BLUE-GRAY, or GRAY-WHITE SMOKE		
Symptom	**Probable cause**	**Remedial action**
Whitish or blue smoke at high speed and light load, especially when engine is cold. As temperature rises, smoke color changes to black. Power loss across the RPM band, especially at full throttle.	Injector pump timing retarded.	Set timing.
Whitish or blue smoke under light load after engine reaches operating temperature. Knocking may be present.	Leaking injector(s).	Repair / replace injector(s).
Blue smoke under acceleration after prolonged period at idle. Smoke may disappear under steady throttle.	Worn rings / cylinder.	Overhaul / rebuild engine.
Light blue or whitish smoke at high speed under light load. Pungent odor.	Over-cooling.	Replace thermostat.

(ON SLIDE #172)

INTERIM TRANSITION: So far we have discussed diesel engine intake and exhaust systems. Are there any other questions? If not let's take a break and then we will move on to the practical application of removing the intake and exhaust systems.

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(BREAK 10min)

INTERIM TRANSITION: Any more questions before we move on to the practical application of removing the intake and exhaust systems.

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(ON SLIDE #173)

INSTRUCTOR NOTE
Perform the following practical application Removal of intake and exhaust systems. **Have students take breaks as required or as instructed.**

PRACTICAL APPLICATION (4 HRS) In groups no larger than 5 the students will have their assigned toolboxes, technical manuals and assigned engines with work stations. There will be at least one instructor supervising the exercise. The purpose of this practical application is to remove the intake and exhaust systems.
PRACTICE: In their groups the students will follow the technical manuals to disassemble and remove the intake and exhaust systems on their assigned engines.
PROVIDE HELP: The instructor may assist in the disassembly process if needed.
1. Safety Brief: At all times proper PPE will be worn to include safety boots. Safety glasses will be worn anytime fuel or liquid under pressure is being used.
2. Supervision and Guidance: The instructor will walk around to the different groups and supervise the disassembly, answering any questions the students may have.

(ON SLIDE #174)

TRANSITION: Over the past 1.15 hours we have reviewed engine respiration and how the components work together, are there any questions? I have some questions for you and then we will take a quiz.

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Opportunity for questions.

1. **QUESTIONS FROM THE CLASS**:

2. **QUESTIONS TO THE CLASS**:

Q: How can a diesel engine's Volumetric Efficiency be increased above 100%?
A: Turbocharging
Q: What component is designed to ensure quick sealing of the combustion chamber after gases have been evacuated?
A: Interference angle of the valves
Q: What are four poisonous gasses found in diesel exhaust?
A: Carbon Monoxide, Nitrogen Oxide, Sulfur Dioxide, Diesel Particulate Matter
Q: What are the four conditions that will decrease Volumetric Efficiency?
A: Shorter duration of the intake stroke, Hotter air less dense, Obstructions on the walls of the intake ports, and elevation.
Q: Describe the three conditions of valve timing that are modified to change the power output of a diesel engine?
A: Valve opening and closing points, how long a given valve will stay open (duration), and valve overlap.
Q: What are the two periods when there is virtually no piston movement?
A: 15-20 degrees before and after bottom dead center and 15-20 degrees before and after top dead center.

INSTRUCTOR NOTE:
Handout quiz for diesel engine intake and exhaust system operation and troubleshooting

(ON SLIDE #175)

QUIZ (30min)
Hand out quiz for diesel engine intake and exhaust system operation and troubleshooting quiz. Give the students 20 minutes to complete and review it with the students after.

(ON SLIDE #176)

TRANSITION: Now that we have covered the intake and exhaust of the engine let's take a break and then we will look at how all the internal components stay lubricated.
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(BREAK 10 min)

TRANSITION: Any more questions before we move on?.
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(ON SLIDE #177)

4. **DIESEL ENGINE LUBRICATION SYSTEM OPERATION AND TROUBLESHOOTING (2hrs)**

(ON SLIDE #178)

INSTRUCTOR NOTE
Computer aided graphic wear analysis 1.15 minutes.
Computer aided graphic lubrication purpose 0.10 minutes.
Computer aided graphic friction 0.21 minutes.

(ON SLIDE #179)

a. **Purpose.** The lubrication system in an 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.

(ON SLIDE #180)

b. **Engine Oil Characteristics.** 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 gears.

(1) Oil as a Lubricant.

(a) Every moving part of the engine is designed to have a specific clearance between it and the bearing it moves on. As oil is fed to the bearing it forms a film, preventing the rotating part from actually touching the bearing.

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

INSTRUCTOR NOTE
Computer aided graphic using plasti-gauge 1.49 minutes.

(ON SLIDE #181)

(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.

(ON SLIDE #182)

(2) 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 removed by 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.

(ON SLIDE #183)

(3) Oil Contamination. 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.

(ON SLIDE #184)

Oil contamination is controlled in the following ways.

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

(b) The use of oil filters removes 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 keeps it from entering the engine.

(ON SLIDE #185)

(4) Oil Dilution. Engine oil thins out when mixed with fuel, causing a dramatic drop in its lubricating qualities. Some of the causes of oil dilution are the following.

(a) Failed fuel injectors causing an over rich mixture and an abundance of unburned fuel to leak past the piston rings into the crankcase.

(b) Failed fuel injection pump. There are some fuel injection pumps (such as the distributor type) that have the oil and fuel in close proximity. When these types of pumps fail the crankcase can and will fill with fuel.

(c) An engine with a malfunctioning thermostat or an engine that is operated for only short durations 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 warm up. When the engine reaches its operational range 180°F (82.2°C) to 200°F (93.3°C)), however, this condition is corrected as the excess fuel vaporizes in the crankcase and is carried off by the crankcase ventilation system.

(ON SLIDE #186)

INSTRUCTOR NOTE
Computer aided graphic acid and contaminants in the Oil .17 minutes

INSTRUCTOR NOTE
If the engines are taken apart and if time permits, each group can check the bearing clearances on one crank shaft journal.

(5) American Petroleum Institute (API) Rating System. 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. The higher the alpha designation, the higher quality the oil is.

(ON SLIDE #187)

(6) Oil Viscosity. The viscosity of 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 it to retain its film strength. The ambient temperature in which a vehicle operates determines weather 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.

(ON SLIDE #188)

(a) Oils are graded according to their viscosity by a series Society of Automotive Engineers (SAE) numbers. The viscosity of the oil will increase progressively with the SEA number. An SAE 4 oil would be very light (low viscosity) and SAE 90 oil would be very heavy (viscosity). 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 oil flows, the lower the viscosity. Any oil that meets SAE low temperature requirements will be followed by the letter W (winter). An example would be SAE 10W.

(b) 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 of 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 30 weight at 210 degrees F

(c) Detergent Oils. Detergent oils contain additives that help keep the engine clean by preventing the formation of sludge and gum.

(ON SLIDE #189)

INTERIM TRANSITION: Now that we have covered what oil is and what it does are there any other questions? Let's go ahead and take a 10 minute break.

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(BREAK – 10 Min)

TRANSITION: Before the break we talked about the purpose of the lubrication system and what oil is and what it does. Now let's talk about the different types of oil pumps.

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(ON SLIDE #190)

c. **Oil Pumps**

(1) Rotor-Type Oil Pump. 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 gear directly from the camshaft. The rotor oil pump makes use of an inner rotor with lobes that match similarly shaped depressions in the outer rotor. 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.

(ON SLIDE #191)

(2) Crescent-Type Oil Pump. The crescent pump is advantageous in situations where high delivery rate of oil is required, particularly at low engine speeds. The basic principle is the same; two rotating wheels build oil pressure near the delivery nozzle. Movements of the two wheels are in tandem as opposed to contrary wheel movements in the gear and rotary pumps. Due to size difference of the two wheels, oil is carried to the delivery nozzle and pressure created by gradually reducing the size of the containment area or the crescent formed between the two wheels.

(ON SLIDE #192)

(3) Gear-Type Oil Pump. Gear pumps operate on the water wheel principle. They have two wheels to create high pressure in the oil pan and inject the oil into all areas that need lubrication. As the engine will be operating at high speeds, high pressure is required for the oil to reach all moving parts in the engine. Two interlocking wheels inside the pump draw oil from the pan and force it into relatively smaller area and build the required pressure. The movements of the wheels or gears and the sides of the pump are so designed that when high pressure is formed near the delivery nozzle, oil will not flow back into the oil pan.

(ON SLIDE #193)

(4) **Oil Strainer and Pickup.** Most manufactures of in-line and V-type engines place at least one oil strainer or screen in the lubrication system. The screen is a fine mesh bronze screen that is located in the oil pump on the end of the oil pickup tube. The oil pickup tube then is 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. The oil strainer is used to filter out larger particles or contaminates.

(ON SLIDE #194)

INSTRUCTOR NOTE
Computer aided graphic abrasive and erosive wear 2.31 minutes.

e. **Oil Filters.**

(1) Purpose. 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 of the engine and is designed to be replaceable readily.

(ON SLIDE #195)

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

(a) Cotton waste or resin-treated paper are the two most popular 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.

(ON SLIDE #196)

INSTRUCTOR NOTE
Computer aided graphic full flow system 0.08 minutes.

(4) Filter System Configuration. The full-flow system is the most popular in current engine 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 circulate through the system without passing through the element in the event that it becomes clogged. This will prevent the oil supply from being cut off to the engine.

(ON SLIDE #197)

INSTRUCTOR NOTE
Computer aided graphic by-pass valves 1.33 minutes.

f. **Pressure Regulator.** The oil pump will produce pressures in great excess. 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.

