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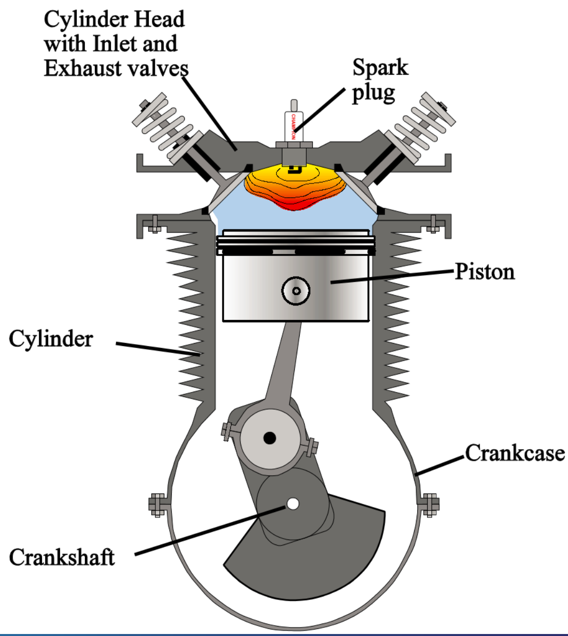
Piston engine

In 1876 Beau de Rochas developed an engine where the combustion process took place inside the engine, but it was Dr '**Otto**' who first succeeded in producing a working engine based on the principle.

The principle of operation of the engine is accomplished by inducing a mixture of air and fuel into a cylinder, which is then **compressed** by a **piston**.

The mixture is ignited and the rapid rise in temperature causes the gas pressure in the cylinder to rise and forces the piston down the cylinder. Linear movement of the piston is converted into rotary motion by a **connecting rod** and **crankshaft**.

The burnt gases are then **exhausted** to atmosphere.

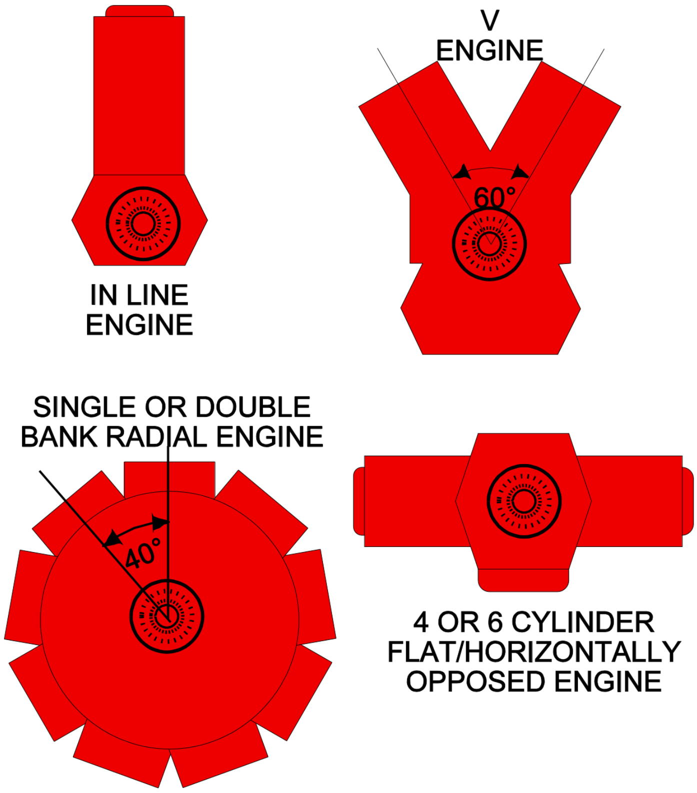


Engine layout

The power of an engine can be increased by adding cylinders producing **multi-cylinder** engines.

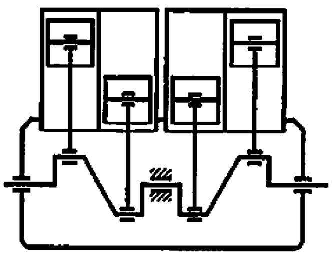
This is a more efficient way of increasing power than making a single cylinder larger, and also has the benefit of making the engine run **smoother**.

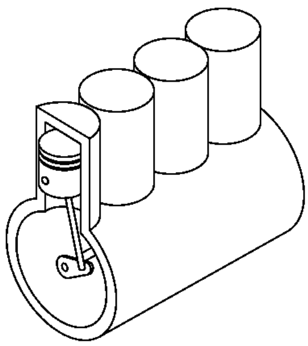
There are various types of engine design with regard to cylinder arrangement.



Engine layout - Inline

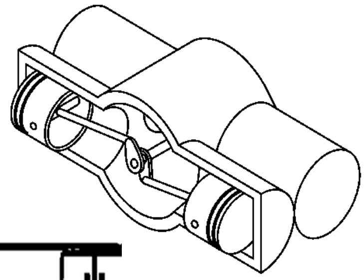
- This type of engine has been extensively used in the past for low power ranges.
- **Four-cylinder** in-line engines are the most common arrangement for automobile engines. It provides **two** torque pulses per **revolution** of the crankshaft, and primary **inertia forces** (though not secondary forces) are **balanced**.
- **Six-cylinder** in-line engines have balanced **primary and secondary** forces
- The M337 is a six-cylinder inline engine made by LOM PRAHA that generates 173 kW of power.

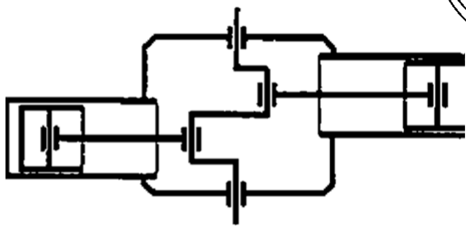




Engine layout - Opposed

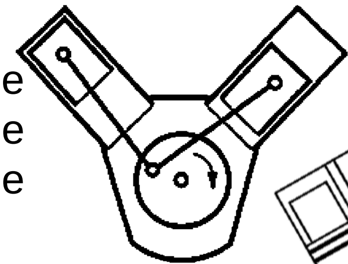
- This is the most extensively used piston type engine for **general aviation** aircraft.
- An example of this type of engine is Teledyne Continental GTSIO-520 mounted on a **Cessna** 182.
- This is a typical modern high-power, opposed-type reciprocating engine that is being extensively used on **general aviation** aircraft.
- The engine has total piston displacement of 520 cubic inches and is equipped with **reduction** gear, supercharger and fuel injection system.

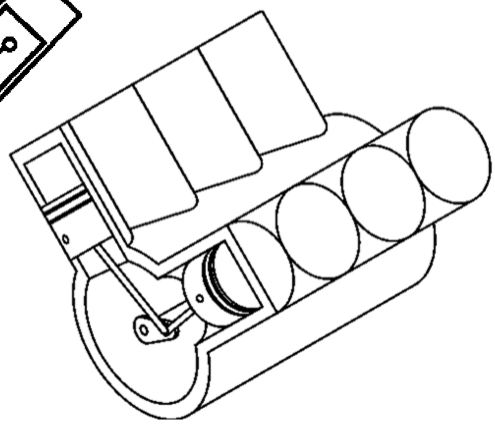




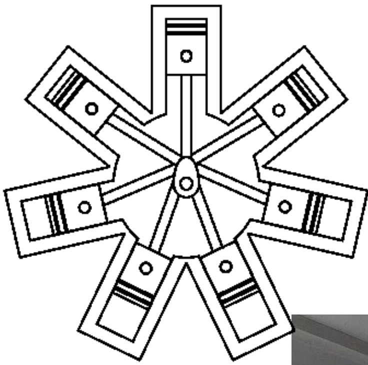
Engine layout - V

- **Two banks** of cylinders at an angle with each other along a single crankshaft, allows a shorter engine block.
- The **angle** between the banks of cylinders can be anywhere from 15° to 120°, with 60°–90° being common.
- V engines usually have **even** numbers of **cylinders** from 2 to 20 or more.
- An example is the Ferrari V12 "Tipo 044" 1995 Formula One Grand Prix racing engine (1995 season).





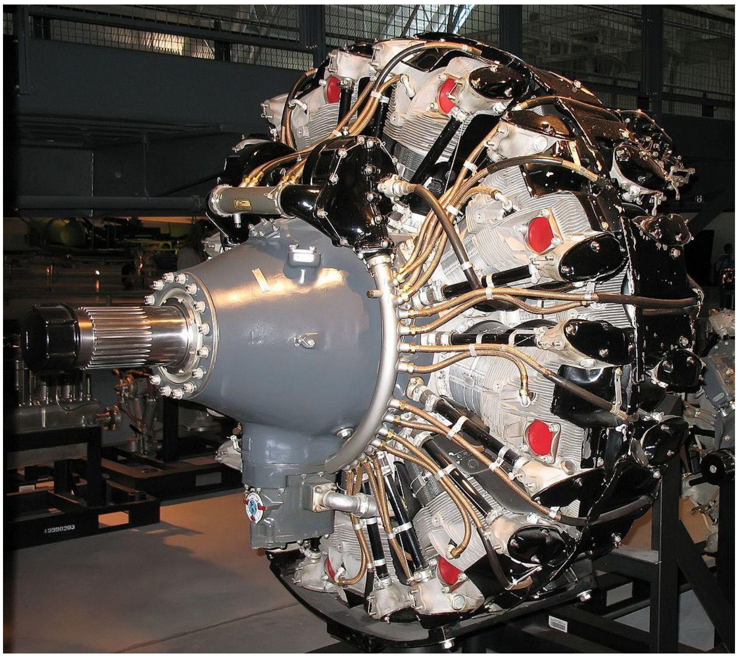
Engine layout - Radial



- Engine with pistons positioned in a **circular** plane around a 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 almost 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.
- The Vedeneyev M14P is a Russian nine-cylinder, four-stroke, air-cooled, petrol-powered radial engine. Producing 360 hp (268 kW).

Engine layout - Radial

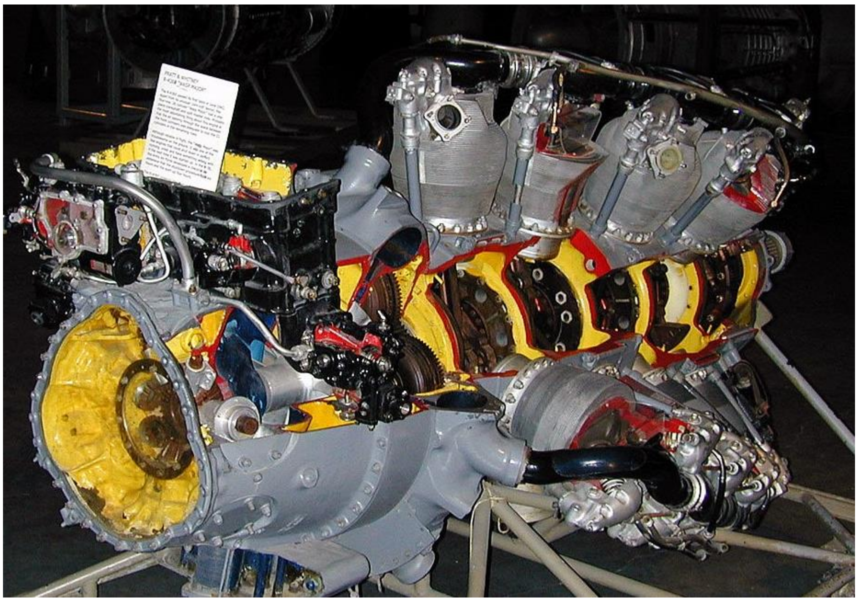
- For large aircraft, **two** or **more banks** of cylinders are mounted together, one behind the other on a single crankshaft, making one powerful smooth engine.
- In the early part of the 20th century there were a **few** experimental radial aircraft engines that had an **even** number of cylinders (4 to 12). These engines operated on a two-stroke cycle and never became standard.



