



Chapter 2

INTRODUCTION TO DIESEL ENGINES

Learning Objectives

As a result of this chapter, you will be able to:

1. Explain the basic energy conversion process in the operation of a diesel engine.
2. Differentiate between the operating principles of 4-stroke cycle and 2-stroke cycle diesel engines.
3. Identify selected basic terms applicable to the design and operation of a diesel engine.
4. Describe the basic heat/power balance which exists during the operation of a diesel engine.

Energy Conversion Processes in the Diesel Engine...

- First: the chemical energy in the fuel injected into the cylinders is converted into thermal energy by means of a process called combustion. During this process, the carbon and hydrogen in the fuel chemically combine with oxygen in the air to create heat and light energy plus carbon dioxide and water as the primary waste products.

Energy Conversion Processes in the Diesel Engine...

- Second: this thermal energy in the form of heated combustion gasses is converted into mechanical energy by expansion cooling of the gasses. This creates the forces on the pistons, connecting rods and crankshaft. These components convert the linear motion of the pistons into rotational output shaft horsepower.

Energy Conversion Processes in the Diesel Engine...

- Third: the generator attached to the engine output shaft converts the rotational mechanical energy into electrical energy by a process called electromagnetic induction.
- These processes are illustrated in Figures 2-1 through 2-6 and 9-2, next.

