INTERNAL COMBUSTION ENGINES

Kashif Liaqat

Department of Mechanical Engineering, BUITEMS, Quetta, Pakistan

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Lecture # 1

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- **2-Operating Characteristics (**Engine parameters, Torque, Power, pressure, Efficiency, Volumetric efficiency**)**
- **3-Engine cycles (**Otto cycle, SI cycle, Diesel cycle, Dual cycle, CI cycle**)**
- **4-Thermochemistry and Fuels (**Hydrocarbon Fuels-Gasoline, Self-Ignition and Octane Number, Diesel Fuel**)**
- **5-Air and Fuel induction (**Fuel Injectors, Carburetors, Supercharging and Turbocharging**)**
- **6-Emission and air pollutions (***Co_2, Co, No_x and solid particles***)**

RECOMMENDED BOOKS/SOURCES

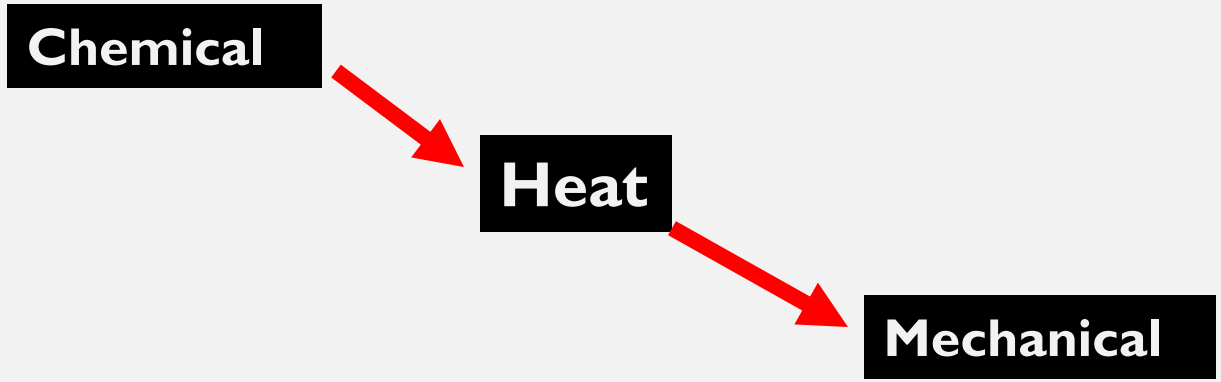
1) Heywood, J.B. (), Internal Combustion Engine Fundamental
   - McGraw-Hill

2) Pulkrabek W.W. (2003), Engineering Fundamentals of the Internal Combustion Engine
   - University of Wisconsin-Platteville.

3) MIT Online Courseware
   - Internal Combustion Engines - https://ocw.mit.edu/courses/mechanical-engineering/2-61-internal-combustion-engines-spring-2017/

INTRODUCTION

The internal combustion engine is a heat engine that converts chemical energy in a fuel into mechanical energy

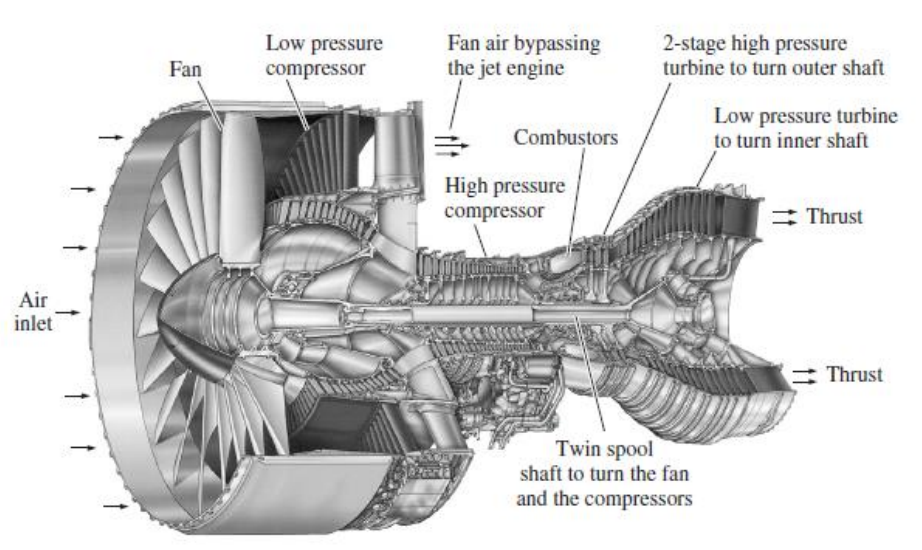


This thermal energy raises the temperature and pressure of the gases within the engine, and the high-pressure gas then expands against the mechanical mechanisms of the engine. This expansion is converted by the mechanical linkages of the engine to a rotating crankshaft, which is the output of the engine.

INTRODUCTION

Internal combustion engines are **reciprocating engines** having pistons that reciprocate back and forth in cylinders internally within the engine.

Engine types not covered by this course include steam engines and gas turbine engines, which are better classified as **external combustion engines** **(i.e., combustion takes place outside the** mechanical engine system)



HISTORY

- 1862 -- Rochas described the basic principles essential for efficient engine operation.
- 1878 – Otto built the first successful 4-stroke cycle engine.
- 1891 – Day built an improved 2-stroke cycle engine.
- 1892 – Diesel patented the compression-ignition (diesel) engine.
- To present – emphasis on improved engine efficiency, through refinement.

- Most widely used:
  - Otto (4 Stroke)
  - Diesel (4 Stroke)

ENGINE CLASSIFICATIONS

- Internal combustion engines can be classified in a number of different ways:

1. Types of Ignition

(a) Spark Ignition (SI). An SI engine starts the combustion process in each cycle by use of a spark plug. The spark plug gives a high-voltage electrical discharge between two electrodes which ignites the air-fuel mixture in the combustion chamber surrounding the plug.

(b) Compression Ignition (CI). The combustion process in a CI engine starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.

ENGINE CLASSIFICATIONS

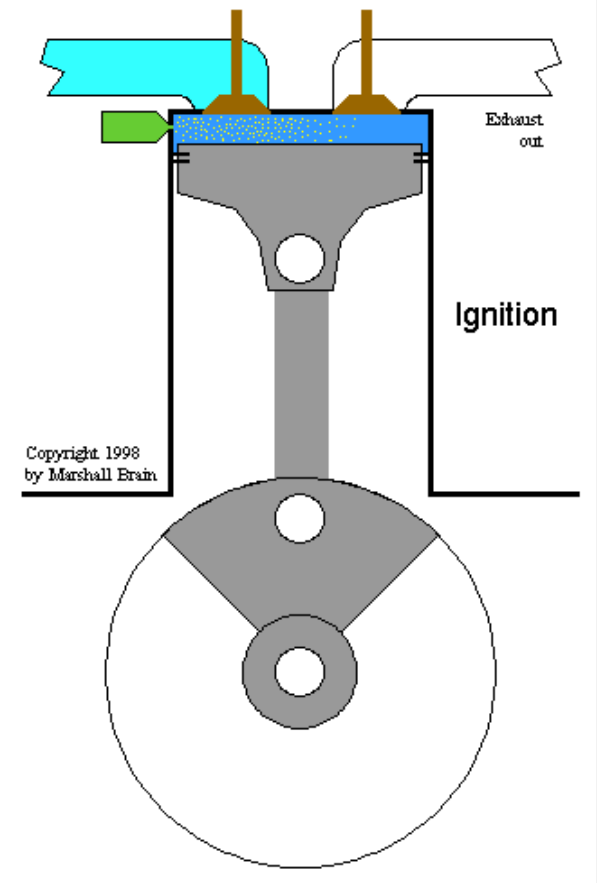
- Internal combustion engines can be classified in a number of different ways:

1. Types of Ignition

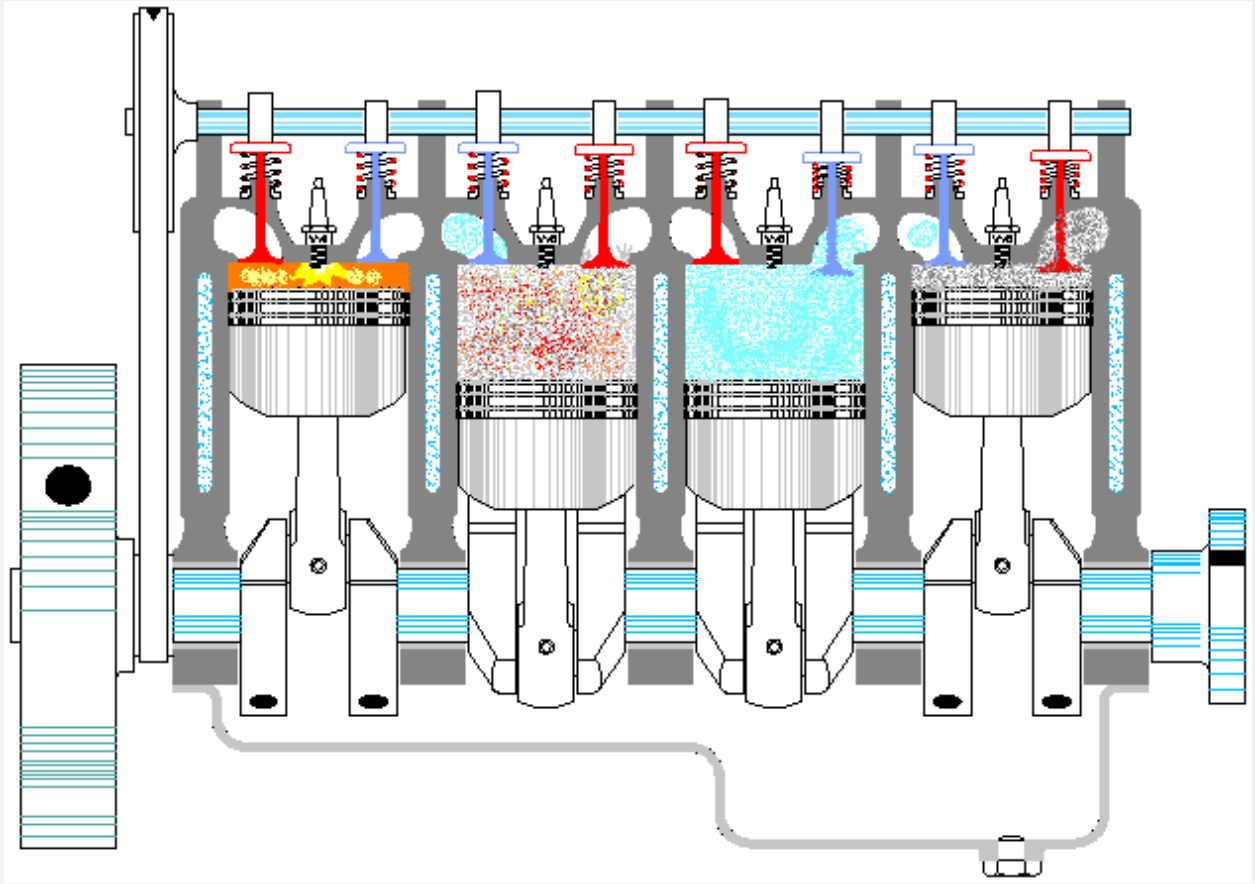
2. Engine Cycle

(a) Four-Stroke Cycle. A four-stroke cycle experiences four piston movements over two engine revolutions for each cycle.
(b) Two-Stroke Cycle. A two-stroke cycle has two piston movements over one revolution for each cycle.