- The Wright R-3350 Duplex-Cyclone is a twin-row, **supercharged**, air-cooled, radial aircraft engine with 18 cylinders displacing nearly 55 L. Power ranged from 2,200 to over 3,700 hp (1,640 to 2,760 kW), depending on the model.

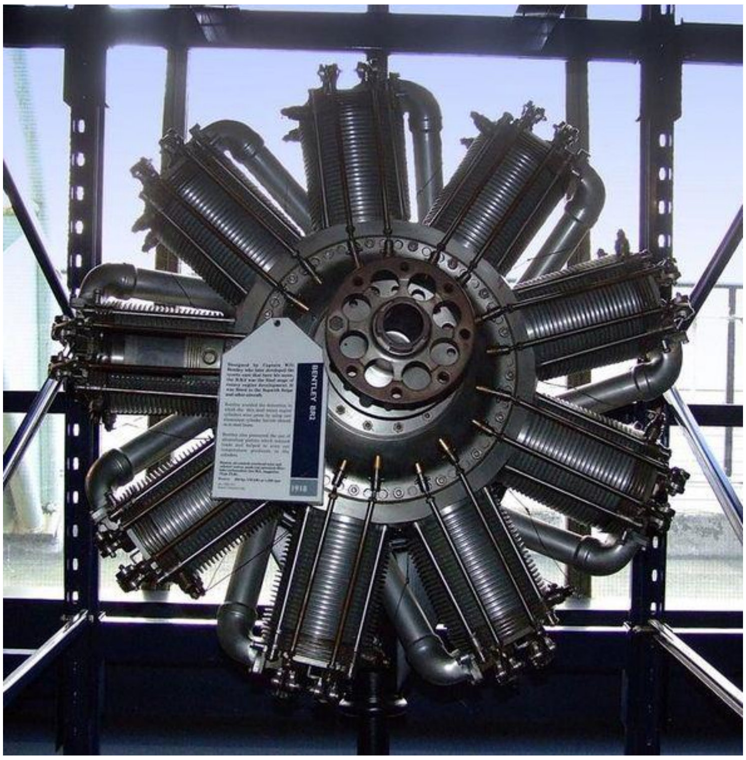
Engine layout - Radial

- The Pratt & Whitney R-4360 Wasp Major is an American 28-cylinder four-row radial piston aircraft engine designed and built during World War II.
- At 71.5 L was the largest-displacement aviation piston engine to be mass-produced in the United States, and at 4,300hp (3,200 kW) was the most powerful. It was the last of the Pratt & Whitney Wasp family, and the culmination of its maker's piston engine technology.



Engine layout - Rotary–Radial

- The **cylinders** of a rotary–radial engine **spin** around the crankshaft, which is mounted rigidly on the airframe. One end of each connecting rod rides in a groove in a cam that is offset from the center of the crankshaft.
- These engines have not been in actual production for a very long time.
- The Bentley B.R.2 was a nine-cylinder British rotary aircraft engine developed during the First World War by the motor car engine designer W. O. Bentley. The initial variant of the BR.2 developed 230 horsepower (170 kW), with nine cylinders measuring 140 mm × 180 mm for a total displacement of 24.9 L. It weighed 220 kg.



Engine layout - Rotary–Radial

Advantages:

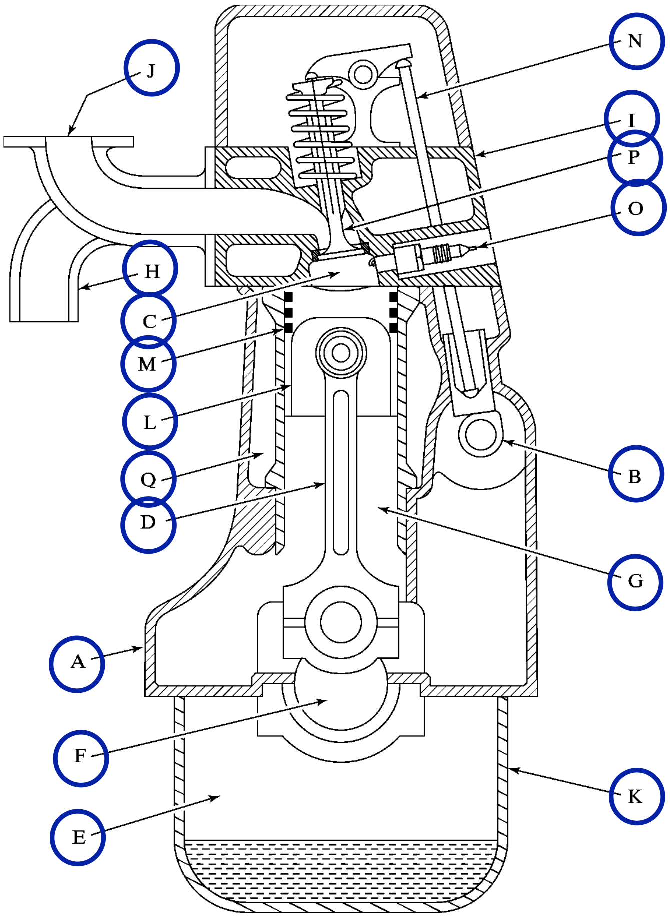
- **Smooth running**: Rotaries delivered power very smoothly because (relative to the engine mounting point) there are no reciprocating parts, and the relatively large rotating mass of the crankcase/cylinders (as a unit) acted as a flywheel.
- **Improved cooling**: when the engine was running, the rotating crankcase/cylinder assembly created its own fast-moving cooling airflow, even with the aircraft at rest.
- **Weight advantage**: rotaries shared with other radial configuration engines the advantage of a small, flat crankcase. The superior air-cooling imparted by the moving engine also meant that cylinders could be made with thinner walls and shallower cooling fins. Their power-to-weight ratio was further enhanced in comparison with engines that required an added flywheel for smooth running.

Engine layout - Rotary–Radial

Engine designers had always been aware of the **many limitations** of the rotary engine so when the static style engines became more reliable and gave better specific weights and fuel consumption, the days of the rotary engine were numbered.

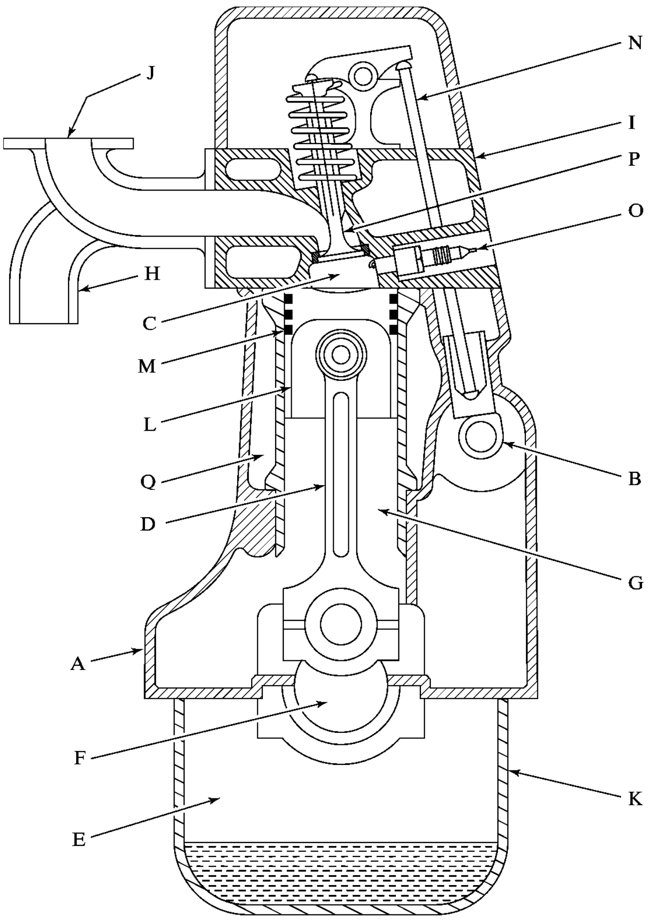
- Rotary engines had a fundamentally **inefficient** total-loss **oiling system**. In order to reach the whole engine, the lubricating medium needed to enter the crankcase through the hollow crankshaft; but the centrifugal force of the revolving crankcase was directly opposed to any re-circulation. The only practical solution was for the lubricant to be aspirated with the fuel/air mixture, as in most two-stroke engines.
- Power increase also came with mass and size increases, multiplying **gyroscopic precession** from the rotating mass of the engine. This produced **stability** and **control problems** in aircraft in which these engines were installed, especially for inexperienced pilots.
- Power output increasingly went into overcoming the **air-resistance** of the **spinning engine**.
- Engine controls were tricky and resulted in fuel waste.

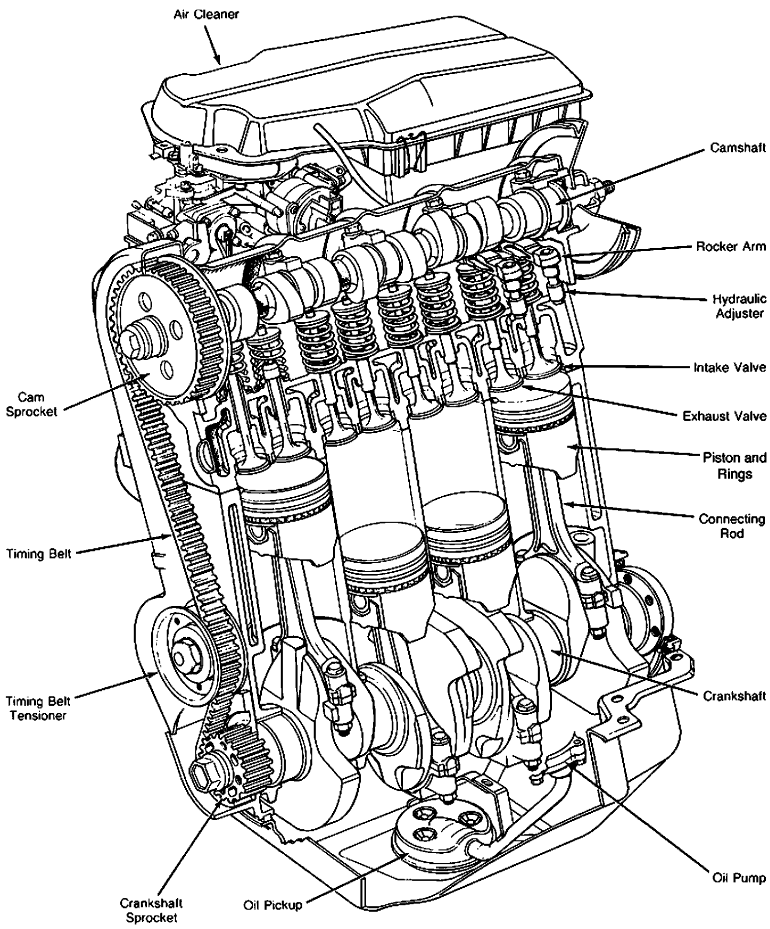
Engine components



- 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
- O) spark plug
- P) valve
- Q) water jacket.

