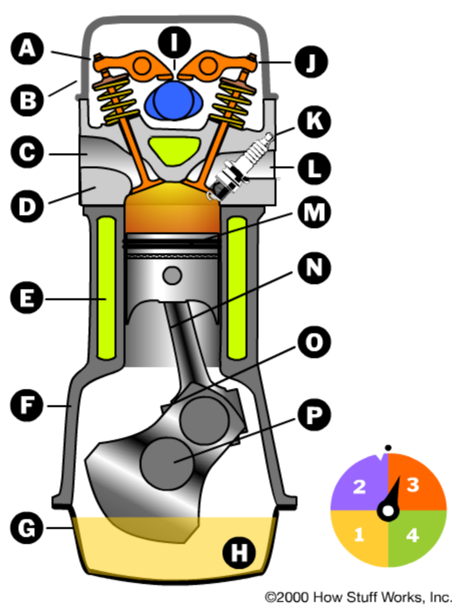
Chapter 1 Introduction
1-3 ENGINE CLASSIFICATIONS

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

1. Types of Ignition

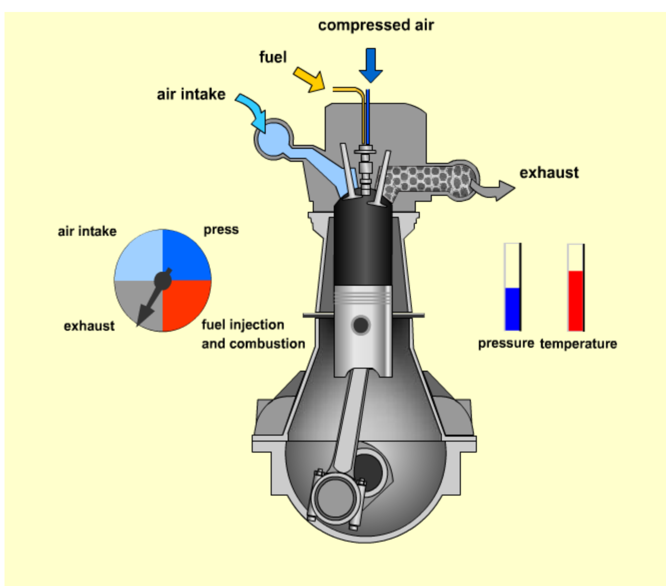
(a) Spark Ignition (SI). •

- 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. **In** early engine development, before the invention of the electric spark plug, many forms of torch holes were used to initiate combustion from an external flame.

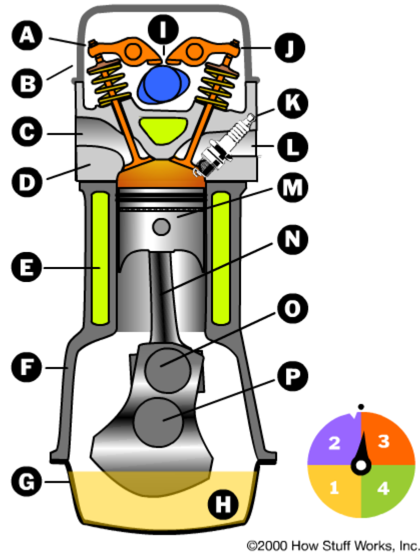


(b) Compression Ignition (CI). •

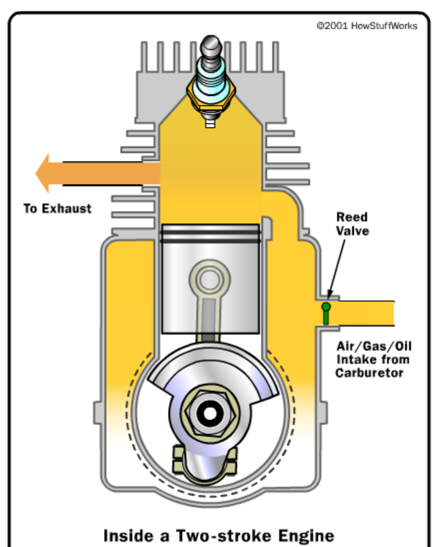
- The combustion process in a CI engine starts when the air-fuel mixture self-ignites due to high temperature in the combustion chamber caused by high compression.