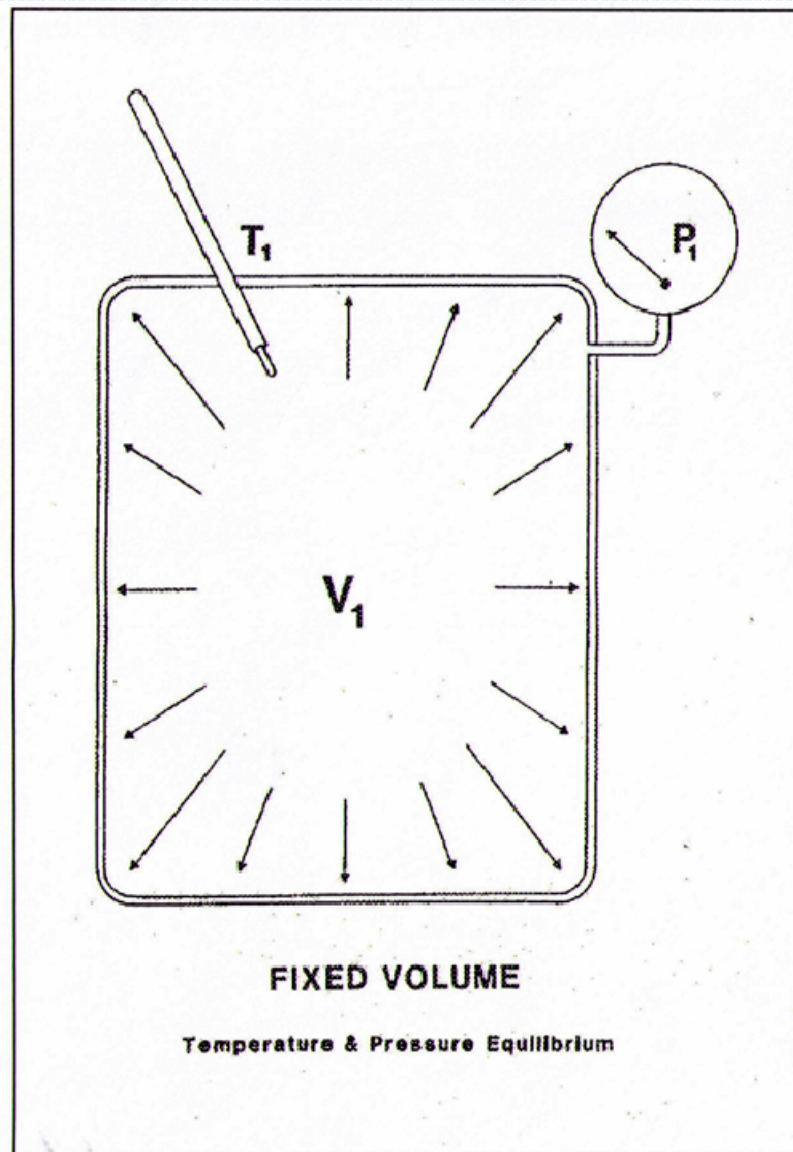


Figure 2-1 Fixed Volume

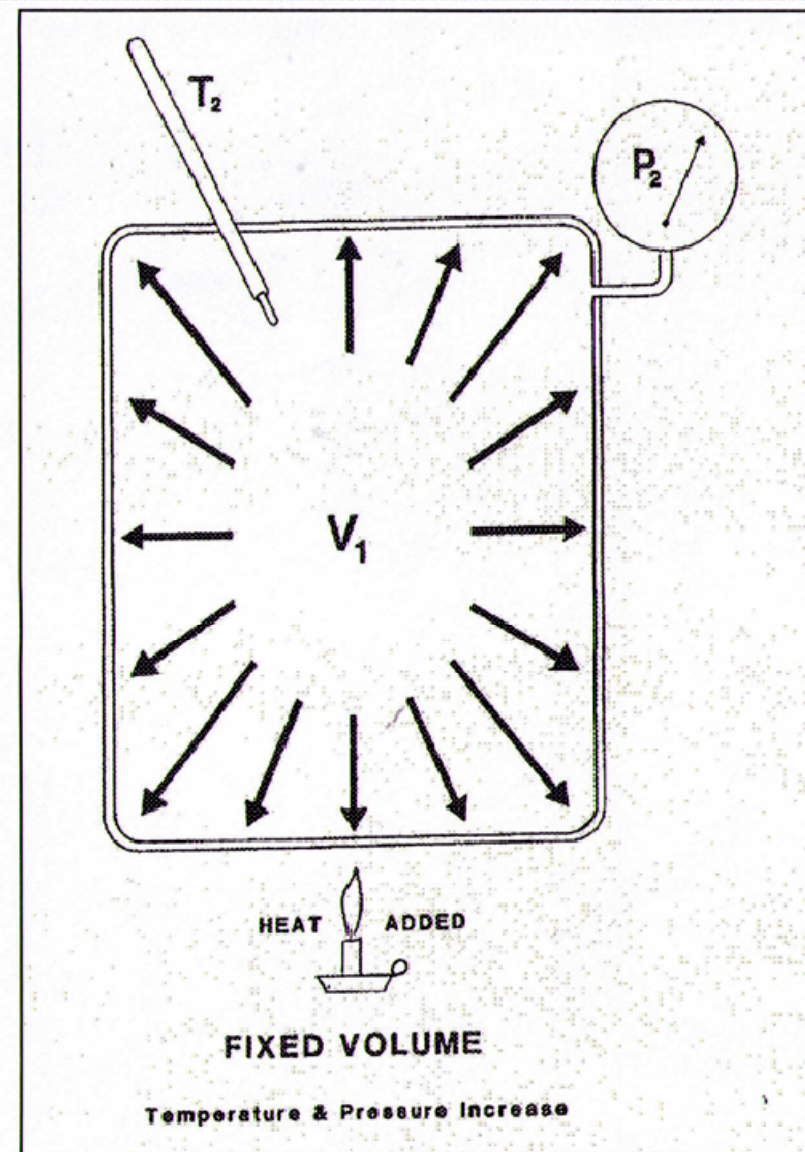


Figure 2-2 Fixed Volume Plus Heat

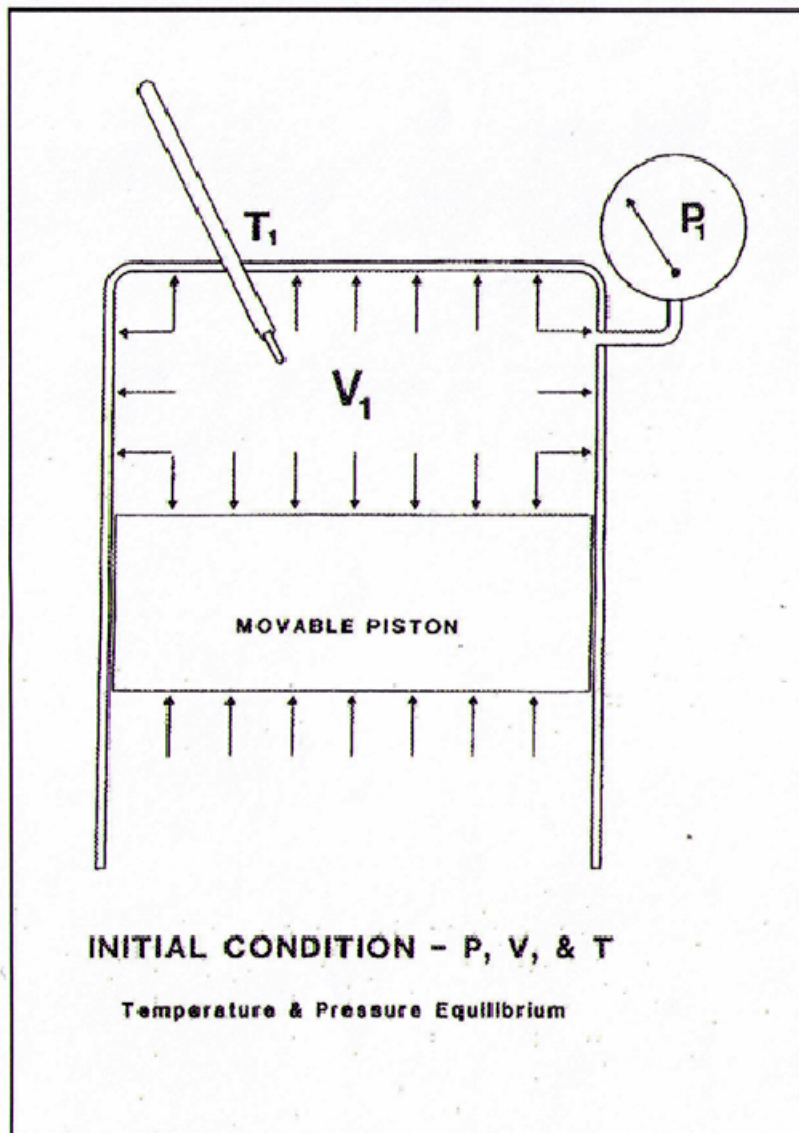


Figure 2-3 Addition of Piston

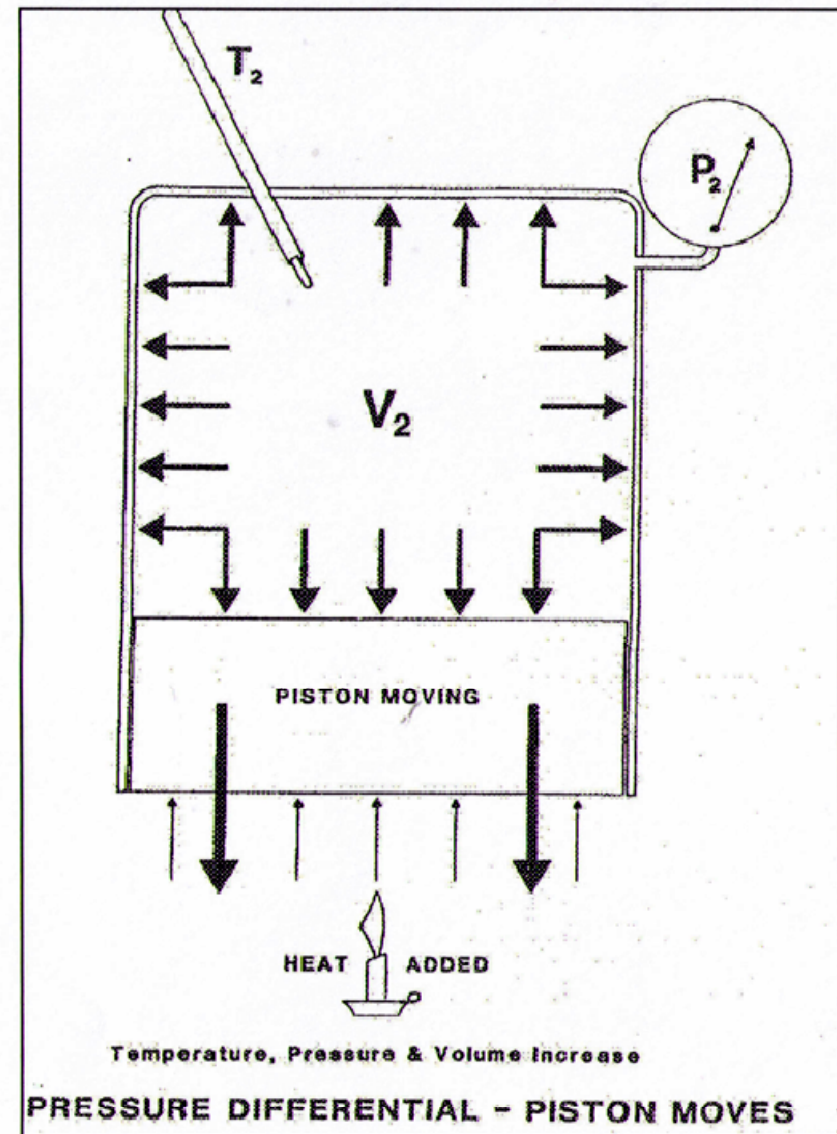


Figure 2-4 Addition of Piston + Heat

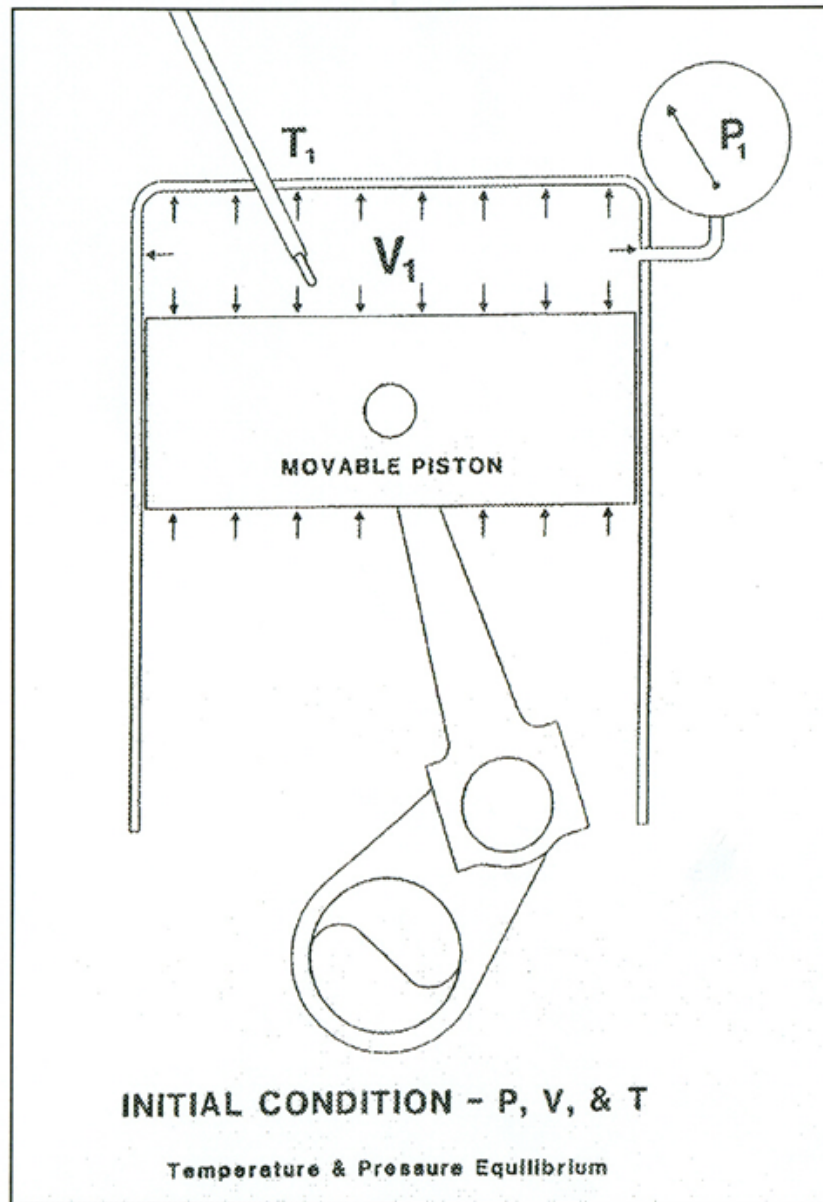


FIGURE 2-5 Addition of Crankshaft

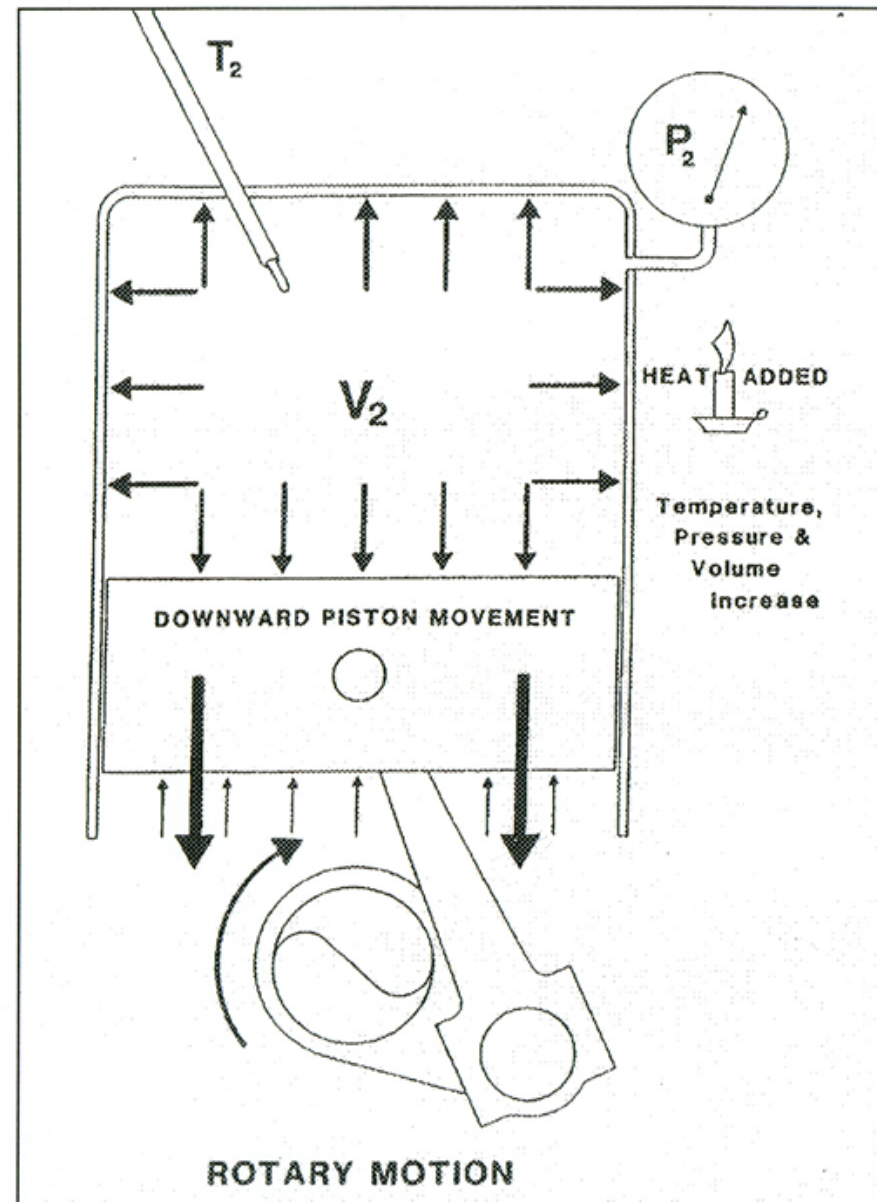


FIGURE 2-6 Addition of Crankshaft plus Heat

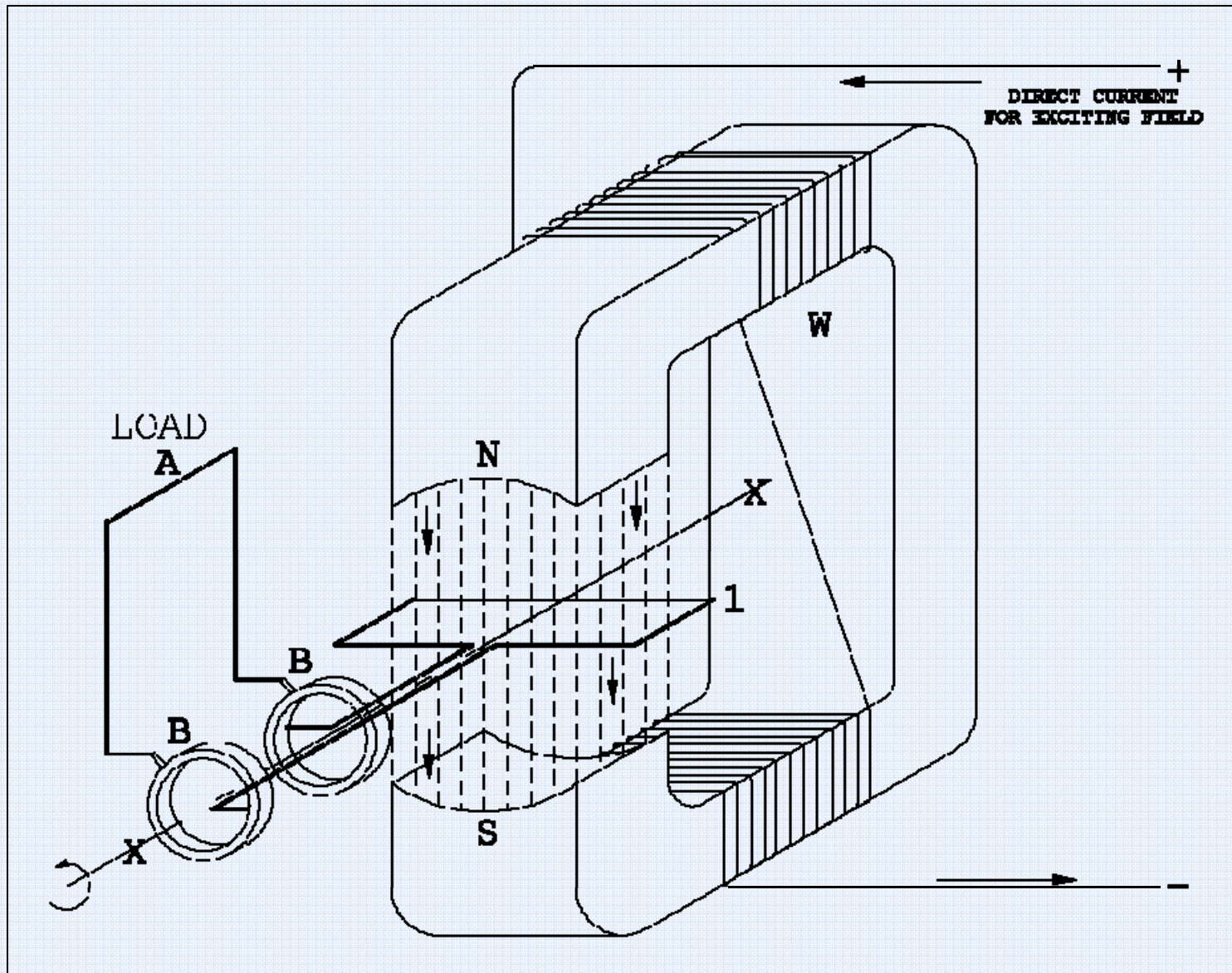


FIGURE 9-2 Simple Generator (Alternating Current)

The combustion process must be repeatable in proper timed sequence for each cylinder to produce useful work:

- A cylinder is charged with fresh air.
- The fresh air must be heated above fuel ignition temperature. That is accomplished by compressing the air.
- A controlled amount of fuel must be injected into the heated air volume at the proper time.

- Combustion occurs, creating the power stroke for the piston -- mechanical energy.
- The mechanical energy provides rotational mechanical power output, as well as energy to activate components and systems for the next cycle of the cylinder.
- Burnt gases must be removed.

The configuration and sequence of events that occur in a 4-stroke cycle engine are illustrated in Figures 2-7 through 2-12

