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EDQP STUDY PAPER

DIESEL PROPULSION AND POWER GENERATION

ENGINEERING DUTY OFFICER SCHOOL

DEDICATED TO PROFESSIONALISM

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ENGINEERING DUTY OFFICER QUALIFICATION PROGRAM (EDQP)

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Lesson Topic. Diesel Propulsion and Power Generation, T-122.

Time. 2 Hours.

Instructional Materials. See attached.

Terminal Objective. Complete the Engineering Duty Basic Qualification Program.

Enabling Objective. Obtain a basic understanding of diesel engines and their application to propulsion and power generation in U.S. Navy ships.

Study Method. See attached paper.

Practical Factors. None.

Supplementary References. See Bibliography attached.

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1. INTRODUCTION

The internal combustion engine principles from which the modern diesel engine evolved were first proposed by Sadi Cornot in the early 19th century. Engines similar to modern diesel engines were operating before 1895. Oil fired engines appeared in several forms more than 30 years earlier. Such engines used a heated bulb or pre-combustion chamber to facilitate compression ignition. However, these engines produced a large quantity of smoke and only a modest amount of power. In the original patent by Dr. Diesel, the diesel operated on the diesel thermal cycle in which heat was added at constant pressure. This was achieved with the "blast injection" principle which used air pressurized fuel to achieve atomization, because oilless or solid injection required high precision manufacturing technology not available at that time. Now the term is universally used to describe any reciprocating engine in which the heat induced by compressing air in the cylinders ignites a finely atomized spray of fuel. The fuel in common use in diesel engines is oil.

1.1 History. Dr. Diesel constructed his first engine to run on coal dust. To increase its efficiency, he used a compression pressure of 1500 psi with no cooling system. Unfortunately the engine exploded during a test seriously injuring its inventor. After recovering from his injuries, Dr. Diesel built another engine which used oil as fuel and which had a water jacket around the cylinder to lower the compression pressure to approximately 550 psi. After a successful test, production rights for this engine were purchased by Adolphus Busch. The first commercial engine was used in the United States to run a pump at the Busch Brewery in St. Louis.

In 1910, the first marine diesel engine was constructed and installed in a ship. Early diesel engines were low power, inefficient and very heavy. By 1914, a modified semi-diesel engine evolved in which all fuel was injected at the top of the stroke and pressure was allowed to fall off during the power stroke. This resulted in a more efficient combustio process and allowed greater crankshaft speed. The semi-diesel is the engine used today. It began to supersede the oil engine as the principal type of large internal combustion engine and by World War II was the predominate means of marine propulsion. During the evolution of the diesel engine design, a shift was made from air pressure fuel injection to solid injectors and from 4 cycle to 2 cycle supercharged designs. This permitted significant weight savings and size reduction for an equivalent power output. Diesel fuel standardization also resulted in a considerable technological improvement because it simplified the engine designers task and permitted development of more reliable and efficient engines. Although five grades of diesel fuel were proposed in the late 1930's, the U.S. Navy now uses one standard fuel with established viscosity and combustion characteristics.

1.2 General. Diesel engines are designated by the number of cylinders, bore, stroke, and RPM or by the cubic inch displacement per cylinder for the total engine. All diesel engines have a cycle of four events: intake, compression, power and exhaust. The events vary with the piston strokes and whether a 2 stroke or 4 stroke cycle is employed, but these events always occur in the same order.

Generally, engines are classified as high, medium, or low speed. There is no clear demarkation between the classifications, but in general, they are categorized as shown in Table 1. There is no unanimity among engine people as to the significance of engine speed. A well-designed high-speed engine which is not overloaded can give service equal to a slow-speed engine. Slow-speed engines are larger than high-speed engines, but wear rates are comparable. A balance must be struck between the use of smaller, lighter, and generally less expensive high-speed engines and larger, heavier, slow-speed engines which usually cost more initially but have lower fuel, operating, and maintenance costs.

TABLE 1-1

Engine Speed Classifications

	Piston Speed, fpm	Shaft Speed, rpm
Low speed.............	1000-1500	100-514
Medium speed..........	1200-1800	700-1200
High speed............	1800-3000	1800-4000

2. COMPARISON OF DIESEL ENGINES RELATIVE TO OTHER TYPES OF PRIME MOVERS

2.1 Diesel Engine Advantages:

a. Reduced risk of fire since diesel fuel oil is less flammable than gasoline.

b. Low carbon dioxide content in exhaust gases (3% in gasoline compared with 0.2% in diesels).

c. Equal power output per cylinder. Equal quantities of fuel are supplied to each cylinder; therefore, fewer cylinder to cylinder pressure variations exist.

d. Lower specific fuel consumption because of a higher compression ratio (no fuel is required when the engine coasts and only a small quantity of fuel is used when the engine is idling).

e. Lower exhaust temperature due to increased expansion of combustion gases (the mean gasoline engine exhaust temperature is about 900°C; the mean diesel engine exhaust temperature is about 550°C).

2.2 Diesel Engines Disadvantages:

a. The noise level of the operating engine is higher.

b. The cylinder pressures are higher and there are wide variation in torque; therefore, heavier parts are required which reduce the power to weight ratio.

c. The efficiency of air utilization is less because excess air is required for smoke free combustion (hence, for a given power output, a diesel engine will normally require larger cylinders than gasoline engines).

2.3 Relative Comparison of Prime Movers

2.3.1 Weight. The weight requirement for an engine varies with the type of application. In general, naval vessels have chronic weight problems, particularly with increasing emphasis on shock resistance. Shipboard equipment therefore, must be carefully analyzed from a weight reduction viewpoint. Figure 2-1 shows the weight (without fuel) of representative complete propulsion plants per unit of rated shaft horsepower plotted against shaft horsepower.

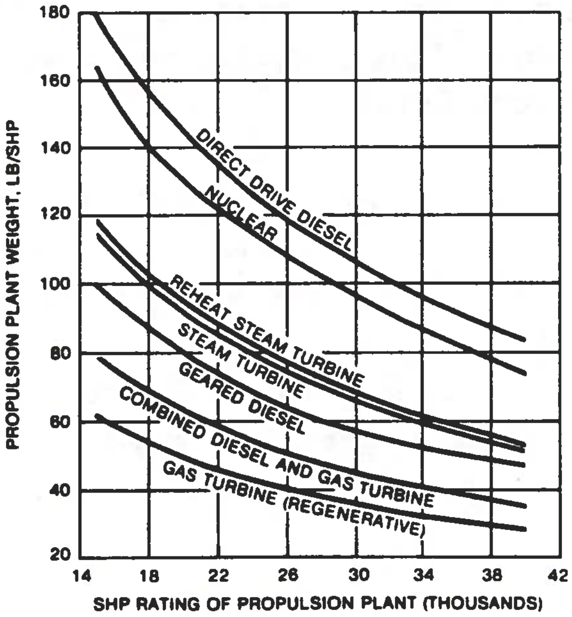


FIGURE 2-1 SPECIFIC WEIGHT OF PROPULSION PLANTS

2.3.2 Thermal Efficiency. Different types of propulsion systems hav different thermal efficiencies and different specific fuel consumption rates. The fuel consumption characteristics of several types of propulsion plants are shown in Figure 2-2, an illustration of the general characteristics of propulsion plant alternatives.

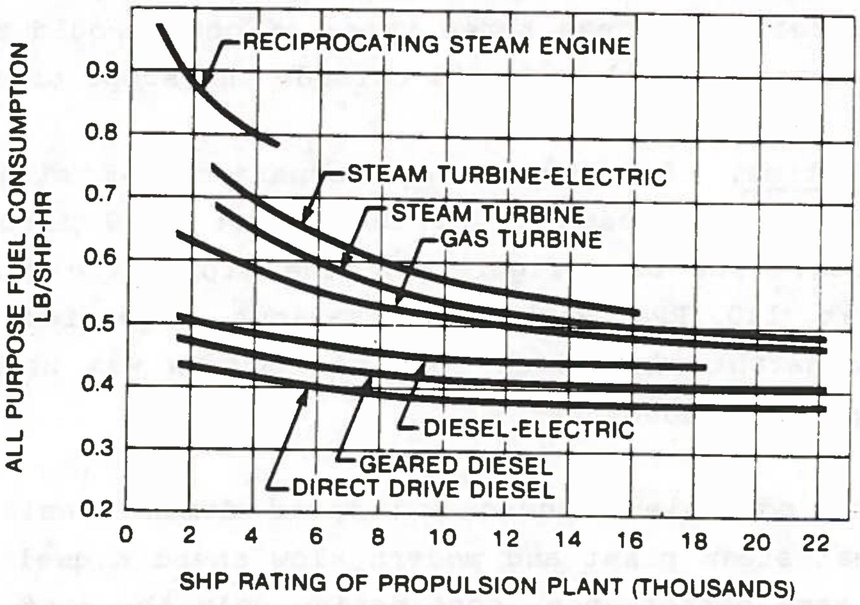


FIGURE 2-2 ALL-PURPOSE FUEL CONSUMPTION

2.3.3 Costs. The installed costs for a propulsion plant are an important consideration. The relative installed costs for various propulsion plants along with the general relationship of plant size are shown in Figure 2-3. Three types of costs should be reviewed and considered in

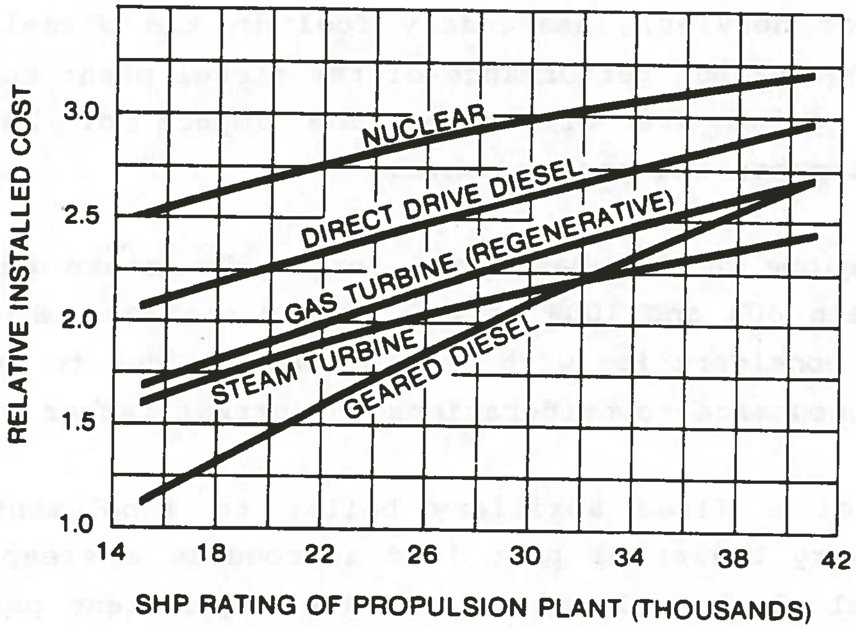


FIGURE 2-3 RELATIVE INSTALLED COSTS OF PROPULSION PLANTS

plant selection: initial cost (e.g. installed costs), recurring cost (e.g. fuel consumption), and contingency costs (e.g. reliability, etc.). A graph which reflects these three types of costs would require consideration of many more variables and is outside the scope of this paper.