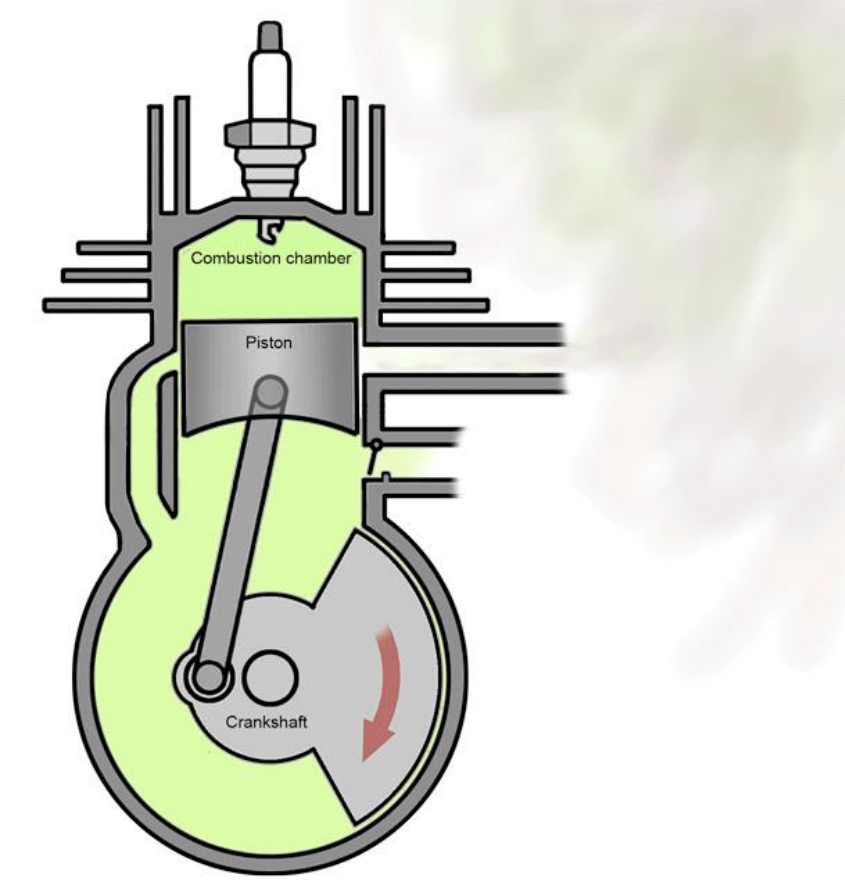
FOUR-STROKE CYCLE I.C. ENGINE



FOUR-STROKE CYCLE I.C. ENGINE



TWO-STROKE CYCLE ENGINES



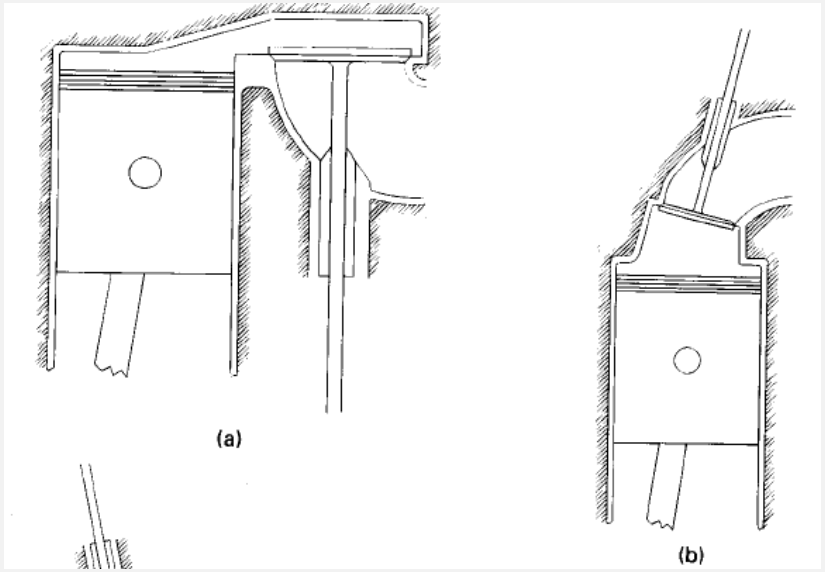
COMPARISON OF TWO-STROKE VS. FOUR-STROKE CYCLE ENGINES

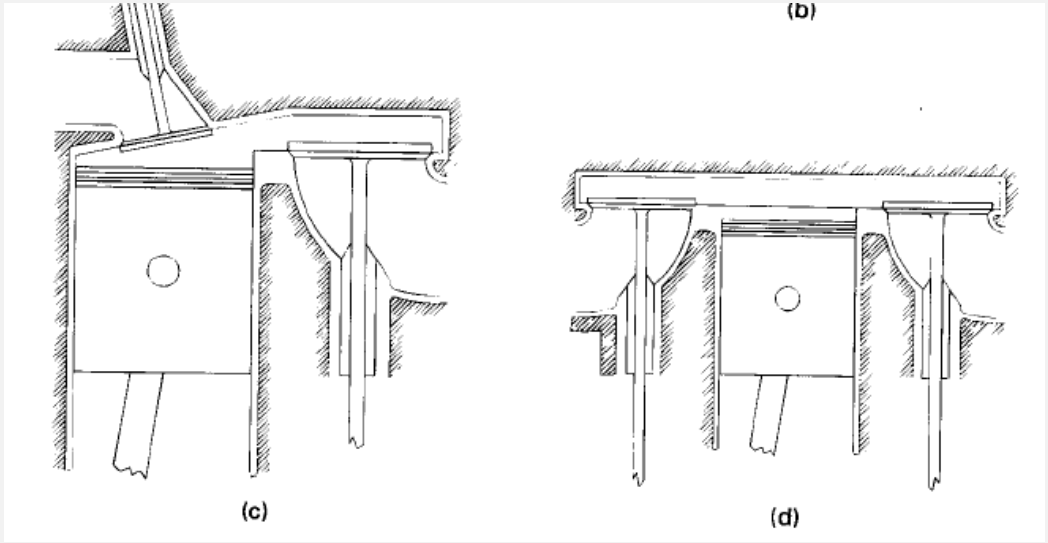
Two-Stroke Cycle Engines	Four-Stroke Cycle Engines
Lighter weight	Heavier weight
Operates in many positions	Operates in limited positions
Higher power to weight ratio	Lower power to weight ratio
Engine oil usually mixed with fuel	Engine oil in a reservoir
Louder operation	Quieter operation
Higher engine speeds	Slower engine speeds
More vibration	Smoother operation
Rough idling operation	Smoother Idling operation

VALVE LOCATION

(a) Valves in head (overhead valve), also called I Head engine.

(b) Valves in block (flat head), also called L Head engine. Some historic engines with valves in block had the intake valve on one side of the cylinder and the exhaust valve on the other side. These were called **T Head engines.**





L Head engine **I Head engine** **F Head engine** **T Head engine**

DESIGNS

(a) Reciprocating. Engine has one or more cylinders in which pistons reciprocate back and forth. The combustion chamber is located in the closed end of each cylinder. Power is delivered to a rotating output crankshaft by mechanical linkage with the pistons.

(b) Rotary. Engine is made of a block (stator) built around a large non-concentric rotor and crankshaft. The combustion chambers are built into the non-rotating block.

5. Position and Number of Cylinders

(a) Single Cylinder.

(b) In-Line.

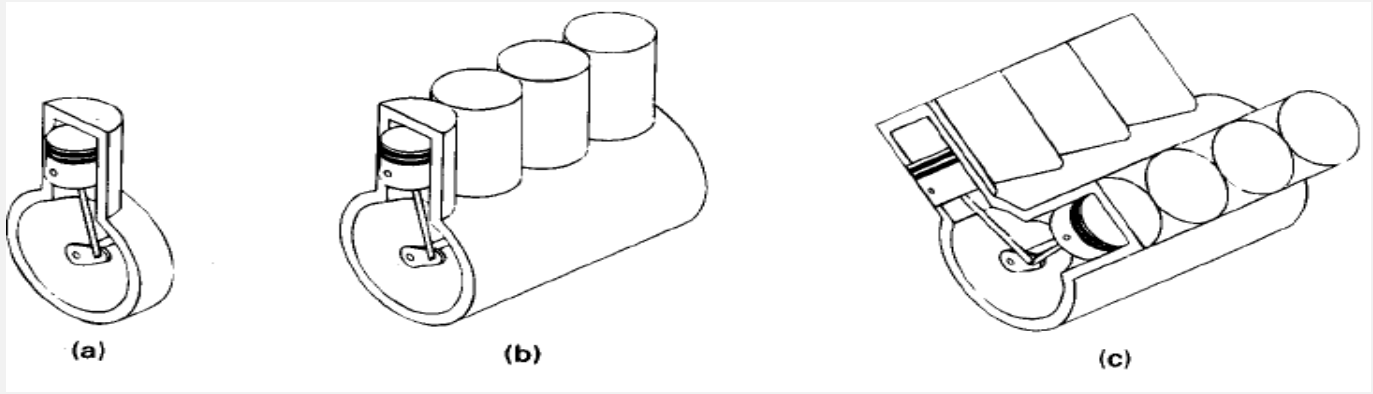
(c) V Engine.

(d) Opposed Cylinder Engine.

(e) W Engine.

(f) Opposed Piston Engine.

(g) Radial Engine.



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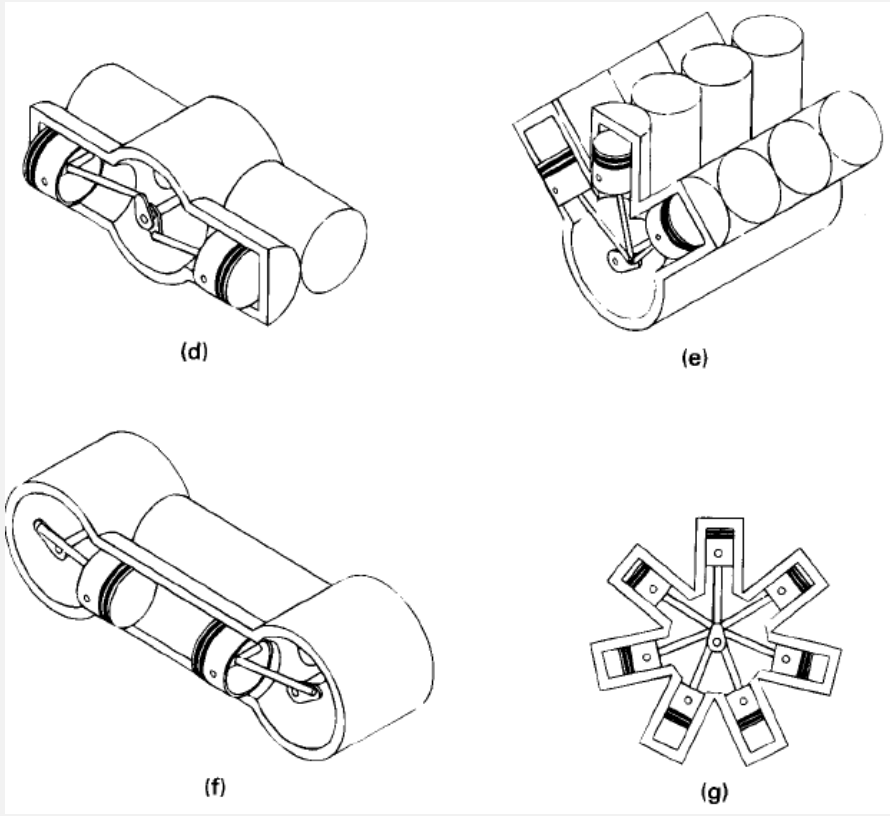
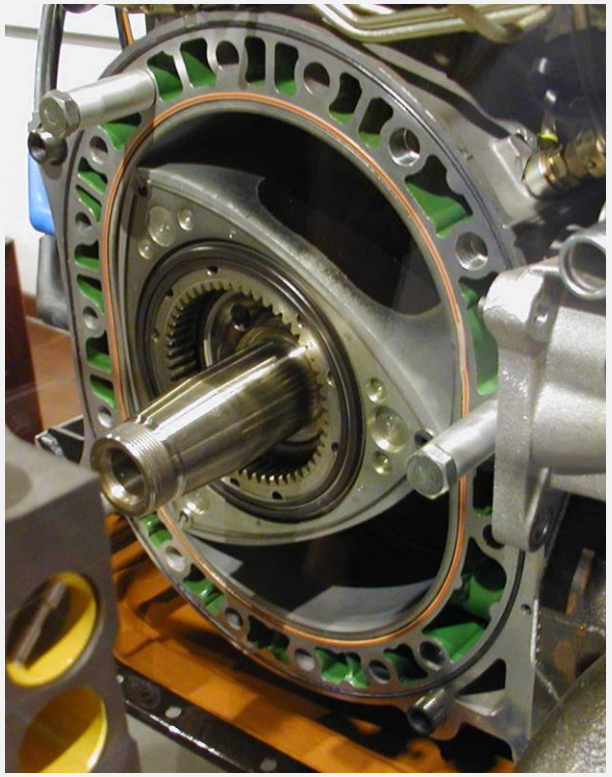


ROTARY ENGINE



AIR INTAKE PROCESS

(a) **Naturally Aspirated**. No intake air pressure boost system.