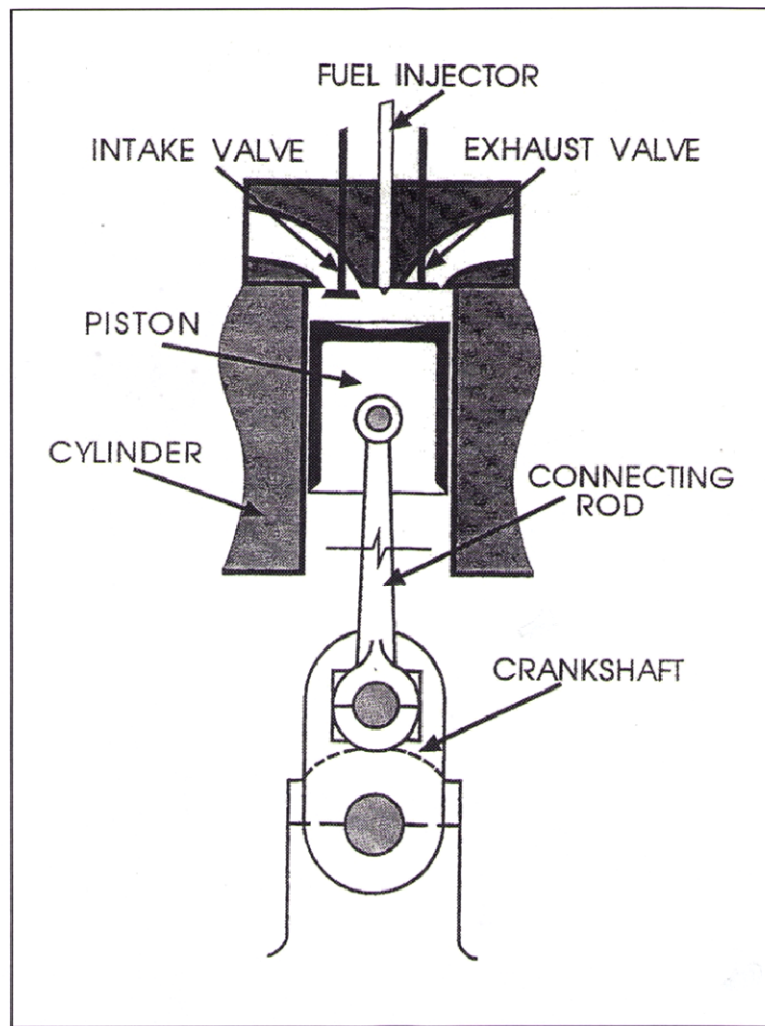


Figure 2-7 Cycle Configuration

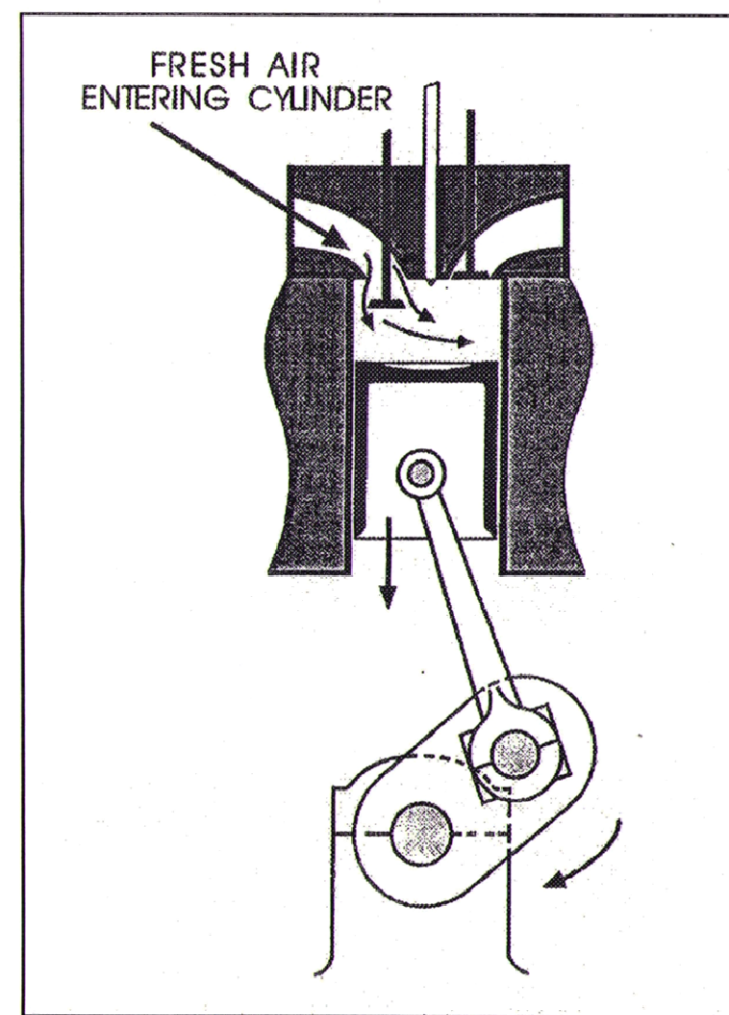


Figure 2-8 Intake of Air Charge

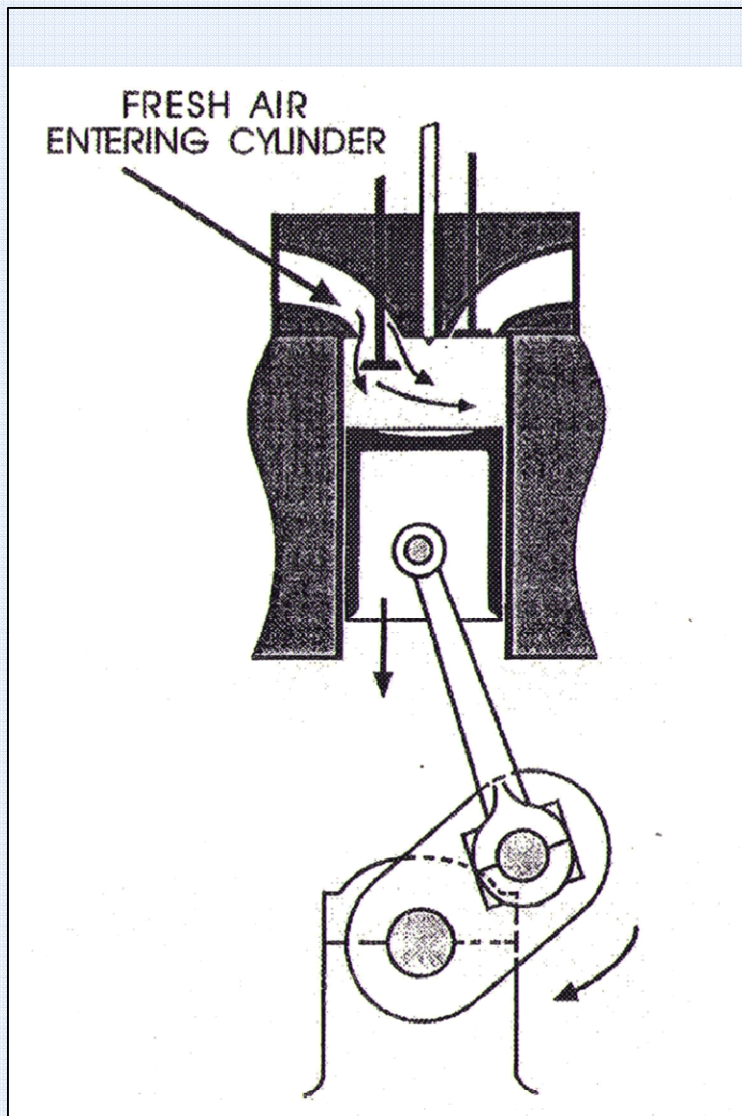


Figure 2-9 Compression of Air Charge

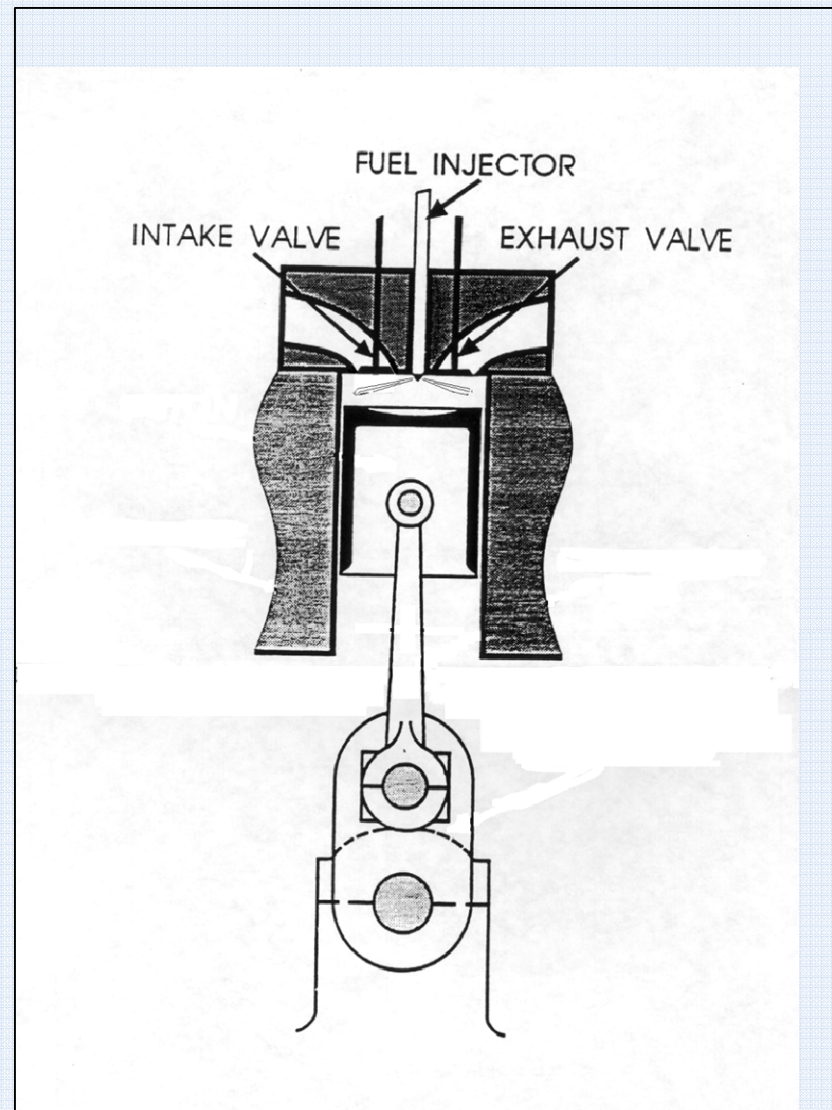


Figure 2-10 Injection of Fuel

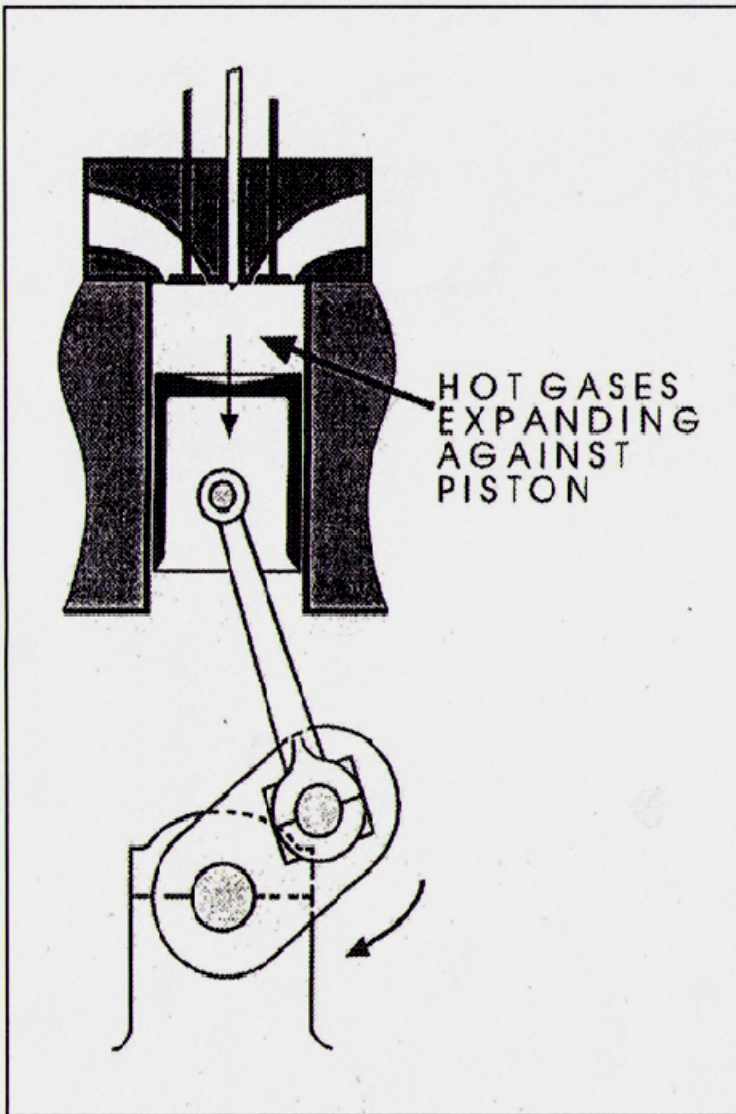


Figure 2-11 Development of Power

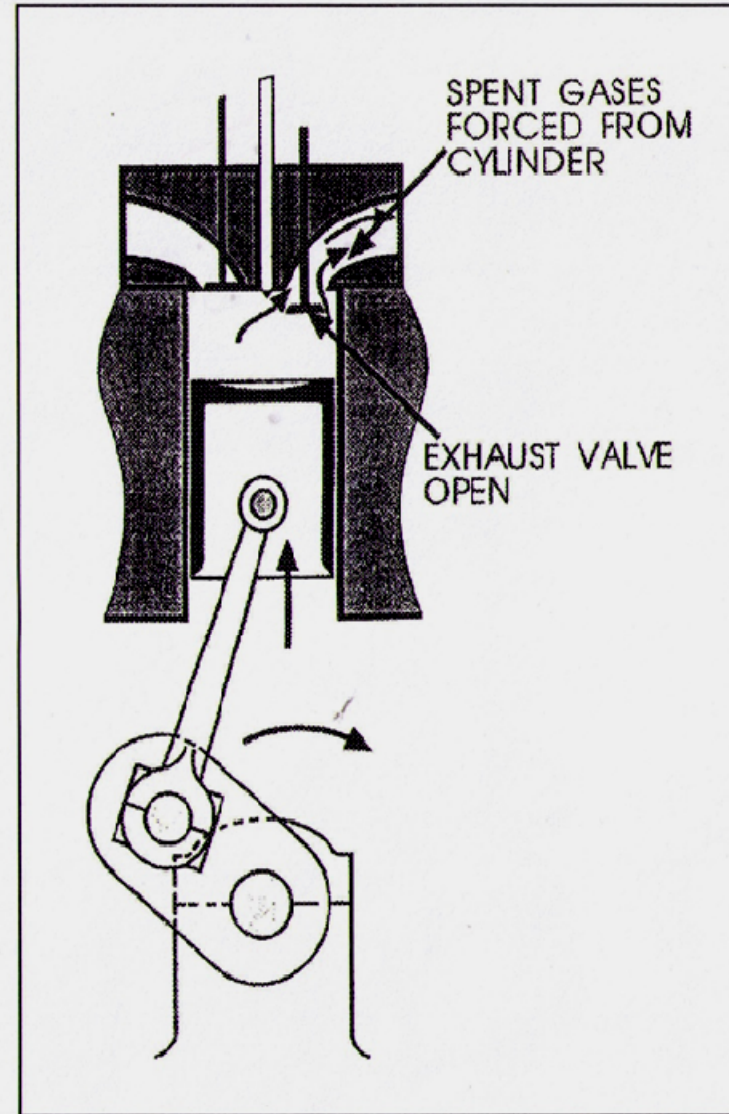


Figure 2-12 Exhaust of Spent Gas

- Diesel engine operation is based upon the ideal air standard cycle illustrated in Figure 2-13 A through C. These are plots of cylinder pressures and volumes during the diesel cycle.