2.3.4 Consumption. An interesting comparison of steam versus diesel fuel consumption was presented in the August 1979 issue of the Marine Engineering Log. The base figure for the propulsion plants studied was 36,000 shp at 110 RPM with compensations made for the slow speed tankers. A constant electrical load of 1000 KW was used for both prime movers. It was concluded that:

a. On an equivalent power and speed demand basis, a modern non-reheat steam plant and modern slow speed diesel have essentially the same performance, considering only the cost of fuel and lube oil.

b. On an equivalent power and speed demand basis, a modern rehea steam plant shows the best performance, considering only the cost of fuel and lubricating oil.

c. Use of heavier, less-costly fuel in the diesel plant improves the equivalent performance of the diesel plant relative to steam. Such gains are offset by the impact of heavier fuels on maintenance and repair costs.

d. The slope of the part load curves for steam and diesel plants between 40% and 100% power is very similar, which is an important consideration with "slow steaming" due to fuel conservation and economical considerations in current tanker operations.

e. Use of a fired auxiliary boiler to supplement a waste heat recovery boiler at part load introduces a steeper slope to the diesel plant fuel rate curve, i.e. equivalent performance rating goes down.

3. FUNDAMENTAL THEORY OF OPERATION OF DIESEL ENGINES

3.1 General. In any field dealing with energy, a knowledge of thermodynamics, the science that deals with energy, energy transformation and transfer of energy from one point to another, is helpful. Several such energy transformations are involved in the operation of a diesel engine. For example, consider the following comparisons of energy flow:

chemical energy ➤ thermal energy ➤ mechanical energy ➤ shaft energy

fuel supplied to engine ➤ combustion in engine ➤ piston moves due to gas pressures ➤ shaft rotates after translating piston motion

The fuel injector provides the fuel (chemical energy). Combustion occurs in the cylinders increasing the temperature and pressure of the trapped gases. High gas pressure forces the piston downward. Its linear motion is converted by a crank shaft into rotary motion, which is the form of the engine's output. Two laws of thermodynamics apply in this situation. The first states that energy must be conserved. The second states that the quality of energy is not conserved. "Quality" in this instance refers to that portion of energy which can be used for work. Looking at the energy flow of an engine, "in" must equal the total energy "out", but the useful part (that which does work) will decrease with each energy transformation.

The combustion process is never ideal or complete. Some of the fuel will not be burned (or only partially burned) which results in the formation of both carbon dioxide and carbon monoxide. Thus, the chemical energy of the fuel will not be totally utilized in raising the temperature and pressure of the fuel and air mixture. Friction between the piston and the cylinder will prevent some movement of the piston by the expanding gases and thus reduce combustion efficiency. Also, some leakage of the gasses by the piston and non-uniformity of the combustion process in the cylinder will also result in decrease in combustion efficiency.

3.2 Ideal Gas Law. The prediction of how an engine will behave requires a determination of how the substances (air, fuel and combustion gases) form and flow.

Fortunately, in most instances involved with diesel engines, the ideal gas law predicts with sufficient accuracy how the air and exhaust gases will behave. This law states:

$P = pRT$ where, P is the pressure (lbs/ft^2)
p is the density (lbs mass/ft^3)
R is the gas constant
T is the absolute temperature degrees Rankine

The value of R depends on the gas under consideration, and for the two gases of most concern (air and exhaust) has a value of 53.34 (using the above English units). Thus, for example, we can calculate the density of air at atmospheric pressure (14.7 psia) and a temperature of 77°F.

$$P = 14.7 \text{ lbs/m}^2 \text{ x } 144 \text{ in}^2/\text{lb}^2 = 2116.8 \text{ lbs/ft}^2$$

$$T = 77^\circ + 460^\circ = 537^\circ \text{ Rankine}$$

$$p = \frac{P}{RT} = \frac{2116.8}{(53.34)(537)} = 0.0739 \text{ lbs/ft}^3$$

By assuming that the working substance in a diesel engine is air of a constant mass (i.e. no air leaves the cylinder) we can analyze the processes involved and compare P, T and p at any point in the cycle.

3.3 Air Standard Diesel Cycle. The air standard diesel cycle represents the behavior of the diesel engine. This model represents a thermodynamic cycle and not a mechanical cycle. Thus, one can analyze the cycle and determine the process and factors involved without going into details or measurement of actual engine performance. The ideal gas cycle which is normally employed for internal combustion engines may be classified into two groups: explosive cycle of gasoline engines (OTTO cycle) and the non-explosive (Diesel cycle). The ideal OTTO cycle is illustrated in Figure 3-1. The ideal diesel cycle is illustrated in Figure 3-2.

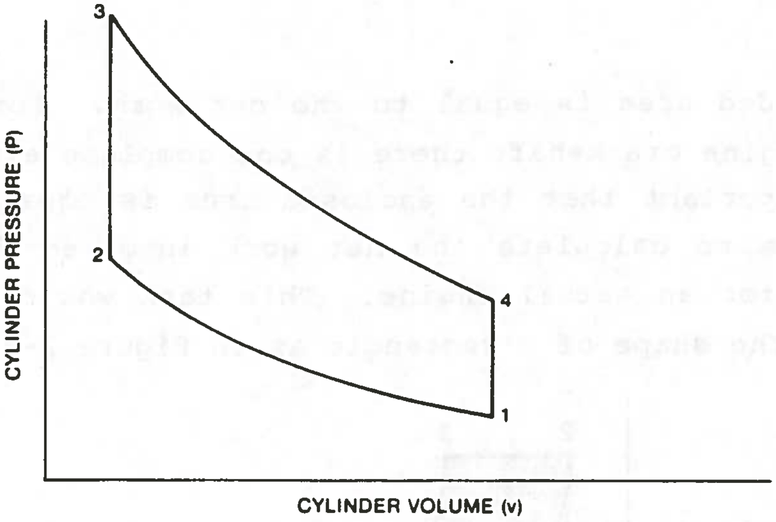


FIGURE 3-1 OTTO CYCLE

Isentropic compression (constant entrophy) (curve 1-2) is followed by ignition and rapid heating at constant volume (curve 2-3). This is followed by isentropic expansion (curve 3-4), and a subsequent constant volume rejection of heat (curve 4-1). The otto (constant volume) cycle is quite closely approached in practice by the low speed gasoline engine.

In the ideal diesel cycle (Figure 3.2), air is compressed to a very high pressure. Fuel is then injected into the air which, due to compression, is at a temperature above the ignition temperature of the fuel. This causes the fuel to burn at a nearly constant pressure over the curve 2-3. Insentropic expansion of the combustion products is then followed by exhaust and intake of fresh air as in the OTTO cycle.

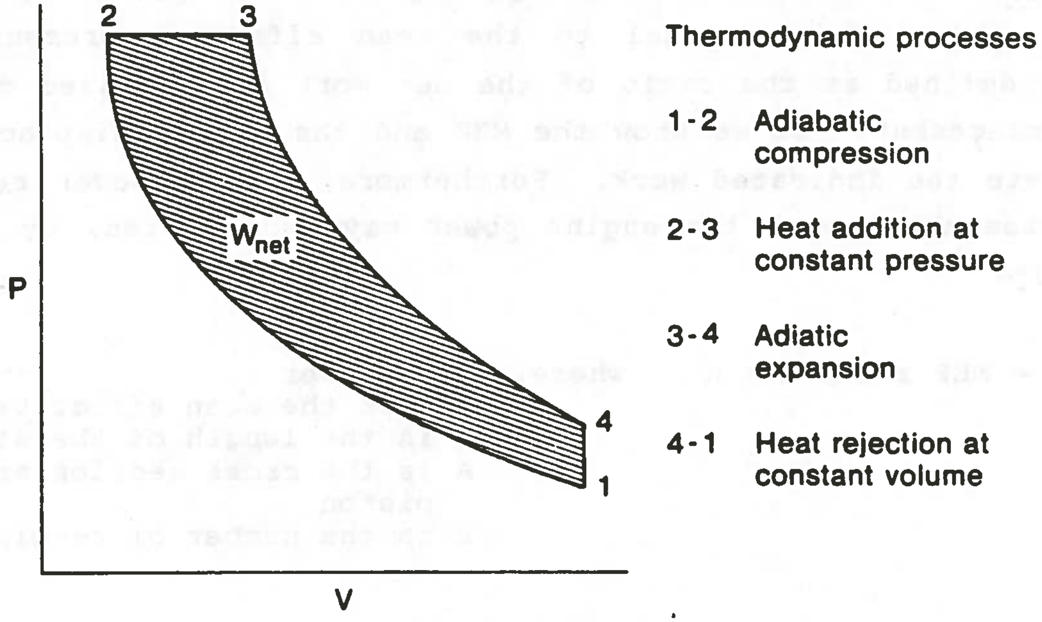


FIGURE 3-2 DIESEL CYCLE

The enclosed shaded area is equal to the net work. For each revolution of a 2 stroke engine crankshaft there is one complete air standard diesel cycle. It is important that the enclosed area is equal to the net work for it allows us to calculate the net work involved from the pressure volume diagrams for an actual engine. This task would be easier if the diagram were in the shape of a rectangle as in Figure 3-3.