(b) **Supercharged**. Intake air pressure increased with the compressor driven off of the engine crankshaft.

(c) **Turbocharged**. Intake air pressure increased with the turbine-compressor driven by the engine exhaust gases.

(d) **Crankcase Compressed**. Two-stroke cycle engine which uses the crankcase as the intake air compressor. Limited development work has also been done on design and construction of four-stroke cycle engines with crankcase compression.

METHOD OF FUEL INPUT FOR SI ENGINES

(a) Carbureted.

(b) Multipoint Port Fuel Injection. One or more injectors at each cylinder intake.

(c) Throttle Body Fuel Injection. Injectors upstream in intake manifold.

(d) Electronic **fuel** injection

- EFI system improves average fuel economy of 13%

FUEL USED

(a) Gasoline.

(b) Diesel Oil or Fuel Oil.

(c) Gas, Natural Gas, Methane.

(d) LPG.

(e) Alcohol-Ethyl, Methyl.

(f) Dual Fuel. There are a number of engines that use a combination of two or more fuels. Some, usually large, CI engines use a combination of methane and diesel fuel. These are attractive in developing third-world countries because of the high cost of diesel fuel. Combined gasoline-alcohol fuels are becoming more common as an alternative to straight gasoline automobile engine fuel.

(g) Gasohol. Common fuel consisting of 90% gasoline and 10% alcohol.

APPLICATIONS

(a) Automobile, Truck, Bus.

(b) Locomotive.

(c) Stationary

- They are used to drive immobile equipment, such as pumps, generators, mills or factory machinery, or cable cars.

(d) Marine.

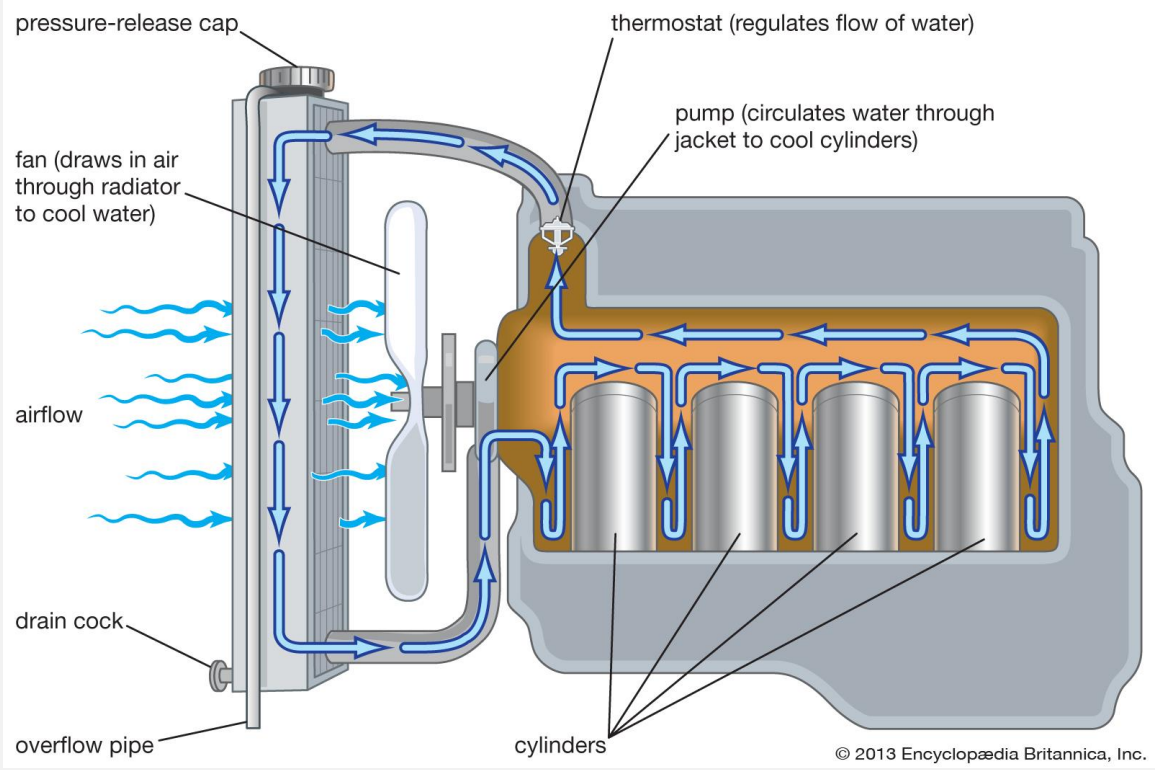
(e) Aircraft.