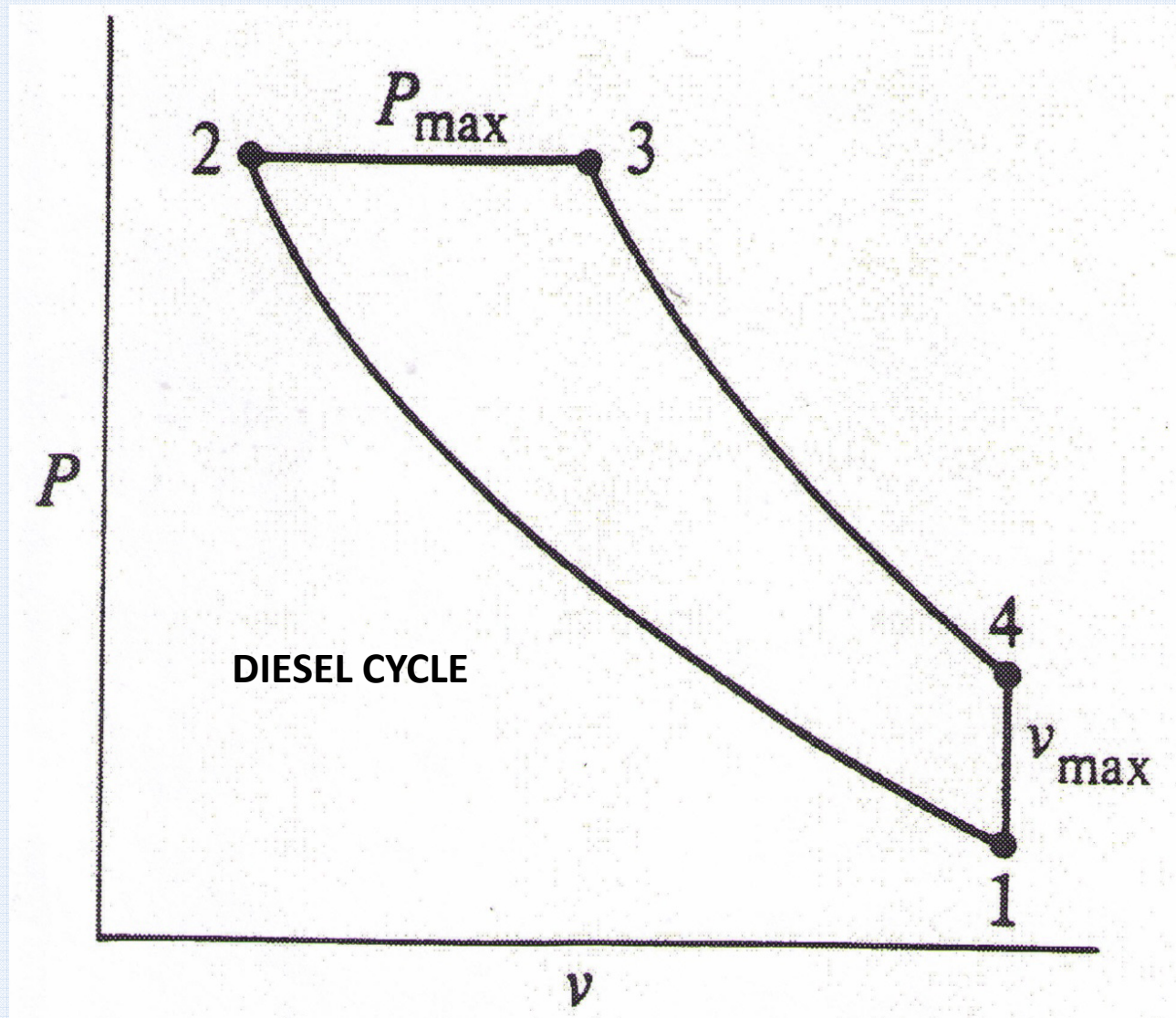


Figure 2-13 Air Standard Diesel Cycle

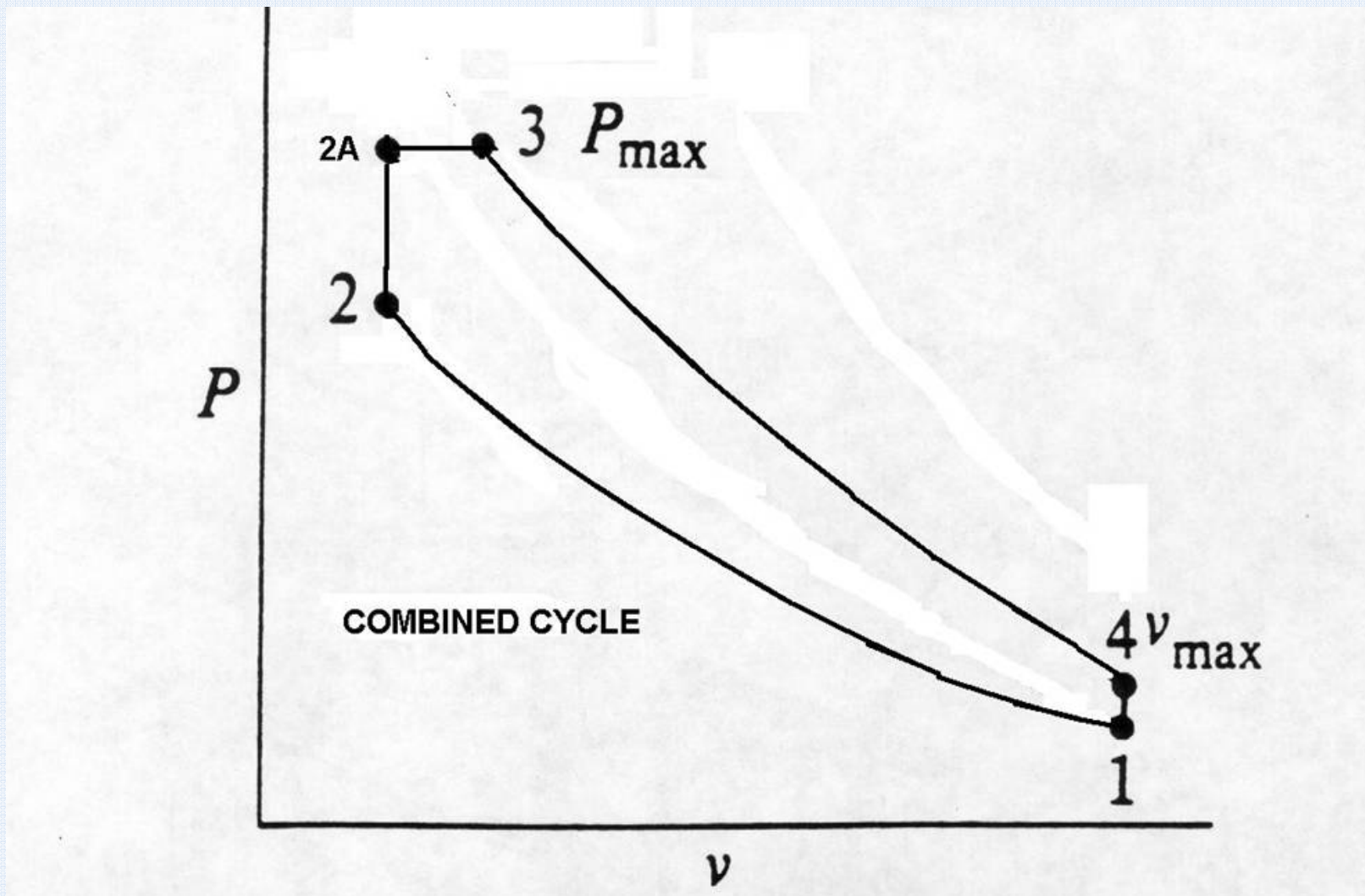


Figure 2-13A Combined Cycle – Intermediate Diesel Cycle

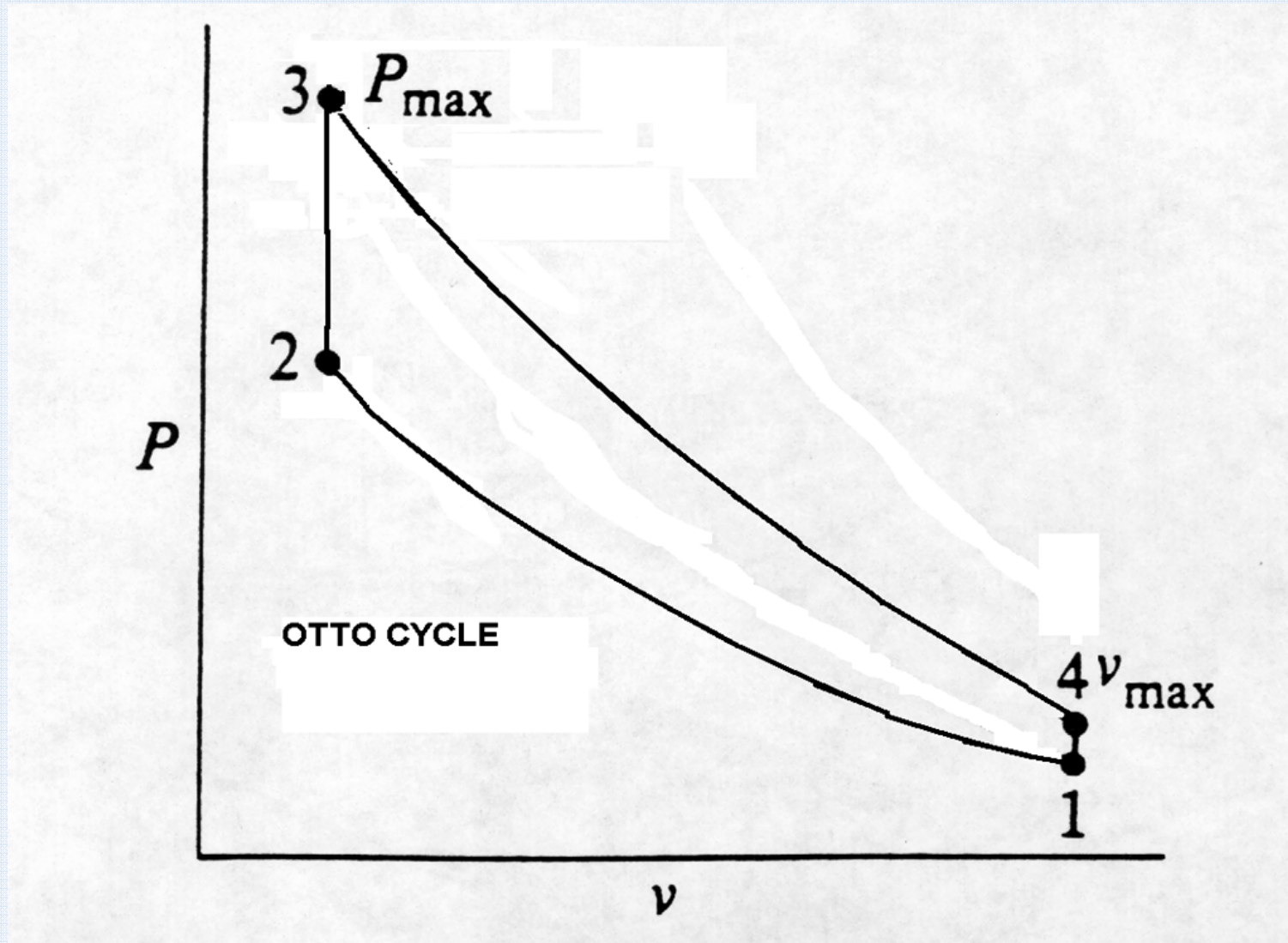


Figure 2-13B OTTO CYCLE – Modern Diesel Engines use this Cycle

The cyclic sequence of events that occur during the operation of a 4-stroke cycle diesel engine are illustrated in Figure 2-14. This is a plot of cylinder pressure at the different crank angle positions in which the diesel cycle occurs.

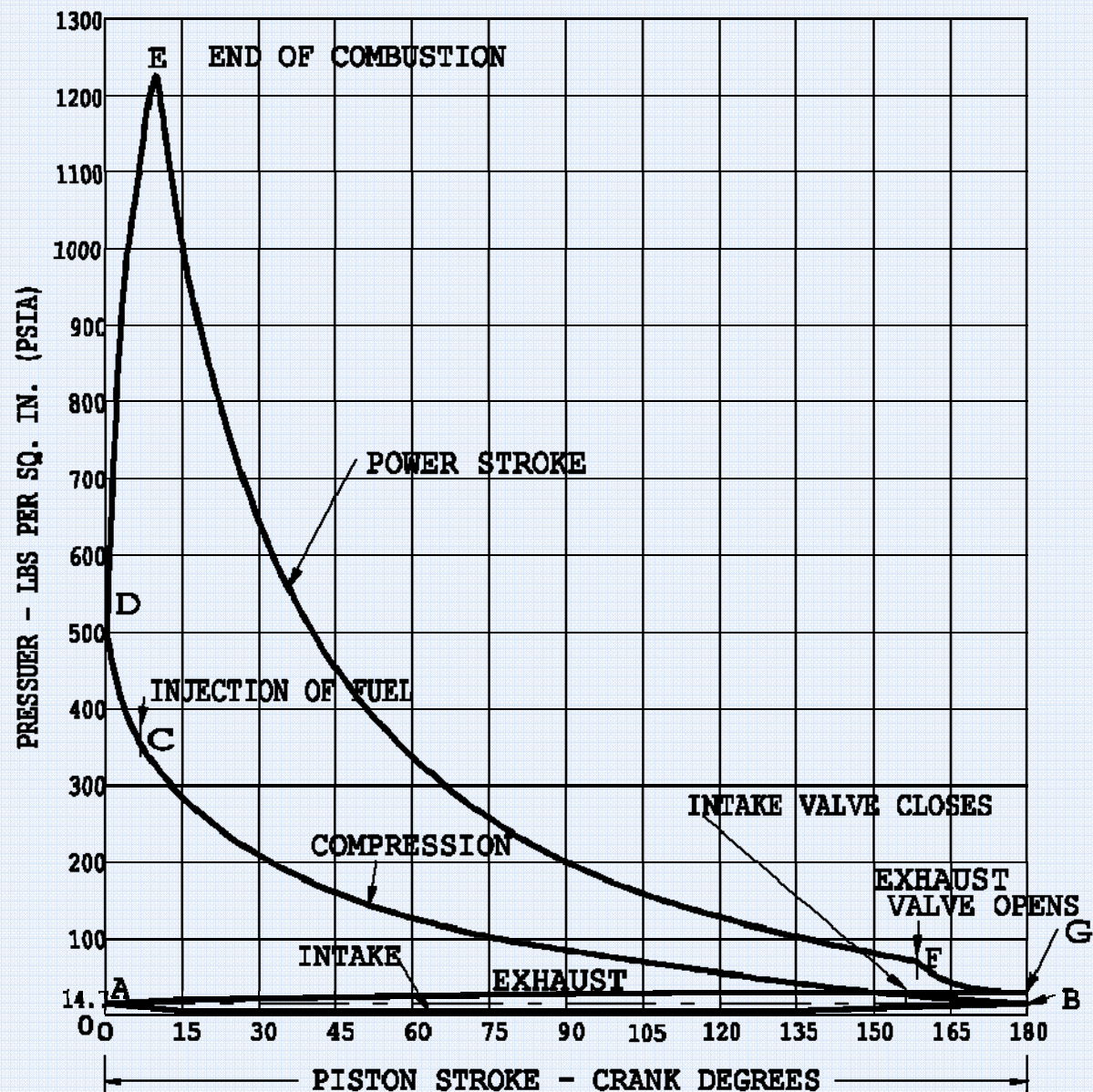


Figure 2-14
PRESSURE
VS. STROKE
DIAGRAM

The basic differences between a 2-stroke and 4-stroke cycle engine are :

- A 2-stroke cycle engine develops power output for each engine revolution (2 piston strokes).
- A 4-stroke cycle engine develops power output for each 2 engine revolutions (4 piston strokes). Four-stroke cycle EDG engines have both intake and exhaust valves which are mounted in the cylinder head.

- The 2-stroke OP engine has no cylinder heads nor valves. Both intake air and exhaust are through ports in the cylinder liner.
- The 2-stroke cycle EMD engine has intake air ports through the lower cylinder liner and exhaust valves mounted in the cylinder head.

- Two-stroke cycle engines used to power the EDG units at nuclear power stations are not operated as naturally aspirated engines. Cylinder exhaust scavenging air and cylinder combustion air are pumped in. A blower and/or a turbocharger are used for this purpose.
- The configuration and sequence of events that occur in an EMD 2-stroke cycle engine are illustrated in Figures 2-15 through 2-18.