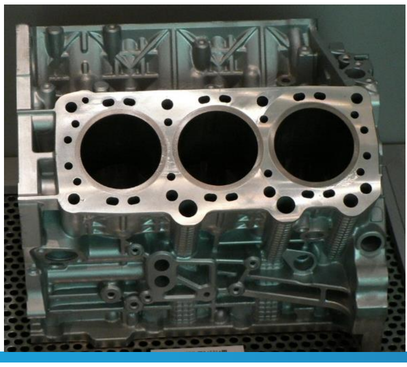
Engine components

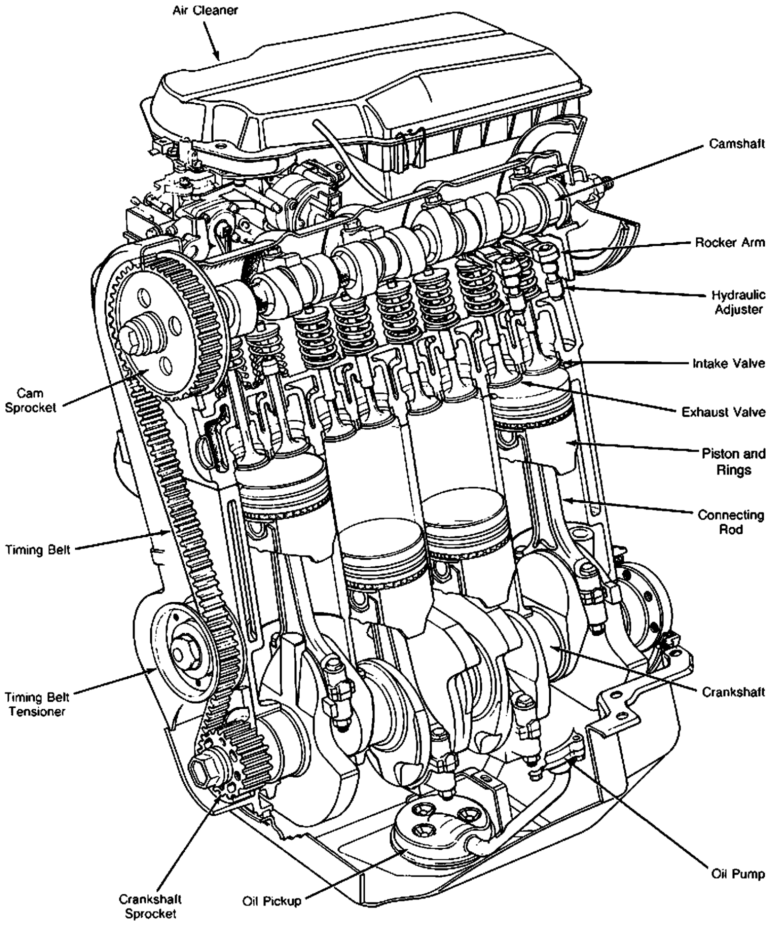




Engine components - Block

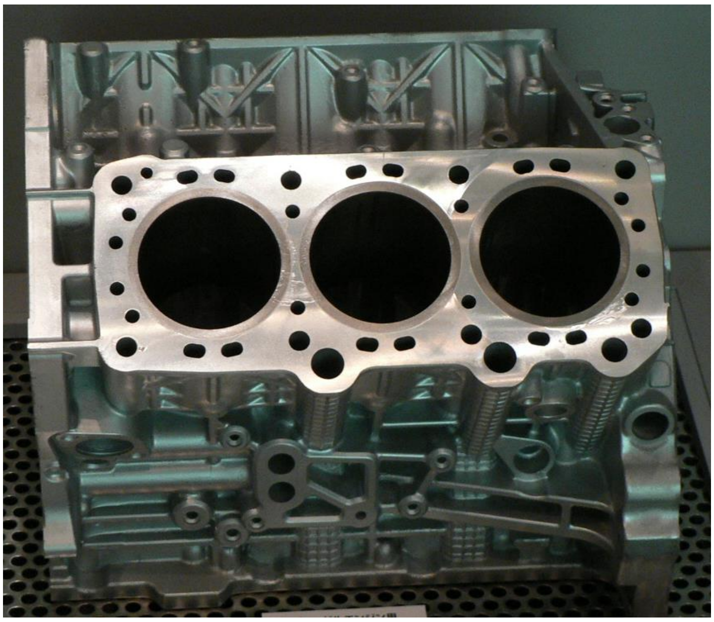
- Body of engine containing the cylinders, made of **cast iron** or **aluminum**. In many older engines, the valves and valve ports were contained in the block.
- About 30% of the **heat** generated during combustion is transferred to the cylinders.





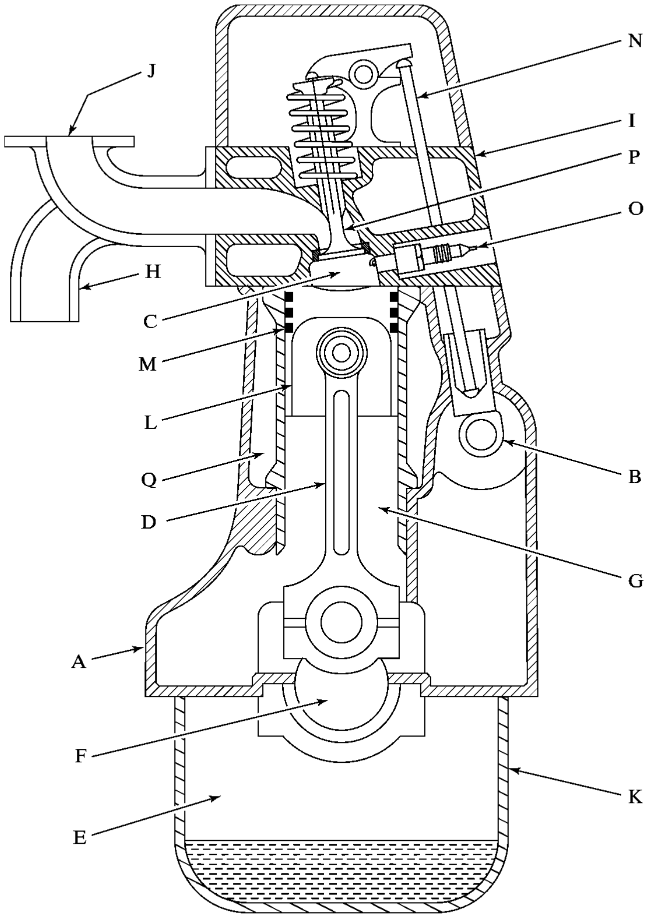
Engine components - Block

- 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.
- About 30% of the **heat** generated during combustion is transferred to the cylinders.
- **Liquid Cooling** has **water jacket** around the cylinders to allow for the flow of a liquid around them and carry the heat away.
- **Air-Cooled** engines, have **cooling fins** machined onto the cylinder to increase the surface area in contact with air, which is used to dissipate the heat.



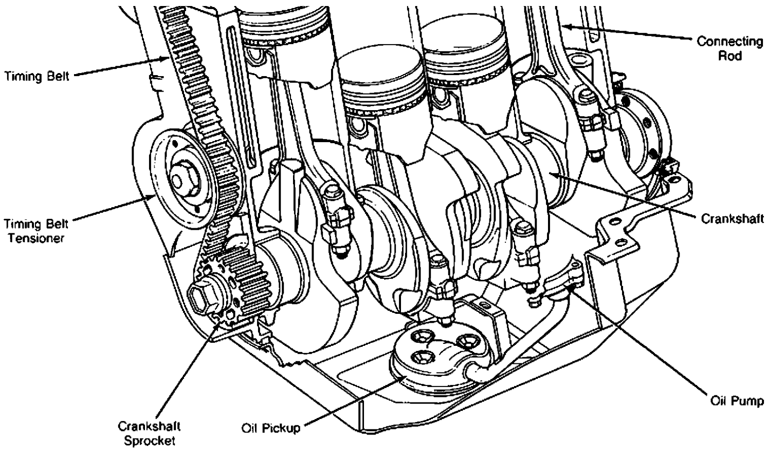
Engine components - Crankcase

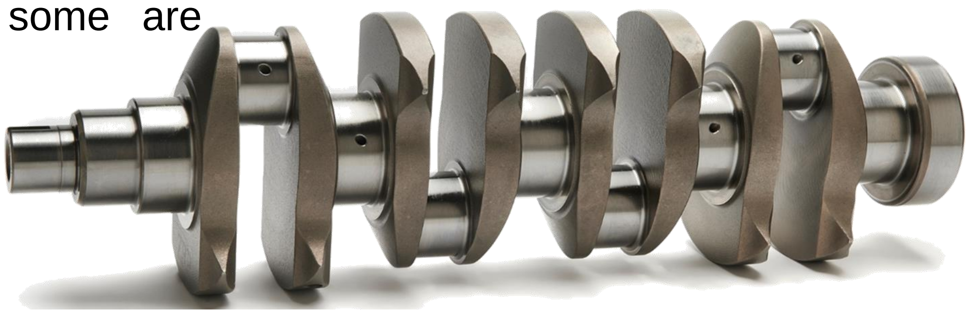
- Part of the engine block surrounding the rotating crankshaft. In many engines the **oil pan** makes up part of the crankcase housing.
- In some high-performance engines the crankcase is designed with “windows” between the piston bays to allow freer air flow between bays.
- This is to reduce air pressure buildup on the backside of the pistons during power and intake strokes.



Engine components - Crankshaft

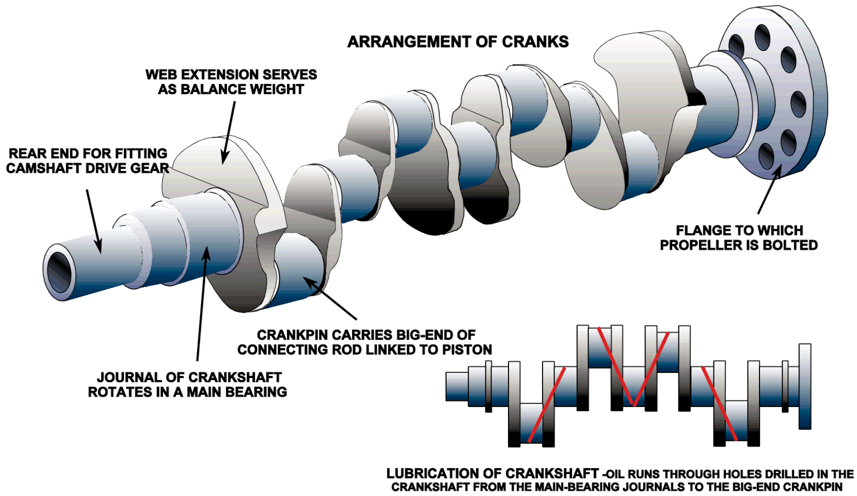
- Rotating shaft through which engine work output is supplied to external systems. The crankshaft is connected to the engine block with the main bearings. It is rotated by the **reciprocating** pistons through connecting rods connected to the crankshaft, offset from the axis of rotation.
- This offset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





Engine components - Crankshaft

- The **Journals**, the main part of the shaft, are supported by the main bearings in the crankcase.
- The **Piston** are attached by the Connecting Rods to the **Crank-pin** .
- The crankshaft often has **as many crank** throws as there are **pistons**. In case of a **radial engine**, several **cylinders** may be connected to a **single** throw, and a horizontally **opposed** engine may have only **two** pistons connected to one crank-pin.
- Oil-ways are drilled through the shaft to transfer the **lubricating** oil onto the bearing surfaces.
- **Plain Bearings** are used to enable the high reciprocating loads to be carried.



Engine components - Crankshaft

The crankshaft is accurately **balanced** to minimise vibration, however, when a shaft has to transmit a torque or twisting moment it must flex to some extent and spring back again when released. If the shaft must have a lot of kinks in it to provide the crank throws, the twisting moments are hard to resist and perceptible **deflection** may take place.

The repeated applications of force to which the crankshaft is subjected may set up oscillations as the shaft recovers its original shape between power impulses. At certain speeds the impulses may coincide with the **natural vibration** period of the shaft and give very rough running even in an engine which is in good mechanical balance.

For these reasons the shafts should be as **short** as possible and adequately supported and counter-weighted to **minimise** these torsional effects.