- **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. Three-stroke cycles and six-stroke cycles were also tried in early engine development



3. Valve Location (see Fig. 1-4)

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

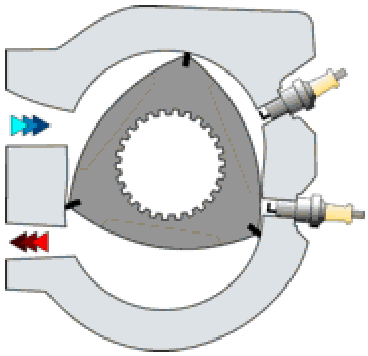
(b) Valves in block (flat head), also called **L Head engine.** Some historic engines with valves in block had the intake valve on one side of the cylinder and the exhaust valve on the other side. These were called **T Head engines.**

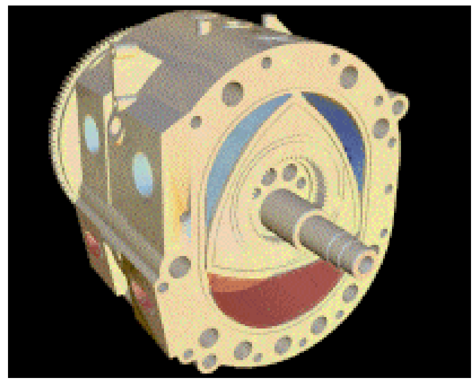
(c) One valve in head (usually intake) and one in block, also called **F Head engine;** this is much less common.

4. Basic Design

(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.

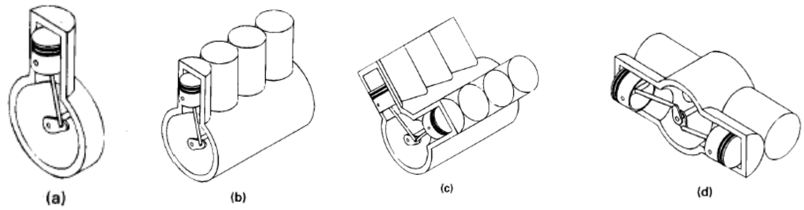
(b) Rotary. Engine is made of a block (stator) built around a large non-concentric rotor and crankshaft. The combustion chambers are built into the nonrotating block.



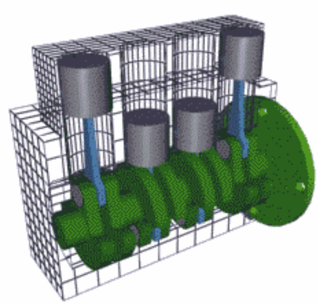


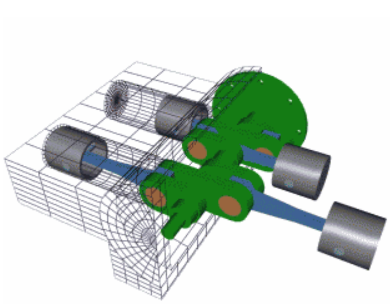
5. Position and Number of Cylinders of Reciprocating Engines (Fig. 1-7)

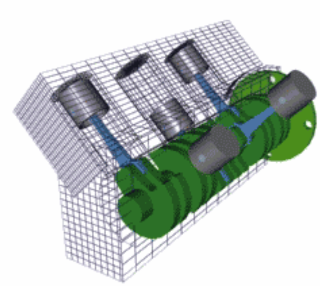
(a) Single Cylinder. Engine has one cylinder and piston connected to the crankshaft.



(b) In-Line. Cylinders are positioned i a straight line, one behind the other along the length of the crankshaft. They can consist of 2 to 11 cylinders or possibly more. In-line four-cylinder engines are very common for automobile and other applications. In-line six and eight cylinders are historically common automobile engines. In-line engines are sometimes called **straight** (e.g., straight six or straight eight).