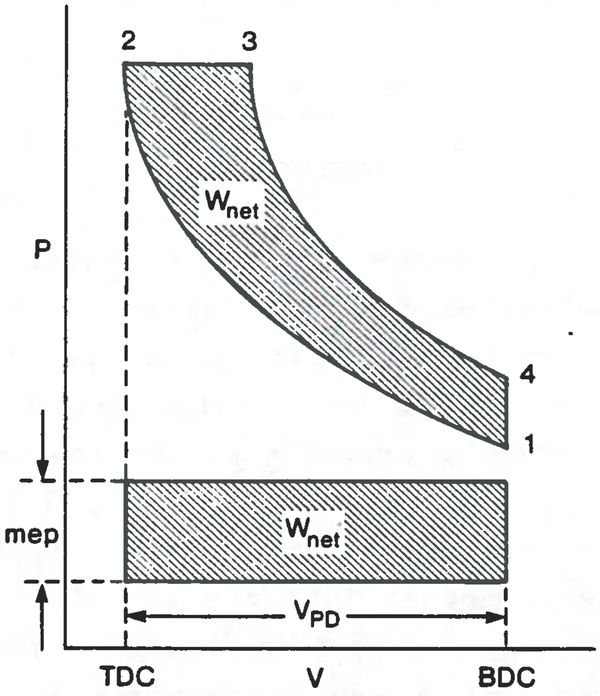


FIGURE 3-3 MEAN EFFECTIVE PRESSURE

The rectangular area shown has a length equal to the piston displacement (V_1 - V_2) and a height equal to the mean effective pressure (MEP). The MEP is defined as the ratio of the net work accomplished divided by piston displacement. If we know the MEP and the piston displacement, we can calculate the indicated work. Furthermore, if the power revolutions per unit time are known, the engine power may be computed, by using the relationship:

$P = MEP \times L \times A \times n$ where,

P is power
MEP is the mean effective pressure
L is the length of the stroke
A is the cross section area of the piston
n is the number of revolutions

To convert to units of horsepower divide the result by 33,000, the number of ft-lbs/min in 1 horsepower.

Some additional terms which are frequently used in describing diesel engines are:

"Displacement" of an engine is the swept volume of all the engine cylinders. It is expressed in cubic inches as:

$$D = \frac{\pi}{4} nB^2S$$

where

n = number of cylinders in the engine

B = bore, in.

S = stroke, in.

The physical size of an engine is approximately proportional to its displacement.

"Brake mean effective pressure" (abbreviated BMEP) stems from the days when it was common to take indicator cards of the pressures in an engine cylinder, and to relate the severity of engine loading to the average or mean pressure in the cylinder. These indicator cards display the actual cylinder pressure versus volume for comparison with theoretical plots as well as actual condition plots obtained under various loadings and design modification. The chart is mounted on a drum which rotates through an angle proportional to the piston displacement. A pen or stylus deflects on a line parallel to the drum axis and proportional to the pressure. The resulting displacement is transmitted to the pen through a mechanical linkage.

BMEP is still used as an indicator of engine loading and is expressed in pounds per square inch (psi):

$$BMEP = \frac{198{,}000 \times C \times bhp}{D \times N}$$

where

C = number of strokes per cycle (two for 2-stroke, four for 4-stroke)
bhp = output shaft brake horsepower, hp
N = revolutions per minute, rpm
D = displacement, cubic inches

The "torque" of the output shaft in units of lb-ft can be computed from the expression

$$T = 5252\frac{bhp}{N}$$

For a given engine, torque and BMEP are directly proportional:

$$T = \frac{D}{37.7C}\ BMEP$$

The "piston speed" is the average speed of the piston during its stroke. It is usually expressed in feet per minute and determined from the expression: $V_p = SN/6$. Piston speed is a useful yardstick for comparing the inertial loading and cylinder component wear characteristics of generally similar engines.

3.4 Four Stroke Cycle. The ideal cycle used for analyzing the thermodynamics of the engine cycle is not an actual engine cycle. It is impossible to recombust or reuse air. A new air supply must be continually drawn into the engine and the products of combustion removed. In the actual engine cycle, unlike the ideal cycle, the mass of air and the products of combustion undergo continual change. First, consider the 4 stroke mechanical cycle found in diesel engines in Figure 3-4.

Since the engine operates by compression ignition, at the top of each compression stroke a selected amount of fuel is injected into the cylinder and is ignited by the high air temperature. The combustion process continues as the piston gasses expand on the power stroke and the pressure remains essentially constant during the combustion process. Because there is only one power stroke for every two revolutions of the crankshaft, it is necessary to know the engine cycle when calculating power. The four strokes may be classified as follows:

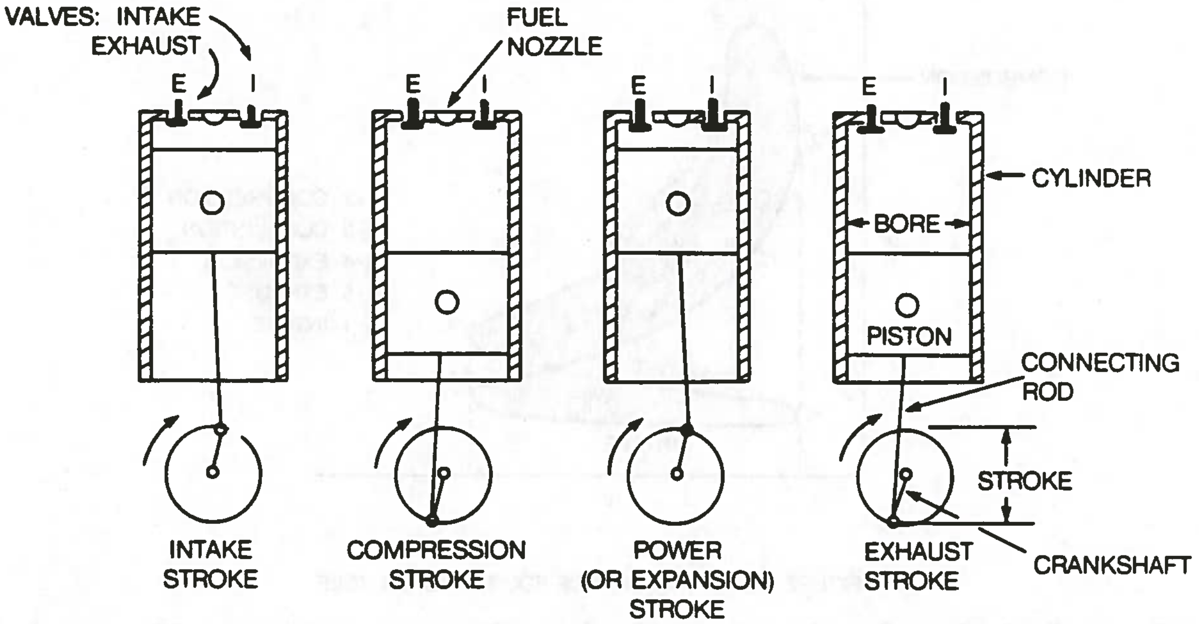


FIGURE 3-4 FOUR STROKE CYCLE

a. The intake stroke - the inlet valve is open and the exhaust valve is closed. The piston moves down bringing fresh air into the cylinder.

b. Compression stroke - both intake and exhaust valves are closed, and the air is compressed by the upward movement of the piston.

c. Power stroke - both intake and exhaust valves are closed and combustion occurs with a resultant increase in pressure forcing the piston downward.

d. Exhaust stroke - the exhaust valve is open and the intake valve is closed. The upward movement of the piston forces products of combustion from the engine.

Since not all products of combustion are removed from the cylinder on the exhaust stroke, there is a dilution of the incoming air by the remaining exhaust products. The greater the cylinder volume of exhaust gases remaining when the intake valves open, the great the dilution. The 4 stroke mechanical cycle has two revolutions for every power cycle. Figure 3-5 represents a 4 stroke cycle p-v diagram.

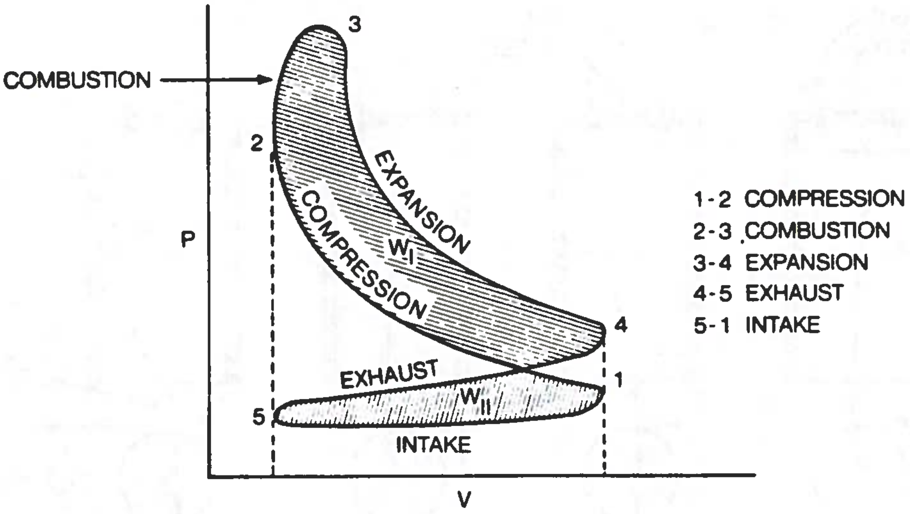


FIGURE 3-5 P-V DIAGRAM OF FOUR-STROKE CYCLE

The area marked W_I represents work done by the engine. The area marked W_{II} represents the work consumed by the engine during the exhaust and intake stroke. The net work is the difference between the two areas. There is an optimum value for exhaust valve opening which affects both areas. Point 4 on the diagram represents the point at which the exhaust valves open. Note that if it occurs earlier on the expansion stroke, less compressive work is done to push the exhaust gases out as they flow

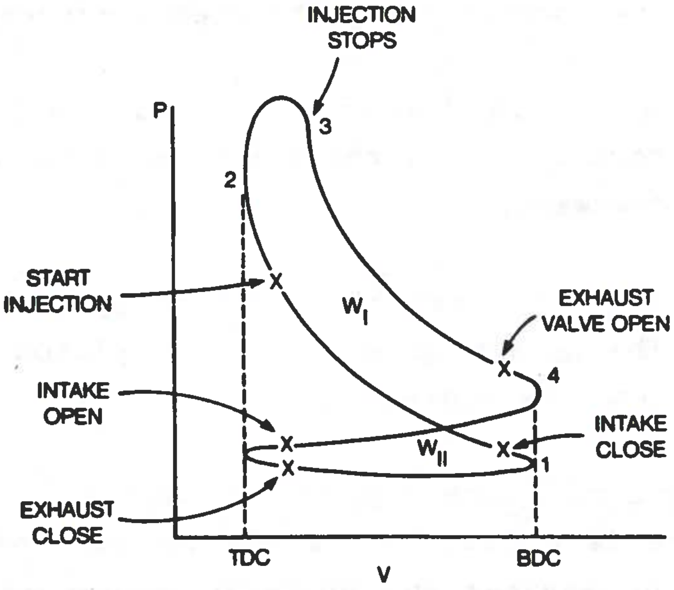


FIGURE 3-6 P-V DIAGRAM WITH OPENINGS AND CLOSINGS

out under their own pressure. This reduces the value of W_{II}. Also, less work is done by the gases pushing the piston and so W_I is also reduced. There is no rule as to how soon or how late the exhaust valves must open; for a given engine design finding the best value is a trial and error process. Figure 3-6 shows a p-v diagram for a 4 stroke cycle engine illustrating the valve opening and closing times and the limits of injection.