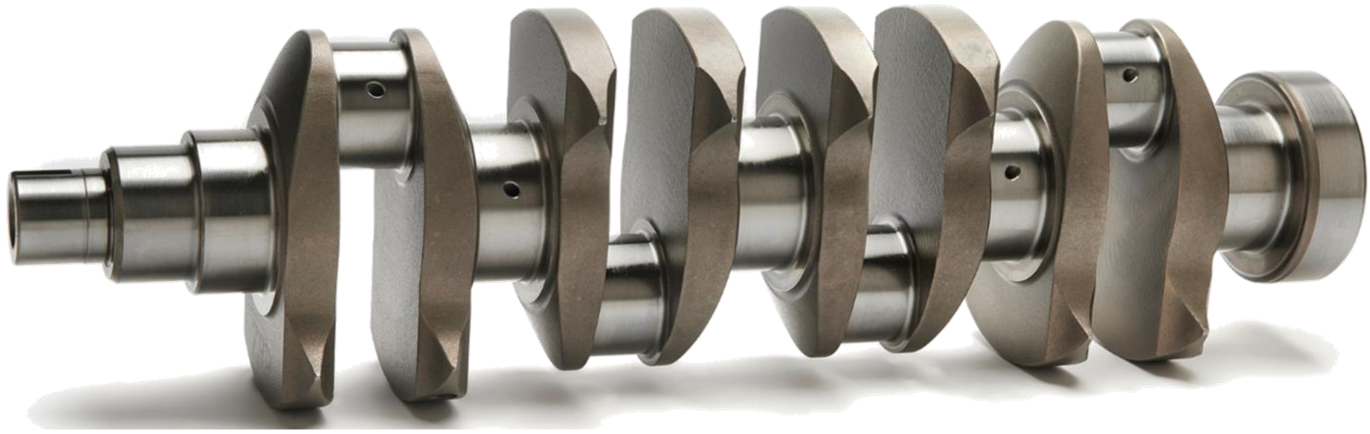
In any event, many engines have RPM ranges which are prohibited for prolonged use (Critical RPM) to prevent unnecessary vibration. This is indicated by a Red Arc on the RPM indicator.

Engine components - Crankshaft

Increasing the number of cylinder improves the power output and makes the engine run smoother because there are more power strokes in the 720° of crankshaft rotation. This is called the **Firing Interval**.

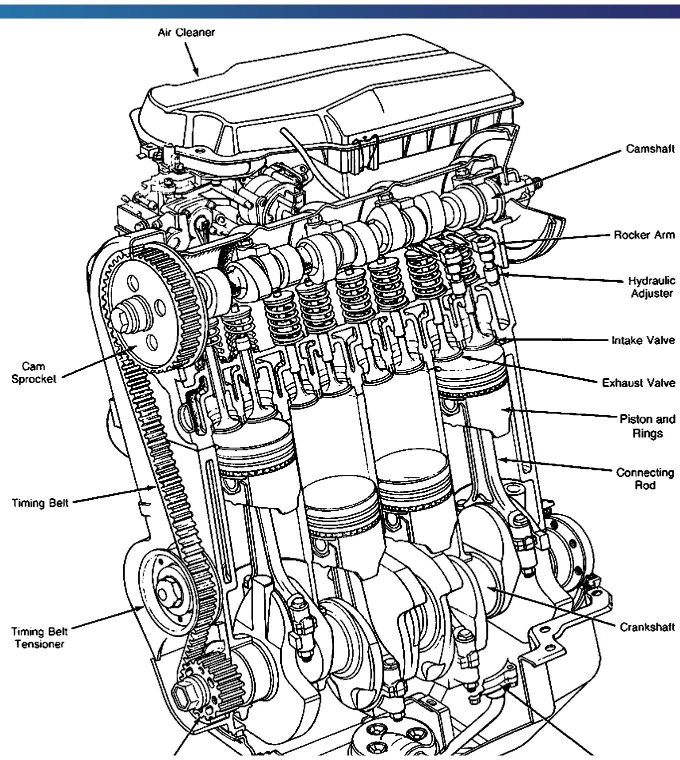
The crankshaft and cylinder arrangement will also determine the order in which the cylinders fire. This is called the **Firing Order** of the engine.

A typical four cylinder engine could have a firing order of 1-3-4-2. The cylinders do not fire consecutively as this reduces the load and vibration on the crankshaft.



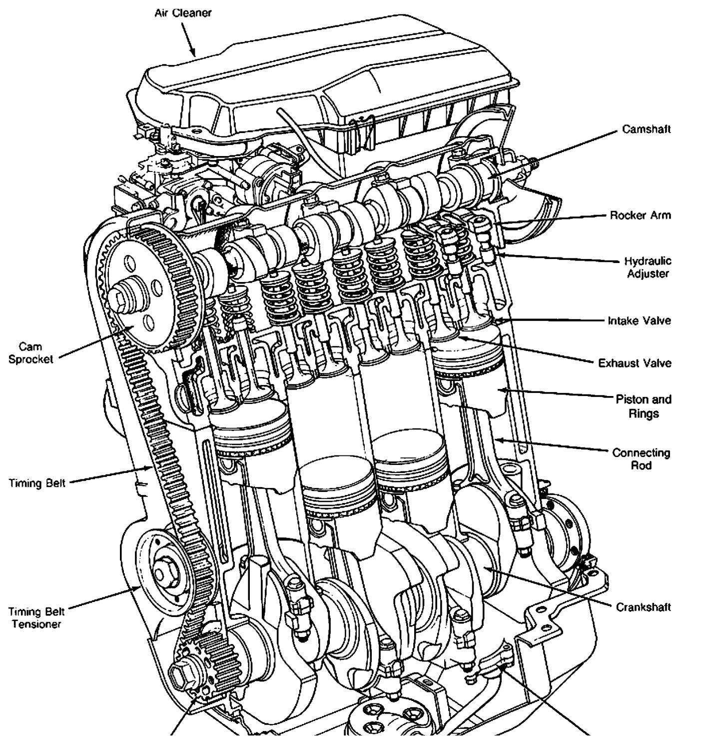
Engine components - Camshaft

- Rotating shaft used to push **open valves** at the proper time in the engine cycle, either directly or through mechanical or hydraulic linkage.
- Most modern automobile engines have one or more camshafts mounted in the engine head (**overhead cam**).
- Most older engines had camshafts in the **crankcase**.



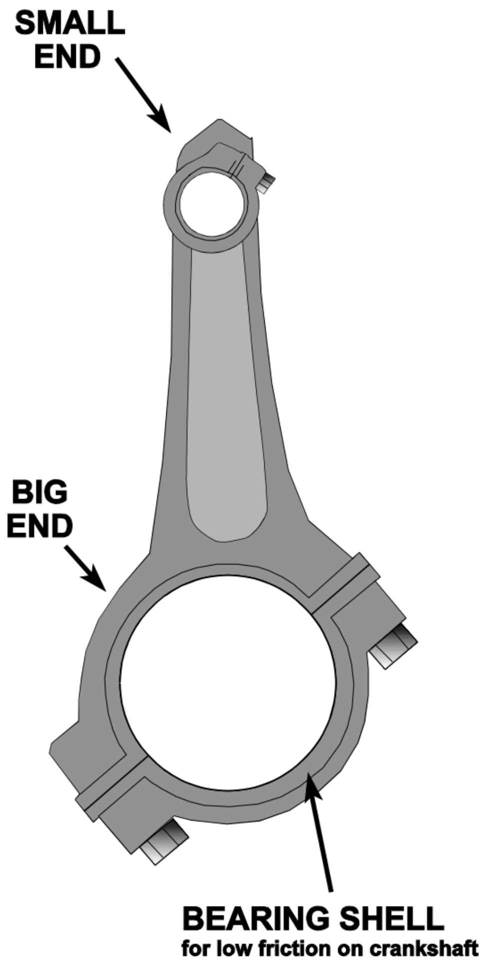
Engine components - Camshaft

- 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**.



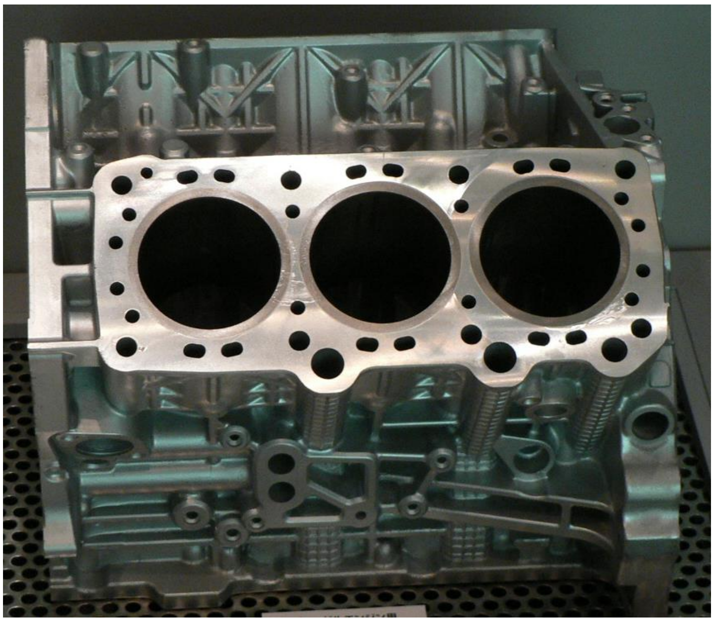
Engine components - Connecting rod

- **Linkage** connecting piston with rotating crankshaft, usually made of H section high tensile **steel**, alloy forging, or **aluminum**.



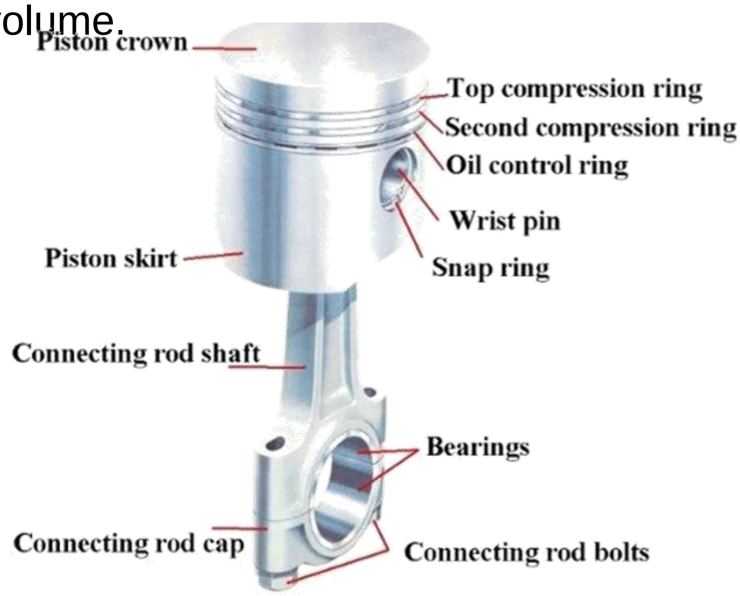
Engine components - Cylinders

- The **Cylinders** are 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.



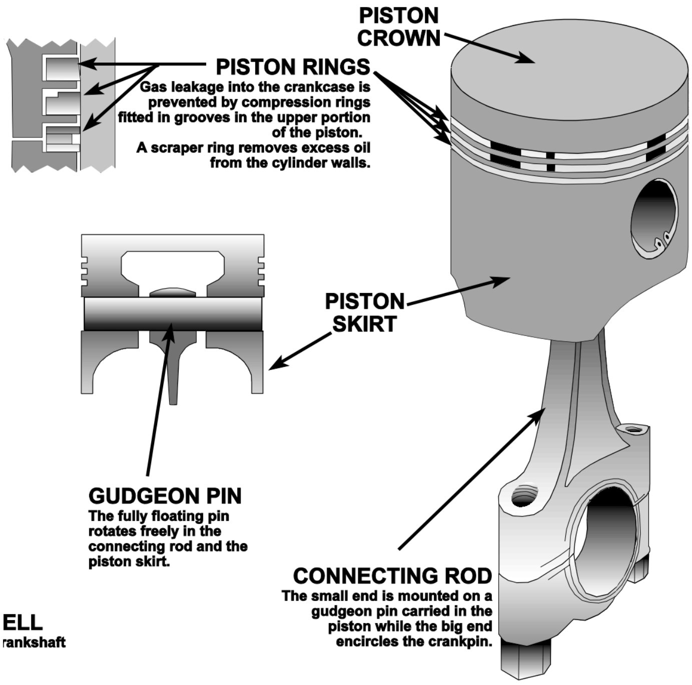
Engine components - Piston

- The top of the piston is called the **crown** and the sides are called the **skirt**.
- The face on the crown makes up one wall of the combustion chamber and may be a **flat** or highly **contoured** surface.
- Pistons are made of **cast iron**, **steel**, or **aluminum**.
- Iron and **steel** pistons can have sharper corners because of their higher strength. They also have **lower thermal expansion**, which allows for tighter tolerances and less crevice volume.
- **Aluminum** pistons are **lighter** and have less mass inertia.
- **Synthetic** or **composite** materials may be used for the body of the piston, with only the crown made of metal. Some pistons have a **ceramic coating** on the face.