(ON SLIDE #198)

g. **Crankshaft Bearings (Friction Type)**. The crankshaft is supported in the crankcase and rotates in the main bearings. The connecting rods are supported on the crankshaft by the rod bearings. One of the main bearings serves as the thrust bearing which prevents excessive axial movement. There are also anti friction type bearings such as ball bearings but they are not used as crankshaft bearings.

(ON SLIDE #199)

(1) Construction. Crankshaft bearings are made as precision inserts. They simply slip into place in the upper and lower halves of the shells. When the halves are clamped together, they form a precision bearing that will be a perfect fit for a properly sized shaft. The bearing inserts and the mating surface that hold them must be sized perfectly. The insert merely slips into place and is held from turning by the locating tab. The crankshaft sits on the lower bearing shelf.

(ON SLIDE #200)

(2) Materials. Most bearings begin with a steel backing to give them rigidity. The lining then is applied to the steel backing. The lining usually consists of an alloy of copper, tin, and lead. The lining also may be made of babbit. Babbit is a popular bearing material that is an alloy consisting of copper, tin, and antimony. The lining thickness usually ranges from 0.002 to0.005 in. (0.051 to 0.127 mm). The bearing then is coated with either aluminum or tin to a thickness of approximately 0.001 in. (0.025 mm).

(ON SLIDE #201)

(3) Bearing Requirements. Bearings must be able to support the crankshaft rotation and deliver power stroke thrusts under the most adverse conditions. A good bearing must have the following qualities.

(ON SLIDE #202)

INSTRUCTOR NOTE
Computer aided graphic stress wear 2.40 minutes.

(a) Strength. Engine bearings are constantly subjected to tremendous forces from the thrust of the power strokes. The bearings must be able to withstand these loads without spreading out or cracking.

(ON SLIDE #203)

INSTRUCTOR NOTE
Computer aided graphic lubrication corrosion 1.59 minutes.

(b) Corrosion resistance. The bearing must be resistant to moisture and acids that always are present in the crankcase.

(ON SLIDE #204)

INSTRUCTOR NOTE
Computer aided graphic adhesive wear 1.52 minutes.

(c) Antiscuffing. The bearing surface should be able to absorb enough oil to keep It from scuffing during startup, or any other time when It must run momentarily without an oil supply.

(ON SLIDE #205)

INSTRUCTOR NOTE
Computer aided graphic embedability 0.49 minutes.

(d) Embedabillty. The surface of the bearing must be soft enough to allow particles of foreign matter to embed themselves and prevent damage of the shaft journal.

(ON SLIDE #206)

(e) Conformability. The bearing must be able to conform or fit itself to the surface of the crankshaft Journal.

(ON SLIDE #207)

INSTRUCTOR NOTE
Computer aided graphic conductivity 0.24 minutes.

(f) Conductivity. The bearings must be able to conduct heat to the connecting rod so that they will not overheat.

(g) Resistance to Heat. The bearing must be able to maintain all of these characteristics throughout its entire operating temperature range.

(ON SLIDE #208)

INSTRUCTOR NOTE
Computer aided graphic lubrication cavitation erosion wear 3.11 minutes.

(4) Connecting Rod Lubrication. The connecting rod bearings fit into the lower end of the connecting rod. They are fed a constant supply of oil through a hole in the Crankshaft Journal. A hole in the upper bearing half feeds a passage in the connecting rod to provide oil to the piston pin.

(ON SLIDE #209)

(5) Crankshaft Main Bearings. The upper halves of the main bearings fit right into the crankcase, and the lower halves fit into the caps that hold the crankshaft in place.
The main bearings have holes drilled in their upper halves through which a supply of oil is fed to them. The crankshaft has holes drilled in the journals that receive oil from the main bearings to feed the rod bearings. It is a common practice to cut a groove In the center of the main bearing Inserts. This supplies a more constant supply of oil to the connecting rod bearings.

(ON SLIDE #210)

INSTRUCTOR NOTE
Computer aided graphic thrust bearing 0.11 minutes.

One of the main bearings also serves as a thrust bearing. This controls back and forth movement of the crankshaft. This thrust bearing is characterized by side flanges.

(ON SLIDE #211)

h. **Lubrication System.** A 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. 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 semi or full floating piston pins.

(ON SLIDE #212)

INTERIM TRANSITION: Over the past 1.15 hours we have reviewed engine lubrication, how frictional losses are minimized, and how engine life is maximized. Are there any questions? If not take a 10 minute break.

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(BREAK – 10 Min)

INTERIM TRANSITION: Before the break we discussed the purpose and components of the lubrication system let's move on to the practical application of removing the oil pan and pump.

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(ON SLIDE #213)

INSTRUCTOR NOTE

Perform the following practical application drainage and removal of the oil pan and pump. **Allow students to take breaks as required or as instructed.**

PRACTICAL APPLICATION (4 HRS) In groups no larger than 5 the students will have their assigned toolboxes, technical manuals and assigned engines with work stations. There will be at least one instructor supervising the exercise. The purpose of this practical application is to remove and drain the engine oil pan and pump.

PRACTICE: In their groups the students will follow the technical manuals to drain and remove the engine oil pan and pump on their assigned engines.

PROVIDE HELP: The instructor may assist in the disassembly process if needed.

1. Safety Brief: At all times proper PPE will be worn to include safety boots. Safety glasses will be worn anytime fuel or liquid under pressure is being used.

2. Supervision and Guidance: The instructor will walk around to the different groups and supervise the disassembly answering any questions the students may have

(ON SLIDE #214)

TRANSITION: We just completed the practical application for removal of the oil pan and pump is there any other questions? If not I have some questions for you and then you will take a quiz.

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Opportunity for questions.

1. QUESTIONS FROM THE CLASS:

2. QUESTIONS TO THE CLASS:

Q: What is the purpose of the lubrication system?
A: Supplies a constant supply of oil to all moving parts of the engine.
Q: What the three functions of the lubricating system?
A: Minimize wear, flush bearing surfaces clean, remove localized heat between moving parts caused by friction.

Q: What are three causes for dilution of lube oil in a diesel engine?
A: Failed Fuel injectors, failed fuel pump, malfunctioning thermostat or a engine that operates for only short periods of time.
Opportunity for questions.
Q: What friction bearing trait allows particles of foreign matter to embed themselves and prevent damage of the shaft journal?
A: Embedability
Q: What friction bearing trait resists tremendous forces from the thrust of the power strokes?
A: Strength

(ON SLIDE #215)

QUIZ (30min)
Hand out quiz for diesel engine lubrication system operation and troubleshooting quiz. Give the students 20 minutes to complete and review it with the students after.

(ON SLIDE #216)

TRANSITION: Are there any questions? If not let's take a break.
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(BREAK 10 min)

TRANSITION: Let's begin this absolutely vital part of the diesel engine and answer a few questions about our source of energy; Diesel Fuel.
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(ON SLIDE #217)

INSTRUCTOR NOTE
Computer aided graphic intro fuel system 0.37 minutes.

5. **DIESEL ENGINE FUEL SYSTEM OPERATION AND TROUBLESHOOTING**
(1hr 50min)

(ON SLIDE #218)

a. **Thermal Efficiency**. Thermal efficiency is the relationship between actual heat energy stored within the fuel and the power produced in the engine (indicated horsepower). The thermal efficiency figure indicates how much of the potential energy contained in the fuel actually is used by the engine to produce power and how much energy is lost through heat.

(ON SLIDE #219)

There is an extremely large amount of energy from the fuel that is lost through heat in an internal combustion engine. This unused heat that is produced while the engine is producing power is of no value to the engine and must be removed from it.

(1) The heat is dissipated in the following ways.

(a) The cooling system removes heat from the engine to control engine operating temperature.

(b) A major portion of the heat produced by the engine exits through the exhaust system.

(c) The engine radiates a portion of the heat to the atmosphere.

(d) A portion of this waste heat may be channeled to the passenger compartment to heat it.

(e) The lubricating oil in the engine removes a portion of the waste heat.

(ON SLIDE #220)

(2) In addition to energy lost through wasted heat, there are the following inherent losses in the piston engine.

(a) Much energy is consumed when the piston must compress the mixture on the Compression stroke.

(b) Energy from the fuel is consumed to push the exhaust gases out of the cylinder.

(ON SLIDE #221)

b. **Characteristics of Diesel Fuel**. Fuels used in modern high-speed diesel engines are derived from the middle distillate fraction of crude oil.

(ON SLIDE #222)

The middle distillates span the boiling range between gasoline and heavy residual oil, and typically include kerosene, jet fuel (aviation kerosene), diesel fuel, and burner fuel (home heating oil). Although large, slow-speed diesel engines used in stationary and marine applications will burn almost any grade of heavy oil, the smaller, high-speed diesel engines used in most military equipment require middle distillate diesel fuels. These fuels must meet exacting specification requirements to ensure proper engine performance.

(ON SLIDE #223)

(1) Cleanliness. Fuel cleanliness is an important characteristic of diesel fuel because the extremely close fit of the injector parts can be damaged by particles.

(a) Dirt or sand particles in the fuel cause scoring of the injector parts, leading to poor performance.

(b) Moisture in the fuel can also damage of injector parts when corrosion occurs.

(ON SLIDE #224)

(2) Stability. Fuel stability is its capacity to resist chemical change caused by oxidation and heat. Good oxidation stability means that the fuel can be stored for long periods without formation of gum or sludge. Good thermal stability prevents the formation of carbon in hot parts such as fuel injectors. Carbon deposits disrupt the spray patterns and cause inefficient combustion.