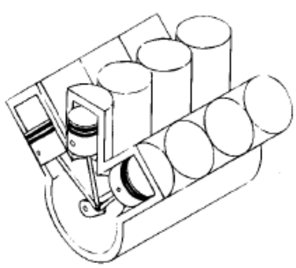




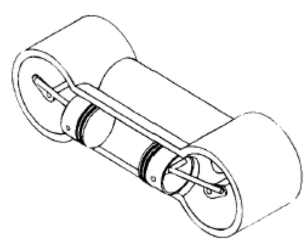
(c) V Engine. Two banks of cylinders at an angle with each other along a single crankshaft. The angle between the banks of cylinders can be anywhere from 15° to 120°, with 60°-90° being common. V engines have even numbers of cylinders from 2 to 20 or more. V6s and V8s are common automobile engines, with V12s and V16s (historic) found in some luxury and high-performance vehicles.

(d) Opposed Cylinder Engine. Two banks of cylinders opposite each other on a single crankshaft (a V engine with a 180°V). These are common on small aircraft and some automobiles with an even number of cylinders from two to eight or more. These engines are often called flat engines (e.g., flat four).

(e) W Engine. Same as a V engine except with three banks of cylinders on the same crankshaft. Not common, but some have been developed for racing automobiles, both modern and historic. Usually 12 cylinders with about a *60°* angle between each bank.

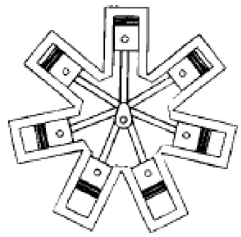


(e)



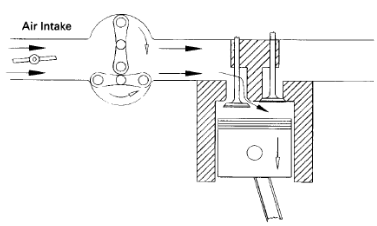
(f)

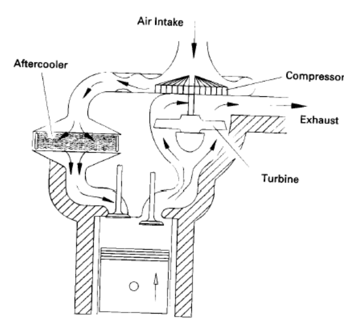
(1) Opposed Piston Engine. Two pistons in each cylinder with the combustion chamber in the center between the pistons. A single-combustion process causes two power strokes at the same time, with each piston being pushed away from the center and delivering power to a separate crankshaft at each end of the cylinder. Engine output is either on two rotating crankshafts or on one crankshaft incorporating complex mechanical linkage.



(g)

(g) Radial Engine. Engine with pistons positioned in a circular plane around the central crankshaft. The connecting rods of the pistons are connected to a master rod which, in turn, is connected to the crankshaft. A bank of cylinders on a radial engine always has an odd number of cylinders ranging from 3 to 13 or more. Operating on a four-stroke cycle, every other cylinder fires and has a power stroke as the crankshaft rotates, giving a smooth operation. Many medium- and large-size propeller-driven aircraft use radial engines. For large aircraft, two or more banks of cylinders are mounted together, one behind the other on a single crankshaft, making one powerful, smooth engine. Very large ship engines exist with up to 54 cylinders, six banks of 9 cylinders each.





6. 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 (Fig. 1-8)

(c) Turbocharged. Intake air pressure increased with the turbine-compressor driven by the engine exhaust gases (Fig. 1-9).

(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

7. 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

8. 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.

9. Application

(a) Automobile, Truck, Bus.
(b) Locomotive.
(c) Stationary.
(d) Marine.
(e) Aircraft.
(f) Small Portable, Chain Saw, Model Airplane.

1O. Type of Cooling

(a) Air Cooled.
(b) Liquid Cooled, Water Cooled.