Fuel injection occurs before top dead center to allow time for the combustion process to begin. This time allowance is called ignition lag and is the difference in time between injection and ignition.

3.5 Two Stroke Cycle. The 2 stroke cycle engine has a power stroke every revolution. Thus, intake, compression, power and exhaust processes must occur within each revolution. Figure 3-7 illustrates the total process for a 2 stroke cycle engine that is not supercharged.

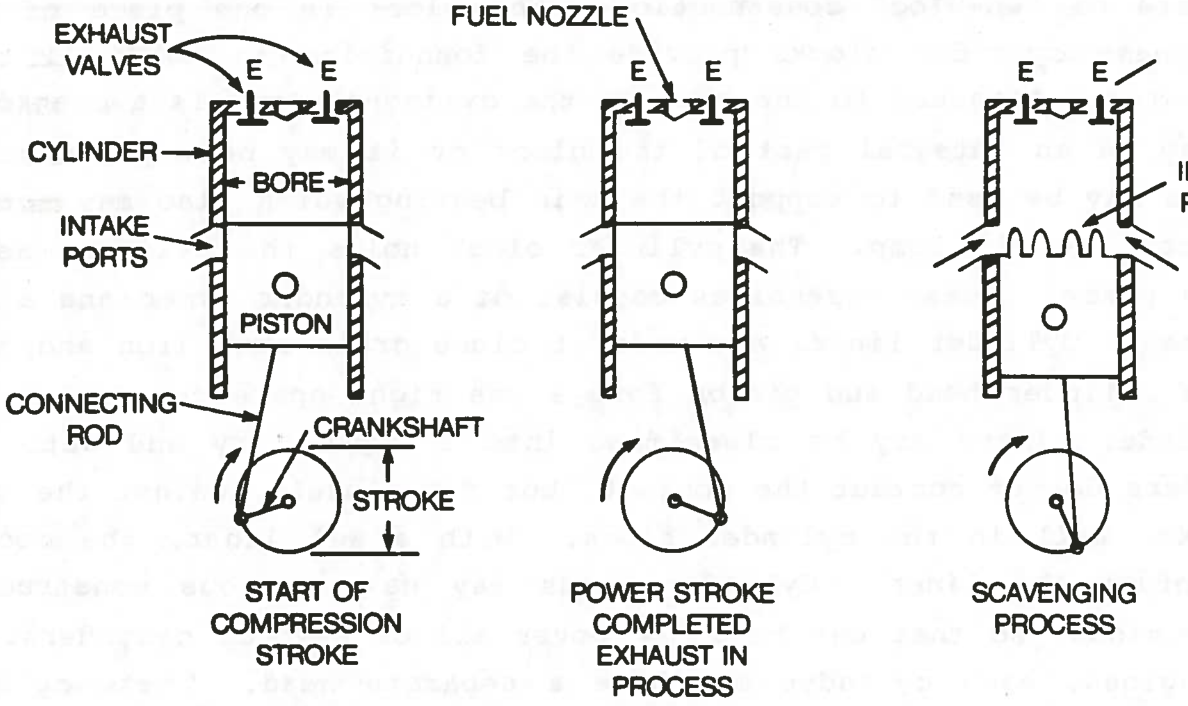


FIGURE 3-7 TWO STROKE CYCLE

To assist the exhaust process in the 2 stroke cycle engine, the engines are equipped with scavenger blowers which raise the inlet pressure 2 to 5 psi above atmospheric pressure. The intake air pushes the exhaust gas out. (This is not the same as supercharging which raises the inlet pressure much higher). The work required to operate the scavenging air pump/compressor is charged against the engine. The net work of a 2 stroke cycle engine is therefore reduced by this amount. In addition to this loss of work, the combustion process often does not go as far toward completion as it does in a 4 stroke cycle engine. Hence, the work of a 2 stroke cycle engine is not two (2) times that of a 4 stroke cycle engine as might be expected, but only about one and one-half (1 1/2) times.

4. DIESEL ENGINE COMPONENTS

4.1 Principal Stationary Parts. The main purpose of an engine's stationary parts is to maintain the moving parts in their same relative positions and to act as a mounting platform. Most large engine cylinder blocks are welded steel plate construction, while smaller engine cylinder blocks are of "en-bloc" construction: the block is one piece of cast iron. These cylinder blocks provide the foundation to hold all other engine parts. Attached to the base of the cylinder block is a crankcase, which may be an integral part of the block or it may be separate. The crankcase may be used to support the main bearing which also may act as, or support, an oil sump. The cylinder block holds the cylinder assemblies in place. These assemblies consist of a cylinder liner and a cylinder head. Cylinder liners are made of close grain cast iron and along with the cylinder head and piston form a gas tight space for combustion. The cylinder liners may be classified into 2 types, dry and wet. Dry type liners do not contact the coolant, but fit closely against the cooling jacket wall in the cylinder block. With a wet liner, the coolant does contact the liner. Cylinder heads may have various construction configurations, so that one head may cover all or several cylinders. On large engines, each cylinder may have a separate head. These cylinder heads may contain valves, injectors, test cocks, safety valves and cooling passages. Gaskets are normally used to seal the heads of the cylinders and the heads are held in place by the head studs. Diesel engine cylinder head assemblies require careful attention to remain trouble free. Gas leaks are most common and distortion or cracks can result from improper torquing of cylinder head nuts. Cylinder head liners are subject to wear which is the most common reason for replacement. Diesel engines must be carefully mounted and secured to keep them in line with the equipment they are driving. Mountings must be strong enough to absorb the power of the engine and must provide flexibility to prevent the shocks which may be transmitted to the engine.

4.2 Principal Moving Parts. Some parts are used to seal and compress gases in the engine cylinders and others transmit the power developed in the engine cylinders. Poppet type valves are used to allow fresh air to reach the cylinders and to remove waste gases. Valves springs are used to return valves to the closed position. Springs are routinely inspected for nicks, cracks or corrosion and replaced if such faults are noted or if the extended length is over 3% shorter than a new spring. Cam followers and lash adjusters are used to change the rotary motion of the cam shaft to reciprocating motion to operate valve actuating mechanisms. Rocker arms, and in some engines push rods, are used to open these valves. Adjustment devices are provided on most rocker arms for valve lash adjustment.

Piston and rod assemblies, each consisting of a piston, piston rings, piston pins and connecting rod are used to seal the cylinder and transmit power developed by combustion to the crank shaft (see Figure 4-1). Since

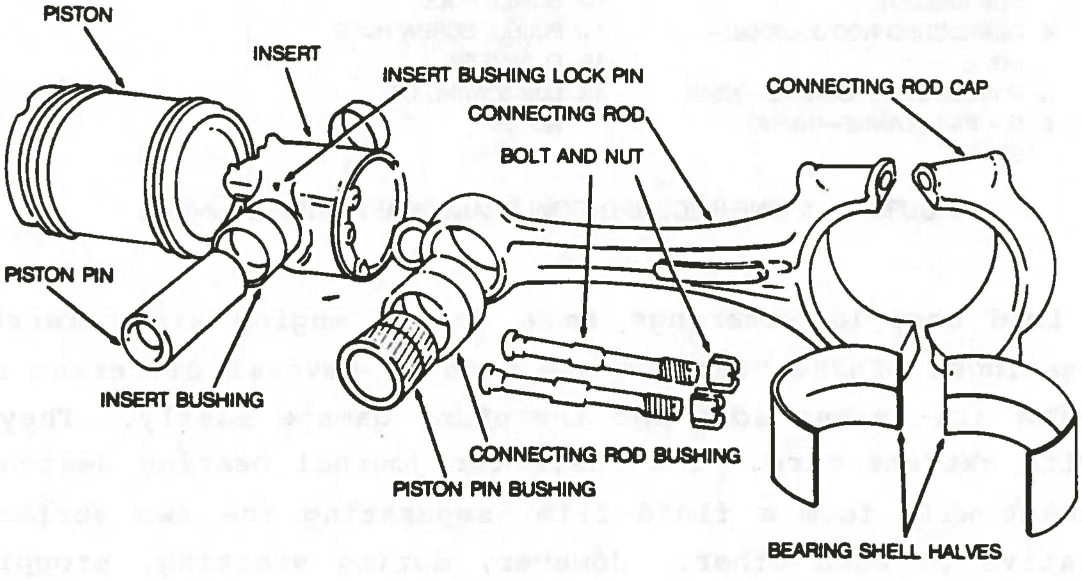
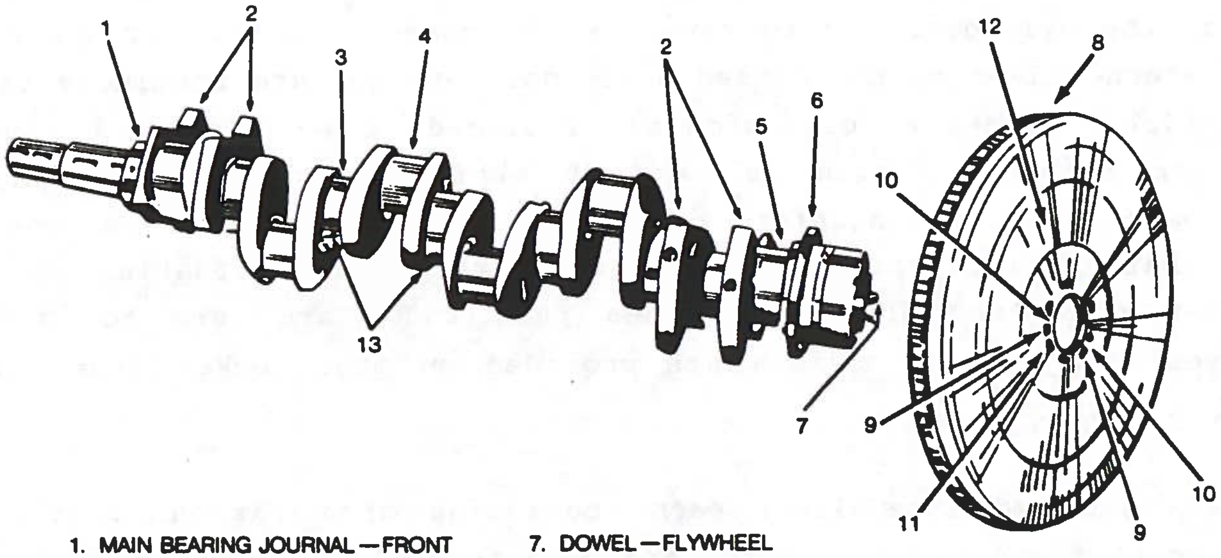