Cylinder Displacement

- The cylinder volume is determined by the formula: $\text{Displacement} = \text{Bore}^2 \times \text{PI} / 4 \times \text{Stroke}$.
- The displacement for the whole engine is the cylinder displacement multiplied by the number of cylinders.

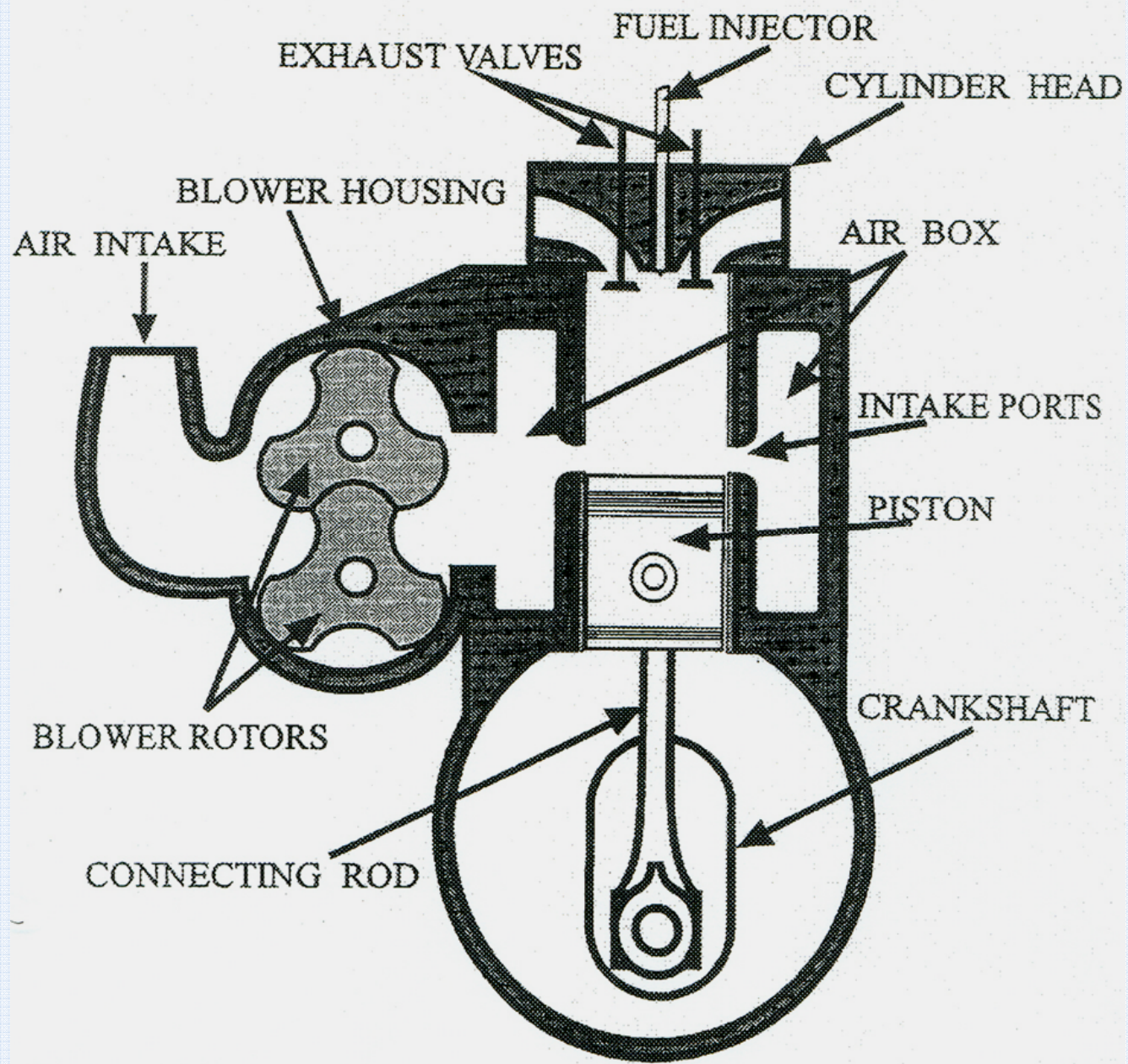


Figure 2-15

**Cylinder Configuration
of 2-Stroke Cycle EMD
Engine**

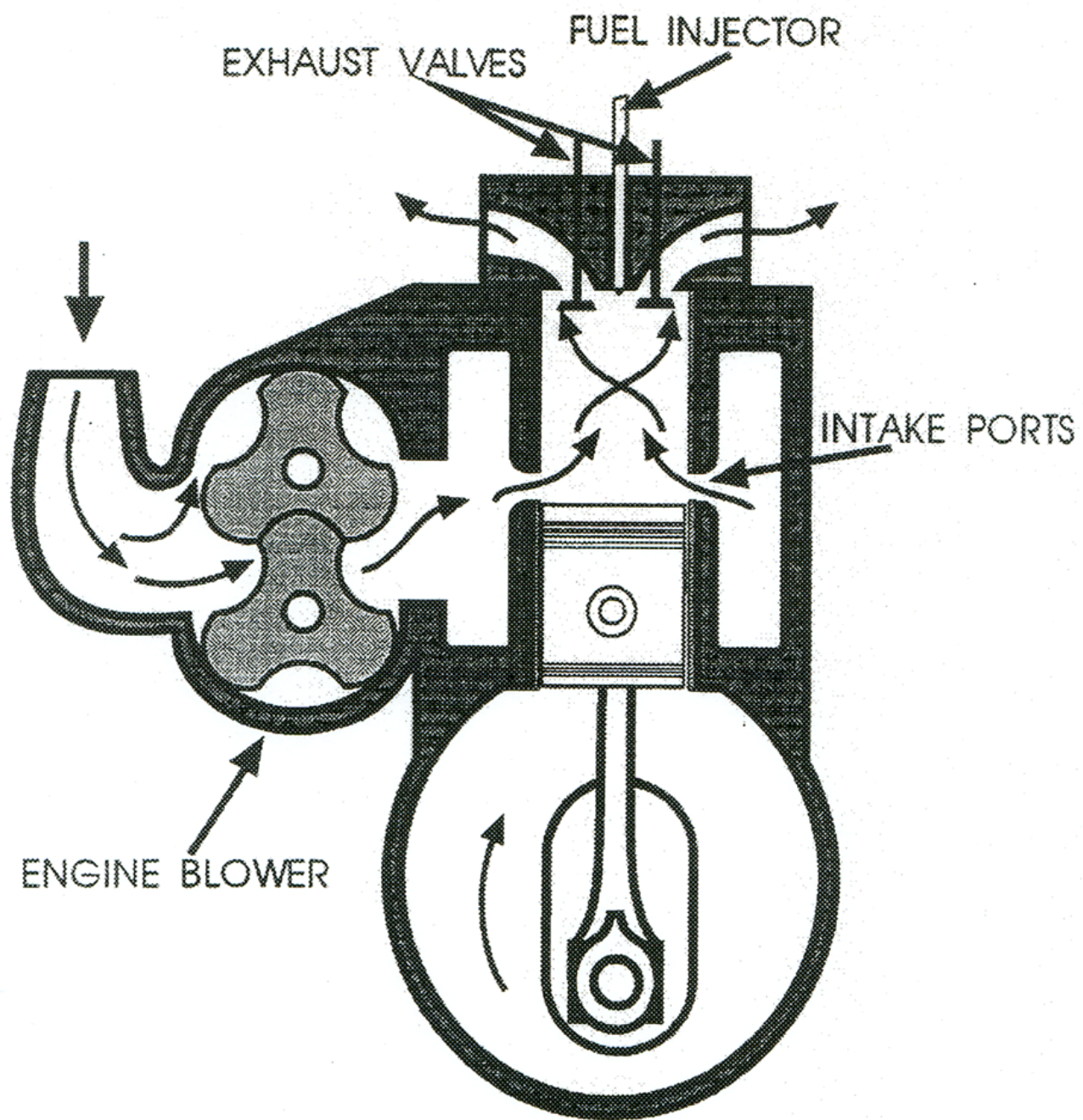


Figure 2-16

Intake Event

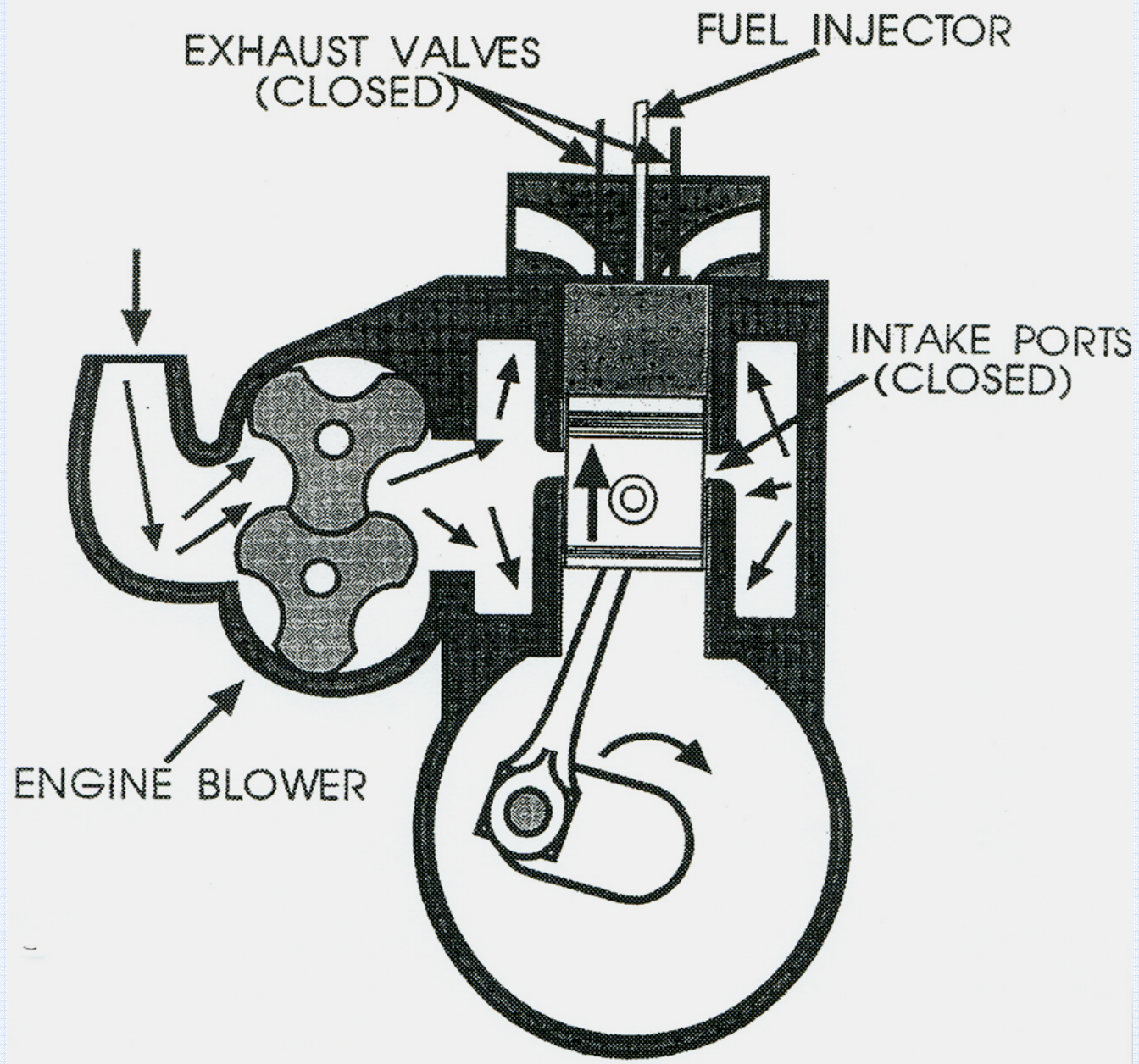


Figure 2-17
Compression
Event

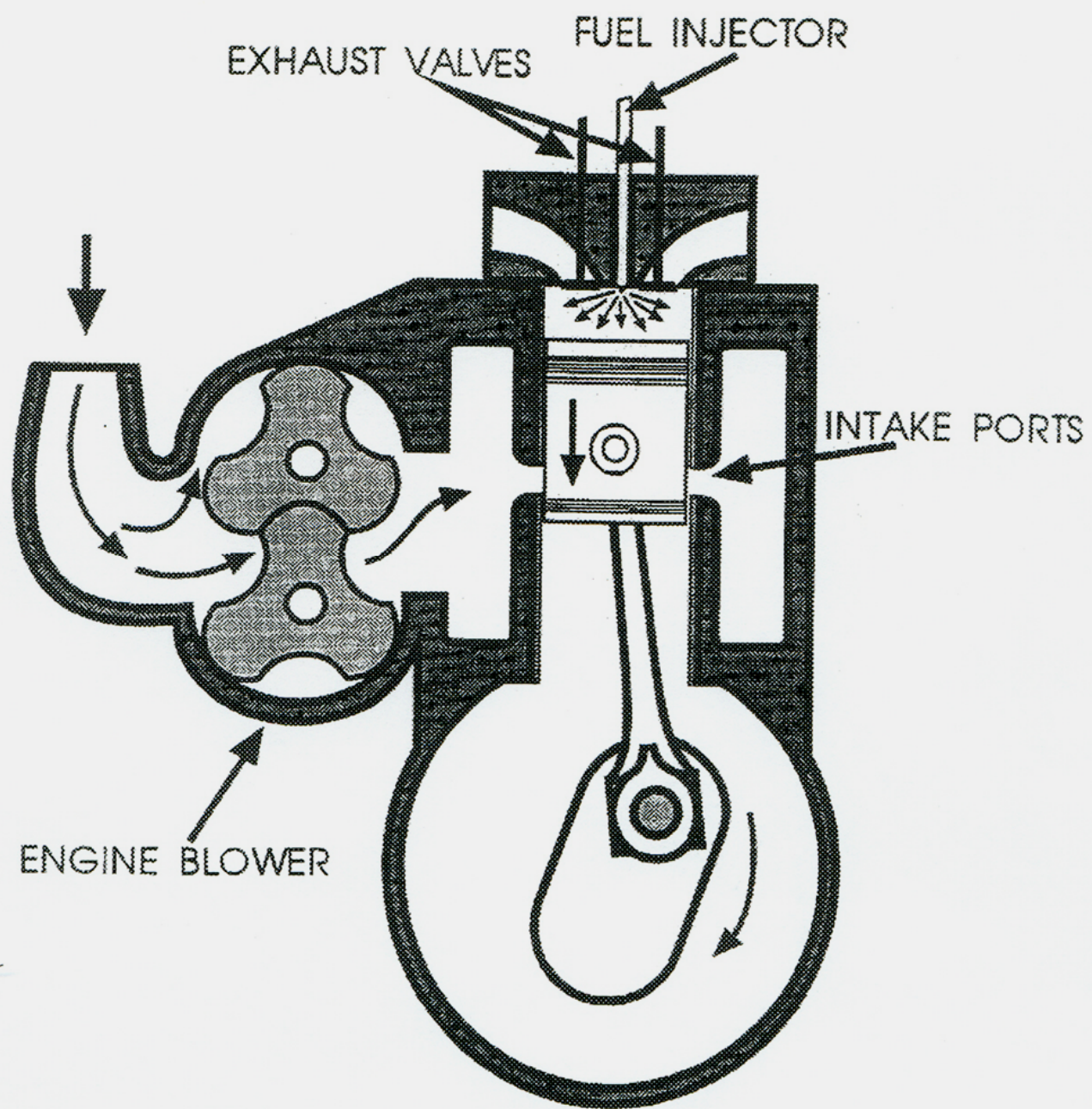


Figure 2-18

**Combustion and
Power Stroke**

- The configuration and sequence of events that occur in a Fairbanks Morse opposed piston 2-stroke cycle engine are illustrated in Figures 2-19 through 2-22.