(ON SLIDE #225)

(3) Cloud point. The lowest temperature to which the fuel can be subjected before it begins to cloud or form paraffin crystals is the cloud point. This is very important if an item of equipment is operated during cold weather. The paraffin or wax will clog fuel filters and cause an engine to shutdown.

(ON SLIDE #226)

(4) Viscosity. The viscosity of a fluid is an indication of its resistance to flow. This means that a fluid with a high viscosity is heavier than a fluid with a low viscosity. The viscosity of diesel fuel must be low enough to flow freely at its lowest operational temperature, yet high enough to provide lubrication to the moving parts of the finely machined injectors. The fuel must also be sufficiently viscous so that leakage at the pump plungers and dribbling at the injectors will not occur. Viscosity will also

determine the size of the fuel droplets, which, in turn, govern the atomization and penetration qualities of the fuel injector spray.

(ON SLIDE #227)

INSTRUCTOR NOTE
Computer aided graphic sulfur2 0.21 minutes.

(5) Sulfur. All diesel fuels contain a certain amount of sulfur, but high sulfur content is detrimental and will cause early engine failure. Sulfur does not burn except at extremely high temperatures, so in many cases it simply accumulates in the engine oil and forms sulfuric acid by combining with moisture during the combustion process. High sulfur content fuels require shorter times between engine servicing.

(ON SLIDE #228)

INSTRUCTOR NOTE
Computer aided graphic fuel injection2 0.30 minutes.

(6) Ignition Quality. The ignition quality of a fuel is its ability to ignite spontaneously under the conditions existing in the engine cylinder. The spontaneous-ignition point (flash point) of a diesel fuel is a function of the pressure, temperature, and time.

(ON SLIDE #229)

(a) The yardstick that is used to measure the ignition quality of a diesel fuel is the cetane-number scale. The cetane number of a fuel is obtained by comparing it to the operation of a reference fuel. The reference fuel is a mixture of alpha-methylnaphthalene, which has virtually no spontaneous-ignition qualities, and pure cetane, which has what are considered to be perfect spontaneous-ignition qualities.

(b) The percentage of cetane is increased gradually in the reference fuel until the fuel matches the spontaneous-ignition qualities of the fuel being tested. The cetane number then is established for the fuel being tested based on the percentage of cetane present in the reference mixture.

(c) Cetane is not the same as octane. Octane is used to rate gasoline and represents the ability of gasoline to resist rapid burning.

(ON SLIDE #230)

(7) Knocking. Diesel engines have a tendency to produce a knock that is noticeable particularly during times when the engine is under a light load. This knocking occurs due to a condition known as "ignition delay" or "ignition lag".

(1) When the power stroke begins, the first molecules of fuel injected into the combustion chamber must first vaporize and superheat before ignition occurs.

(2) During this period, a quantity of unburned fuel builds up in the combustion chamber. When ignition occurs, the pressure increase causes the built-up fuel to ignite instantly. This causes a disproportionate increase in pressure, creating a distinct and audible knock.

(3) The sudden ignition of the diesel fuel when injected into the combustion chamber causes a pressure wave.

(4) Increasing the compression ratio of a diesel engine will decrease ignition lag and the tendency to knock. This is opposite of a gasoline engine, whose tendency to knock will increase with an increase in compression ratio.

(5) Knocking in diesel engines is also affected by the type of combustion chamber, airflow within the chamber, injector nozzle type, air and fuel temperature, and the cetane number of the fuel.

(ON SLIDE #231)

INSTRUCTOR NOTE
Diesel fuel image.

(ON SLIDE #232)

c. Fuel circuit components.

(1) Fuel Tank. The location of the fuel tank is dependent on utilizing an area that is protected from flying debris, shielded from collision damage, and one that is not subject to bottoming. A fuel tank can be located just about anywhere in the equipment that meets these requirements.

(a) Construction. Fuel tanks take many forms in military equipment the most common material for fuel tanks is thin sheet metal. The walls of the tank are manufactured with ridges to give them strength. Internal baffles are sometimes installed in the tank to prevent the fuel from sloshing and to increase overall strength.

(b) Filler Pipe. A pipe is provided for filling the tank or cell that is designed to prevent fuel from being spilled into the passenger, engine, or cargo compartment. The filler pipes used on military vehicles are designed to allow their tanks to be filled at a rate of at least 50 gallons per minute.

(c) Fuel return line. The return line is normally located near the top of the fuel tank. Since diesel fuel is used to cool and lubricate the internal components of the system, returning fuel carries heat to the tank to be dissipated.

(d) Fuel supply line. The supply line is normally located just above the bottom of the fuel tank. This location is ideal to allow sediment to fall to the bottom of the tank without it being drawn into the fuel system.

(e) Drain plug. A threaded drain-plug is usually provided at the bottom of the tank for draining and cleaning.

(ON SLIDE #233)

(2) Fuel Tank Ventilation. The most common methods of venting a fuel tank are either venting the fuel tank cap to the atmosphere, or providing a line to the fuel tank that vents at a point that is high enough to prevent water from entering during fording operations. The following are reasons why a fuel tank needs a good ventilation system:

(a) Air must be allowed to enter the tank as the fuel is pumped out. Without ventilation of the tank, the pressure in the tank would drop to the point where the fuel pump would not be able to draw any more fuel from it. In some cases, the higher pressure around the outside of the tank could cause it to collapse.

(b) Temperature changes cause the fuel in the tank to expand and contract. Absence of a ventilation system could cause excessive or insufficient fuel line pressure.

(3) Fuel Gage Provision. A provision usually is made to install a fuel gage. This provision is normally in the form of a flanged hole.

(ON SLIDE #234)

INSTRUCTOR NOTE
Computer aided graphic no fuel bypass 0.12 minutes.

d. **Fuel filtration**. Thorough and careful filtration is necessary to keep diesel engines efficient. Diesel fuels are more viscous than gasoline and contain more gums and abrasive particles that may cause premature wear of injection components. The abrasives may consist of material that is difficult to eliminate during refining, or they even may enter the tank during careless refueling. Whatever the source, it is imperative that means be provided to protect the system from abrasives.

(ON SLIDE #235)

(1) Types. Diesel engine designs usually include two filters (primary and secondary) in the fuel supply systems to protect the closely fitted parts in the pumps and nozzles. Additional filtering elements are frequently installed in the system to provide additional protection.

(2) Diesel fuel filters are referred to as full-flow filters, because all the fuel must pass through them before reaching the injection pumps. A diesel fuel filter usually incorporates a drain valve where foreign matter and water that settles to the bottom of the bowl can be removed.

(ON SLIDE #236)

e. **Fuel transfer (lift) pump.**

(1) Fuel injection pumps must be supplied with fuel under pressure for the following reasons:

(a) The injection pumps lack the suction ability to draw fuel from the tank by themselves.

(b) It is important to supply fuel to the injection pump in excess so that fuel may be used to cool and lubricate the system before bypassing it back to the tank.

(c) Without a supply pump, the system would lose its prime whenever the pump is in the no-delivery mode. The supply pumps in use generally are of the positive displacement type with a performance that is independent of any reasonable variations in viscosity, pressure, or temperature of the fuel.

(2) Types. In a majority of the equipment, the fuel supply pump is built into the injection pump unit. This cuts down on fuel tubing and the complexity of the equipment, and allows the supply pump to share the same engine power takeoff as the injection pump. However, the pump may be located on the engine block and driven by an eccentric lobe on the engine cam shaft.

(ON SLIDE #237)

INSTRUCTOR NOTE
Computer aided graphic rotor pump 0.17 minutes.

(a) Vane-type supply pump. An integral steel rotor and shaft, one end supported in the pump flange and the other end in the cover, revolves in the body, the bore of which is eccentric to the rotor. Two or more sliding vanes are placed at equal distances apart in slots in the rotor and are pressed against the body bore by springs in the slots or centrifugal force. When the shaft is rotated, the vanes pick up fuel at the inlet port and carry it around the body to the outlet side, where the fuel is discharged. Pressure is produced by the wedging action of the fuel as it is forced toward the outlet port by the vane.

(ON SLIDE #238)

(b) Plunger-type supply pump. The plunger follows the camshaft by the force of its plunger spring. As the follower comes off the high point of the cam lobe, the plunger moves toward the retracted position, this plunger movement creates suction in the pump chamber. This causes fuel to enter through the inlet valve. As the cam lobe comes around again, it forces the plunger upward. This forces the fuel out of the chamber through the outlet valve and the injection pump. The cam follower drives the plunger through a spring. The spring is calibrated so that it will flex rather than drive the plunger when the pressure in the pump chamber reaches the desired maximum. This effectively regulates pump pressure.

(ON SLIDE #239)

(c) Gear-type supply pump. In this type, a primary gear, driven by an external member, drives a companion gear. Fuel is forced into the pump cavity, around each gear, and out the other side into the fuel passages. The pressure is derived from the action of the meshed gear teeth, which prevent fuel from passing between the gears, and forces it around the outside of each gear instead. The pump incorporates a pressure relief valve, which is a spring-loaded ball that rises when the desired pressure is reached and allows the excess oil to be delivered to the inlet side of the pump.

(ON SLIDE #240)

(d) Piston-type supply pump (Figure 9. The fuel pump is moved by a cam on the camshaft of the fuel injection pump or the engine. As the cam lobe rotates towards the transfer pump, the push rod and piston are forced into the pump causing the fuel to open the pumping check valve. As the cam lobe rotates away, spring force pushes the push rod out opening the outlet check valve for fuel delivery while the piston draws fuel in through the inlet check valve.