Engine components - Piston

- Circumferential grooves are machined in the piston to accommodate **Piston Rings** which provide the means of preventing pressure leakage past the piston in one direction and oil leakage in the other.
- A **number** of piston rings can be fitted to a piston and their arrangement will vary from engine to engine.
- The **Compression Rings** prevent gas **leakage** into the crankcase. They are fitted into grooves cut into the upper portion of the piston. Gas passing down between the piston and the cylinder wall forces a compression ring down in its groove and outwards against the cylinder wall.
- A small amount of gas will pass the top ring; so a **second** (and sometimes a **third**) compression ring is fitted.



Engine components - Piston

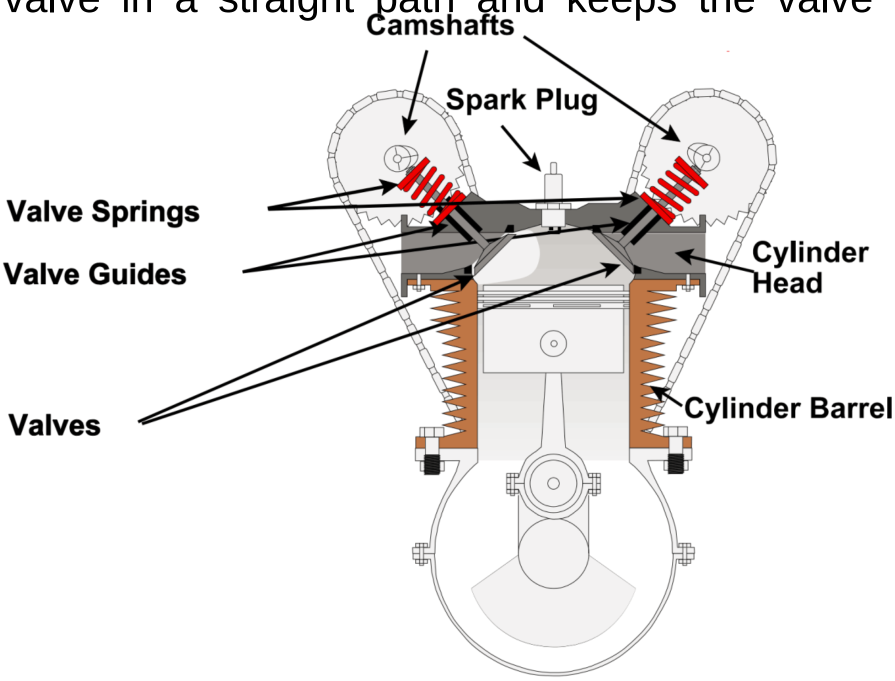
- The **Scraper Rings** or Oil **Control Rings** prevent excess oil passing into the combustion chamber and spread the oil evenly around the cylinder bore. They are designed so that the bearing face is reduced in area and the bearing pressure consequently increased.
- The rings are generally made of a **special grade** of **cast iron**; the rings are sprung against the cylinder walls.
- Cast iron has the ability to retain its elasticity when heated. It also has **self lubricating qualities** due to the graphitic content of the metal. This is desirable because during the power stroke the walls of the cylinder are exposed to the hot combustion gases, and the thin film of oil is burned away.
- Piston **rings** which are **worn** or stuck in their grooves will cause excessive blue smoke (**burning oil**) to be ejected from the exhaust pipe.

Engine components - Head

- The **Head** is the piece that closes the end of the cylinders, usually containing part of the clearance volume of the combustion chamber.
- The cylinder head may be detachable but more commonly it is **screwed** and shrunk onto the block.
- The head is usually **cast iron** or **aluminum**, and bolts to the engine block.
- The head contains the **spark plugs** in SI engines and the **fuel injectors** in CI engines and some SI engines.
- Most modern engines have the **valves** in the **head**, and many have the camshaft(s) positioned there also (**overhead valves** and **overhead cam**).

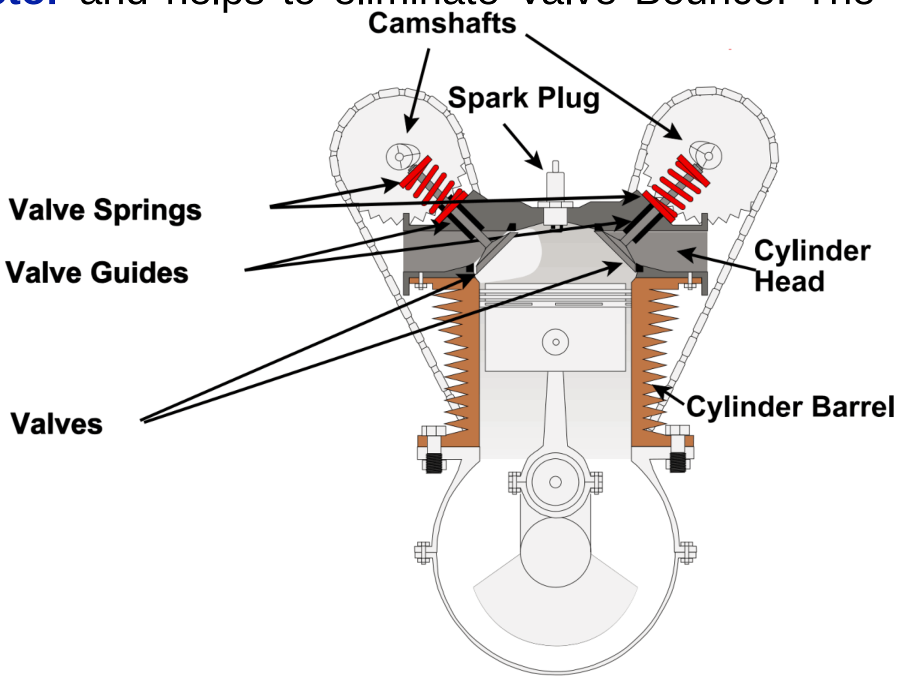
Engine components - Head

- The cylinder head **accommodates** the Valves, Valve Guides and Sparking Plugs, and supports the valve Rocker Arms.
- **Valve Seats**, the surfaces against which the valves close, are cut into the cylinder head, which form gas tight seals with the valves.
- **Valve Guide** - guides the valve in a straight path and keeps the valve concentric to its seat. Usually, the valve guide is pressed into the cylinder head.
- **Valve Seat** - ground to form a gas tight seal with the face of the valve, cut at various angles (30°or 45°).



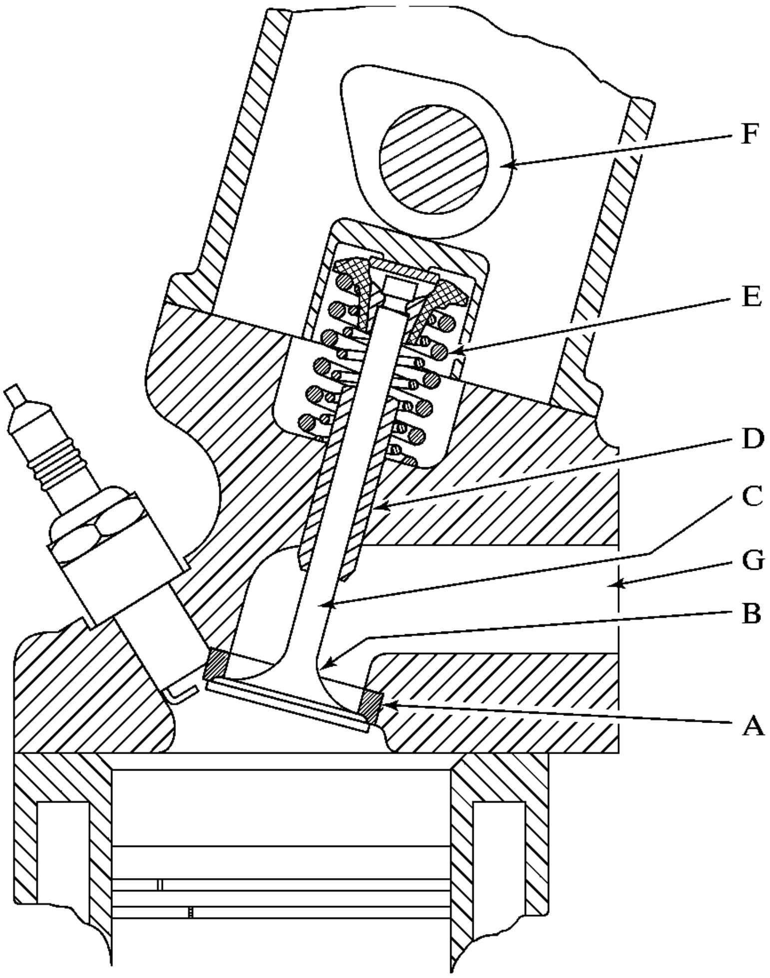
Engine components - Head

- **Valve Springs** - made of special spring steel, to ensure that the valves remain closed except when operated by the cams. The springs are of the helical coil type, the usual practice being for two springs to be fitted to each valve, one inside the other.
- This provides a **Safety Factor** and helps to eliminate Valve Bounce. The springs are held compressed between the cylinder head and the valve spring cap.



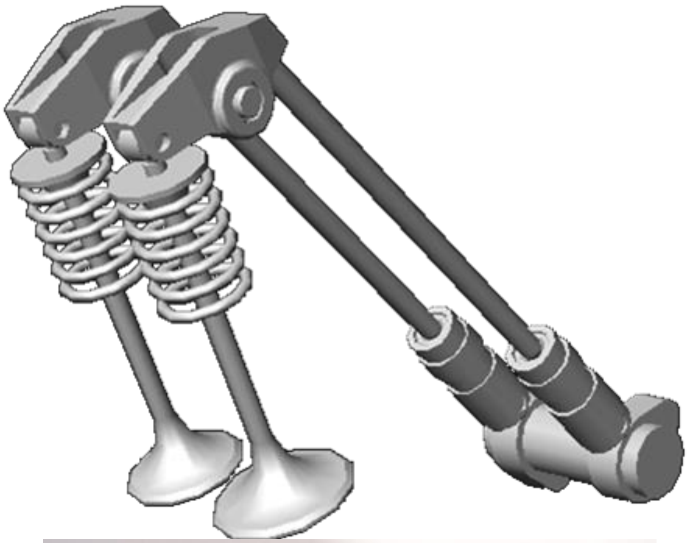
Engine components - Valves

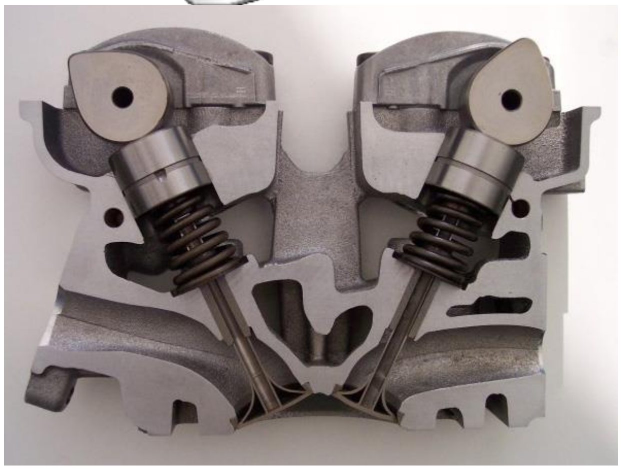
- Valves are used to **allow flow** into and out of the cylinder at the proper time in the cycle.
- Most engines use **poppet** valves, which are **spring loaded** closed and pushed open by camshaft action.
- Valves are mostly made of **forged steel**. The valve seats and are made of hardened steel or ceramic.
- Exhaust valve stems are sometimes hollow and partly filled with **sodium** to assist in cooling.