FIGURE 4—1 PISTON AND ROD ASSEMBLY WITH SLEEVE BUSHING TYPE BEARINGS.

piston and rod assemblies are exposed to extreme heat, they must be disassembled carefully and subjected to a detailed inspection procedure.

It may be said that a crankshaft is the heart of any diesel engine. Crankshafts convert the reciprocating motion of connecting rods to rotary motion and deliver power to the unit to be driven (see Figure 4-2). Many bearings support the crankshaft. These bearings receive and transmit through the crankshaft a constant supply of oil for lubrication and cooling.



1. MAIN BEARING JOURNAL—FRONT
2. COUNTER.
3. MAIN BEARING JOURNAL—INTERMEDIATE
4. CONNECTING ROD JOURNAL—NO. 3
5. MAIN BEARING JOURNAL—REAR
6. BOLTING FLANGE—TIMING GEAR
7. DOWEL—FLYWHEEL
8. RING GEAR
9. RETAINING BOLT HOLE
10. DOWEL HOLE
11. PULLER SCREW HOLE
12. FLYWHEEL
13. LUBRICATING OIL HOLES

FIGURE 4—2 ONE-PIECE, 6-THROW CRANKSHAFT WITH FLYWHEEL.

The main load carrying bearings in a diesel engine are referred to as journal bearings. These bearings are made of several different materials all of which are rather soft and therefore damage easily. They must be handled with extreme care. The basis for journal bearing design is that the lubricant will form a fluid film, separating the two surfaces which slide relative to each other. However, during starting, stopping, high shock loads or when the oil temperature is too high to maintain adequate viscosity, metal to metal contact occurs. Hence, the need for soft bearing materials to avoid damage to the journals.

Camshafts are driven by the crankshaft and are used primarily for valve actuation. Some cams may actuate injectors or drive other engine accessories such as attached oil pumps.

The crankshaft rotational speed increases each time the crankshaft receives a power impulse from one of the pistons. To stabilize crankshaft rotation, a flywheel is mounted on one end of the crankshaft. This flywheel may also be used as part of a starting system which operates by means of an attached gear ring. It also may be used to assist in the adjustment of engine timing. This is accomplished by timing marks inscribed

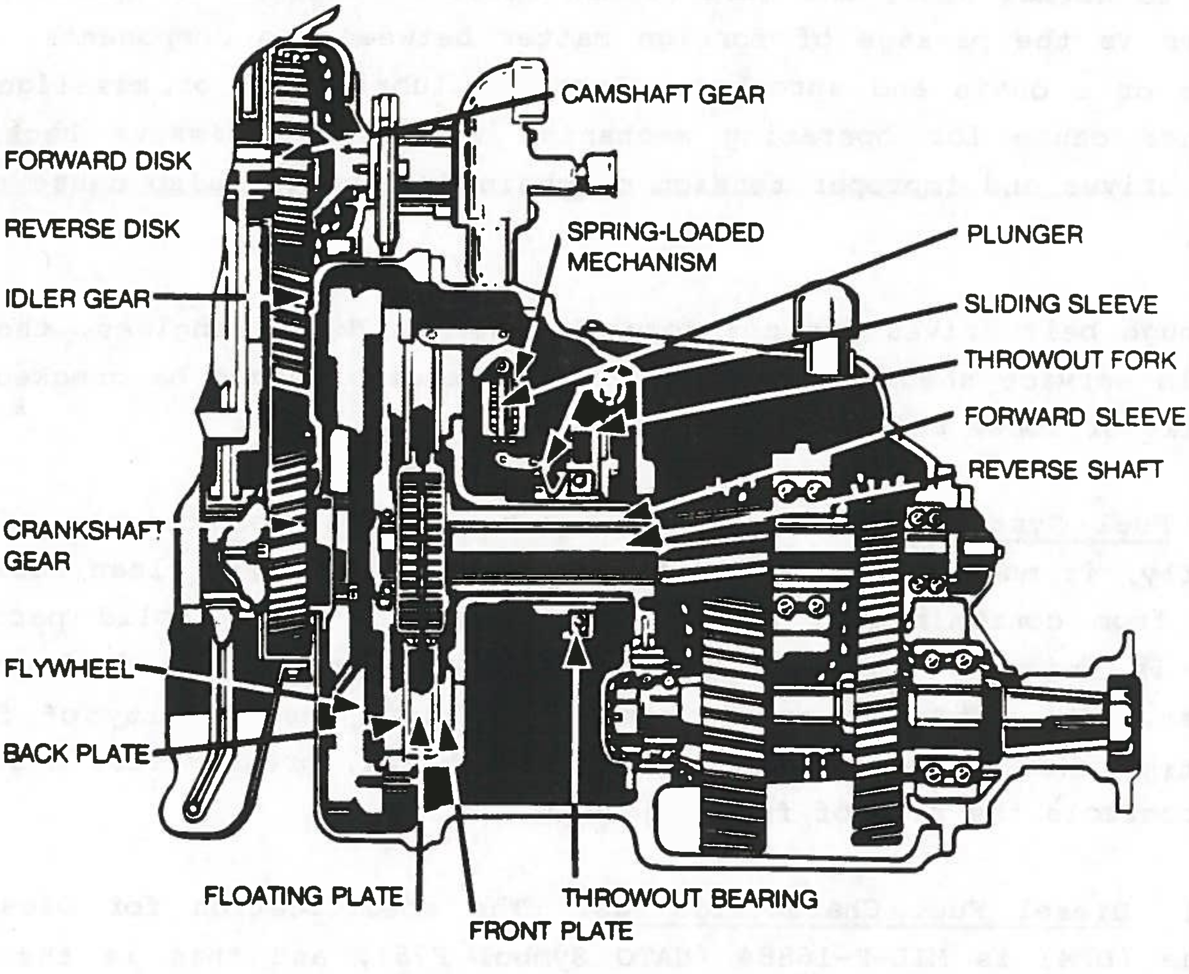


FIGURE 4—3 TRANSMISSION WITH INDEPENDENT OIL SYSTEMS

on the rim which are aligned to a stationary pointer. Figure 4-3 shows a fly wheel arrangement in a transmission assembly.

4.3 Operating Mechanisms. Operating parts for diesel engines may be divided into two groups: drive mechanisms and actuating mechanisms. Drive mechanisms may be driven either directly or indirectly by the crank shaft. Drive mechanisms may be gear, belt or chain type. The gear type is the most common and is used to drive camshafts, blowers, oil pumps, etc. Actuating mechanisms are devices used to change rotary motion to reciprocating motion. The change in motion is necessary to actuate valves and fuel injection pumps.

Next to normal wear, the most common cause of failure in operating mechanisms is the passage of foreign matter between two components, such as gears or a chain and sprocket. Improper lubrication or misalignment is another cause for operating mechanism failure. Excessive backlash on gear drives and improper tension on chain drives will also cause abnormal wear.

Although belt drives are not commonly used on diesel engines, those that are in service should be kept clean and tension should be checked often. An oily or loose belt will wear extremely fast.

4.4 Fuel Systems. For a diesel engine to operate properly and efficiently, it must be supplied with an adequate amount of clean fuel (i.e., free from contamination from water, sludge or other solid particles). Fuel is injected into the engine cylinders through the fuel injection system. The injection system times and meters the quantity of fuel and the time when it is injected. It also atomizes, pressurizes, distributes and controls the rate of fuel injected.

4.4.1 Diesel Fuel Characteristics. The specification for Diesel Fuel Marine (DFM) is MIL-F-16884 (NATO Symbol F75), and this is the primary fuel for diesel engines. DFM is used whenever possible at temperatures above 0°C. At temperatures below 0°C, JP-5 (MIL-T-5624) should be used since it has a higher flash point. Commercial diesel engines run on a variety of diesel fuels ranging from gases to heavy oils. Because of the cost escalation in the price of black oil, commercial companies as an economy measure have shifted to high viscosity fuels similar to tar, with specific gravities approaching 0.99. Such fuels require preheating to 105-110° C in order to permit proper operation of fuel oil separators, remove water and foreign matter, and provide an adequate fuel flow to the injectors. A general shortage of medium distillates has led to a noticeable increase commercially in the proportion of fuels from new refining processes such as catalyst cracking, visbreaking, etc. In the residues from the catalyst cracking process and the mixing of different grades of oil, there can be materials present in the fuel which lead to extensive engine wear if they are not separated out. It is therefore preferable for ships to receive ready mixed fuels. Such fuels should be low in vanadium and sodium content to minimize high temperature corrosion which can occur on exhaust valves and supercharger turbine vanes when burning heavy fuel containing these elements. A low ash content in heavy fuels is also important because the ash content determines the mechanical wear in the engine. "Fuel-saving" has become a byword among the highly competitive marine diesel engine manufacturers. The search for engines with still lower fuel consumption without loss of power and the ability to burn lower quality and even synthetic fuels continues. Efforts to lower fuel consumption and increase engine efficiency ratios have resulted in a shift from the impulse pressure supercharging system to the constant pressure supercharging system. Other efforts include the employment of propellers designed to run at lower RPM, automatic fuel injection timing controls, and the concept of using residual energy in the exhaust to drive turbo-generating systems. In the future, economics and fuel availability may well dictate that the U.S. Navy return to fuels of higher viscosity and slower speed diesel engines.