(f) Small Portable, Chain Saw, Model Airplane

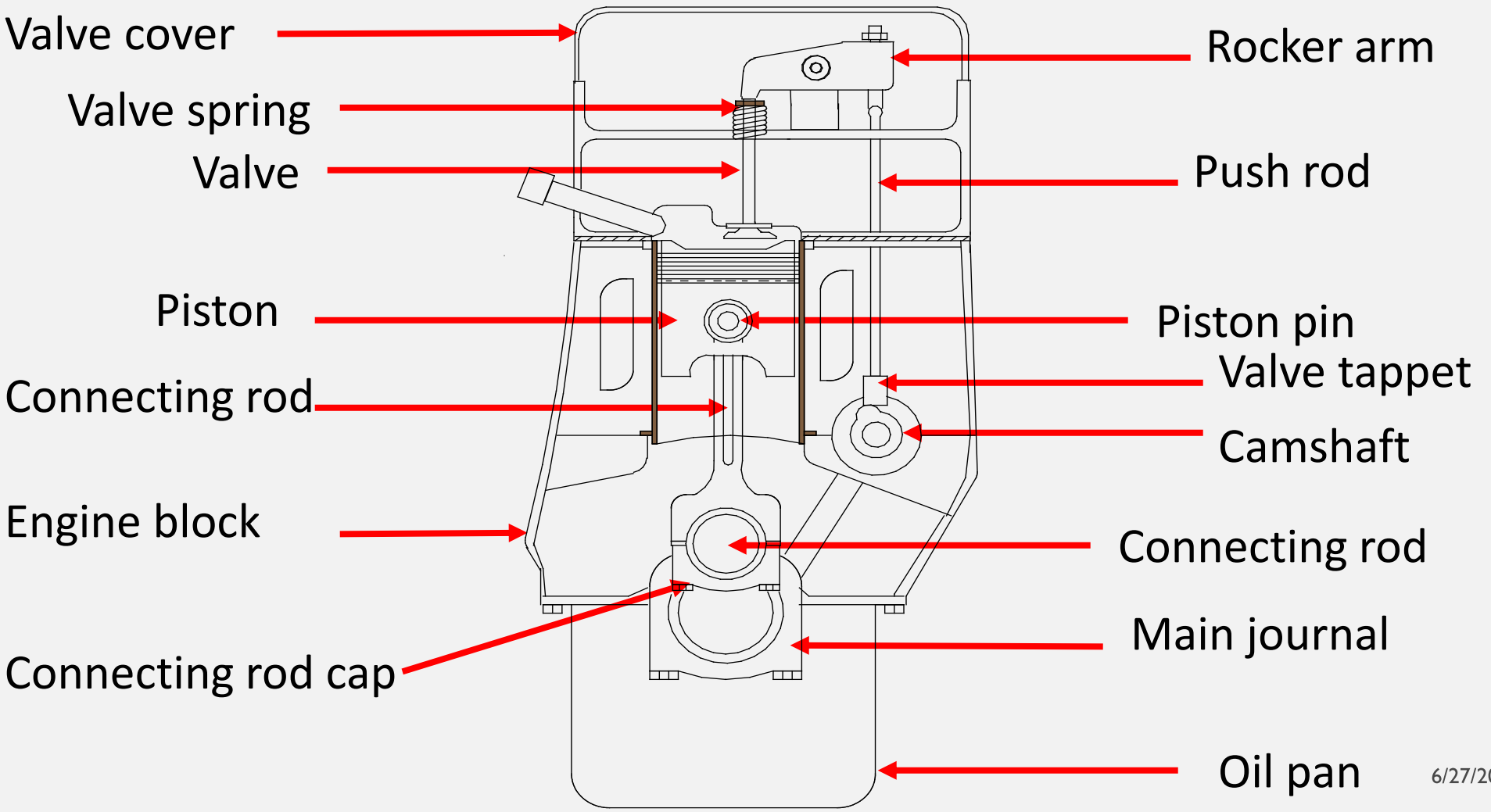
TYPE OF COOLING

(a) Air Cooled

(b) Liquid Cooled, Water Cooled



ENGINE PARTS



CYLINDER BLOCK

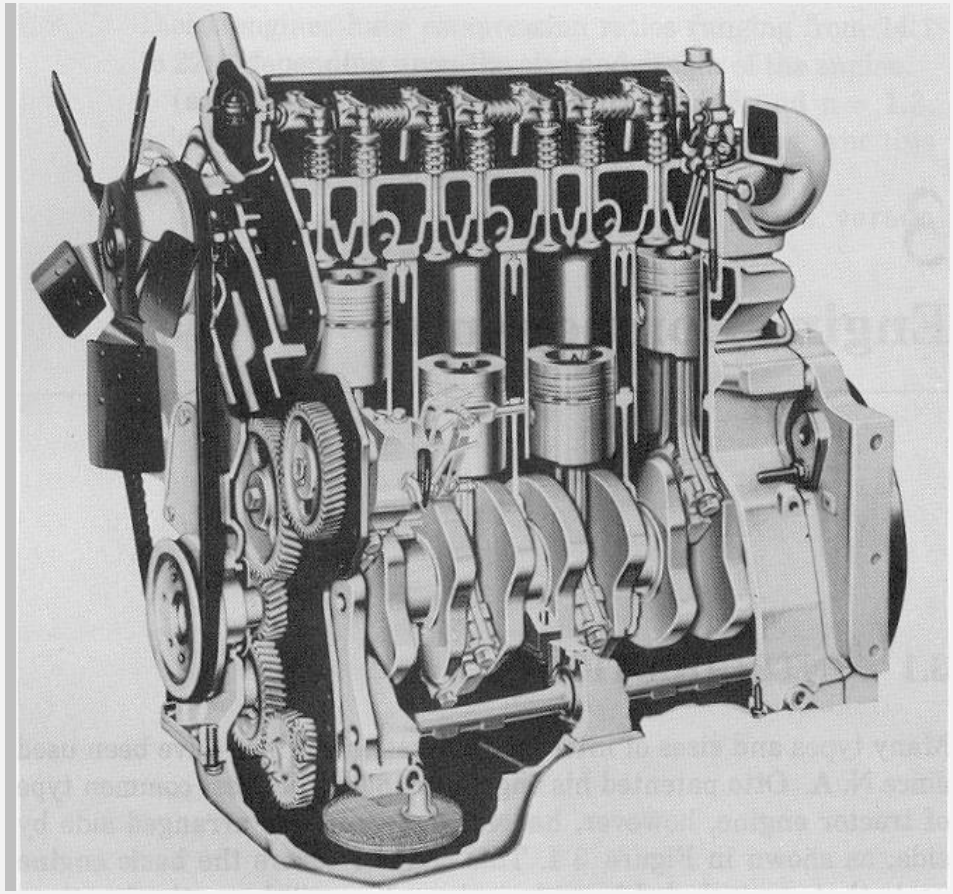
"Backbone" of the engine.

- Supports / aligns most other components.
- Part of basic tractor frame.

Contains:

- Cylinders
- Coolant passages
- Oil passages
- Bearings

One-piece, gray cast iron



CYLINDERS

- Cylindrical holes in which the pistons reciprocate.
- Cylinder bore – diameter of cylinder

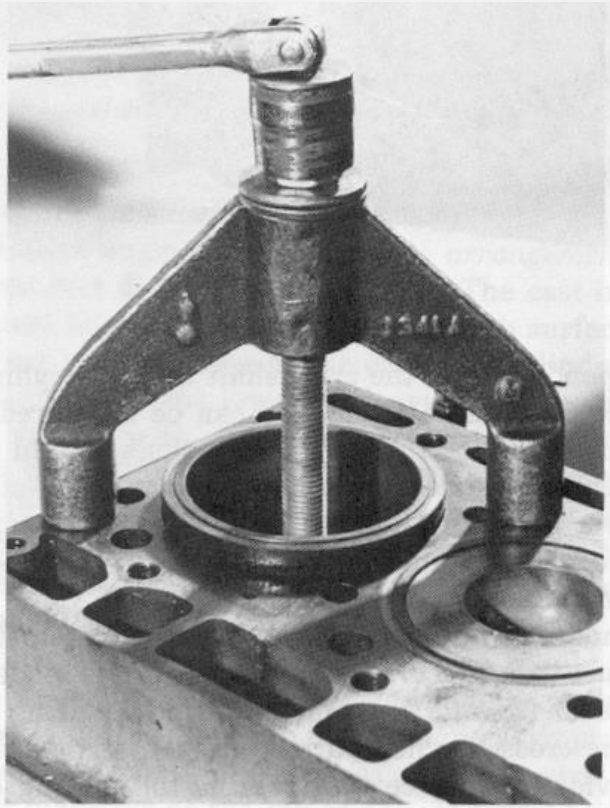
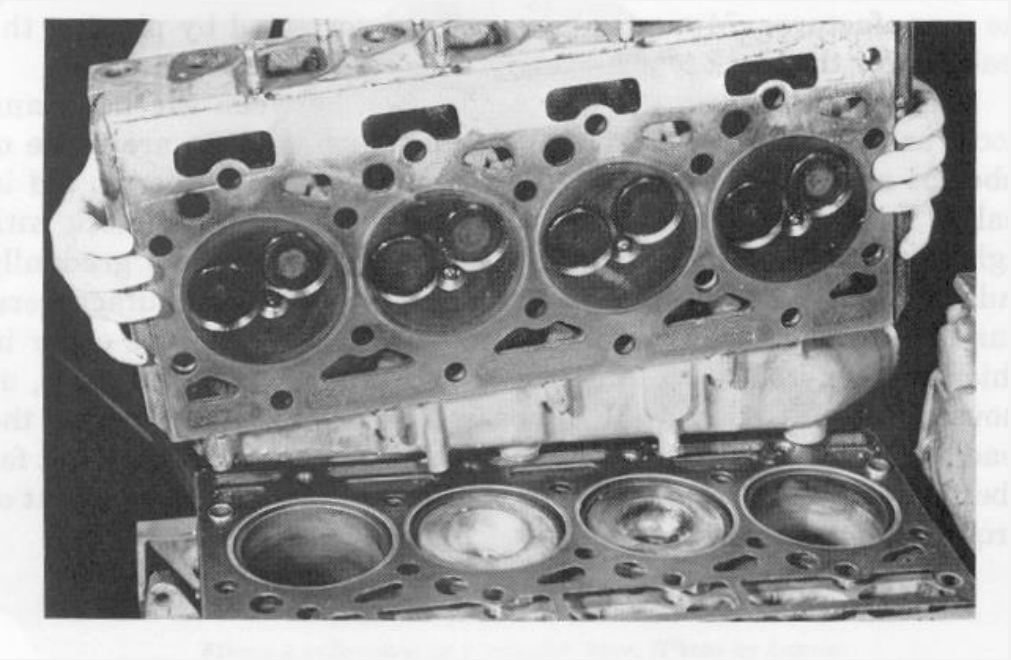


Figure 3.4–Removal of a cylinder liner. (Photo by Laurie Goering.)