(ON SLIDE #241)

(e) Electric-powered lift pump. Fuel flow begins as the fuel lift pump pulls fuel from the supply tank. This electric lift pump supplies low-pressure fuel (10 to 12 psi) to the filter head, through the filter, and then to the electronic distributor injection pump. The electronic distributor pump builds the high injection pressures required for combustion and routes the fuel through individual high-pressure fuel lines to each injector.

(ON SLIDE #242)

(f) High pressure pump. This pump draws fuel and brings it up to injection pressure. Fuel at injection pressure is sent to the "common rail" where it is made available to each injector. Each injector draws fuel from the rail by a high pressure line. Since there is always injection pressure in the rail, the injectors have the ability to draw fuel at any time.

(ON SLIDE #243)

INSTRUCTOR NOTE
Computer aided graphic amount of fuel 0.19 minutes.

(1) Engine speed in a diesel is controlled by the amount of fuel injected. The injection, therefore, is designed to supply the maximum amount of fuel that will enable it to operate at full load while reaching a predetermined maximum speed (rpm). If, however, the maximum fuel charge were supplied to the cylinders while the engine was operating under a partial or unloaded condition, the result would be over speeding and catastrophic failure. Thus, it can be seen that the ECM must control the amount of fuel injected in order to control the engine speed.

(ON SLIDE #244)

g. **Fuel Injection Principles**.

(1) Method. In engineer equipment the most common method of delivering fuel to the combustion chamber is solid injection, where direct mechanical pressure is placed on the fuel itself to force it into the combustion chamber.

(ON SLIDE #245)

(2) Fuel Atomization and Penetration. The fuel spray entering the combustion chamber must conform to the chamber's shape so that the fuel particles will be well distributed and thoroughly mixed with the air. The amount of fuel pressure for injection is dependent on the pressure of the air in the combustion chamber, and the amount of turbulence in the combustion space. The shape of the spray is determined by the degree of atomization and penetration produced by the orifice through which the fuel enters the chamber.

(a) Atomization is the term used to indicate the size of the droplets the fuel is broken down into.

(b) Penetration is the distance from the orifice that the fuel droplets attain at a given phase of the injection period. The dominant factors that control penetration are the length of the nozzle orifice, the diameter of the orifice outlet, the viscosity of the fuel, and the injection pressure of the fuel.

(c) Increasing the ratio of the length of the orifice to its diameter will increase penetration and decrease atomization.

(d) Decreasing this ratio will have an opposite effect. Because penetration and atomization are opposed mutually and both are important, a compromise is necessary if uniform fuel distribution is to be obtained.

(ON SLIDE #246)

(3) Function of the diesel injection systems. If the four basic functions of diesel fuel injection are kept in mind while studying the operation of the systems, it will be easier to understand how they work. The four basic functions are:

(a) Time. The timing of fuel injected into the cylinder is very important during engine starting, full load, and high speed operation. Diesel engines start best when fuel is injected at or very close to **top dead center (TDC)**, since it is at this point that air in the chamber is the hottest. After the engine is started and running at high speed, the injection timing may have to be advanced to compensate for injection lag, ignition lag, and other factors that influence combustion within the engine cylinder.

(b) Atomize. The fuel must be atomized when it is injected into the combustion chamber since unatomized fuel will not burn easily. The degree of atomization required will vary from engine to engine depending on the combustion chamber design.

(c) Meter. The fuel injection system must measure the fuel supplied to the engine very accurately since fuel requirements vary greatly with engine speed. Fuel is metered within the injection pump or injector by measuring it as it fills the pumping chamber (inlet metering) or as it leaves the pumping element (outlet metering).

(d) Pressurize. The fuel system must pressurize the fuel to open the injection nozzle or the injector tip. In addition to the pressure required to open the nozzle, some pressure is required to inject fuel into the combustion chamber to offset the pressure of compression.

(ON SLIDE #247-248)

INTERIM TRANSITION: Over the past hour we have talked about some of the fuel system components. Are there any other questions? Let's go ahead and take a tem minute break.

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(BREAK – 10 Min)

INTERIM TRANSITION: Before the break we talked about some of the fuel system components. The principles of fuel injection is built on fundamental hydraulic principles, and if this is kept in mind, understanding how the fuel systems found in Marine Corps Engineer Equipment work will be much easier. First let's review the pressure timed (common rail system).

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(ON SLIDE #249)

h. **Pressure-Timed (PT) Injection System.**

(1) Features of a Common Rail System (PT). On the C6.6 model engine, the ECM has new software for more accurate timing control. It has a high-pressure fuel system to deliver adequate amounts of fuel at any given time. The new 4 valve head allows for better volumetric efficiency.

(ON SLIDE #250)

(2) Overall System Operation. The pressure-timed injection system (also known as a common rail system) has a metering system that is based on the principle that the volume of liquid flow is proportional to the fluid pressure, the time allowed to flow, and the size of the passage the liquid flows through.

(ON SLIDE #251)

(3) Pump Facts. The common rail system is a self bleeding system. This means you **DO NOT** crack the fuel lines to let out excess air. Failure to do so will result in serious injury. If fuel pump is removed, fuel lines must be replaced. Ensure fuel pump is timed to the engine and locked into place before removal.

(ON SLIDE #252)

The operation of the system is as follows:

(a) A fuel tank with a vented filler cap stores the fuel supply.

(b) Fuel is supplied from the tank to the pressure-timed gear (PTG) pump through the delivery line. An in-line filter is placed in series in the line to trap foreign matter and moisture.

(c) An internal bleed line from the PTG pump is provided to bleed off excess fuel so that operating pressures can be regulated. (Self-Bleeding)

(d) The PTG pump delivers controlled amounts of fuel from the ECM to the pressure-timed delivery (PTD) injectors.

(e) Delivery of fuel to the PTD injectors is through a common-rail type delivery line.

(f) A common-rail type return line connects the PTD injectors to the fuel tank so that excess fuel may be diverted back to the fuel tank.

(ON SLIDE #253)

(4) PTG (Pressure Timed Gear) Injection Pump (Figures 13 and 14). The PTG pump is driven directly by the engine at a one-to-one speed ratio.

(ON SLIDE #254)

(a) Operation and Construction.

1 The gear-type pump draws fuel from the supply tank and forces it through the pump filter screen to the governor. It is driven by the pump main shaft and picks up and delivers fuel throughout the fuel system. A pulsation damper mounted to the gear pump contains a steel diaphragm that absorbs pulsations and smoothes fuel flow through the fuel system.

(ON SLIDE #255)

2 The PTG pumps are equipped with a bleed line that is attached to the engine injector return line. This prevents excessive fuel temperature within the fuel pump by using the surplus fuel as a coolant. The bleed line functions primarily when the pump throttle is set at idle speed, but gear pump output is high due to engine operating speed, as occurs during downhill operation. A special check valve is used in the gear pump to accomplish the bleed action.

3 The governor controls the flow of the fuel from the gear pump, as well as the maximum and idle speeds. The mechanical governor is actuated by a system of springs and weights and has two functions:

a The governor maintains sufficient fuel for idling with the throttle control in idle position.

b It restricts fuel to the injectors above maximum rated rpm.

3 During operation between idle and maximum speeds, fuel flows through the governor to the injectors in accordance with the engine requirements, as controlled by the throttle and limited by the size of the idle spring plunger counter bore. When the engine reaches governed speed, the governor weights move the governor plunger, and fuel flow to the injectors is restricted. At the same time, another passage opens and dumps the fuel back into the main pump body. In this manner, engine speed is controlled and limited by the governor, regardless of throttle position. Fuel leaves the pump, flows through the shutdown valve, inlet supply lines, and to the injectors.

4 The fuel shutdown valve is located on top of the fuel pump. It shuts off fuel to the injectors. With the master

switch on, the solenoid opens the valve. With the switch off, the spring loaded valve returns to the OFF position. In case of an electrical failure, rotation of the manual knob clockwise will permit fuel to flow through the valve. The knob is located on the front of the valve.

(ON SLIDE #256)

(5) PTD (Pressure Timed Delivery) Injector. A PTD injector is provided at each engine cylinder to spray the fuel into the combustion chambers. PTD injectors are of the unit type, operated by an engine-based camshaft.

(ON SLIDE #257)

(a) Fuel flows from a connection at the top of the fuel pump shutdown valve through a supply line into the lower drilled passage in the cylinder head at the front of the engine.

(b) A second drilling in the head is aligned with the upper injector radial groove to drain away excess fuel.

(ON SLIDE #258)

(c) A fuel drain at the flywheel end of the engine allows return of the unused fuel to the fuel tank.

(d) Decreasing fuel injector travel would (overtime) foul the injector and decrease engine speed. There are four phases of injector operation:

(ON SLIDE #259)

1 Metering. This phase begins with the plunger just beginning to move downward and the engine is on the beginning of the compression stroke. The fuel is trapped in the cup, the check ball stops the fuel from flowing backwards, and the fuel begins to be pressurized.

(ON SLIDE #260)

2 Pre-injection. The plunger is almost all the way down, the engine is almost at the end of the compression stroke, and the fuel is being pressurized by the plunger.

(ON SLIDE #261)

(e) Injection. The plunger is almost all the way down, the fuel is injected out the eight orifices, and the engine is on the very end of the compression stroke.

(ON SLIDE #262)

(f) Purging. The plunger is all the way down, injection is finished, and the fuel is flowing into the injector, and out through the fuel drain. The cylinder is on the power stroke. During the exhaust stroke, the plunger moves up and waits to begin the cycle all over again.