4.4.2 Fuel Injection. Since the essence of diesel engine operation is the introduction of finely atomized fuel into the air compressed in a cylinder, every droplet of fuel must be exposed either to a correct amount of air to achieve complete oxidation or to an excess of air. Naturally aspirated engines have a degree of swirl to provide additional fuel and air mixing and have an injection pressure of around 800 bar

(12,000 psi). Highly turbocharged engines with four valve heads have virtually no swirl but generally have an injection pressure of 1200 bar (17,640 psi) to provide the mixing energy.

The following points concerning direct injection of fuel should be noted:

a. At least some of the fuel injected is atomized sufficiently fine to initiate combustion. Until a droplet of fuel has reached the temperature for spontaneous ignition, ignition cannot take place. Since the heat taken up is a function of surface area and the quantity of heat needed to achieve a temperature rise is a function of volume, only a small number of fine droplets are needed to initiate combustion. In fact high speed photography of combustion has shown that ignition takes place in a random manner near the injector tip, usually outside the main core of the spray.

b. Fuel has to mix with the air in order to burn. Since most of the air in a roughly cylindrically space is for geometric reasons near the periphery, most of the fuel must penetrate there and this is achieved easier with large droplets. This accounts for the wide use of course angles and multiple spray holes.

c. The fuel should not reach the liner walls or it will result in contaminating the lube oil. An advantage of the combustion spaces in piston crowns in some designs is that the walls of the chamber form a safe target towards which spray may be directed. This type of combustion chamber in the piston has the further advantage that during the piston descent, air above the piston is progressively drawn into the mixing area.

d. The injection period should be reasonably short and should end sharply. Dribble or secondary injection cause smoke and the lubricating oil to become diluted with fuel oil or with insoluble residues. Dribble is a condition in which fuel continues to emerge from the nozzle at pressures too low for it to properly atomize. This is caused by bad seating surfaces or by slow injector closing. Secondary injection happens when the pressure wave caused by closing the injector parts at the end of the main injection is reflected back to the pump and then again back to the injector. The reflected wave strikes the injector with sufficient force to reopen at a relatively late stage in the combustion process. The unburnt or partially burned fuel may find its way to the cylinder walls and be drawn by the piston rings into the sump.

An injector must snap open when a high pressure wave from the pump traveling along the high pressure pipe reaches the injector needle valve to assure proper atomization of the fuel. Needle lift is limited by the gap between the upper shoulder and the main body of the holder. Needle lift is opposed by a spring set to keep the needle seated until the "release pressure" of the injector is reached by the fuel as the pressure wave arrives from the pump. This pressure is chosen by the engine designer to ensure there is no tendency for the needle to reopen as the closing pressure waves are reflected back and forth along the high pressure pipe. The setting selected has some effect on injection delay and the quality of injection achieved and is usually between 200 to 300 bar (3000 - 4500 psi).

4.5 Engine Controls. Governors (mechanical or hydraulic) are installed on diesel engines to regulate the engine speed under variations in load. Overspeed and overload devices may be either integral or mounted separately on the engine.

When any repair, replacement or adjustment is made on the fuel injection systems, or engine control devices, care must be taken to follow authorized repair procedures to avoid damage to the engine from speed, overloading or pressure imbalance between cylinders.

4.6 Air Intake and Exhaust Systems. Air enters the engine through a filter which cleans it and passes it through a silencer to reduce the noise created by the air moving at high velocity. The air may next pass through a blower or supercharger to increase its pressure before entering the cylinders. The air enters the cylinders by way of an inlet manifold or air box.

Crankcase ventilation devices are used on diesel engines to reduce the amount of gases, condensation and explosive fumes which might otherwise collect in the crankcase.

The exhaust system of a diesel engine consists of an exhaust manifold, exhaust pipe, exhaust muffler and tailpipe. In some cases a spark arresting device may also be used. The principal means of supplying air to diesel engines is through natural aspiration, scavenging, and supercharging. On naturally aspirated engines, air is drawn into the cylinder as the piston moves from top to bottom dead center of the stroke. The pressure in the cylinder at the start of the compression stroke is below one atmosphere due to the pressure drop in the intake passages and valves. A scavenged engine is a 2 stroke design of the naturally aspirated 4 stroke cycle engine. The air for combustion is supplied at low pressure (2 to 5 psi) by either a centrifugal or positive displacement scavenging blower. The scavenging air pressure required is a function of the size and arrangement of the exhaust, air ports and passages, and speed of the engine. In supercharged engines, combustion air is supplied by a centrifugal or positive displacement compressor driven from the crankshaft by gears or driven by an exhaust gas turbine which is connected to the compressor shaft. This latter arrangement is called a turbosupercharger or more commonly, a turbocharger.

4.6.1 Turbocharger. When supercharging is accomplished by means of a blower mechanically driven from the engine, the power expended in driving the blower, must be subtracted from the indicated engine horsepower to arrive at the net shaft horsepower. The power expended in driving a compressor has an important influence on the operating efficiency of a diesel engine. It is relatively uneconomical to drive the compressor directly from the engine because of the additional power absorbed. This results in an increase in specific fuel consumption for the extra power obtained. Since about 35% of the total heat energy in the fuel is dissipated in the exhaust gases, an increase in power and efficiency of the combustion process could be obtained by using some of the energy from these exhaust gases to drive the air compressor. Exhaust gas turbocharged single acting 4 stroke cycle marine engines can deliver up to three times as much power as naturally aspirated engines of the same speed and dimensions. Even higher output power ratios are achieved on some of the more recent engine types with two stage turbochargers in which the turbocharger units are configured in series operation.

The application of pressure charging to a 2 stroke engine is more complicated than a 4 stroke engine because until a certain level of speed is obtained and power output reached, the turboblower is not self supporting. At lower engine loads there is not sufficient energy in the exhaust gases to drive a turboblower at the speed required for necessary air mass flow. Accordingly, starting the engine is much more difficult and running under a light load can be very inefficient. Turbocharging 2 stroke engines is achieved by one of two methods, constant pressure or pulse. The constant pressure system is used by all slow speed 2 stroke engines. In the constant pressure operation, all cylinders exhaust to a common receiver in which gas pulses tend to dampen out and an almost constant pressure is attained. The advantage of this system is that it eliminates complicated multiple exhaust pipe arrangements and leads to higher turbine efficiencies with lower specific fuel consumptions. The main disadvantage of the constant pressure system is poor performance for part load conditions. The engine is also insensitive to changes in engine operating conditions. Additionally, poor combustion is achieved during transition periods as a result of delay in turboblower acceleration or deceleration. Under the pulse system of operation, at least 120 degrees of engine crank shaft rotation separation must be achieved between cylinders exhausting to a common manifold. The sudden drop in manifold pressure with each successive exhaust pulse results in a greater pressure differential across the cylinder during the scavenge period than is obtained with a constant pressure system. This is a factor which makes for better scavenging.

4.7 Lube Oil Systems. Diesel engines must be supplied with an adequate amount of clean, cooled lube oil at a pressure sufficient to provide all bearings with a thin film of lube oil to reduce heat and to keep the internal components of the engine clean.

Oil tanks or sumps store oil which is drawn through a pump or pumps. From the pump the oil may go to several places depending on the type system used on the engine. Regardless of the system, filters and strainers are used to clean the oil. Temperature regulating devices are used to control oil temperature and relief valves are used to protect the system from excess pressure.

4.8 Cooling Systems. A diesel engine must operate at its designed temperature. If it runs cold, the design clearances will not be correct, the lubricating oil will not flow properly, and combustion products, such as water and carbon dioxide (which form an acid solution) will collect on cylinder walls and dilute the lubricating oil. Most normal engine wear occurs when engines are warming up. If a diesel engine runs hot, lubricating oil films will break down, overheated parts will distort and wear unevenly, and the exhaust valves will be subject to burning.

Cooling for diesel engines is either liquid or air. Since there is a considerable amount of heat generated in the cylinders, the heat of the cylinder boundaries must be controlled to prevent them from exceeding safe limits. Circulating water or air over the outside surfaces controls these temperatures and in most marine engines, a heat exchanger is used to transfer heat from the fresh water primary coolant to the seawater secondary coolant. In some cases heat from the fresh water may be transferred to the atmosphere by means of a water to air heat exchanger similar to an automotive type radiator.

In a circulating fresh water system, fresh water is cooled by sea water and circulated into the engine's block, normally entering at a low point and then flowing up and around the cylinders. In some designs, the water is used in a jacket to cool the exhaust manifold.

The condition and temperature of the fresh water coolant are important factors in the durability and performance of the engine. The water must be chemically balanced so it will neither leave deposits nor corrode the cooling water pressure passages.

Cooling system water is treated to prevent the formation of sludge or other deposits in the system. Deposits can come from mineral deposits in the water or from oil entering the cooling system from the lube oil cooler. Treatment consists of adding chemicals or soluble oil inhibitors. The type of treatment depends on water test results, whether engine cooling water is used to heat evaporators, and controls established by the Naval Ships Systems Engineering Center.

The temperature is controlled by a by-pass valve which permits the cooling water to flow around the cooler or heat exchanger. More water is bypassed when the engine is cool and vice versa. An expansion tank is located in the highest point in the cooling system. Piping connects the tank with the rest of the system permitting air to leave the water and collect in the expansion tank. If the air remains disolved in the cooling water, it will accelerate corrosion of cooling system parts. The air accumulated in the expansion tank provides a cushion which permits the water to expand from the cooling system as it becomes heated. Make up water and chemicals which need to be added to the system are normally added at the expansion tank.