OPPOSED PISTON ENGINE

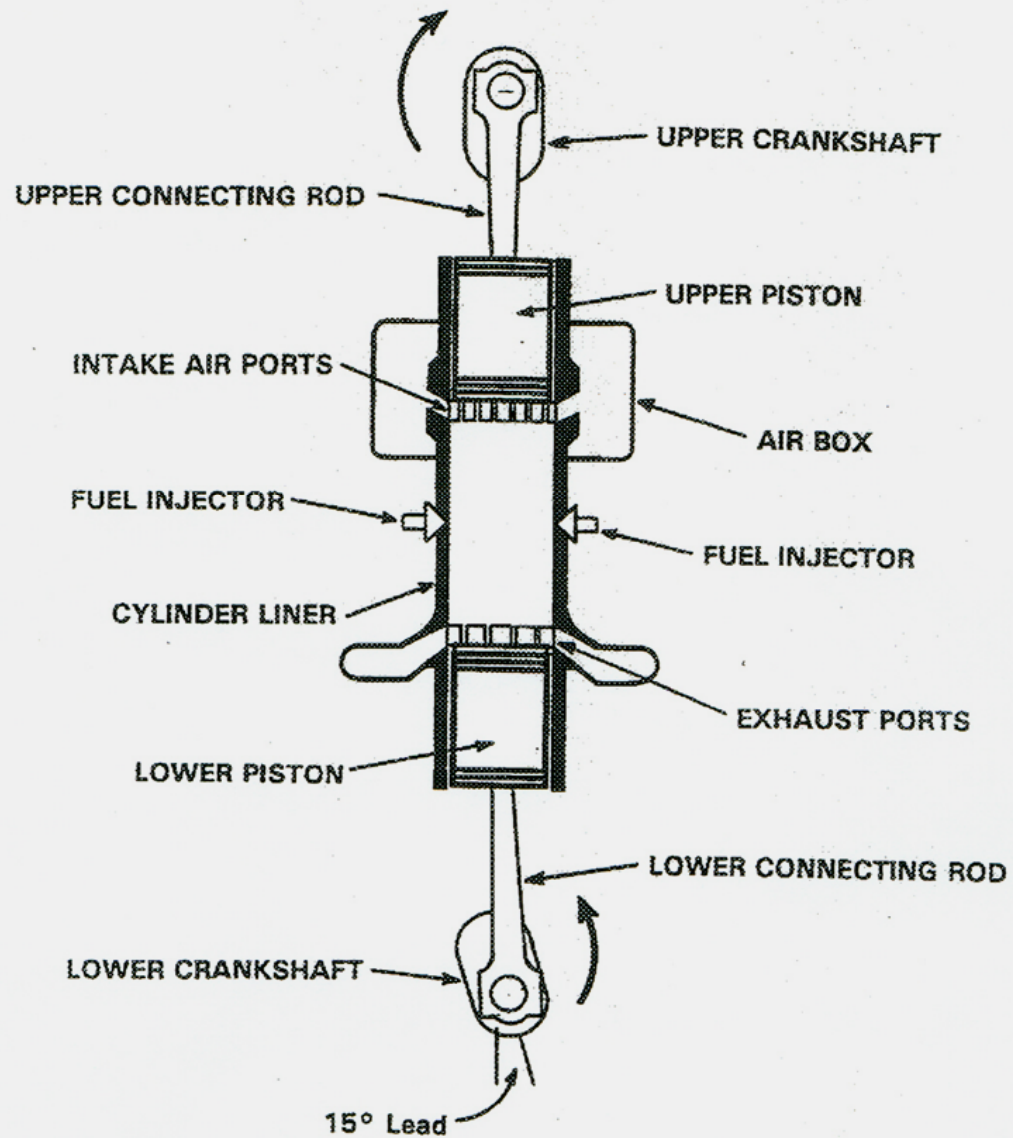


Figure 2-19

**Cylinder Configuration of
2-Stroke Cycle Opposed
Piston Engine**

INTAKE AND EXHAUST

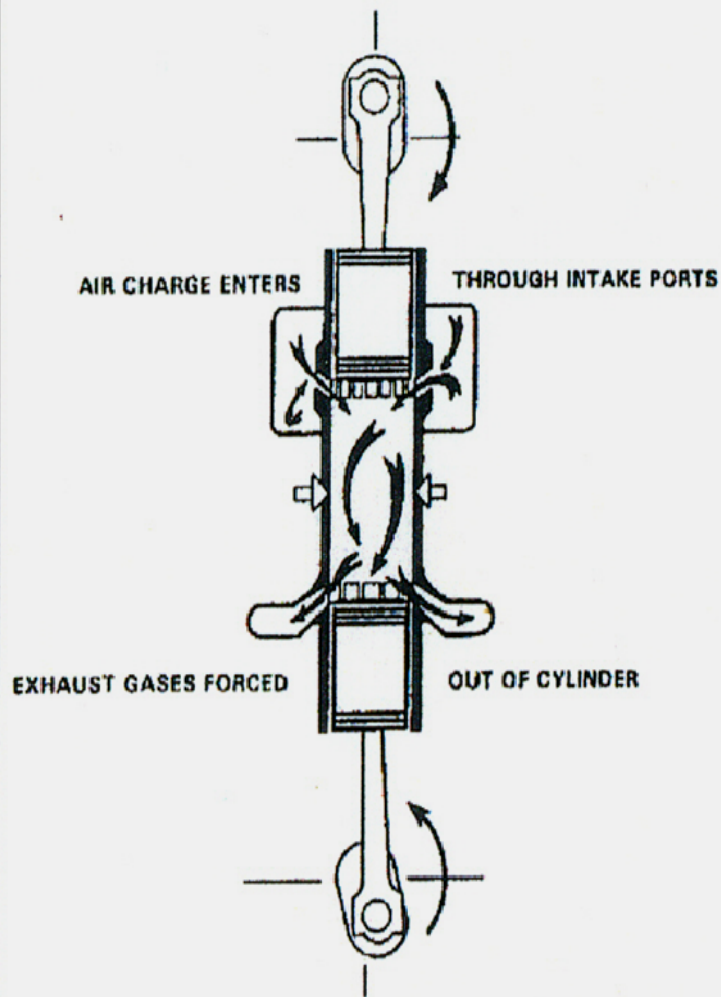


FIGURE 2-20
Intake Event

COMPRESSION

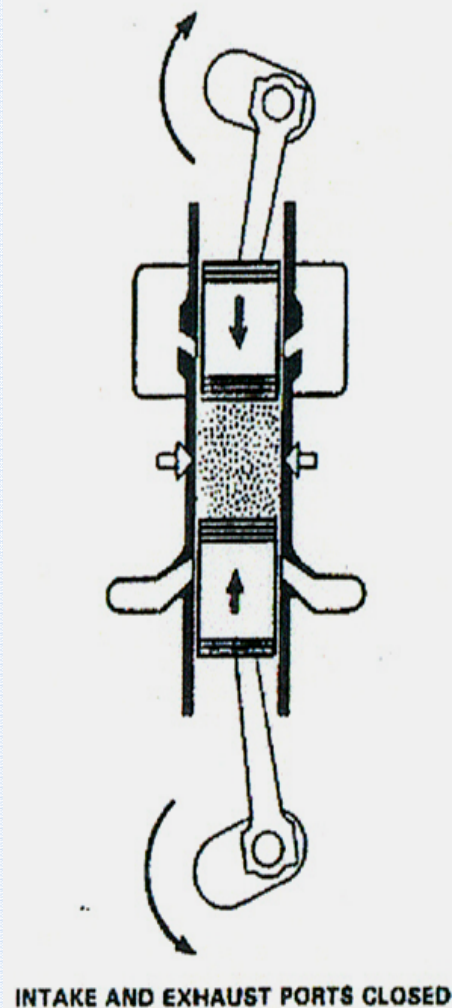


FIGURE 2-21
Compression Event

COMBUSTION AND POWER

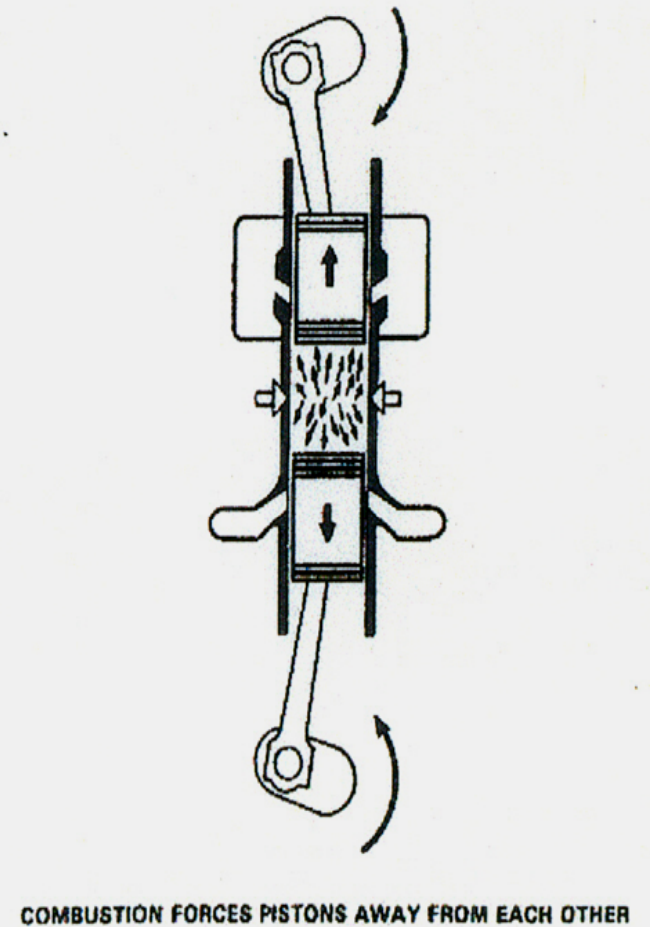


FIGURE 2-22
Combustion and
Power Event

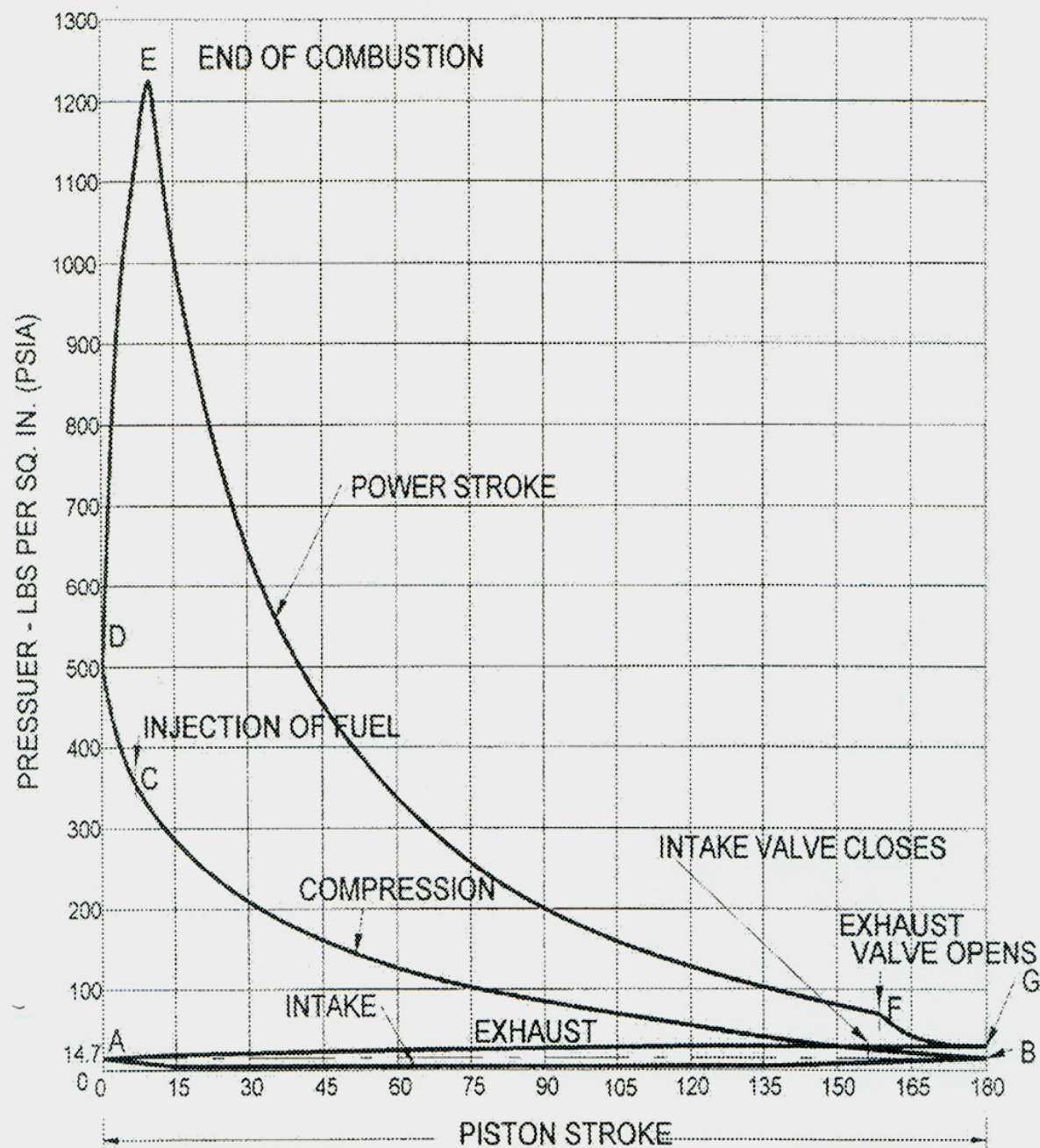


Figure 2-14
Repeated 2-Stroke
Application

Understanding Engine Terminology:

Figures 2-23 through 2-25 illustrate and define some diesel engine terminology.