(ON SLIDE #263)

INSTRUCTOR NOTE
Computer aided graphic inspecting fuel lines for leaks 0.30 minutes.

(ON SLIDE #264)

i. **Inline Injection System**.

(1) Overall system operation (Figure 21, schematic representation only).

(a) The fuel transfer pump and the fuel filters provide a low-pressure supply of fuel to the multiple unit injection pump.

(b) The multiple unit injection pump contains an individual injection pump for each engine cylinder. Fuel is delivered to the injectors at each cylinder from the injection pumps in a timed sequence and a regulated amount based on accelerator pedal position and engine speed.

(c) The injectors receive fuel charges from their respective injection pumps and spray it into the combustion chambers in a spray pattern that is tailored to provide the best overall performance for their particular application.

(ON SLIDE #265)

(2) Governor servos and solenoids.

(a) Hydraulic servo (Caterpillar). The servo consists basically of a hydraulic piston and an oil control valve (the cylinder). The servo gives hydraulic assistance to the mechanical governor force to move the fuel rack.

(ON SLIDE #266)

(b) Dashpot (Caterpillar). The dashpot helps the governor better control speed when there are sudden speed and load changes by dampening the movement of the governor spring. If the governor movement is slow, the dashpot gives no restriction to the change in governor linkage position, but if there is sudden movement in the "FUEL OFF" direction of governor position, the dashpot will move slowly due to supply oil movement through a the needle valve.

(ON SLIDE #267)

(c) Fuel ratio control (Caterpillar). The fuel ratio control limits the amount of fuel to the cylinders during an increase of engine speed to reduce exhaust smoke.

1 While the engine is stopped, the fuel ratio control stem is in the fully extended position allowing maximum fuel to the engine for easier starts.

2 With the engine running, oil fills the pressure oil chamber.

3 When the governor is moved to increase fuel to the engine, the fuel ratio control stem limits the movement of the fuel rack in the "FUEL ON" direction in proportion to the inlet air pressure in the air chamber.

4 The fuel ratio control is designed to restrict fuel until the air pressure in the inlet manifold is high enough for complete combustion. It prevents large amounts of black exhaust smoke caused by an air-fuel mixture with too much fuel. When engine speed or load is increased rapidly, it is possible for a standard (unlimited) governor to supply more fuel than can be burned with the amount of available air too much smoke and poor acceleration are the result. The fuel ratio control works to limit the movement of the governor terminal shaft in the increase fuel direction as a direct result of inlet manifold pressure. Thus, fuel which can be burned is limited to the air available for combustion as the engine speed is increased. This gives more complete combustion and keeps smoke to a minimum while acceleration is improved.

(ON SLIDE #268)

(d) Aneroid (Bosch). The aneroid (also called Air Fuel ratio Control A.F.C.is a diaphragm air fuel ratio control usually mounted on the governor housing, but it can be mounted on the front of the pump as well. It is operated by boost pressure from the intake manifold. Like the fuel ratio control used by Caterpillar, the aneroid eliminates unnecessary smoke by limiting control rack movement until sufficient manifold pressure is built up in the intake manifold to effectively burn a full charge of fuel.

(ON SLIDE #269)

(3) The Multiple Unit Injection Pump.

(a) The multiple unit injection pump contains an individual plunger-type injector pump for each cylinder. These pumps are arranged in a line so that they may be driven by a common camshaft.

(ON SLIDE #270)

(b) The lobes of the camshaft are arranged so that they operate the injection pumps in a sequence that coincides with the firing order of the engine.

(c) This camshaft is driven by the engine through gears at a speed of exactly one-half that of the crankshaft. This exact speed is maintained so that the injectors will each deliver their fuel charge at the beginning of their respective cylinder's power stroke. Power strokes occur during every other crankshaft revolution in a four-stroke cycle diesel engine.

(ON SLIDE #271)

(d) Excess fuel flows from the injection pump through the relief valve and back to the fuel tank.

(e) The pumps consist of a finely fitted plunger that is actuated by the camshaft against the force of the plunger spring.

(ON SLIDE #272)

(f) The bore that the plunger rides in has two passages machined into it. One of these passages is the delivery port, through which the pump is filled. The other passage is the spill port, through which excess fuel is discharged. Fuel flows into the pump cavity through the uncovered delivery port and out of the pump cavity through the uncovered spill port when the plunger is fully in its return position. The pump cavity is always kept full as the fuel flows through. The plunger moves up in its bore as it is actuated by the camshaft, sealing the ports. The fuel that is trapped in the cavity is forced out of the pump and to its respective injector.

(g) The pump plunger has a rectangular slot cut into it that leads from the top face, down the side, and finally connecting to a helical shaped cavity. In operation, the slot will allow fuel to pass to the bypass helix. As the bypass helix passes over the spill port, it will allow a portion of the fuel charge to bypass rather than being injected into the engine cylinder. Either the outer pump sleeve or the inner plunger is made to rotate and will have gear teeth around its outer diameter. A horizontal toothed rack meshes with these gear teeth to rotate either the sleeve or plunger.

(ON SLIDE #273)

INSTRUCTOR NOTE
Image of inline injection pump.

(ON SLIDE #274)

(h) By moving the rack back and forth, the delivery and spill ports are changed in relation to the bypass helix on the pump plunger. This enables the volume of fuel injected to the volume of fuel injected to the cylinders to be varied by changing the effective length of the pump stroke (the length of the pump stroke that occurs before the spill port is uncovered by the bypass helix). The rack extends down the whole row of Injection pumps so that they are all operated simultaneously. The end result is that the Injection pumps can be moved from full to no-fuel delivery by moving the rack back and forth. The movement of the rack is controlled by the governor.

(ON SLIDE #275)

(i) When the plunger begins its pump stroke it covers both ports. When this happens, the pressure exerted on the fuel causes the spring-loaded delivery valve to lift off of Its seat, thereby permitting fuel to discharge into the tubing that leads to the spray nozzle.

(j) At the instant that the bypass helix uncovers the spill port, the fuel begins to bypass. This causes the pressure in the pump cavity to drop. The high pressure in the delivery line combined with spring pressure causes the delivery valve to close.

(k) When the delivery valve closes, it prevents fuel from the line from draining back into the pump, which could cause the system to lose its prime. As the delivery valve seats, it also serves to reduce pressure in the delivery line. The delivery valve has an accurately lapped displacement piston Incorporated into It to accomplish pressure relief. The pressure is relieved in the line by the increase in volume as the delivery valve seats.

(ON SLIDE #276)

INSTRUCTOR NOTE
Image Large Diesel Engine.

(ON SLIDE #277)

j. **Distributor systems.**

(1) Overall system operation.

(a) The distributor system and pump develops pressure for injection through a single or paired set of plungers which are then timed to the injectors by means of a distributor.

(ON SLIDE #278)

(b) Most modern pumps discharge from one side of the plunger, which rotates to align the discharge point with a fixed distributor head.

(ON SLIDE #279)

(c) The major advantage of this type of system is each cylinder receives precisely the same amount of fuel. The economic advantage is that a single plunger or plunger set costs less than the alternative scheme of individual plungers for each cylinder.

(d) The most significant disadvantage is the pumping elements are susceptible to wear from a lack of lubrication due to improper viscosity of the fuel. Since all lubrication for the pump comes from the diesel fuel, an improper grade of fuel will cause early failure due to lower fuel viscosity.

(ON SLIDE #280)

(2) Single plunger distributor pump.

(a) Construction.

1	Shut off solenoid	2	Control Lever	3	Mechanical Governor
4	Feed Pump	5	Feed Pump	6	Roller Holder
7	Cam Disk	8	Timing Advance Mechanism		
9	Control Sleeve	10	Plunger	11	Delivery Valve

(ON SLIDE #281)

(b) Operation.

1 The single plunger distributor pump combines transfer and high pressure pump functions in a single unit. A cam disk, driven from the engine at a two to one ratio, is pinned to the plunger, which has a reciprocating and rotary motion.

2 Lobes on the cam disk cause the plunger to reciprocate, alternately drawing fuel and pressurizing it. The plunger also rotates with the cam disk to align its discharge grove successively with each of the injector ports on the pump body.

3 The control sleeve limits the plungers effective stroke. The distance the plunger moves is fixed by the cam lobes; the effective stroke is determined by the position of the control sleeve.

4 Moving the sleeve to the right uncovers the spill port, before the beginning of injection, reducing the amount of fuel delivered. Conversely, moving it to the left blocks the spill port , so that more of the charge is delivered.

5 The pump also includes a timing advance mechanism, which initiates injection early by advancing the plunger carrier assembly relative to the cam plate during high speed operation. Like most such mechanisms, the unit takes its cue from the increase in pump pressure at speed.

6 The shutoff solenoid is normally closed. When electricity is applied, the plunger opens the fuel delivery passage for normal operation.

(ON SLIDE #282)

INTERIM TRANSITION: Over the 20 minutes we have reviewed the components, operation, troubleshooting, and repair of the distributor fuel system. Are there any questions? Take a 10 minute break.

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(BREAK – 10 Min)

TRANSITION: Before the break we discussed distributor type fuel pumps. Are there any other questions? Now let’s find out what happens after the fuel pump has stepped up injection pressure, metered the amount of fuel, and timed it to coincide with TDC on the compression stroke. The last phase is atomization. This is accomplished by the multiple unit injectors.

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(ON SLIDE #283)

k. **Multiple Unit Fuel Injector**. For proper engine performance, the fuel must be injected into the combustion space in a definite spray pattern. This is accomplished by the fuel Injector.