Several or all of these classifications can be used at the same time to identify a given engine. Thus, a modern engine might be called a turbocharged, reciprocating, spark ignition, four-stroke cycle, overhead valve, water-cooled, gasoline, multipoint fuel-injected, V8 automobile engine.

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. CI engines are often called **Diesel** engines, especially in the non-technical community.
Top-Dead-Center (TDC) Position of the piston when it stops at the furthest point away from the crankshaft. *Top* because this position is at the top of most engines (not always), and *dead* because the piston stops at this point. Because in some engines top-de ad-center is not at the top of the engine (e.g., horizontally opposed engines, radial engines, etc.), some Sources call this position

Bottom-Dead-Center (BDC) Position of the piston when it stops at the point closest to the crankshaft. Some sources call this **CrankEnd Dead-Center** (CEDC) because it is not always at the bottom of the engine. Some sources call this point **Bottom-Center** (BC). During an engine cycle things can happen before bottom-dead-center, bBDC or bBC, and after bottom-de ad-center, aBDC or aBe.

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. Displacement can be given for one cylinder or for the entire engine (one cylinder times number of cylinders). Some literature calls this *swept volume.*

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.
Brake Maximum Torque (BMT) Speed at which maximum torque occurs.

1-5 ENGINE COMPONENTS

The following is a list of major components found in most reciprocating internal combustion engines (see Fig. 1-15).
Block Body of engine containing the cylinders, made of cast iron or aluminum. **In** many older engines, the valves and valve ports were contained in the block. The block of water-cooled engines includes a water jacket cast around the cylinders. On air-cooled engines, the exterior surface of the block has cooling fins.
Camshaft Rotating shaft used to push open valves at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage (push rods, rocker arms, tappets). Most modern automobile engines have one or more camshafts mounted in the engine head (overhead cam). Most older engines had camshafts in the crankcase. Camshafts are generally made of forged steel or cast iron and are driven off the crankshaft by means of a belt or chain (timing chain). To reduce weight, some cams are made from a hollow shaft with the cam lobes press-fit on. In four-stroke cycle engines, the camshaft rotates at half engine speed.

Carburetor Venturi flow device which meters the proper amount of fuel into the air flow by means of a pressure differential. For many decades it was the basic fuel metering system on all automobile (and other) engines. It is still used on low cost small engines like lawn mowers, but is uncommon on new automobiles.
Catalytic converter Chamber mounted in exhaust flow containing catalytic material that promotes reduction of emissions by chemical reaction.
Combustion chamber The end of the cylinder between the head and the piston face where combustion occurs. The size of the combustion chamber continuously changes from a minimum volume when the piston is at TDC to a maximum when the piston is at BDC. The term "cylinder" is sometimes synonymous with "combustion chamber" (e.g., "the engine was firing on all cylinders"). Some engines have *open* combustion chambers which consist of one chamber for each

cylinder. Other engines have *divided* chambers which consist of dual chambers on each cylinder connected by an orifice passage.
Connecting rod: Rod connecting the piston with the rotating crankshaft, usually made of steel or alloy forging in most engines but may be aluminum in some small engines.
Connecting rod bearing Bearing where connecting rod fastens to crankshaft.
Cooling fins Metal fins on the outside surfaces of cylinders and head of an aircooled engine. These extended surfaces cool the cylinders by conduction andconvection

Crankshaft Rotating shaft through which engine work output is supplied to external systems. The crankshaft is connected to the engine block with the *main bearings.* It is rotated by the reciprocating pistons through connecting rods connected to the crankshaft, offset from the axis of rotation. This offset issometimes called *crank throw* or *crank radius.* Most crankshafts are made of forged steel, while some are made of cast iron.