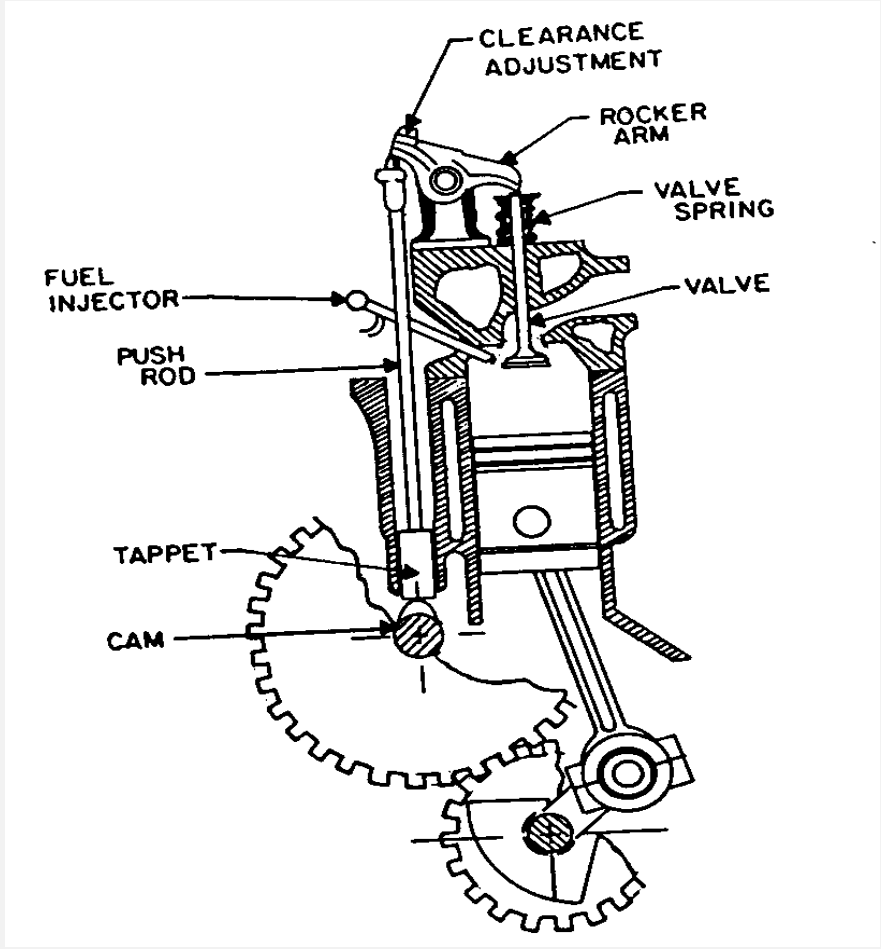
CYLINDER HEAD

- Seals the "top-end" of the combustion chamber.
- Contains the valves and the intake and exhaust "ports".
- Head bolts and head gasket ensure air-tight seal of the combustion chamber.
- Contains oil and coolant passages.



VALVE TRAIN

- Controls flow into and out of the combustion chamber.
  - **Time and Duration**
- Components
  - **Camshaft**
  - **Valve tappets**
  - **Push rods**
  - **Rocker arm**
  - **Valves**
  - **Valve springs**
  - **Valve rotators**
  - **Valve seats**

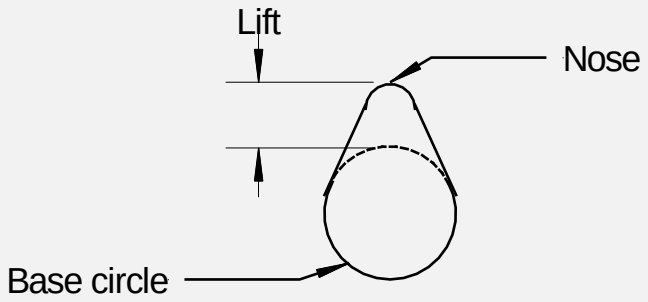


CAMSHAFT

Open the intake and exhaust valves at correct time and for correct duration.

Driven by gear (or chain) from the crankshaft.

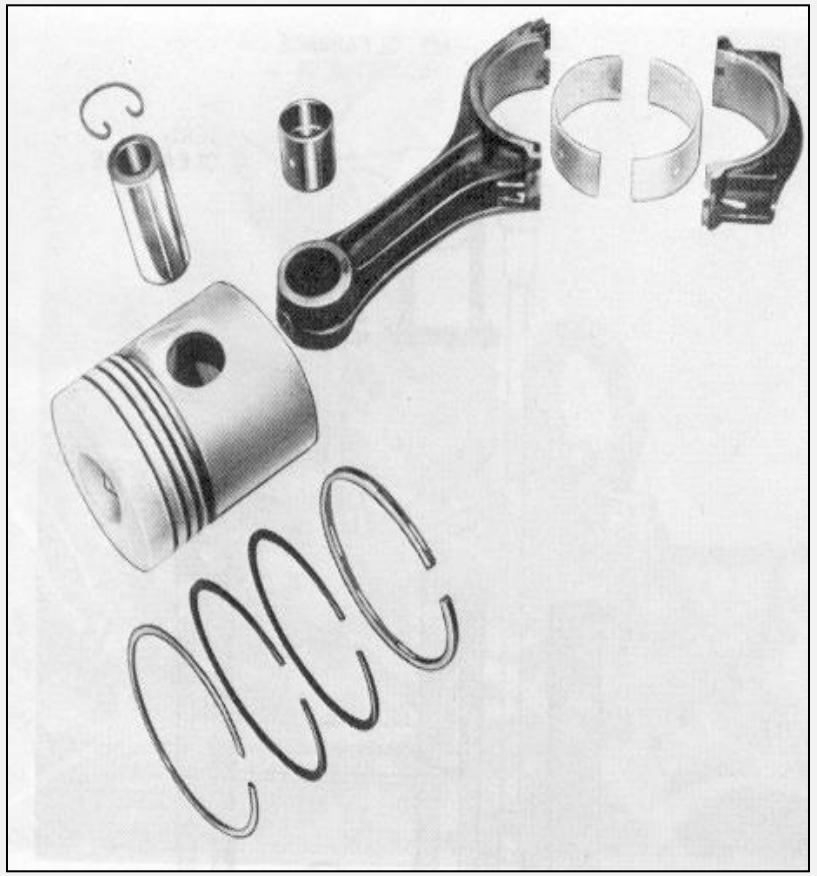
2:1 crankshaft to camshaft gear ratio.



Cam Profile

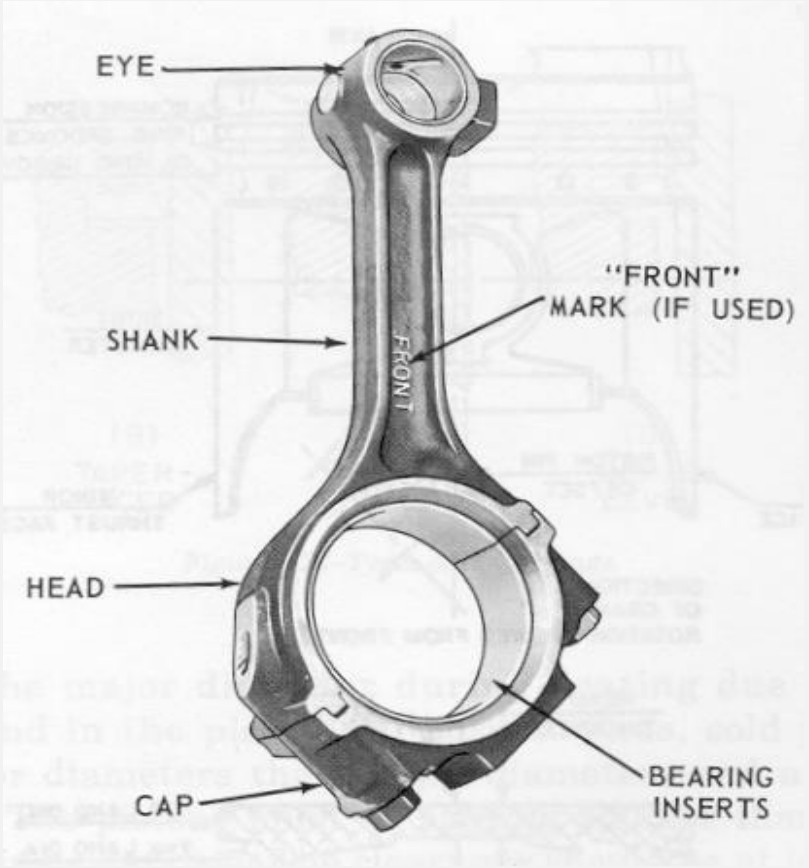
PISTON AND RINGS

- Piston
  - Forms the “moveable bottom’ of the combustion chamber.
    - Iron alloy or aluminum
- Rings
  - Compression
  - Oil-control
    - Cast iron
- Piston pin