Heat gained by the engine cooling system is transferred to the sea water which circulates through the engine cooler. The sea water flows at a constant rate from the sea water circulating pump, takes its suction through a strainer in the sea chest, and after flowing through a cooler is discharged overboard. In some installations, part of the overboard discharge is directed into the exhaust manifold to help cool the exhaust gases.

4.9 Starting Systems. In U.S. Navy applications there are 3 principal classes of starting systems for diesel engines: electric, hydraulic and air. All starting systems include a source of stored energy and a means of transmitting a rotating force to the engine to obtain combustion pressures in some or all of the cylinders.

Ignition or starting aids are sometimes needed to start engines in cold weather. These may be either of two types: one which injects a highly volitile fluid such as ether into the intake or one which preheats the intake air. The first type presents some risk in carrying and handling a flammable and toxic substance. The second system can place extra demands on batteries reducing their available power for cranking and starting.

4.10 Transmission of Engine Power. Transmission of power from the engine to a propeller requires a variety of clutches and gears to increase the efficiency, reverse shaft direction and isolate the engine from the propeller shaft. Clutches to connect or disconnect the engine from the driven unit may be one of several types: friction or dog, hydraulic or induction coupling. Reduction gears are used for one or more functions: direction, reversal reduction of engine or shaft speed stepping up engine torque, or allow two or more engines to drive on shaft. Reduction gears may also incorporate such items as propeller shaft braking, locking devices or shaft turning gear. Couplings are used to connect driving units to driven units. Flexible couplings are used between the engine and the reduction gear or generator to absorb vibration and to correct slight misalignment. Solid couplings are used to connect the propeller shaft and the reduction gears. Thrust bearings are used on propeller shafts to control the axial thrust on the shaft exerted by the propeller. Spring and strut bearings are used to support the weight of the propeller and to handle radial movements of the propeller.

5. EMERGENCY DIESEL GENERATORS

Practically all U.S. Navy ships are equipped with diesel-driven emergency generators. Diesel engines are particularly well suited for this application because of their self-sufficiency and quick-starting ability. Emergency generators furnish power directly to the electrical auxiliaries, radio, radar, weapons systems, vital machinery spaces an other spaces. In addition, emergency generators serve as a source of power for casualty power installations.

The typical shipboard plant consists of two emergency diesel generators, one forward and one aft, in spaces outside the engine rooms and fire rooms. Each emergency generator has its individual switchboard and switching arrangement for control of the generator and for distribution of power to certain vital auxiliaries plus a minimum number of lighting fixtures in vital spaces.

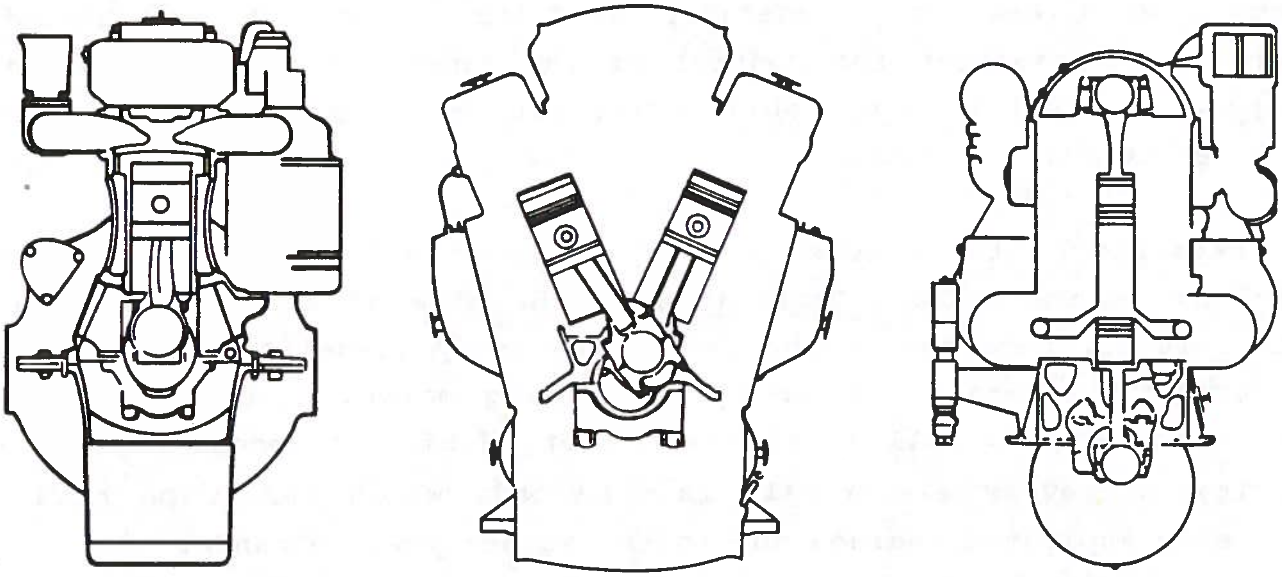
The capacity of the emergency unit varies with the size of the ship on which it is installed. Regardless of the size of the installation, the principle of operation is the same. Emergency diesel engines are started either by compressed air or by a starting motor. The engines are designed to develop full rated load power within 10 seconds. This often results in severe electrical transit loads which cannot be handled by naturally aspirated engines due to the sudden power demands.

In a typical installation, the starting mechanism is actuated when the ship's supply voltage on the bus falls to approximately 80% of normal. In a 440 volt system this would be about 350 volts. The generators are not designed for parallel operation, thus when the ships supply fails, a transfer switch automatically disconnects the emergency switchboard from the main distribution switchboard and connects the emergency generator to the emergency switchboard. With this arrangement transfer from the emergency switchboard is accomplished manually. The emergency generator must then be manually stopped and reset for automatic starting.

Diesel engines can almost always be stopped by securing the flow of fuel to it. Occasionally, this does not work, since a blower seal leak or similar cause permits the engine to run on its own lubricating oil. If the engine cannot be stopped by increasing the load on it, some means of stopping air flow must be found. Discharging a CO_2 fire extinguisher into the air intake is effective, or the air intake may be covered by some means. If the latter is done, be sure the covering used will not be sucked into the blower causing an additional casualty.

6. DIESEL ENGINE APPLICATION IN THE U.S. NAVY

6.1 Types of Engines. The three major engine designs used by the U.S. Navy are the in-line, the V type and the opposed piston type as illustrated in Figure 6-1.



IN-LINE ENGINE

VEE ENGINE

OPPOSED-PISTON ENGINE

FIGURE 6-1 COMMON ENGINE CYLINDER ARRANGEMENTS

A review of the current inventory of diesel engines in operation on U.S. Navy ships shows a wide variety of models. Almost all of the D series engines manufactured by Catepiller have been used in various applications as have most of the Detroit Diesel series 52, 71, 92 and 149. A number of Fairbanks Morse engines (particularly models 38F5 and 38D8) have been used on emergency generator installations and submarines. General Motors, Alco, and MTU engines are found in a number of installations. Smaller Westerbeak engines are used for small boats or lifeboat application. Table 6-1 summarizes diesel propulsion applications for current and planned U.S. naval vessels.

6.2 LSD-41 Propulsion System. In January 1985, a new landing ship dock class of ship, USS Whidbey Island (LSD-41) began naval service. This design incorporates a commercially available low speed diesel, model Colt-Pielstick, PC 2.5V. Four of these engines are installed and each has 16 cylinders arranged in a 45 degree Vee configuration with a rating of 8500 bhp @520 rpm. The turbochargers are powered by the engine exhaust gas and provide combustion air at the required temperature and positive pressure. No adjustments to the turbocharger performance are required during engine operation since turbocharger output is directly related to engine load. As engine loading increases, engine exhaust quantity and velocity increase with a consequent increase in combustion air quantity. When engine loading decreases, a decrease in combustion air will occur. A relief valve and an indicator cock are installed on each cylinder. The relief valve will protect the engine against breakdown should an overpressure condition occur in any cylinder. The indicator cock is used to remove liquids (water, fuel, and lubricating oil) before starting and after extended shutdown. The indicator cock is also used when performing regular maintenance checks, as outlined in normal preventive maintenance procedures. Thermocouples, which are part of the remote temperature monitoring system, are installed in each cylinder exhaust, and combined exhaust upstream and downstream of the turbochargers.

6.2.1 <u>Propulsion Control System</u>. The Colt-Pielstick 2.5V engine operation is readily adaptable to remote control and automatic monitoring. Various engine mounted sensors are wired to the lower electrical connection box mounted on the left side of the engine free end. These sensors include Resistance Temperature Detectors (RTD) for each main bearing, rocker arm lube oil, and air manifold. The following sensors are also wired to this connection box:

- overspeed trip indicator
- barring device interlock
- fuel oil leak detector
- engine speed tachometer generator and magnetic pickup
- high level rocker arm
- lube oil tank alarm
- high rocker arm lube oil strainer differential pressure alarm

Exhaust thermocouples for each cylinder bank are wired to electrical connection boxes located on the sides of the engine at the free end.

Since engine operation is very noisy, Fairbanks Morse engineers have designed systems meeting ASCG and ABS 1976 rules (ACCU requirements) for a "no-man" engine room watch. In the LSD-41, the propulsion control system controls and monitors two identical and independent diesel propulsion plants, one each on the portside aft and the starboard side forward. Each plant consists of two diesel engines designated A and B, a reduction gear assembly, a drive shaft, and a controllable pitch propeller. The propulsion control system provides the basic controls for the plant as well as the controls for supporting and auxiliary equipments. In addition, the propulsion control system monitors all pertinent plant, support equipment, and auxiliary equipment conditions.