(1) The fuel enters the injector body through the high-pressure Inlet. At the moment that the pressure developed by the injection pump exceeds the force exerted by the pressure adjusting spring, the nozzle valve will be lifted off of its seat, resulting in the injection of fuel into the cylinder. The valve opening pressure depends greatly on the engine combustion chamber requirements.

(ON SLIDE #284)

INSTRUCTOR NOTE
Computer aided graphic fuel nozzles 0.14 minutes.

(2) Injector Nozzles. Because of the widely differing requirements in the shapes of the fuel spray for various chamber designs and the wide range of engine power demands, there is a large variety of injector nozzles in use. Hole nozzles are generally used in open chamber engines and therefore will be the focus of this discussion.

(ON SLIDE #285)

(a) The hole nozzles have one or more spray orifices that are straight, round passages through the tip of the nozzle body beneath the valve seat. The spray from each orifice is relatively dense and compact, and the general spray pattern is determined by the number and the arrangement of the holes.

(b) As many as 18 holes are provided in larger nozzles, and the diameter of these drilled orifices may be as small as 0.006 in. (0.152 mm). The spray pattern may not be symmetrical, where the spray pattern is off to one side so as to deposit the fuel properly in the spherical combustion chamber.

(c) The size of the holes determines the degree of atomization attained. The smaller the holes, the greater the atomization; but if the hole is too small, it will be impossible to get enough fuel into the chamber during the short time allowed for injection. If the hole is too large, there will be an over rich mixture near the nozzle tip and a lean mixture at a distance from it.

(d) Using multiple holes in the injector tips usually overcomes both difficulties because the holes can be drilled small enough to provide proper atomization and a sufficient number can be provided to allow the proper amount of fuel to enter during the injection period.

(ON SLIDE #286)

(3) Injector spray patterns. Proper fuel delivery to the combustion chamber is vital to the combustion process in a diesel engine.

(ON SLIDE #287)

A malfunctioning injector will not thoroughly mix the fuel with air for complete combustion, not deliver a proportional amount of fuel to the amount air, or not quickly start and stop injection.

(ON SLIDE #288)

INSTRUCTOR NOTE
Computer aided graphic testing fuel injectors 0.21 minutes.

(ON SLIDE #289)

l. Cold Weather Starting Aids. Diesel engines are very difficult to start in cold weather. The two most popular methods of assisting a diesel engine in starting are:

(1) The two most popular methods of assisting a diesel engine in starting are:

(a) Preheating. To preheat the induction air in the intake manifold so that adequate vaporization will take place for combustion. Glow plugs and intake-air heaters are electric heating elements that heat the air inhaled by the cylinders and use the same direct current battery power as the cranking motor.

(ON SLIDE #290)

(b) Injecting a fuel into the engine that remains impulsive enough in cold weather to initiate combustion.
1 The ether injection system assists in the cold weather starting of a diesel engine by injecting ether into the

intake manifold. Ether, which is very explosive, will vaporize readily in cold weather, initiating combustion.

2 With this method of cold starting, the engine MUST BE CRANKING and used sparingly, otherwise the possibility of "vapor lock" exists. High compression diesel engines will pre-detonate on ether which causes gases and other materials to blow past the rings. It will also remove the oil from the cylinder walls and cause the engine to lock up from lack of lubrication damaging the rings and scoring the cylinder walls.

3 Requiring ether to start on a regular basis is a sign of a worn out engine, with little compression, poor injectors, fouled or out of adjustment valves, cracked heads, bad gaskets or a variety of other problems.

(ON SLIDE #291)

4 Ether starting fluid should **NEVER** be used with an electronically controlled engine. The uncontrolled combustion **WILL** damage the engine's sensors or at a minimum throw them out of calibration.

5 The two methods should **NEVER** be combined. Ether can ignite in the intake manifold of an engine that is also using an intake heater or glow plugs, cause catastrophic engine failure, and personal injury.

(2) Cold weather starting systems may contain a coolant temperature sensor that will keep the system from functioning when coolant temperature is above 50°F (100C).

(ON SLIDE #292)

INSTRUCTOR NOTE
Computer aided graphic listen closely to the customer 1.31 minutes.

(ON SLIDE #293)

INTERIM TRANSITION: Over the past 2 hours we have reviewed diesel inline and distributor fuel system operation concepts that aid in diagnosing and troubleshooting engine malfunctions caused by incorrect fuel delivery to the engine. Are there any questions? Lets take a 10 minute break.

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(BREAK – 10 MIN)

INTERIM TRANSITION: Before the break we discussed the different types and components of the diesel engine fuel systems. Are there any other questions? If not, let’s move on to the practical application of removing the fuel system.

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(ON SLIDE #294)

INSTRUCTOR NOTE

Perform the following practical application. **Allow students to take breaks as required or as instructed.**

PRACTICAL APPLICATION (4 HRS) In groups no larger than 5 the students will have their assigned toolboxes, technical manuals and assigned engines with work stations. There will be at least one instructor supervising the exercise. The purpose of this practical application is to remove the fuel pump, all fuel lines and fuel filter.
PRACTICE: In their groups the students will follow the technical manuals to remove the fuel pump, fuel lines and fuel filter on their assigned engines.
PROVIDE HELP: The instructor may assist in the disassembly process if needed.
1. **Safety Brief:** At all times proper PPE will be worn to include safety boots. Safety glasses will be worn anytime fuel or liquid under pressure is being used.
2. **Supervision and Guidance:** The instructor will walk around to the different groups and supervise the disassembly answering any questions the students may have.

(ON SLIDE #295)

TRANSITION: Over the past 8 hours we have reviewed diesel inline and distributor fuel system operation and did a practical application to remove the fuel system. Are there any questions? I have some questions for you and then we will take a quiz.

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Opportunity for questions.

1. <u>QUESTIONS FROM THE CLASS</u>:

2. <u>QUESTIONS TO THE CLASS</u>:

Q: Explain thermal efficiency.
A: Relationship between actual heat energy stored within the fuel and the power produced in the engine
Q: When do diesel engines produce a "knock"?
A: Under a light load.
Q: What is cloud point?
A: The lowest temperature to which the fuel can be subjected before it begins to cloud or form paraffin crystals is the cloud point
Q: What characteristic of diesel fuel refers to its ability to ignite spontaneously?
A: Ignition quality
Q: Name the fuel tank components.
A: Filler pipe, fuel return line, fuel supply line, drain plug.
Q: What are the four types of supply pumps?
A: Vane, Plunger, Gear, Piston
Q: Why are diesel fuel filters referred to as full-flow?
A: Because all the fuel must pass through it before reaching the fuel injection pump.
Q: What is the purpose of the Anneroid?
A: Reduce exhaust smoke
Q: What affect will changing the effective length of the plunger stroke of an inline pump have on the engine?
A: Increasing the stroke will increase engine speed
Q: What is the purpose of the Anneroid?
A: Reduce exhaust smoke
Q: What affect will changing the effective length of the plunger stroke of an inline pump have on the engine?
A: Increasing the stroke will increase engine speed
Q: What kind of injector nozzle is generally used in open chamber engines?
A: Hole nozzles
Q: What are the two most popular ways of assisting a diesel engine to start?
A: Pre heaters and glow plugs
Q: Can you use ether to start a engine with glow plugs?
A: No either can be ignited in the intake manifold by the glow plugs.

(ON SLIDE #296)

QUIZ (30min)

Hand out quiz for diesel fuel system operation. Give the students 20 minutes to complete and review it with the students after.

(ON SLIDE #297)

(BREAK 10 min)

TRANSITION: Now that we have covered the fuel system and all of its components let's talk a little about the cooling system.

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INSTRUCTOR NOTE

Computer aided graphic intro to cooling 1.12 minutes.

(ON SLIDE #298)

6. **DIESEL ENGINE COOLING SYSTEM OPERATION AND TROUPLESHOOTING (1hr 50min)**

(ON SLIDE #299)

a. **Principles of the Cooling System**. All internal combustion engines are equipped with some type of cooling system because of the high temperatures they generate during operation. High temperatures are necessary to generate 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 thin and break down, and bearings and pistons will overheat, resulting in engine seizure.

(ON SLIDE #300)

Heat is moved from hot spots in the engine in the following ways.

(1) Conduction. Heat is a form of energy, and when it comes into contact with matter it makes the atoms and molecules move. Once atoms or molecules are moving,
they collide with other atoms or molecules, making them move too. In this way, the heat is transferred through matter.

(2) Convection. Convection occurs when a substance that can flow, like water or air is heated. When this medium is heated it becomes less dense (lighter) and rises. As it rises it forces the surrounding medium down and closer to the heat source. This sets up a circular heating and cooling motion of the fluid medium.

(3) Radiation. Radiation happens when heat moves as energy waves, called infrared waves, directly from its source to something else. This is how the heat gets from the Sun to the Earth. All hot things radiate heat to cooler things. When the heat waves hit the cooler material, they make the molecules of the cooler object speed up. When the molecules of that material speed up, the object becomes hotter.

(ON SLIDE #301)

(4) There are other sources of heat dissipation for the engine in addition to the cooling system.

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

(b) The engine oil removes heat from the engine and dissipates it to the air from the sump or oil cooler.

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

(ON SLIDE #302)

b. **Air Cooled Engines**.

(1) 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 is not a good conductor of heat causing the engine to run at uneven temperatures. Additionally, extensive use of aluminum is required to dissipate heat.

(ON SLIDE #303)

(2) An air-cooled engine uses air as the principal cooling medium. 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.