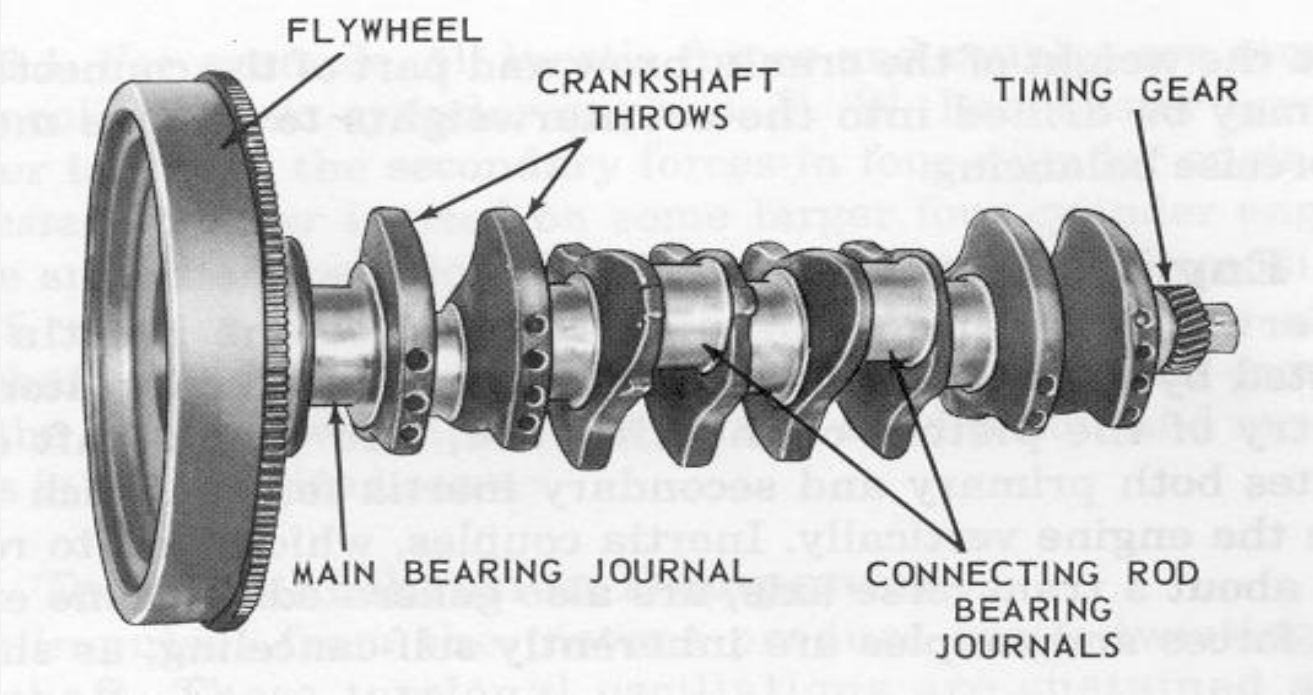
CONNECTING ROD

- Connects the piston to the crankshaft
- Converts reciprocating piston motion to rotary motion at the crankshaft.
- Nomenclature
- Drop-forged steel



CRANKSHAFT

- Works with connecting rod to change reciprocating to rotary motion.
- Transmits mechanical energy from the engine.
- Made of heat-treated steel alloys.



TERMINOLOGY AND ABBREVIATIONS

The following terms and abbreviations are commonly used in engine technology

- **Internal Combustion (IC)**

- **Spark Ignition (SI)** An engine in which the combustion process in each cycle is started by use of a spark plug.

- **Compression Ignition (CI)** An engine in which the combustion process starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.

- **Top-Dead-Center (TDC)** Position of the piston when it stops at the furthest point away from the crankshaft.

- **Bottom-Dead-Center (BDC)** Position of the piston when it stops at the point closest to the crankshaft.

TERMINOLOGY AND ABBREVIATIONS

- **Direct Injection (DI)** Fuel injection into the main combustion chamber of an engine.

- **Indirect Injection (IDI)** Fuel injection into the secondary chamber of an engine with a divided combustion chamber.

- **Bore** Diameter of the cylinder or diameter of the piston face, which is the same minus a very small clearance.

- **Stroke** Movement distance of the piston from one extreme position to the other: TDC to BDC or BDC to TDC.

- **Clearance Volume** Minimum volume in the combustion chamber with piston at TDC.

- **Displacement or Displacement Volume** Volume displaced by the piston as it travels through one stroke.

TERMINOLOGY AND ABBREVIATIONS

- **Smart Engine** Engine with computer controls that regulate operating characteristics such as air-fuel ratio, ignition timing, valve timing, exhaust control, intake tuning, etc.

- **Air-Fuel Ratio (AF)** Ratio of mass of air to mass of fuel input into engine.

- **Fuel-Air Ratio (FA)** Ratio of mass of fuel to mass of air input into engine.

- **Ignition Delay (ID)** Time interval between ignition initiation and the actual start of Combustion

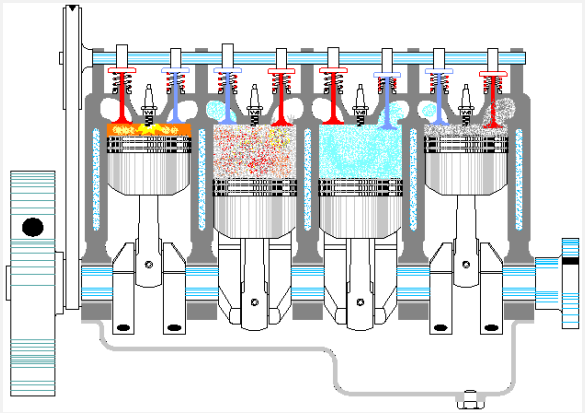
FOUR-STROKE SI ENGINE CYCLE

Most internal combustion engines, both spark ignition and compression ignition, operate on either a four-stroke cycle or a two-stroke cycle.

1. First Stroke: Intake Stroke or Induction *The piston travels from TDC to* BDC with the intake valve open and exhaust valve closed. This creates an increasing volume in the combustion chamber, which in turn creates a vacuum.

2. Second Stroke: Compression Stroke *When the piston reaches BDC, the* intake valve closes and the piston travels back to TDC with all valves closed. This compresses the air-fuel mixture, raising both the pressure and temperature in the cylinder.

3. Combustion: *Combustion of the air-fuel mixture occurs in a very short but* finite length of time with the piston near TDC (i.e., nearly constant-volume combustion).



4. Third Stroke: Expansion Stroke or Power Stroke *With all valves closed,* the high pressure created by the combustion process pushes the piston away from TDC. This is the stroke which produces the work output of the engine cycle.

5. Exhaust Blowdown *Late in the power stroke, the exhaust valve is opened,* and exhaust blow down occurs.

6. Fourth Stroke: Exhaust Stroke *By the time the piston reaches BDC,* exhaust blowdown is complete, but the cylinder is still full of exhaust gases at approximately atmospheric pressure.

FOUR-STROKE CI ENGINE CYCLE

1. First Stroke: Intake Stroke *The same as the intake stroke in an SI engine* with one major difference: no fuel is added to the incoming air.