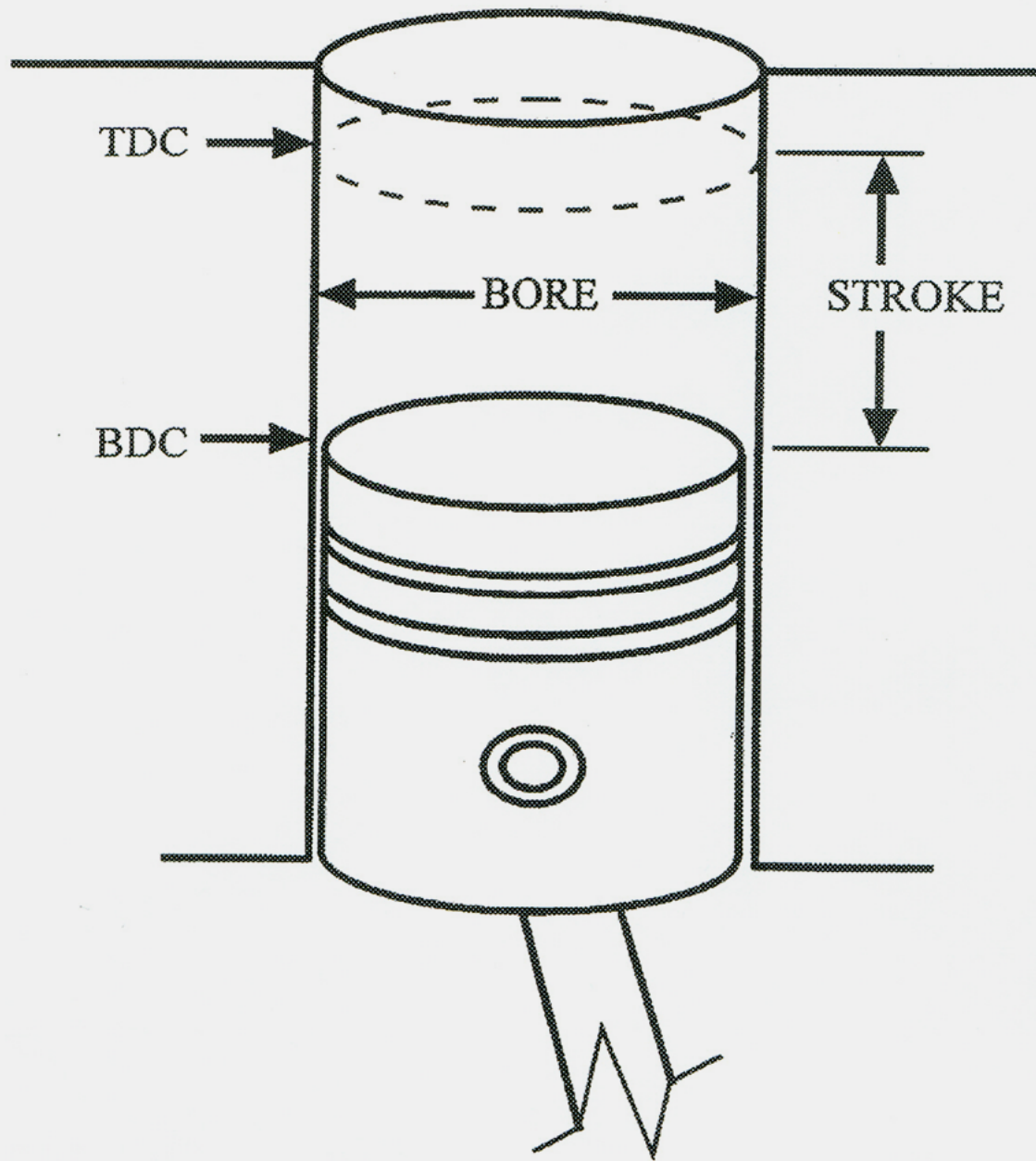


Figure 2-23
Cylinder Bore and Stroke

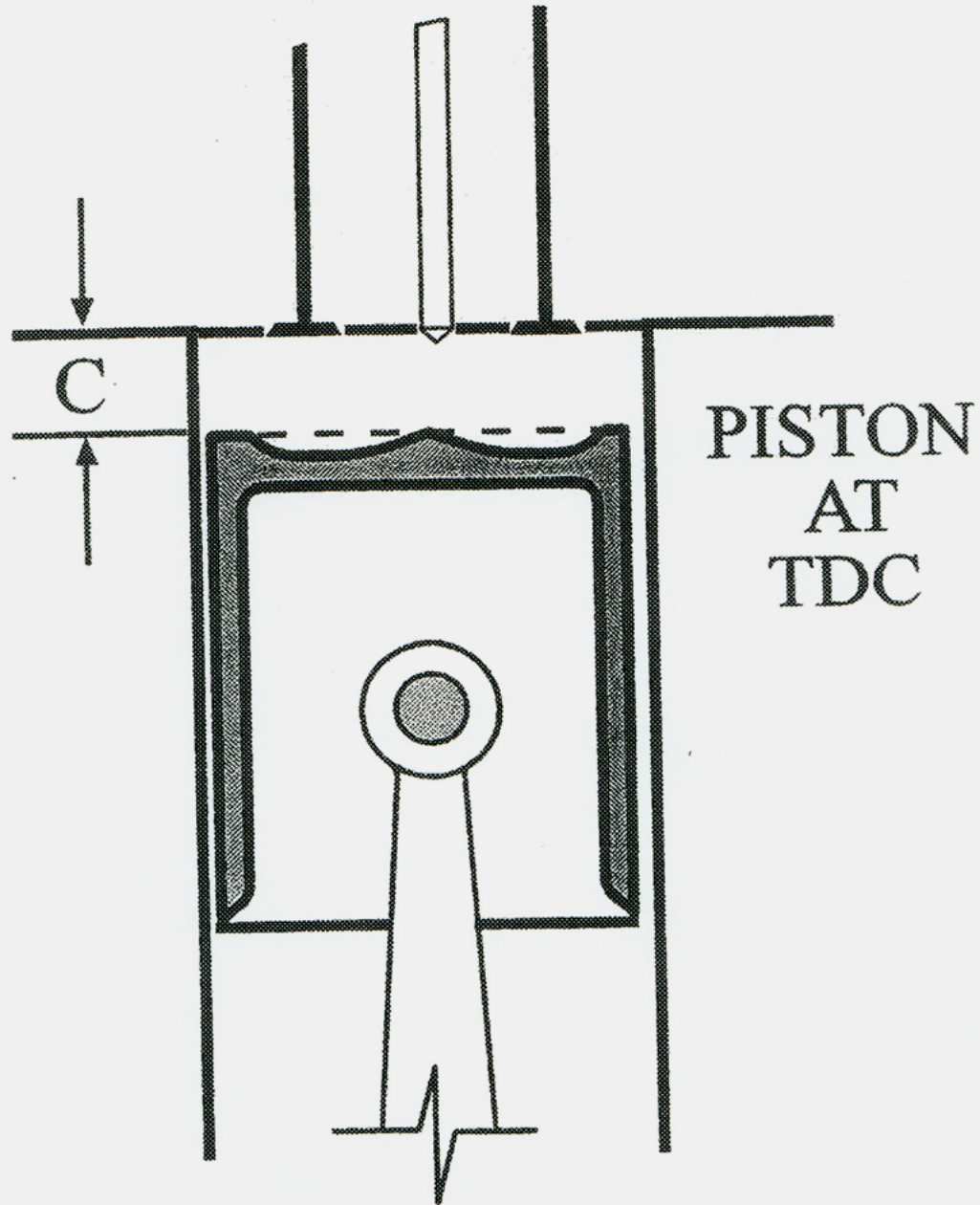


Figure 2-24
Clearance Volume
including piston cup
or head recesses.

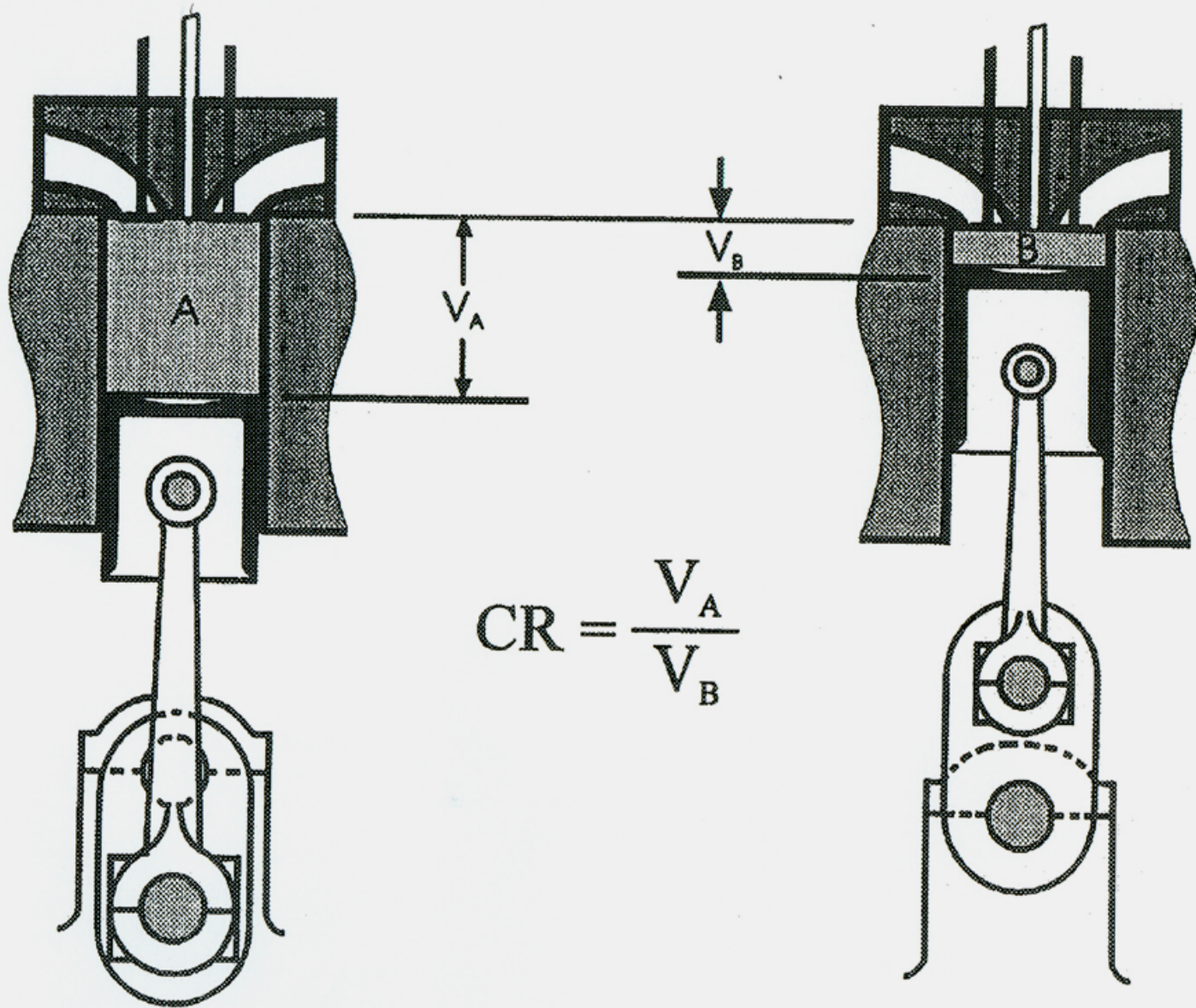


Figure 2-25 Compression Ratio = Ratio of Volumes, where V_B is the Clearance Volume

Engine Performance...

➤ Output Brake Horsepower (BHP)

- It represents the net power output of the engine at the crankshaft
- $BHP = T * N / 5252$
- T = torque in foot pounds
- N = engine speed in rpm
- Torque is usually measured by use of a prony brake or similar torque measuring device – water brake or generator output converted to HP.

➤ Indicated Horsepower (IHP)

- $IHP = P_i LAN / 33,000$

P_i = mean effective pressure in psi

L = length of stroke in **feet**

A = area of the piston in square inches

N = number of power strokes per minute

- If L is in **inches**, the constant becomes 396,000
- Area (square inches) * L (inches) = Displacement of a cylinder. That multiplied by the number of cylinders gives the Engine Displacement (DISP).

➤ Frictional Horsepower (FHP)

- This is the power required to operate the engine components and move air into and exhaust gasses out of the engine.
- The relationship between horsepowers is:
$$\text{BHP} = \text{IHP} - \text{FHP}$$

➤ Torque (T)

- This represents the twisting or turning effort of the engine.

$$T = 5252 \cdot \text{BHP} / N$$

where N = number of engine revolutions/minute

Also

$$T = \text{BMEP} \cdot \text{DISP} / 75.4$$

where DISP is that per revolution.