(3) The primary means of removing heat from an air-cooled engine is by dissipation to the air. The cooling fan/flywheel causes a constant flow of air over and around the cylinders and cylinder

heads. The duct work directs this flow of air to engine components. The finned design of these components adds a tremendous amount of surface area to them so that they are able to dissipate an adequate amount of heat.

(ON SLIDE #304)

(4) An air cooling system must be controlled to prevent overcooling of the engine. To accomplish this, a system of thermostatically controlled doors is usually incorporated into the ducting. The thermostat is usually a bellows that is 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.

(5) Because an air cooling system does not employ a liquid coolant, it often is assumed that air alone acts as the cooling medium. However, this is not true because the fuel and the lubrication systems also help in cooling the engine. The lubrication system of an air-cooled engine always utilizes an air-cooling system. There is also a certain amount of cooling as the fuel vaporizes in the intake manifolds and combustion chambers.

(6) Many air-cooled engines utilize an oil cooler to help in the cooling process. The oil cooler unit usually is located in the ducting so that it is exposed to the forced air from the cooling fan.

(ON SLIDE #305)

(7) Cylinder Heads. The cylinder head is a separate one-piece casting that bolts to the top of the cylinders on an air-cooled engine.

(ON SLIDE #306)

(a) <u>Construction</u>. The cylinder heads on air-cooled engines are made almost exclusively from aluminum. This is due to the fact that aluminum will conduct heat approximately three times as fast as cast iron. This is a critical consideration with air cooling.

(b) <u>Sealing</u>. Cylinder heads on air-cooled configurations are sealed to the tops of the cylinders by soft metal rings.

(ON SLIDE #307)

(8) Cylinders. The cylinders on air-cooled engines are separate from the crankcase. They usually are made of forged steel. This material is most suitable for cylinders because of its excellent wearing qualities, and its ability to withstand the high temperatures that air-cooled cylinders do obtain. The cylinders have rows of deep fins cast into them to dissipate engine heat. The cylinders commonly are mounted by securing the cylinder head to the crankcase with long studs, and sandwiching the cylinders between the two. Another way of mounting the cylinders is to bolt them to the crankcase, and then secure the heads to the cylinders.

(ON SLIDE #308)

(9) Crankcase.

(a) Purpose. The crankcase is the basic foundation of all air-cooled engines. It is made as a one- or two-piece casting that supports the crankshaft, provides the mounting surface for the cylinders and the oil pump, and has the lubrication passages cast into it.

(ON SLIDE #309)

(b) Construction. Crankcases in air-cooled engines are made of aluminum because it has the ability to dissipate large quantities of heat. There is usually are movable lower half to the crankcase that holds the reservoir of lubricating oil. It commonly is referred to as the oil pan. On air-cooled engines, the oil pan usually is cast aluminum. Its surface is covered with fins. The oil pan on an air-cooled engine plays a key role in the removal of waste heat from the engine through its lubricating oil.

(ON SLIDE #310)

INTERIM TRANSITION: So far we have covered cooling principals and air cooled engines. Let's take a tem minute break.

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(BREAK – 10 Min)

INTERIM TRANSISTION: Before the break we covered the cooling principles applied to air cooled engines, now let's next apply the principles to the more common liquid cooled engine.

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(ON SLIDE #311)

INSTRUCTOR NOTE
Computer aided graphic cooling system overview 0.11 minutes.

(ON SLIDE #312)

c. **Liquid Cooled Engines.**

(1) Overview. A simple liquid-cooled cooling system consists of a liquid medium, 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. Cooling of the engine parts is accomplished by keeping the coolant circulating and in contact with the metal surfaces to be cooled.

(ON SLIDE #313)

(2) Liquid coolant mediums. Liquid is the most popularly used cooling system. A liquid cooling system provides the most positive cooling and is best for maintaining an even engine temperature. The liquid in a cooling system must perform four key functions:

(ON SLIDE #314)

(a) Absorb and transfer heat. The amount of heat a liquid can readily absorb and release is directly proportional to the efficiency of the cooling system.

(ON SLIDE #315)

(b) Freeze protection. When equipment is operated in areas where the temperature is extremely low, an antifreeze solution must be added to the coolant.

(ON SLIDE #316)

(c) 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. Additionally, electrolysis occurs in an engine that has two dissimilar metal, such as aluminum and iron, components in a liquid that carries an electrical current. Just like a battery, one of the metals acts like a positive plate and the other like the negative plate. During electrolysis, metal leaves one of the "plates" and is deposited on the other. Most commercially available antifreeze solutions contain corrosion inhibitors.

(ON SLIDE #317)

INSTRUCTOR NOTE
Computer aided graphic cooling cavitation erosion 2.53.

(d) Erosion and cavitation resistance. As coolant is moved through the cooling system it is subjected to different temperatures and pressures. When liquid is moved through a low pressure/high temperature area, gas bubbles form in the liquid. Once those bubbles pass into a high pressure area (after the water pump for example), they implode causing the surrounding material to be damaged from the tremendous force of the implosion.

(ON SLIDE #318)

(3) Types of additives and coolants.

(a) Water is able to absorb more heat per gallon than any other liquid engine coolant and allows the soluble additives to be mixed together. Under standard conditions, water boils at 212° F (100° C) and freezes at 32° F (0° C).

1 When water boils it expands, changes to steam, and is less capable of heat transfer. Coolant that boils in an engine will develop into pockets of steam displacing the liquid coolant and causing a significant loss of cooling efficiency. The physical change from liquid to gas is dependent on the pressure of the water.

2 When water freezes, it increases in volume approximately 9%. The expansion of the freezing water can easily crack engine blocks, cylinder heads, and radiators. To prevent this core ("freeze") plugs are cast into the block and designed to rupture before the block cracks.

(ON SLIDE #319)

(b) Coolant additive package. There are a variety of additives that are included in engine coolant. Because of the tendency of water in the coolant to corrode or rust metal, the addition of inhibitors is required. Other than inhibitors, a coolant additive contains absorbers and buffers, cavitation retarders, corrosion inhibitors for aluminum, electric galvanic activity preventers, antifoam additives, and dyes. Typical coolant additives may include:

1 Borax: Acid neutralizer.

2 Phosphate: Acid buffer and cavitation retarder.

3 Sodium silicate: Aluminum protection.

4 Sodium nitrate: Solder corrosion.

5 Trizoles: Galvanic corrosion inhibitor.

6 Sodium hydroxide: pH stabilizer (usually 10 – 11).

7 Phosphorescent dye: Ultraviolet leak detector (various colors are for identification purposes only).

(ON SLIDE #320)

(c) Inorganic Additive Technology (IAT) coolants. IAT coolants have been around for generations. The most commonly used one has been Ethylene Glycol (antifreeze compound). It has an extremely high boiling point, does not evaporate in use, is non-corrosive, has no odor, and 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 above 60% in the solution, it will result in a higher freezing point for the solution, and consequently give less freeze protection. If a 100% solution of ethylene glycol were used, its freezing point would be 0° F (-18° C) and though it wouldn't freeze solid it would form a slush and clog the cooling system. It also contains silicates that form a protective barrier on everything in the cooling system to prevent corrosion and erosion, and it contains phosphates to keep the ph level high enough to prevent the coolant from becoming acidic.

(d) Organic Additive Technology (OAT) coolants. Although their freezing/boiling protection is similar to IAT coolants, the newer OAT coolants (such as Propylene Glycol) work differently. Aluminum and ferrous metals form a surface layer of corrosion in the presence of moisture (even the little bit of moisture in the air). OAT coolants anneal (toughen) this metal oxide layer into a thin surface coating that protects against further corrosion.

(e) Hybrid Organic Additive Technology (HOAT) coolants. HOAT coolants use silicate and organic acid corrosion inhibitors in combination to protect against freezing, corrosion, and erosion of Aluminum, Iron, and Iron Alloys. Many HOAT coolants contain an additives package to meet manufacture specifications based on the operating conditions, construction, and maintenance considerations to ensure efficient cooling system operation. For example Caterpillar® recommends the use of "Extended Life Coolant", it is a deep violet color, protects aluminum (the radiator), and should not require changing more frequently than 6,000 hours or 6 years (according to the 420 DIT LO).

(ON SLIDE #321)

(4) Types of liquid cooling systems. There are three movement methods in liquid cooling systems employed by engineer equipment.

(a) Open-type cooling system. This is the simplest type of liquid cooling system, and is found on earlier equipment models. As the temperature of the cooling system rises, the pressure also rises. This will open the pressure valve in the radiator cap, causing coolant to exit through the overflow tube, thus venting excess pressure. The overflow line usually extends down the side radiator, and empties to the ground if the radiator is overfill or the cooling system overheats.

(ON SLIDE #322)

(b) Closed-type cooling system. 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. As the temperature of the cooling system rises, the pressure will also rise. This will open the pressure valve in the pressure cap, causing coolant to exit through the overflow tube, thus venting excess pressure. 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. During an overheating condition, the closed cooling system prevents coolant loss through the overflow line by collecting it in the recovery tank.

(ON SLIDE #323)

(c) Thermo-siphoning. In a liquid cooling system, the downward flow of coolant through the radiator creates what is known as a thermo-siphon action. This was mostly used in early engine application. 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.

(ON SLIDE #324)

INSTRUCTOR NOTE
Computer aided graphic coolant pump 0.12 minutes.

(5) Coolant pump. The pump draws the coolant from the bottom of the radiator, forces it through the water jackets and passages, ejects it into the top of the radiator, where heat from the coolant is removed as it passes through a set of tubes to the bottom of the radiator, and the cooling cycle begins again.