2. Second Stroke: Compression Stroke *The same as in an SI engine except* that only air is compressed, and compression is to higher pressures and temperature.

3. Combustion *Combustion is fully developed by TDC and continues at* about constant pressure until fuel injection is complete and the piston has started towards BDC.

4. Third Stroke: Power Stroke *The power stroke continues as combustion* ends and the piston travels towards BDC.

5. Exhaust Blowdown *Same as with an SI engine.*

6. Fourth Stroke: Exhaust Stroke *Same as with an SI engine.*

TWO-STROKE SI ENGINE CYCLE

1. ***Combustion*** *With the piston at TDC combustion occurs very quickly, raising* the temperature and pressure to peak values, almost at constant volume.

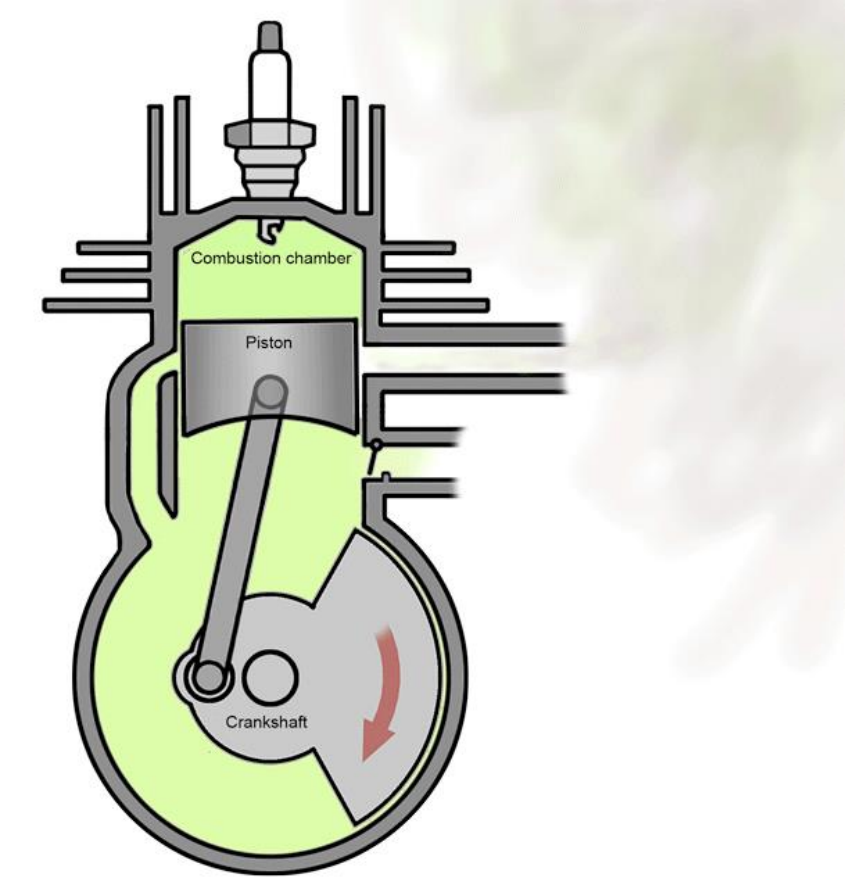
2. First Stroke: Expansion Stroke or Power Stroke *Very high pressure created* by the combustion process forces the piston down in the power stroke. The expanding volume of the combustion chamber causes pressure and temperature to decrease as the piston travels towards BDC.

3. Exhaust Blowdown *At about 75° bBDC, the exhaust valve opens, and* blowdown occurs. The exhaust valve may be a poppet valve in the cylinder head, or it may be a slot in the side of the cylinder which is uncovered as the piston approaches BDC. After blowdown the cylinder remains filled with exhaust gas at lower pressure.

4. Intake and Scavenging *When blowdown is nearly complete, at about 50°* bBDC, the intake slot on the side of the cylinder is uncovered and intake air-fuel enters under pressure.

5. Second Stroke: Compression Stroke *With all valves (or ports) closed, the* piston travels towards TDC and compresses the air-fuel mixture to a higher pressure and temperature. Near the end of the compression stroke, the spark plug is fired; by the time the piston gets to IDC, combustion occurs, and the next engine cycle begins.

TWO-STROKE CYCLE ENGINES

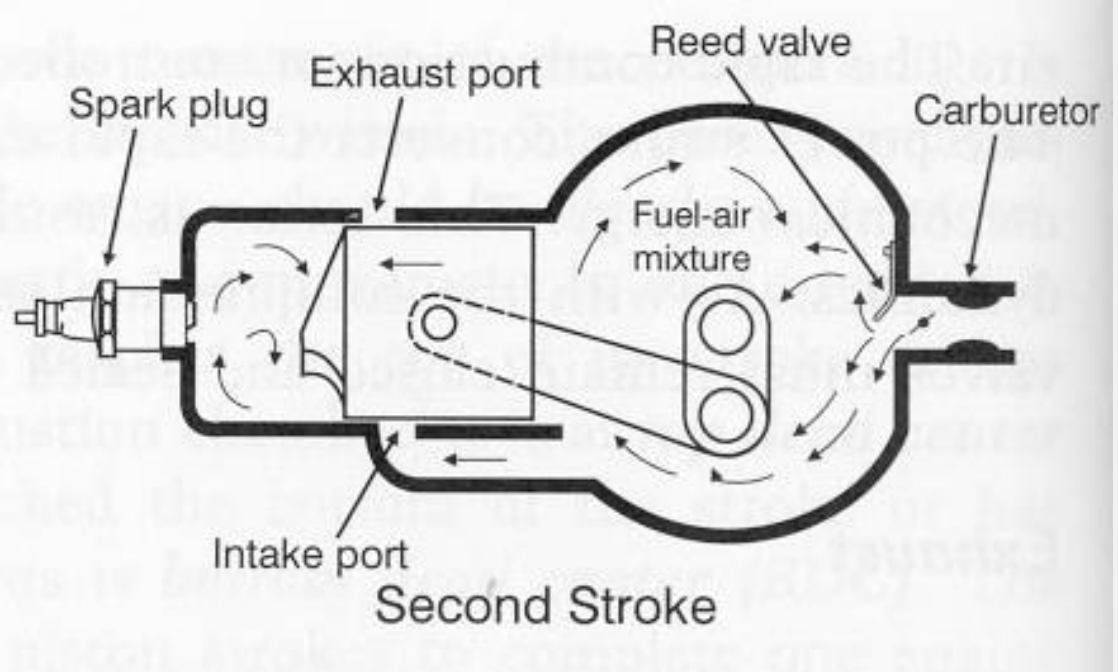


TWO-STROKE CI ENGINE CYCLE

The two-stroke cycle for a CI engine is similar to that of the SI engine, except for two changes.

1- No fuel is added to the incoming air, so that compression is done on air only.

2- Instead of a spark plug, a fuel injector is located in the cylinder. Near the end of the compression stroke, fuel is injected into the hot compressed air and combustion is initiated by self-ignition.



ENGINE EMISSIONS AND AIR POLLUTION

- The exhaust of automobiles is one of the major contributors to the world's air pollution problem.
- Recent research and development has made major reductions in engine emissions, but a growing population and a greater number of automobiles means that the problem will exist for many years to come.

Four major emissions produced by internal combustion engines are hydrocarbons (He), carbon monoxide (CO), oxides of nitrogen (NOx), and solid particulates.

ENGINE EMISSIONS AND AIR POLLUTION

1- Hydrocarbons are fuel molecules which did not get burned and smaller non-equilibrium particles of partially burned fuel.

2- Carbon monoxide occurs when not enough oxygen is present to fully react all carbon to CO_2 or when incomplete air-fuel mixing occurs due to the very short engine cycle time.

3- Oxides of nitrogen are created in an engine when high combustion temperatures cause some normally stable N_2 to dissociate into monatomic nitrogen N, which then combines with reacting oxygen.

4- Solid particulates are formed in compression ignition engines and are seen as black smoke in the exhaust of these engines. Other emissions found in the exhaust of engines include aldehydes, sulfur, lead, and phosphorus.

END OF THE LECTURE