Engine components - Valves

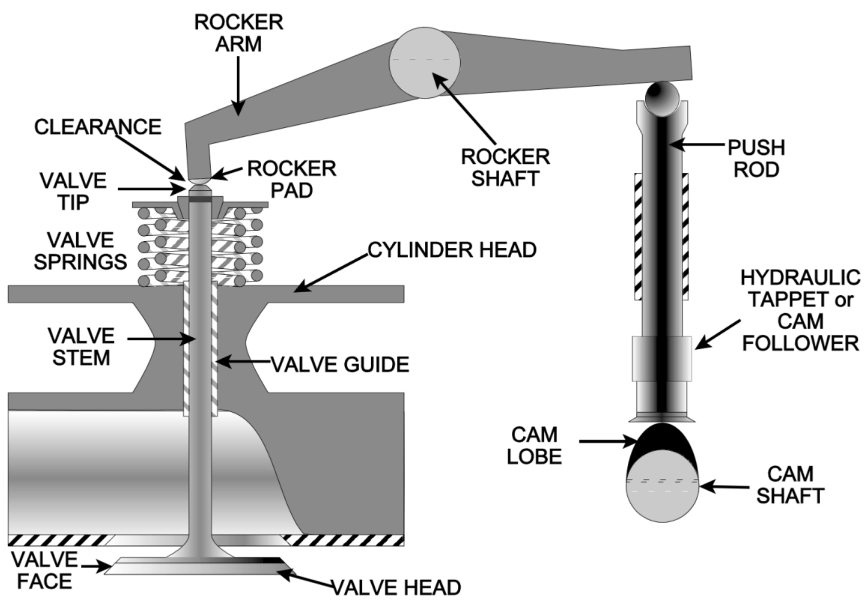
- Many **two-stroke** cycle engines have ports (slots) in the side of the cylinder walls instead of mechanical valves.
- Most modern automobile engines have one or more camshafts mounted in the engine head (**overhead cam**).
- Most older engines had camshafts in the crankcase. In this case a **push rod** and a **rocker arm** are used to move the valve.





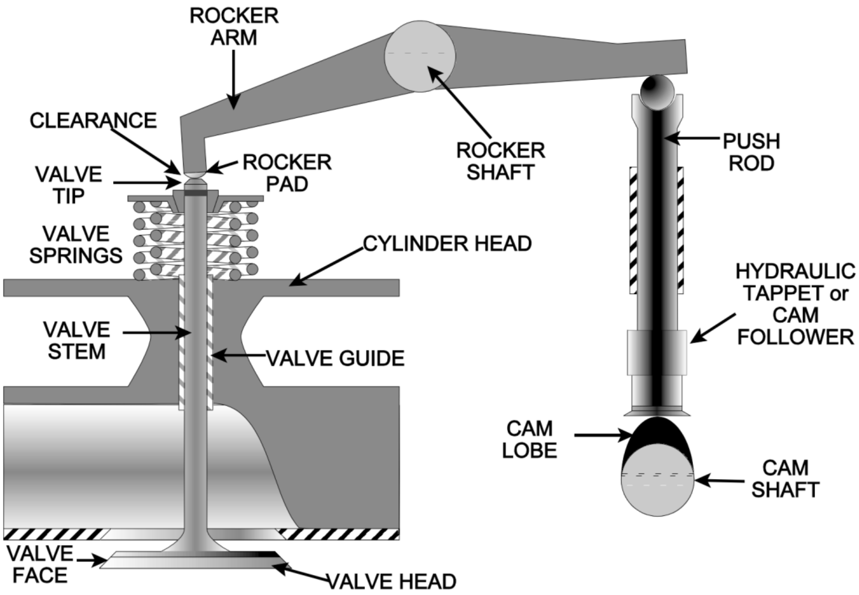
Engine components - Valves

- To ensure that the valves close fully, it is necessary for there to be a **Valve Clearance**. This is a small gap measured between the Rocker Pad; and the Valve Tip.
- The valves are continuously **heated** by combustion and **expand** at a greater rate than the rest of the operating mechanism. As the engine heats up, the valve clearance allows the valve to expand at its own rate.
- **Excessive** valve clearance will cause the valve to **open late** and **close early**.
- Too **little** clearance will cause the valves to **open early** and **close late** and may even prevent the valves closing at all, thereby producing an event called Popping back into the Carburetor (backfire).



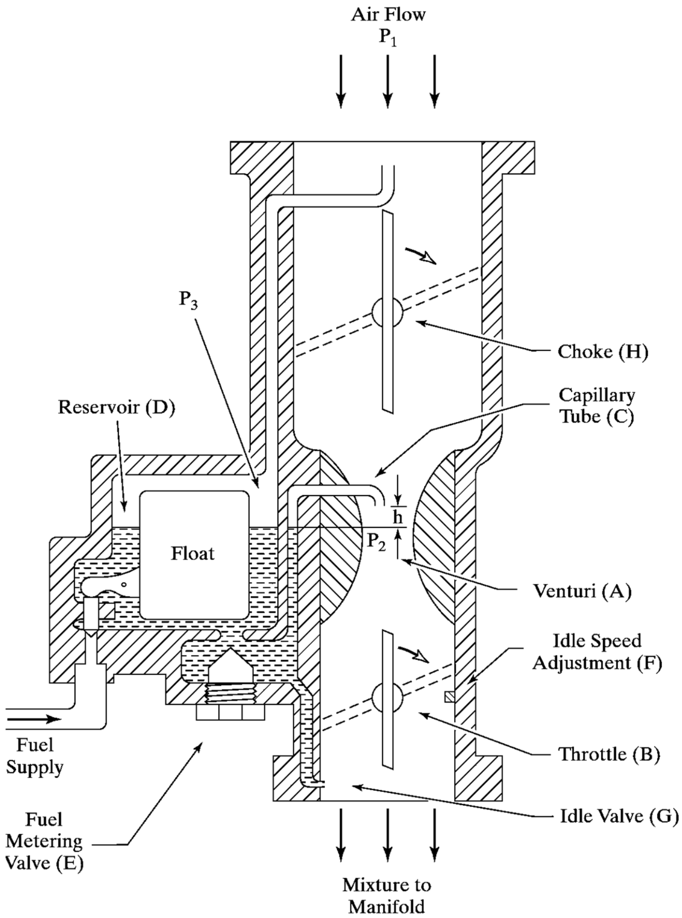
Engine components - Valves

- The same effect can be caused by an inlet valve which is **sticking** in its guide.
- Some designs of engine use **Hydraulic Tappets** (Hydraulic Valve Lifter). These are self adjusting and operate with no clearance and thus there is no tappet noise.
- A hydraulic tappet is made in two main parts, one sliding within the other. **Oil**, which is supplied under pressure, causes the tappet to lengthen and take up any clearance when the engine is running.



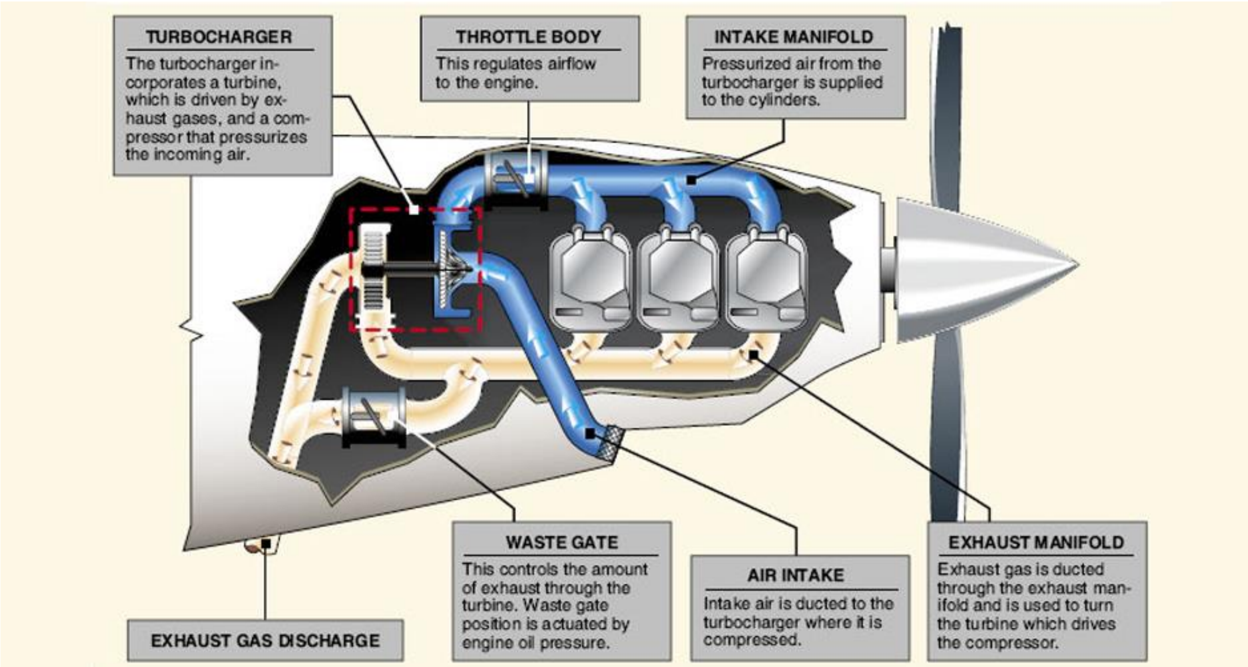
Engine components - Carburetor

- The Carburetor meters the air entering the engine and adds the required amount of fuel as a fine spray under all conditions of engine running. For an aircraft engine the **correct mixture** must be supplied **regardless of altitude** or attitude of the aircraft.
- **An Injector** can be fitted instead of a carburetor on some engines.
- They are attached to the base of the crankcase, metal pipes (**Induction Manifold**) connect the outlet from the carburetor or injector to the cylinders.



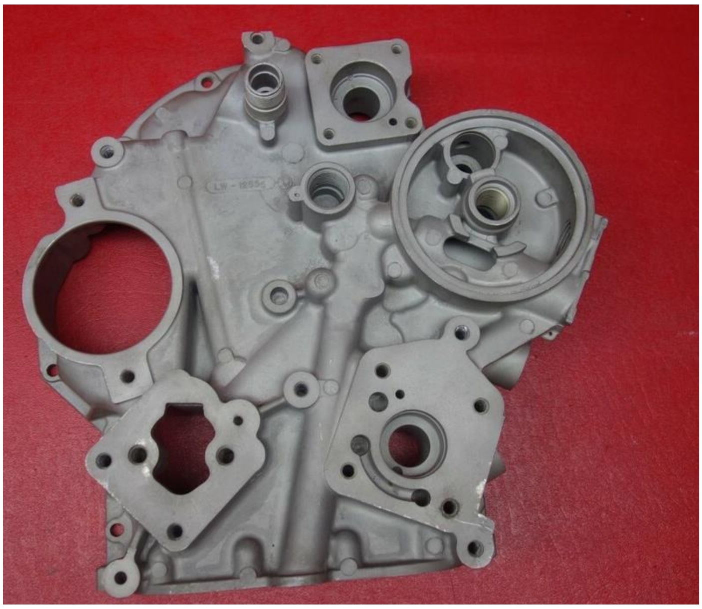
Engine components - Carburetor

- The waste gases after combustion are carried away from the cylinders by the **Exhaust System**.
- The exhaust consists of steel pies connected to each of the cylinders. The pipes from each cylinder usually connect up and go into one or two pipes which then carry the hot gases **outside** the aircraft to atmosphere.