(a) All modern cooling systems have water pumps to circulate the coolant. The pump is usually located on the front side of the engine block. The pump is a non-positive displacement centrifugal type and has an impeller with blades that force coolant outward as the impeller rotates. It usually is driven by the engine crankshaft through a belt, but may also be driven through timing gears on the crank shaft.

(ON SLIDE #325)

(b) Advantages of a centrifugal pump as a water pump are that it is inexpensive, circulates great quantities of coolant for its size, isn’t clogged by small amounts of foreign matter, and permits a limited amount of thermo-siphon action after the engine is shut down to help prevent boil over.

(ON SLIDE #326)

(c) The pump housing usually is cast from iron or aluminum. The impeller can be made from 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.

(ON SLIDE #327)

(d) The most common cause of pump failure occurs when coolant seeps past the seal, damages the bearings, and leaks out of the pump through the “weep hole”.

(ON SLIDE #328)

(5) Coolant Bypass. 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. It also reduces warm up time.

(ON SLIDE #329)

(6) Cylinder block. 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. However, in some engine configurations 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 cooler where water jackets come in contact with the bores.

(ON SLIDE #330)

(7) There are two types of cylinder sleeves: the wet and the dry type.

(a) The dry type is a sleeve that presses into a full cylinder that completely covers the water jacket. Because the sleeve has the block to support it, it can be very thin.

(b) The wet sleeve also presses into the cylinder. The difference is that the water jacket is open in the block and is completed by the sleeve. Because it gets no central support from the block, the wet sleeve must be made thicker than a dry sleeve. Also, because the sleeve completes the water jacket, it must fit so as to seal in the coolant.

(ON SLIDE #331)

(8) Cylinder head. 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 they are located in the head. 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. 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 cylinder-head gasket.

(ON SLIDE #332)

(9) Thermostat. The water pump starts the coolant circulating through the system as soon as the engine is started, no matter how low the temperature. Therefore, it is necessary to install a thermostat to ensure quick warm up 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.

(ON SLIDE #333)

(a) Construction. The pellet type, which is the most commonly used thermostat because its accuracy is unaffected by modern pressurized cooling systems, consists of a valve that is operated by a piston or 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.

(ON SLIDE #334)

INSTRUCTOR NOTE
Computer aided graphic temperature regulator 1.13 minutes.

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

(c) Thermostat heat ranges. Manufactures use a variety of thermostats that allow the coolant to operate at different temperatures. The standard heat ranges are available from 160°F (71°C) to 210°F (99.8°C).

(ON SLIDE #335)

INSTRUCTOR NOTE

Computer aided graphic testing a thermostat 0.29 minutes.

(ON SLIDE #336)

(10) Cooling fan and shrouding. The fan ensures airflow through the radiator. The fan pulls or pushes a large volume of air through the radiator core so that engine heat can be dissipated effectively. In most cases the fan works in an enclosure called a shroud to ensure maximum efficiency of the fan. **There are three methods of driving a fan:**

(ON SLIDE #337)

(a) Direct drive fan. Driven directly by a belt ran off the crankshaft.

(b) Electrically motorized fan. The fan blade is mounted on the motor shaft. The motor and fan blade assembly then is mounted directly behind the radiator core. 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. Some models incorporate a timed relay that allows the fan to run for a short time after engine shutdown. This, in conjunction with thermo-siphon action in the cooling system, helps to prevent boil over after engine shutdown.

(ON SLIDE #338)

(c) Hydraulically motorized fan. The vehicle's cooling fan is driven by a hydraulic motor. A thermostatically, or electrically, controlled proportional pressure control valve modulates the fan speed depending on a temperature reading. In a cold condition, the fan idles with very low power consumption. During the hot condition, the maximum fan speed is controlled by a pressure control valve, which adjusts the fan speed to meet the cooling needs of the total system. Every system has a temperature, which allows for the most efficient performance. The thermovalve, or an electronic control system, attempts to maintain the system at the optimum temperature.

(ON SLIDE #339)

(11) Radiator. The radiator is situated in front of the cooling fan. It consists of two tanks with a heat exchanging core between them. The upper tank contains an outside pipe called an inlet. The filler neck is placed on the top of the upper tank and

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.

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

(b) The core is made up 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 this heat 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.

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

(d) 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 will prevent rupture of cooling system components.

(ON SLIDE #340)

INSTRUCTOR NOTE
Computer aided graphic Radiator cap 0.36 minutes.

(12) Radiator Pressure Cap. Modern liquid cooling systems use a pressurized cooling system that allows 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 boiling over.

(ON SLIDE #341)

(a) Construction. The cap contains two spring-loaded valves that are normally closed, sealing the system.

(b) Operation. The larger of these two valves is the pressure valve and 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.

(ON SLIDE #342)

(13) Expansion tank. Some equipment uses 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 also are mounted on the expansion tank.

(ON SLIDE #343)

(14) Accessory heat exchangers.

(a) Operator compartment heater core. The heater core is a small heat exchanger (radiator) that engine coolant is circulated through. It is usually located inside or near the operator's compartment and provides the operator's compartment with heat. An electrical blower motor passes air across the fins of the heater core, transferring heat from the engine to warm the operator's cab.

(ON SLIDE #344)

(b) Oil Coolers. Some 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 is able to. An oil cooler is installed in all of these cases.

(ON SLIDE #345)

INSTRUCTOR NOTE
Computer aided graphic cooling system service 3.02.

(ON SLIDE #346)

INSTRUCTOR NOTE
"Burping the radiator" is when the mechanic periodically squeezes the radiator hoses while the engine is running to remove air pockets in the engine.

(ON SLIDE #347)

INTERIM TRANSITION: Over the past 2 hours we have covered the cooling systems, are there any questions? Take a 10 minute break.

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(BREAK – 10 MIN)

INTERIM TRANSITION: Before the break we covered the different types of cooling systems and how they work. Are there any other questions? Now let's move into the practical application to remove the radiator and water pump.

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(ON SLIDE #348)

INSTRUCTOR NOTE
Perform the following practical application removal of the radiator and water pump. **Allow students to take breaks as required or as instructed.**

PRACTICAL APPLICATION (4 HRS) In groups no larger than 5 the students will have their assigned toolboxes, technical manuals and assigned engines with work stations. There will be at least one instructor supervising the exercise. The purpose of this practical application is to remove the radiator and water pump.

PRACTICE: In their groups the students will follow the technical manuals to remove the radiator and water pumps on their assigned engines.

PROVIDE HELP: The instructor may assist in the disassembly process if needed.

1. **Safety Brief:** At all times proper PPE will be worn to include safety boots. Safety glasses will be worn anytime fuel or liquid under pressure is being used.
2. **Supervision and Guidance:** The instructor will walk around to the different groups and supervise the disassembly answering any questions the students may have.

(ON SLIDE #349)

INTERIM TRANSITION: Over the past four hours we completed the practical application for the removal of the radiator and water pump. Are there any questions? If not we will take a quiz and then move into the final practical application the completion of the tear down and the rebuilding of your engines.

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(ON SLIDE #350)

QUIZ (30min)

Hand out quiz for diesel cooling system. Give the students 20 minutes to complete and review it with the students after.

(ON SLIDE #351)

(BREAK 10 min)

(ON SLIDE #352)

INTERIM TRANSITION: Are there any questions? Now let's move into the final practical application the completion of the tear down and the rebuilding of your engines.

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INSTRUCTOR NOTE

Have students perform the final practical application, the completion of the engine tear down and rebuild. **Allow students to take breaks as required or as instructed.**

PRACTICAL APPLICATION (42 HRS) In groups no larger than 5 the students will have their assigned toolboxes, technical manuals and assigned engines with work stations. There will be at least one instructor supervising the exercise. The purpose of this practical application is to complete the engine tear down and rebuild.
PRACTICE: In their groups the students will follow the technical manuals and the instructor's direction to complete the engine tear down. Once the tear down is complete the students will in groups assemble their engines making all proper adjustments in order for the engine to run properly.
PROVIDE HELP: The instructor may assist in the disassembly process if needed.
1. Safety Brief: At all times proper PPE will be worn to include safety boots. Safety glasses will be worn anytime fuel or liquid under pressure is being used.

2. Supervision and Guidance: The instructor will walk around to the different groups and supervise the disassembly answering any questions the students may have.

(ON SLIDE #353)

TRANSITION: For the last 42 hours we completed the engine tear down and rebuild practical application. Are there any questions? If not I have some questions for you.

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Opportunity for questions.

1. QUESTIONS FROM THE CLASS:

2. QUESTIONS TO THE CLASS:

Q: What are the 3 ways heat is removed from the engine?
A: Conduction, convection, radiation.
Q: What are the cylinder heads on air-cooled engines made out of?
A: Aluminum
Q: What are the four functions that liquid coolant must perform?
A: Absorb and transfer heat, freeze protection, corrosion resistance and erosion and cavitation protection.
Q: What are the two types of cooling systems?
A: Open and closed type.
Q: What type of pump is the engine water pump?
A: Centrifugal.

(ON SLIDE #354)

SUMMARY: **(5 Min)**

Over the past ten days we have covered diesel engine construction, principals of operation, intake and exhaust, lubrication, fuel, and cooling system operation. With all the information that you have received I am confident that you will be able to conduct your job with higher efficiency. At this time fill out any IRF’s that you have after that take a ten minute break.

REFERENCES:

FOS3007NC Engines

RENR9722-01 Disassembly and Assembly Caterpillar C6.6 Industrial Engine

SENR9968-02 Systems Operation Testing and Adjusting Caterpillar C6.6 Industrial Engine