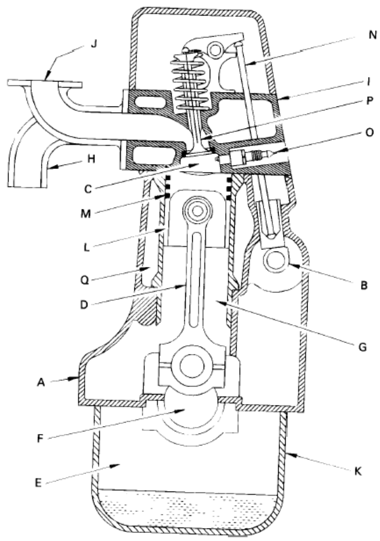


Figure 1-15 Cross-section of four-stroke cycle SI engine showing engine components; (A) block, (B) camshaft, (C) combustion chamber, (D) connecting rod, (E) crankcase, (F) crankshaft, (G) cylinder, (H) exhaust manifold, (I) head, (J) intake manifold, (K) oil pan, (L) piston, (M) piston rings, (N) push rod, (0) spark plug, (P) valve, (Q) water jacket.

Cylinders The circular cylinders in the engine block in which the pistons reciprocate back and forth. The walls of the cylinder have highly polished hard surfaces. Cylinders may be machined directly in the engine block, or a hard metal (drawn steel) sleeve may be pressed into the softer metal block. Sleeves may be dry sleeves, which do not contact the liquid in the water jacket, or wet sleeves, which form part of the water jacket. In a few engines, the cylinder walls are given a knurled surface to help hold a lubricant film on the walls. In some very rare cases, the cross section of the cylinder is not round

Exhaust manifold Piping system which carries exhaust gases away from the enginecylinders, usually made of cast iron.

Exhaust system Flow system for removing exhaust gases from the cylinders, treating them, and exhausting them to the surroundings. It consists of an exhaust manifold which carries the exhaust gases away from the engine, a thermal or catalytic converter to reduce emissions, a muffler to reduce engine noise, and a tailpipe to carry the exhaust gases away from the passenger compartment.

Fan Most engines have an engine-driven fan to increase air flow through the radiator and through the engine compartment, which increases waste heat removal from the engine. Fans can be driven mechanically or electrically, and can run continuously or be used only when needed.
Flywheel Rotating mass with a large moment of inertia connected to the crankshaft of the engine. The purpose of the flywheel is to store energy and furnish a large angular momentum that keeps the engine rotating between power strokes and smoothes out engine operation. On some aircraft engines the propeller serves as the flywheel, as does the rotating blade on many lawn mowers.

Fuel injector A pressurized nozzle that sprays fuel into the incoming air on SI engines or into the cylinder on CI engines. On SI engines, fuel injectors are located at the intake valve ports on multipoint port injector systems and upstream at the intake manifold inlet on throttle body injector systems. In a few SI engines, injectors spray directly into the combustion chamber.

Fuel pump Electrically or mechanically driven pump to supply fuel from the fuel tank (reservoir) to the engine. Many modern automobiles have an electric fuel pump mounted submerged in the fuel tank. Some small engines and early automobiles had no fuel pump, relying on gravity feed.

1-6 BASIC ENGINE CYCLES

Most internal combustion engines, both spark ignition and compression ignition, operate on either a four-stroke cycle or a two-stroke cycle. These basic cycles are fairly standard for all engines, with only slight variations found in individual designs Four-Stroke SI Engine Cycle (Fig. 1-16)

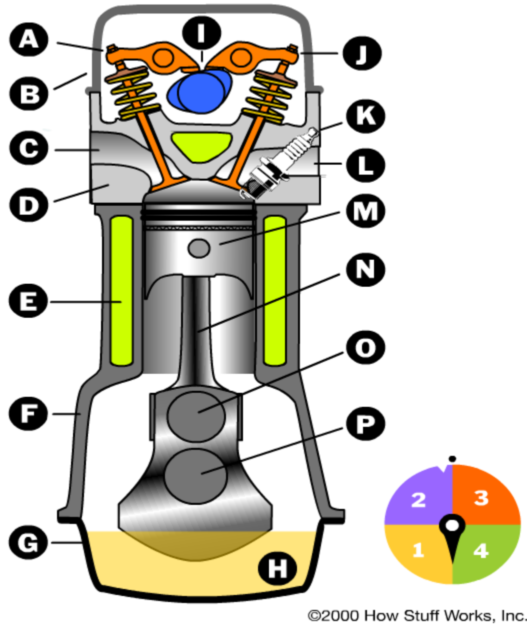
1. First Stroke: Intake Stroke or Induction The piston travels from TDC to BDC with the intake valve open and exhaust valve closed. This creates an increasing volume in the combustion chamber, which in turn creates a vacuum. The resulting pressure differential through the intake system from atmospheric pressure on the outside to the vacuum on the inside causes air to be pushed into the cylinder. As the air passes through the intake system, fuel is added to it in the desired amount by means of fuel injectors or a carburetor.