Engine components - Accessory Housing or Wheelcase

- For the engine to operate supporting systems are needed, and they may need power to drive them. **Oil Pumps**, **Fuel Pumps**, **Superchargers** and **Magneto Ignition** systems are fitted to the Accessory Housing and driven via gears by the crankshaft.
- The **housing casing** is bolted to the rear of the crankcase which encloses the gear train and provides mounting pads for the ancillary equipment.



Engine components - Accessory Housing or Wheelcase

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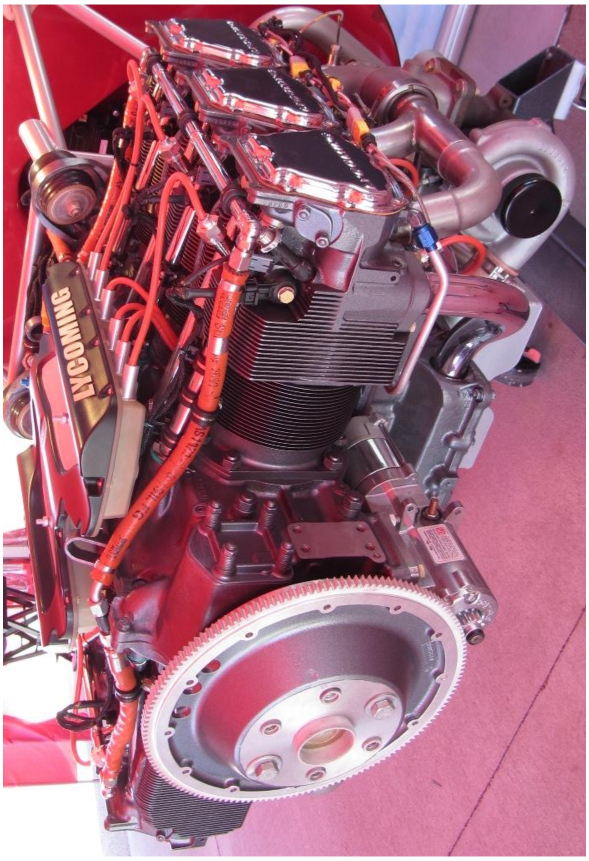
- The **housing casing** is bolted to the rear of the crankcase which encloses the gear train and provides mounting pads for the ancillary equipment.
- A **Starter Motor** can be connected to the housing to initially rotate the crankshaft and start cycle of operation.
- The accessory housing can also provide the drive to power aircraft systems such as **Electrical Generation**, **Hydraulics** and **Pneumatic systems**.
- Some engines may also have a Gearbox fitted between the crankshaft and the propeller. This is a **Reduction Gearbox** to reduce the speed of propeller rotation. For the propeller to operate efficiently a comparatively low speed is required.
- The lower powered engines have the propeller connected directly onto the crankshaft. These are called **Direct Drive** engines.

Engine components - Accessory Housing or Wheelcase

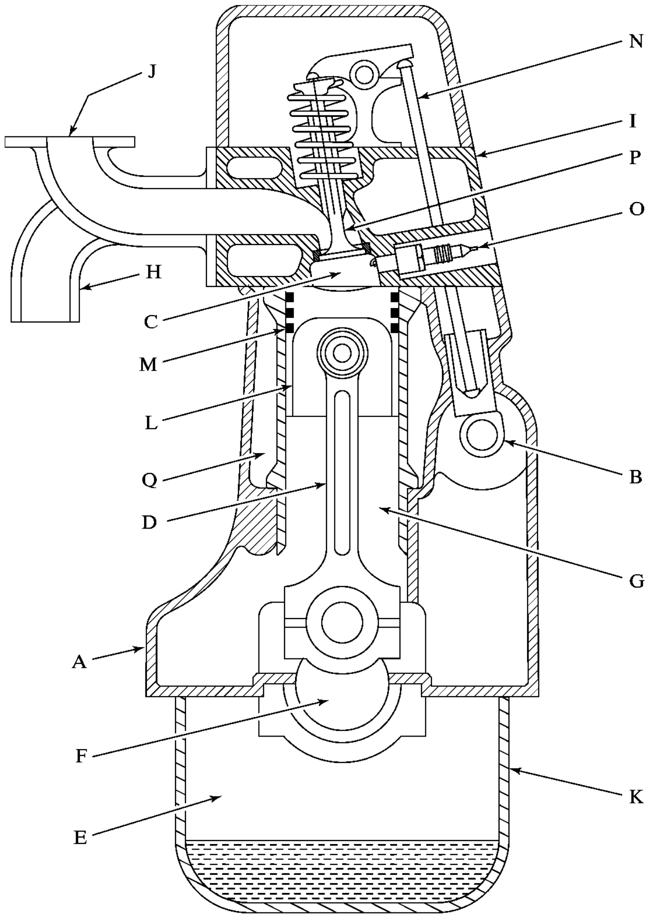
The figure shows the **Texron Lycoming** model AEIO 540 LIB5. The model number is used to define the engine:

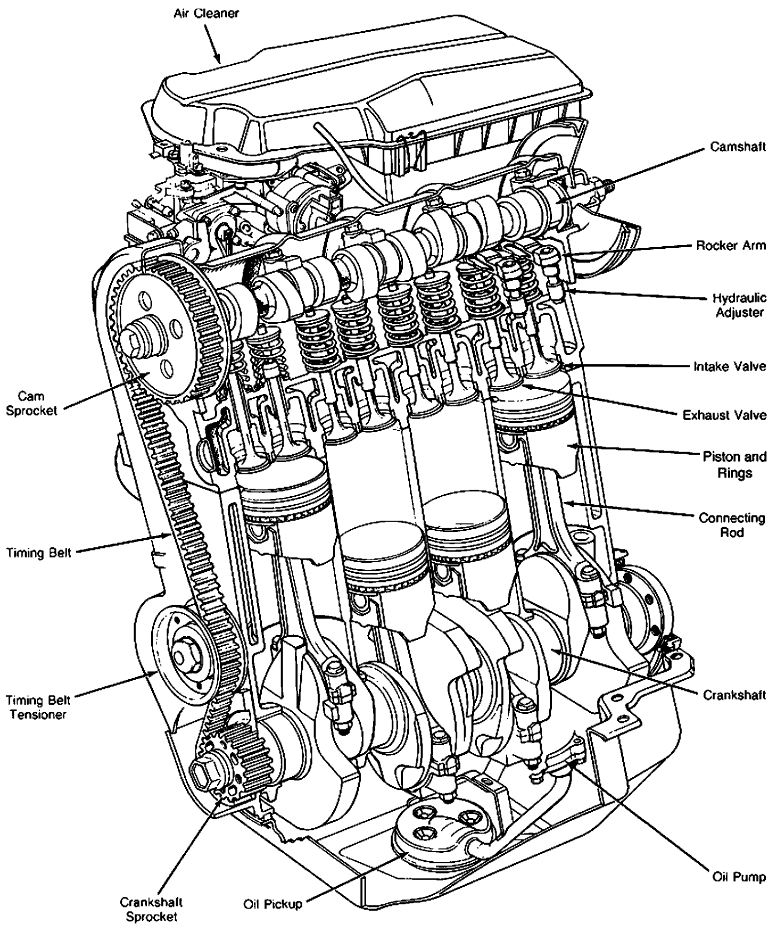


- AE Aerobatic Engine.
- I Injected Fuel System
- O Horizontally opposed Cylinder.
- 540 Cylinder displacement = 540 cubic inches.
- L Left hand Rotation.
- 1B5 Modifications from basic model.

This type of model numbering system is used by most manufacturers. If the letters G and S were included it would imply the engine was geared and supercharged.

Engine components

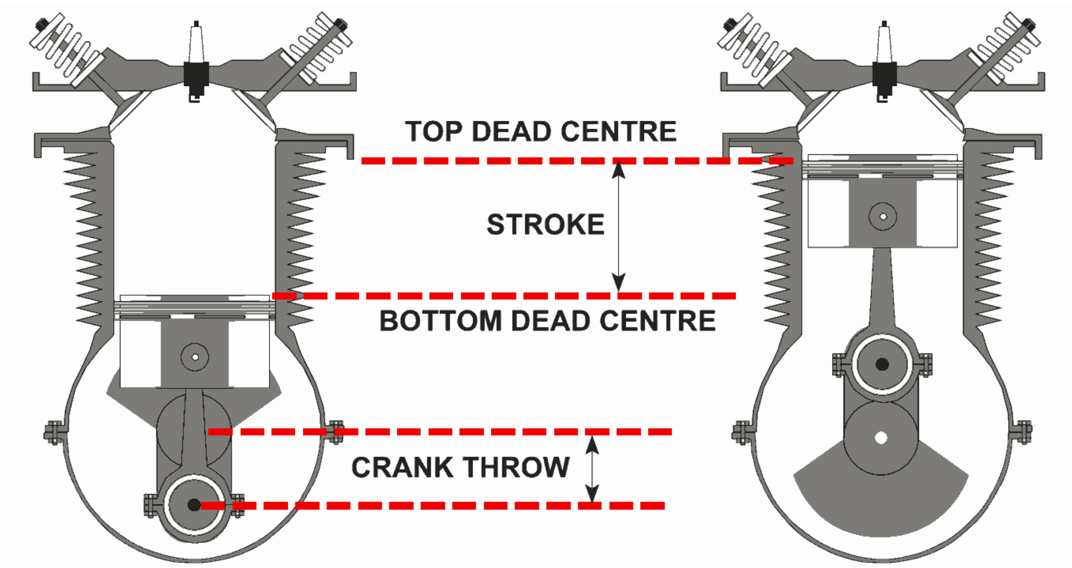




Otto cycle

A **Stroke** is defined as the linear distance that the piston moves in the cylinder. When the piston is at the top of the stroke it is said to be at **Top Dead Centre** (TDC), and when at the bottom of the stroke **Bottom Dead Centre** (BDC.).

The piston is connected to a crankshaft and as the piston moves from TDC to BDC the crankshaft rotates 180° The complete cycle taking 720° (4 x 180).



Otto cycle

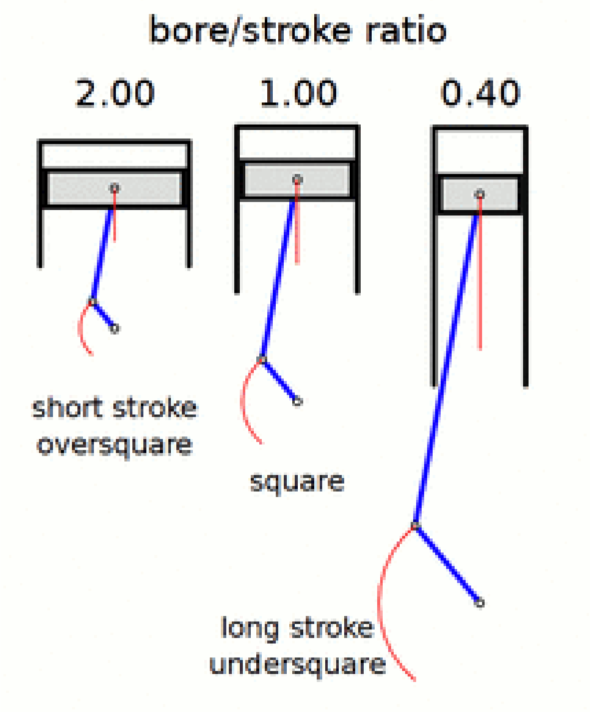
The internal diameter of the cylinder is called the **Bore**.