➤ Brake Mean Effective Pressure (BMEP)

- This is a theoretical term. It represents the mean effective pressure in psi (pounds per square inch) for each power stroke at rated BHP for the 4-stroke and 2-stroke cycle engines respectively.

$$\text{BMEP} = 792,000 \times \text{BHP} / (\text{D} \times \text{N}) \quad [4 \text{ cycle}]$$

$$\text{BMEP} = 396,000 \times \text{BHP} / (\text{D} \times \text{N}) \quad [2 \text{ cycle}]$$

where:

D = DISP = total cylinder displacement of engine

N = Number of revolutions per minute

Typical Engine Design Criteria

There are some limits imposed by physical forces that limit the power output of an engine to ensure reliability and longevity. They are as follows:

- BMEP – Typical BMEP for 2-stroke engines run from 150 to 160 psi and for 4-stroke engines run from 300 to 320 psi.
- Peak Firing Pressure – 1200 to 1500 psi
- Piston Speed – 1500 to 2000 fpm (large engines)
where $\text{Piston Speed} = \text{piston stroke (in)} \cdot 2 \cdot \text{rpm} / 12$
(OP engine at 900 rpm has a piston speed of 1500 fpm.)

Engine Efficiency

➤ Mechanical Efficiency

- $e_m = \text{BHP} / \text{IHP}$

➤ Thermal Efficiency

- $e_t = \frac{\text{energy output of crankshaft}}{\text{energy input of fuel oil}}$

(all in Btu units)

Typical heat balance for a diesel engine (HEAT IN = HEAT OUT)

- Power output (BHP) = 33 - 40%
- Exhaust and radiation = 30 - 33%
- Jacket water cooling = 10 - 15%
- Lube oil cooler = 4 - 8%
- Turbocharger aftercooler = 5 - 10%
- Generator inefficiency = 3 - 5%
- Radiation (engine to room) = 2%

Brake Specific Fuel Consumption (bsfc)

- This is an indication of engine efficiency.
- $\text{bsfc} = \text{fuel burned per hour} / \text{BHP}$
- Typical bsfc for modern engine is about .30 to .325 lbs per bhp-hr.

Super charging with blowers and/or turbochargers

- Blowers are gear-driven from engine and require engine horsepower.
- Turbochargers are powered from the energy in the engine exhaust and do not usually require engine horsepower. The EMD turbocharger requires engine horsepower during startup and at low power levels.

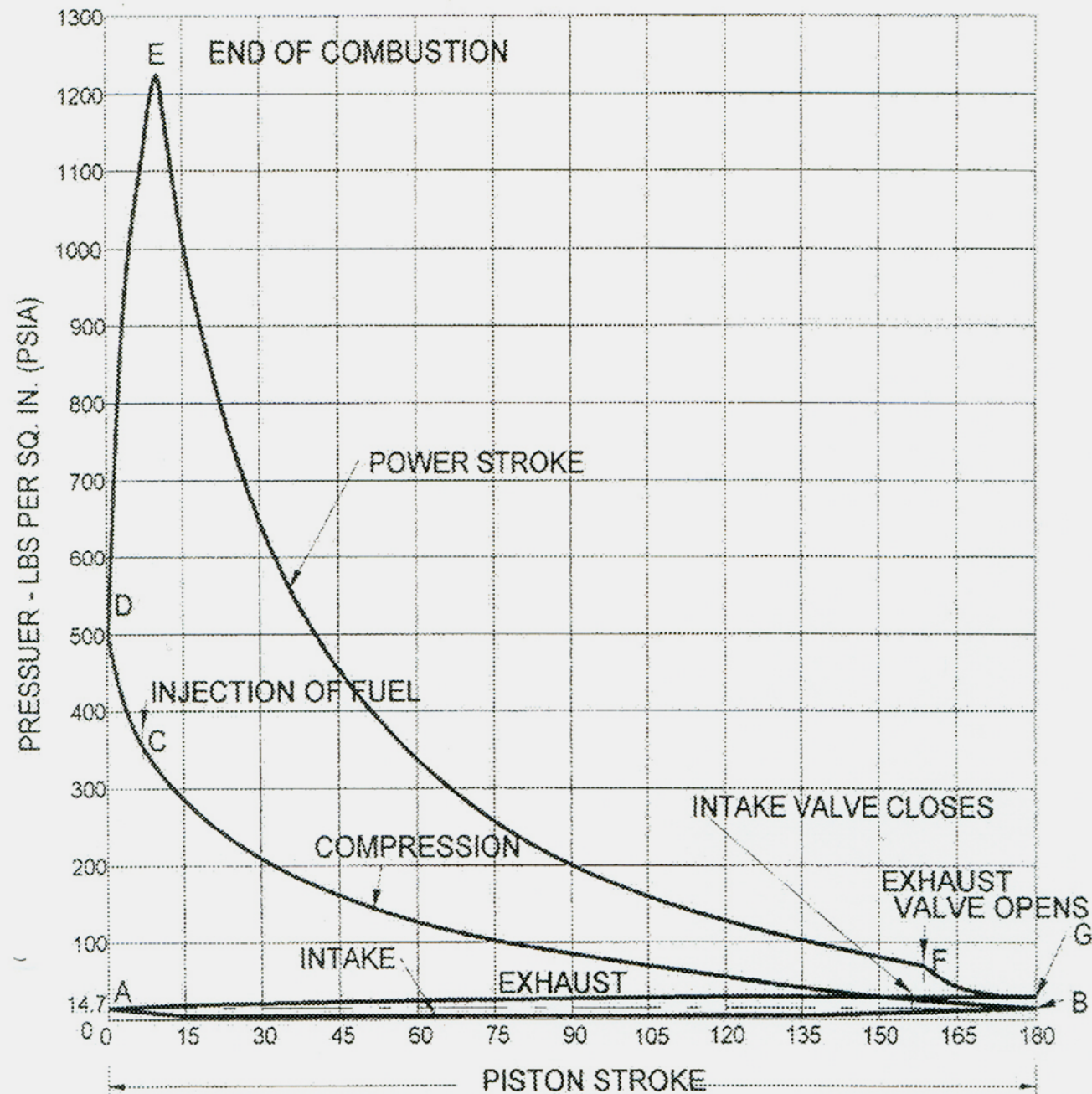


Figure 2-14
Repeated Effect of
Turbocharging

Typical times for events to occur in a 900 rpm, 2-stroke or 4-stroke diesel engine are shown in Figures 2-26 and 2-27. Note that all events in the 2-stroke cycle engine at 900 rpm must occur within 67 thousandths (.067) of a second.

<u>Event</u>	<u>2-Cycle Engines Fraction of a Second</u>	<u>4-Cycle Engines Fraction of a Second</u>
Fuel Injection	.003	.003
Power	.022	.026
Exhaust	.005	.031
Scavenging	.018	.022
Intake	.002	.033
Compression	.020	.025

The above figures are based on an engine operating at 900 rpm. For a 2-cycle engine, all events must occur within one revolution or .067 seconds. For the 4-cycle engine, there is twice as much time.

Note: Some events overlap; therefore, not all figures are cumulative.

FIGURE 2-26 Typical Times for Events 900 rpm Diesel Engines

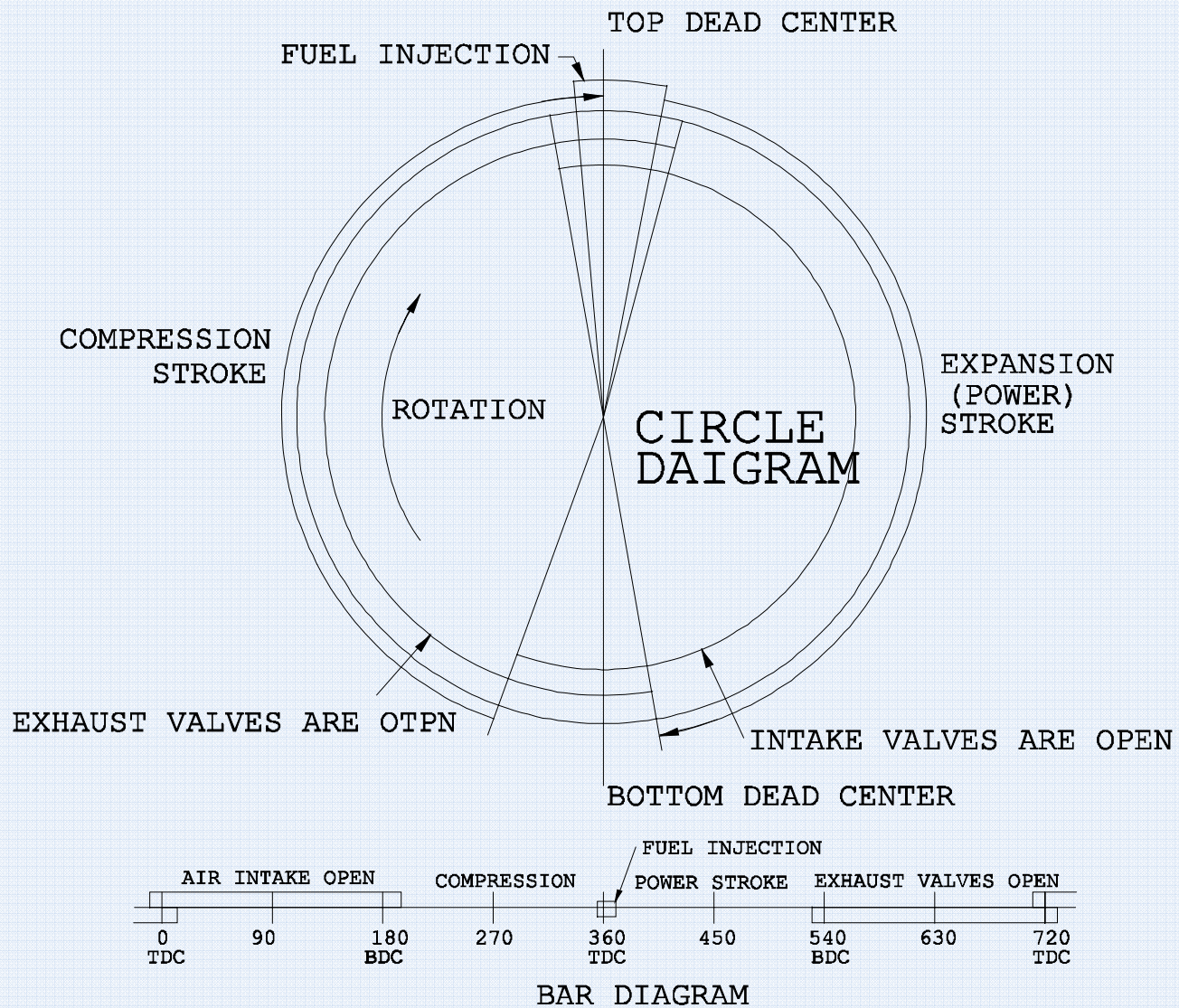


Figure 2-27A Typical Timing Diagrams – 4 Stroke Cycle

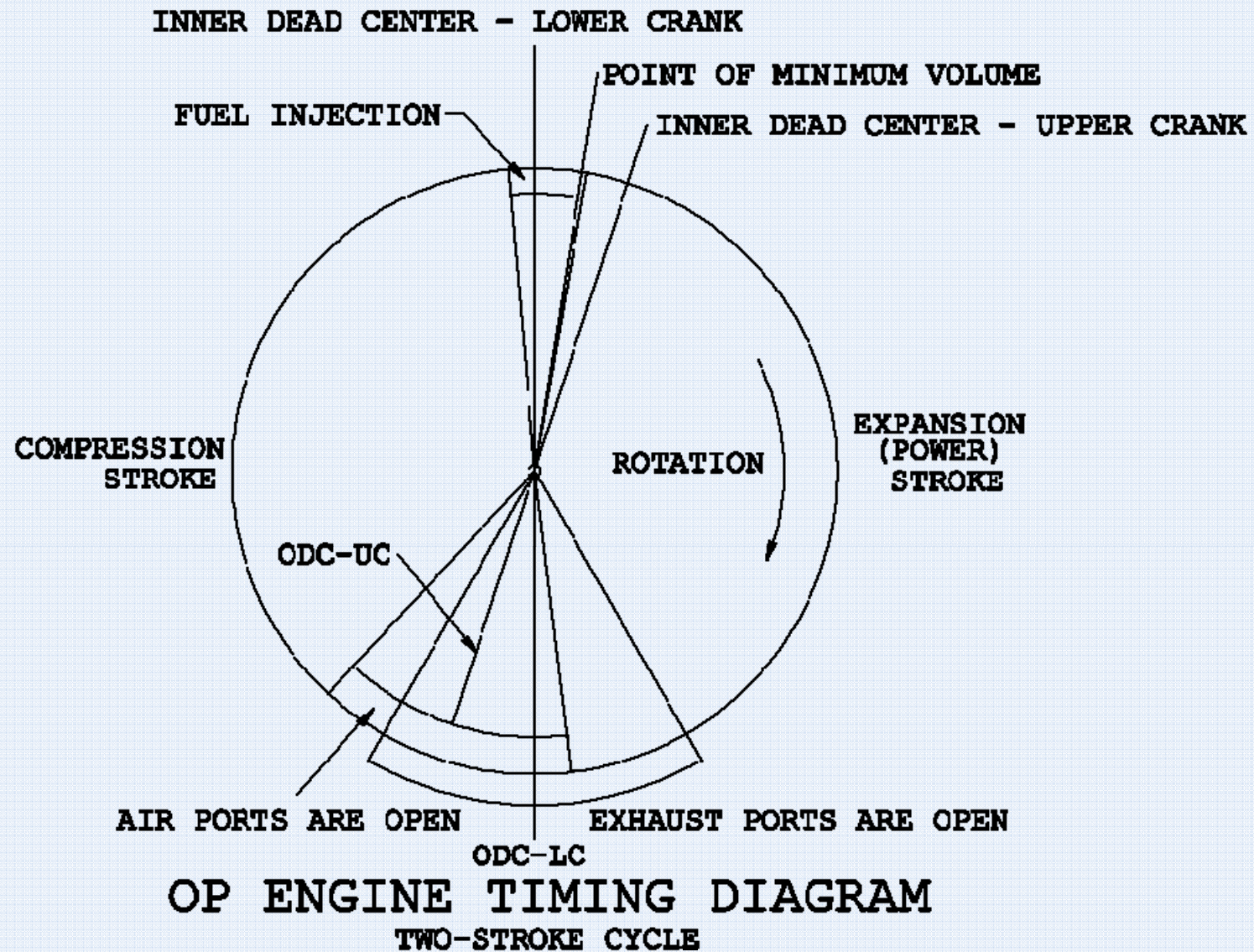


Figure 2-27B Typical Timing Diagrams – OP Engine

Hands-On Training Session...

We will now begin Hands-on training, utilizing the motorized cutaway 2-stroke cycle OP engine and the motorized cutaway 4-stroke cycle ALCO engine.

END OF CHAPTER 2