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. The finite time required to close the intake valve means that actual compression doesn't start until sometime aBDC. Near the end of the compression stroke, the spark plug is fired and combustion is initiated.

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). It starts near the end of the compression stroke slightly bTDC and lasts into the power stroke slightly aTDC. Combustion changes the composition of the gas mixture to that of exhaust products and increases the temperature in the cylinder to a very high peak value. This, in turn, raises the pressure in the cylinder to a very high peak value.

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. As the piston travels from TDC to BDC, cylinder volume is increased, causing pressure and temperature to drop.
5. Exhaust Blowdown Late in the power stroke, the exhaust valve is opened and exhaust blow down occurs. Pressure and temperature in the cylinder are still high relative to the surroundings at this point, and a pressure differential is created through the exhaust system which is open to atmospheric pressure. This pressure differential causes much of the hot exhaust gas to be pushed out of the cylinder and through the exhaust system when the piston is near BDC. This exhaust gas carries away a high amount of enthalpy, which lowers the cycle thermal efficiency. Opening the exhaust valve before BDC reduces the work obtained during the power stroke but is required because of the finite time needed for exhaust blowdown.

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. With the exhaust valve remaining open, the piston now travels from BDC to TDC in the exhaust stroke. This pushes most of the remaining exhaust gases out of the cylinder into the exhaust system at about atmospheric pressure, leaving only that trapped in the clearance volume when the piston reaches TDC. Near the end of the exhaust stroke bTDC, the intake valve starts to open, so that it is fully open by TDC when the new intake stroke starts the next cycle. Near TDC the exhaust valve starts to close and finally is fully closed sometime aTDC. This period when both the intake valve and exhaust valve are open is calledvalve overlap.



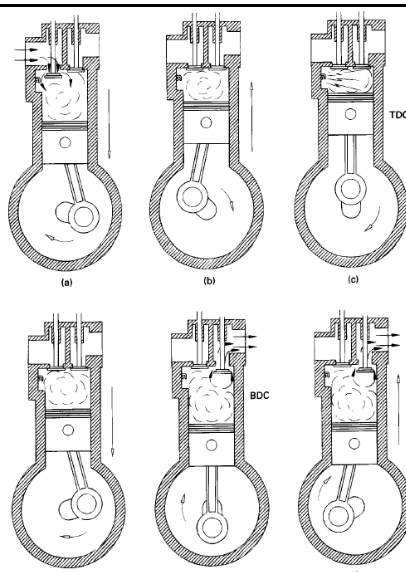


Figure 1-16 Four-stroke SI engine operating cycle. **(a)** Intake stroke. Ingress of air-fuel as piston moves from TDC to BDC. **(b)** Compression stroke. Piston moves from BDC to TDC. Spark ignition occurs near end of compression stroke. **(c)** Combustion at almost constant volume near TDC. **(d)** Power or expansion stroke. High cylinder pressure pushes piston from TDC towards BDC. **(e)** Exhaust blowdown when exhaust valve opens near end of expansion stroke. **(f)** Exhaust stroke. Remaining exhaust pushed from cylinder as piston moves from BDC to TDC.

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. Late in the compression stroke fuel is injected directly into the combustion chamber, where it mixes with the very hot air. This causes the fuel to evaporate and self-ignite, causing combustion to start.

3. Combustion Combustion is fully developed by TDC and continues atabout 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.