6.3 Submarine Applications. Currently the principal application of diesel engines on submarines is for electrical power generation to recharge the main batteries since most of the newer submarine designs employ nuclear power for propulsion. During the 1920s, the conventional submarine propulsion plant for surface operation consisted of heavy, slow-speed, four-cycle diesel engines coupled directly to the propeller shafts. Mounted on the same shafts were the electric motors for submerged operation. These engines had two basic deficiencies. First, they were so massive in relation to their power output that the submarine was unable to obtain the 20 knot speed required by a fleet submarine. Secondly, the solidly coupled system of engines, shafting and propellers was subject to synchronous torsional vibration at critical speeds, many of which were within the normal operational range. To solve this latter problem, the U.S. Navy in 1932 initiated a design competition to develop a powerful high speed diesel engine for use with the all-electric drive propulsion system. Contracts were negotiated with 5 engine builders, one of which resulted in the successful General Motors-Winton engine. The company built two, eight cylinder, Model 201 engines to provide power for an exhibit at the Century of Progress exhibit in Chicago in 1933. As a result of the exhibition, both the Burlington Railroad and the Union Pacific Railroad placed orders for this engine, Model 201A, and the U.S. Navy capitalized on the situation without the expenditure of a large amount of funds and effort for research. Fairbanks Morse concurrently produced another design making use of the opposed piston principle to produce high power while holding size and weight to a minimum. After many early problems, these engines were improved to become standard submarine equipment for many years.

To supply the needed air for combustion, a submarine diesel must run on the surface or come to a depth where snorkling is possible. Special care must be taken to avoid taking water into the engine cylinders. Diesel engines on submarines must not be started until steps have been taken to ascertain that there is no water in the cylinders. Also, because of the higher back pressure under which such engines must operate, they are usually greatly derated from the normally performance characteristics for a similar engine in a surface ship.

Submarine diesel installations require special design considerations for support and alignment of the engine, piping, associated components, and supporting systems because the hull structure is compressed as the submarine submerges. As a result of lessons learned from the losses of USS THRESHER and USS SCORPION, many of the vital water, hydraulic and gas systems for diesels must be "SubSafe'd" and so maintained during operations. Proper pipe hangers, adequate thread engagement, special precautions for welding/joint brazing, must all be given special attention during any repair or alternation performed on the engines.

Engine maintenance is further complicated because of the confined work spaces available in the machinery spaces. Tools and repair parts storage is limited as is personnel access space around the engine. As a result, major repairs are deferred, if possible, until availability periods alongside tenders or during overhaul periods at shipyards.

6.4 <u>Minesweeper Applications of Diesel Engines</u>. In addition to other engine requirements for surface ships, the minesweeper installation must meet special requirements for shock, non-magnetic, and noise criteria. As a result, special engine alloys must be used in the engine manufacture to provide the strength and non-magnetic properties required. Most of the older minesweepers have been decommissioned or transferred to other navies. However, as indicated in Table 6-1, the new mine countermeasure ships (MCMs) are being outfitted with Wakesha Model 1616 engines or with a type new to the U.S. Navy made by Isotta-Fraschini. These engines have successfully met the special design specifications for this ship application and are mounted on special shock resisting foundations. The diesel engines driving the electric generators for minesweeping and countermeasure operations must be capable of carrying large loads and of withstanding large load and transient variations.

TABLE 6-1
U.S. NAVY DIESEL PROPULSION APPLICATION

SHIP CLASS	TYPE	NUMBER OF SHIPS	MANUFACTURER	MODEL	QUANTITY	DIESEL ELECTRIC	DIRECT DRIVE	NUMBER SHAFTS	TOTAL HP
BARBELL	SS	3	Fairbanks Morse		3	yes		1	3150
DARTER	SS	1	Fairbanks Morse		3	yes		2	5500
GREYBACK	LPSS	1	Fairbanks Morse		3	yes		2	5500
TANG	SS	6	Fairbanks Morse		3	yes		2	5500
DOLPHIN	AGSS	1	Detroit Diesel	12V71	2			1	1650
	PHM	6	MTU	8V331PC81	2				1600
ASHEVILLE	PG	4	Cummins		2			2	1450
HIGHPOINT	PCH	1	Packard					1	600
	PB	19	General Motors	8V71T1			yes	3	950
	PCF	5	General Motors	12V71N	2		yes		850
	PBR	39	General Motors	6V53N	2		yes		430
	ATC	22	General Motors	8V53N	2		yes		566
WHIDBEY ISLAND	LSD	12	Colt-Pielstick	16PC2.5V	4		yes	2	41600
NEWPORT	LST	20	General Motors or Alco		6			2	16000
DESOTO COUNTY	LST	3	Cooper Bessemer or Fairbanks Morse		6		yes	2	13700

TABLE 6-1 (CONT'D)
U.S. NAVY DIESEL PROPULSION APPLICATION

SHIP CLASS	TYPE	NUMBER OF SHIPS	MANUFACTURER	MODEL	QUANTITY	DIESEL ELECTRIC	DIRECT DRIVE	NUMBER SHAFTS	TOTAL HP
1610	LCU	51	Detroit Diesel		4			2	1000
1466	LCU	4	Grey Marine		3			3	675
LCM-8	LCM		Detroit Diesel or General Motors		2			2	650
LCM-6	LCM							2	450
	LCVP							1	325
LWT	LWT	2	Harbor Master		2			2	420
								2	2400
ACME	MSO	2	Packard		2			2	2280
ELTANIN	AK	1	Alco			yes		2	2700
COLUMBIA	ATO	1	Pielstick	16 cylinder	2	yes			15000
SEALIFT	ATO	9	Pielstick	14 cylinder	2			1	19200
TONTI	AOG	1	Nordberg					1	1400
ZEUS	ARC	1	General Electric					2	10200
NEPTUNE	ARC	2	General Electric			yes		2	4000
POWHATTAN	ATF	7	General Motors		2			2	4500
Maritime Pre-position		5			1			1	
Maritime Pre-position		5			2			1	26400

TABLE 6-1 (CONT'D)
U.S. NAVY DIESEL PROPULSION APPLICATION

SHIP CLASS	TYPE	NUMBER OF SHIPS	MANUFACTURER	MODEL	QUANTITY	DIESEL ELECTRIC	DIRECT DRIVE	NUMBER SHAFTS	TOTAL HP
STALWART	AGOS	18				yes		2	
CHAUVNET	AGS	2	Alco		1			1	3600
SILAS BENT & WILKES	AGS	4	Westinghouse or General Electric			yes		1	3000
COVE	MSI	2	General Motors		2			1	650
Ex-BRITISH LYNESS	AFS	3	Wallsend-Sulzer	8 Cyl. RD76					11520
HAYES	AGOR	1	General Motors				yes	2	5400
ROBERT D. CONRAD	AGOR	1	Caterpillar & Cummins		3	yes		1	1000
MELVILLE	AGOR	2	De Leval		2			2	2500
AVENGER	MCM	14	Wakesha or Isotta-Fraschini	1616	4 3			2	2400
CARDINAL	MSH	17	(to be determined)						
Bell Halter Design	SES	1	General Motors & General Motors	16V-149T 8V-92T	2 2			2	3200
HENRY J. KAISER	AO	18	SEMT-Pielstick	10PC4				1	32540
AGGRESSIVE	MSO	19	Packard or Wakesha		4		yes	2	2280
	MSB	7	Packard		2		yes	2	600
Deep Salvage(ex)	AG	1	Nordberg		5	yes		2	1320

TABLE 6-1 (CONT'D)
U.S. NAVY DIESEL PROPULSION APPLICATION

SHIP CLASS	TYPE	NUMBER OF SHIPS	MANUFACTURER	MODEL	QUANTITY	DIESEL ELECTRIC	DIRECT DRIVE	NUMBER SHAFTS	TOTAL HP
S.P. LEE	AG	1			2			1	1000
ACHELOUS	ARL	1	General Motors					2	1800
SAFEGUARD	ARS	4							4200
DIVER & BOLSTER	ARS	7	Cooper Bessemer or Caterpillar			yes		2	3060
HUNLEY	AS	2	Fairbanks Morse		6	yes		1	15000
FULTON & PROTEUS	AS	4	General Motors or Allis Chalmers					2	11200
PIGEON	ASR	2	Alco		4			2	6000
CHANTICLEER	ASR	4	Alco or General Motors					1	3000
SOTOYOMO	ATA	1	General Motors					1	1500
CHEROKEE & ABNAKI	ATF	8	General Motors or Busch-Sulzer					1	3000
EDENTON	ATS	3	Paxman		4			2	6000
1X306 (converted army supply ship)		1						1	
BENEWAH	Z-APB	3	General Motors					2	1800
CONVERTED LST-1		1	General Motors		3			2	1800
CONVERTED YW 83	YAG	1							

TABLE 6-1 (CONT'D)
U.S. NAVY DIESEL PROPULSION APPLICATION

SHIP CLASS	TYPE	NUMBER OF SHIPS	MANUFACTURER	MODEL	QUANTITY	DIESEL ELECTRIC	DIRECT DRIVE	NUMBER SHAFTS	TOTAL HP
UTILITY CRAFT	YFU	10	General Motors		2			2	1000
YP 654	YP	19	General Motor		4			2	660
YP 673	YP	3	Detroit Diesel		2			2	680
YP 676	YP	7	Detroit Diesel		2			2	875
LARGE HARBOR TUG	YTB	8			2			2	2000
MEDIUM HARBOR TUG	YTM	48							
	YTL	6							
WATER BARGES	YW	9							
RABENFELS	AKR	2	Kawasaki-Man or Man		2			1	18980
MODIFIED T6-M-98		4	Fairbanks Morse					2	14000
TRANSPORT OILERS		3	Fairbanks Morse					2	
WATER TANKER	AW	1	Fairbanks Morse						

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EDQP STUDY PAPER EVALUATION (CRITIQUE) SHEET

Study Paper Topic: DIESEL PROPULSION & POWER GENERATION; No._____________

1. The information contained in this Study Paper was:

	YES	NO
a. Technically Correct		
b. Current		
c. Clearly Presented		
d. Understandable		
e. Presented at Proper Level of Detail for your needs.		

2. The Practical Factors were:

	YES	NO
a. Possible at your command		
b. Of value in understanding subject		

	YES	NO
3. Did the questions provide a sound basis for studying and understanding the subject?		

4. List and Describe references, other than those noted in this paper, that were helpful or you believe would enhance the value of subject Study Paper:

5. General comments regarding contents or presentation of subject. If you have a "no response, please provide an explanation:

Return To:
Commanding Officer
EDO School, Code 1081
Mare Island Complex
ValleJo, CA 94592

Submitted By: ______________ Date _______
EDO School Class Attended ________________
Present Command __________________________