The Stroke is equal to Twice the **Crank-throw**.

An engine which has a bore equal to the stroke is known as **over-square**.

The four strokes of an internal combustion engine are:

1. Induction or Intake (Aspirazione)
2. Compression (Compressione)
3. Power (Combustione ed espansione)
4. Exhaust (Scarico)



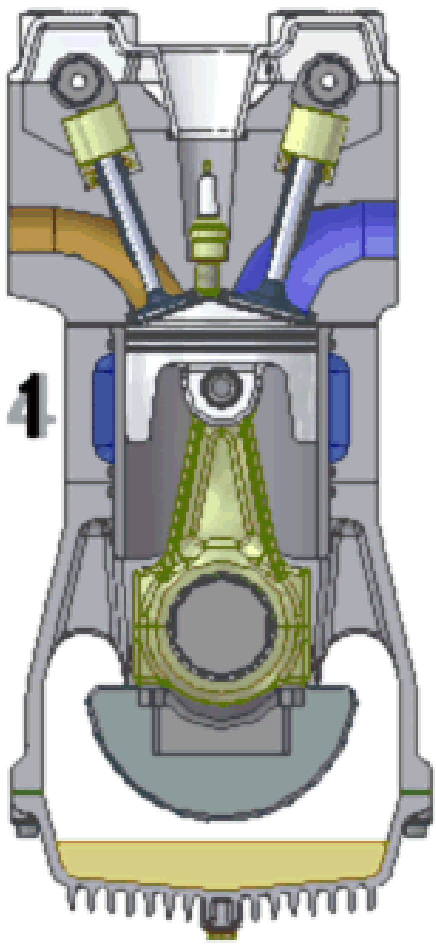
Otto cycle

The four strokes of an internal combustion engine are:

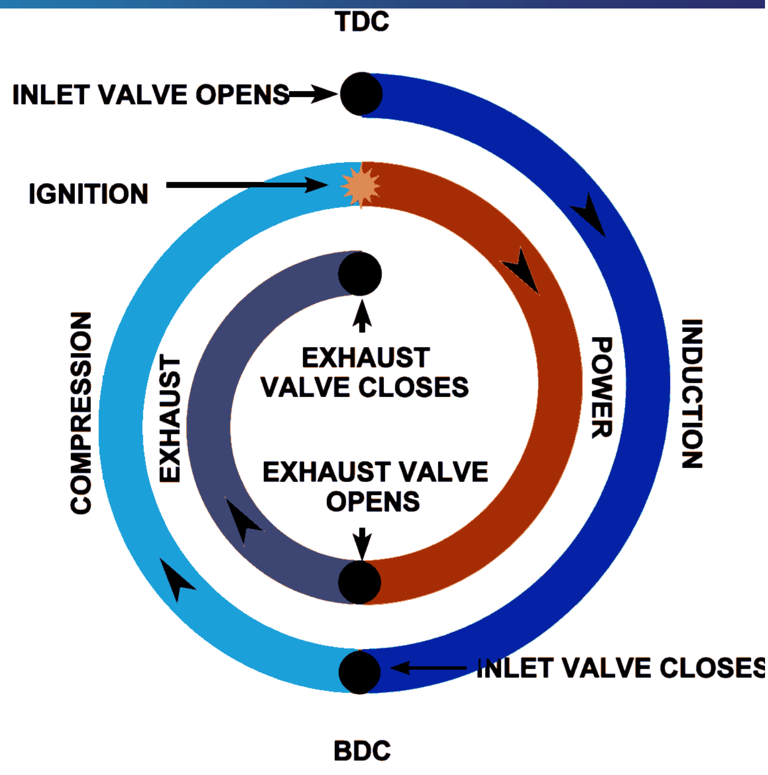
1. Induction or Intake (Aspirazione)
2. Compression (Compressione)
3. Power (Combustione ed espansione)
4. Exhaust (Scarico)

When the piston is at TDC at the end of the compression stroke an **electrical spark** is produced at the spark plug, and ignites the fuel air mixture. This does not result in an explosion of the mixture, but is a controlled burning.

The combustion process takes place with the piston at TDC. The **volume** in the cylinder at that moment in time **is constant**. Combustion is said to take place at Constant Volume.



Otto cycle



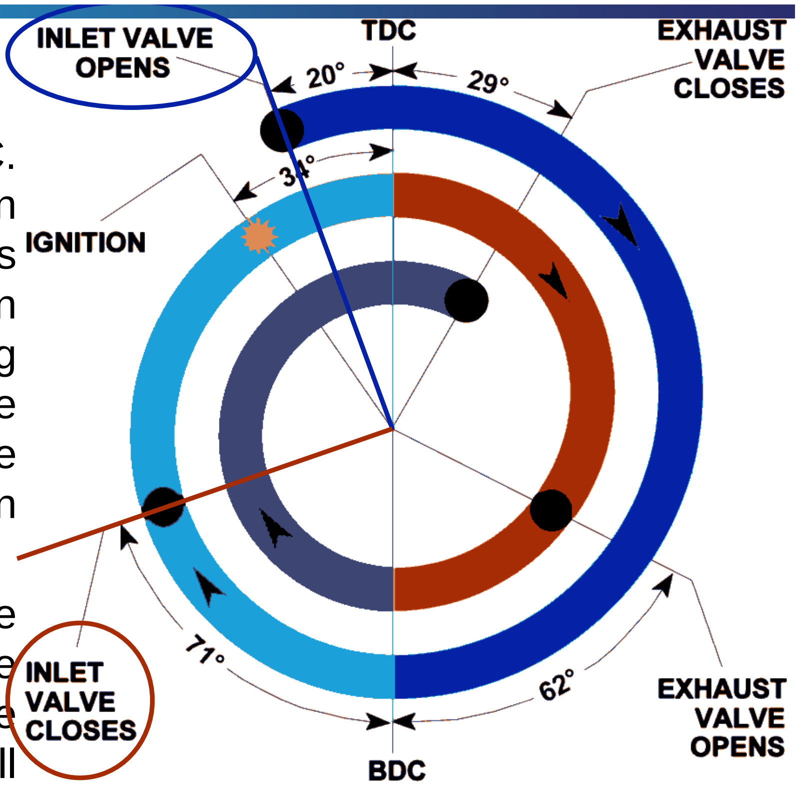
In the Otto cycle there are **five Events:**

1. Induction
2. Compression
3. Combustion
4. Power
5. Exhaust

The **timing diagram** shows the relationship between the events, and degrees of crankshaft rotation. Each arc between TDC and BDC represents 180° of crankshaft rotation.

In practice the theoretical cycle proved to be inefficient and it was necessary to **modify the times** of valve openings and closings and ignition.

Otto cycle - Induction

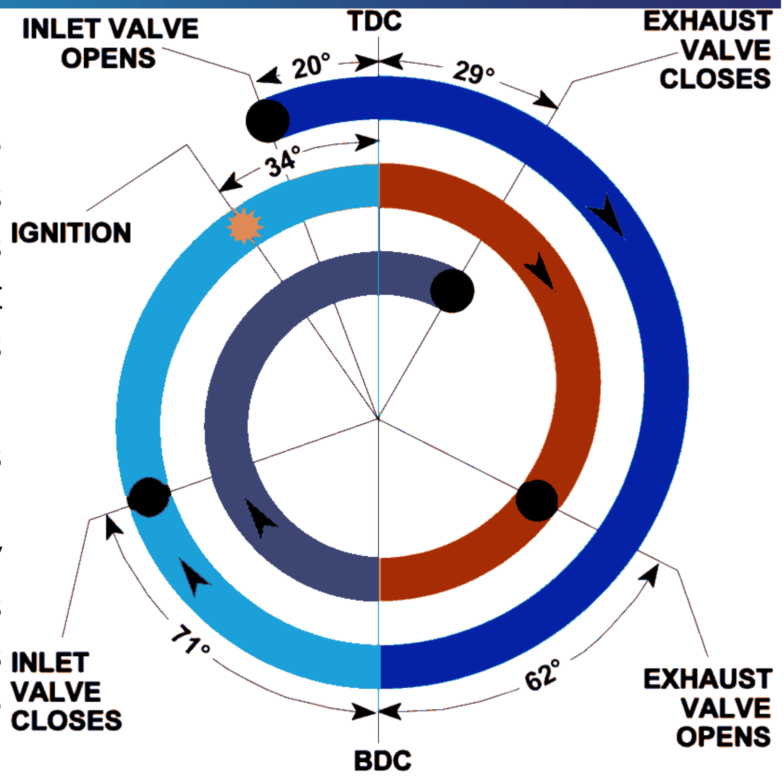


Opening the inlet valve **before** TDC. ensures that the valve is fully open early in the induction stroke, there is then no time-lag between the piston moving down and the mixture flowing into the cylinder as would otherwise occur due to the inertia of the mixture. The **inflowing mixture** can keep up with the descending piston.

The **momentum** of the mixture increases as the induction stroke proceeds, and towards the end of the stroke, it is such that the gases will **continue to flow** into the cylinder even though the piston has passed BDC and is moving upwards slightly.

The closing of the inlet valve is therefore **delayed** until after BDC when the gas pressure in the cylinder approximately equals the gas pressure in the induction manifold.

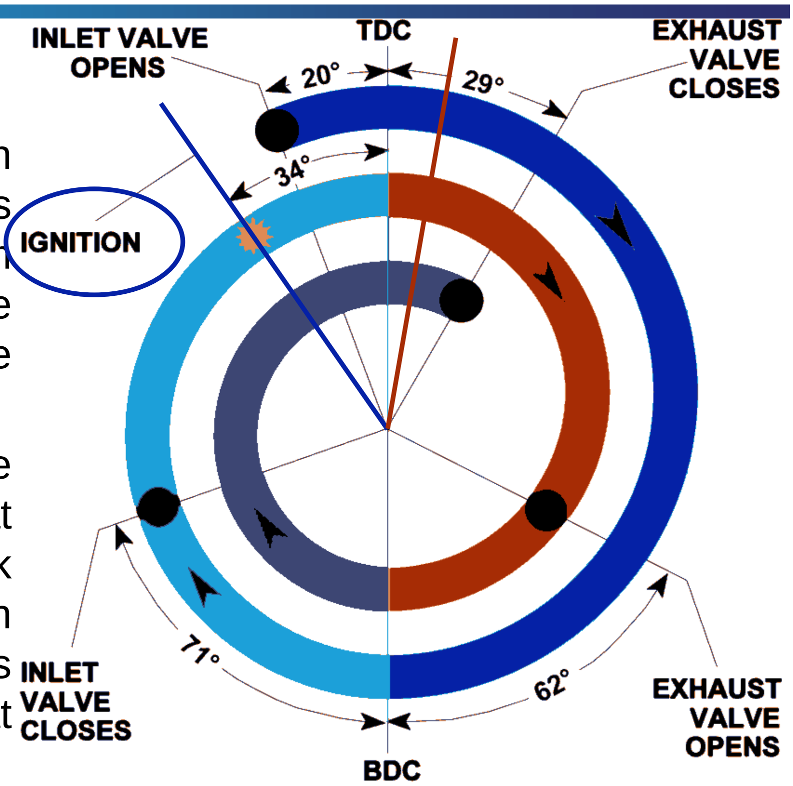
Otto cycle - Compression



As the piston moves upwards, the **inlet** valve **closes** and the gas is compressed. By squeezing the gas into a smaller space the pressure that it will exert when burnt is proportionally increased.

It should be noted that as the gas is **compressed** it becomes heated **adiabatically** as well as by **conduction** from its hot surroundings and the pressure consequently rises to a higher value than that to be expected from the reduction in volume alone.

Otto cycle - Power

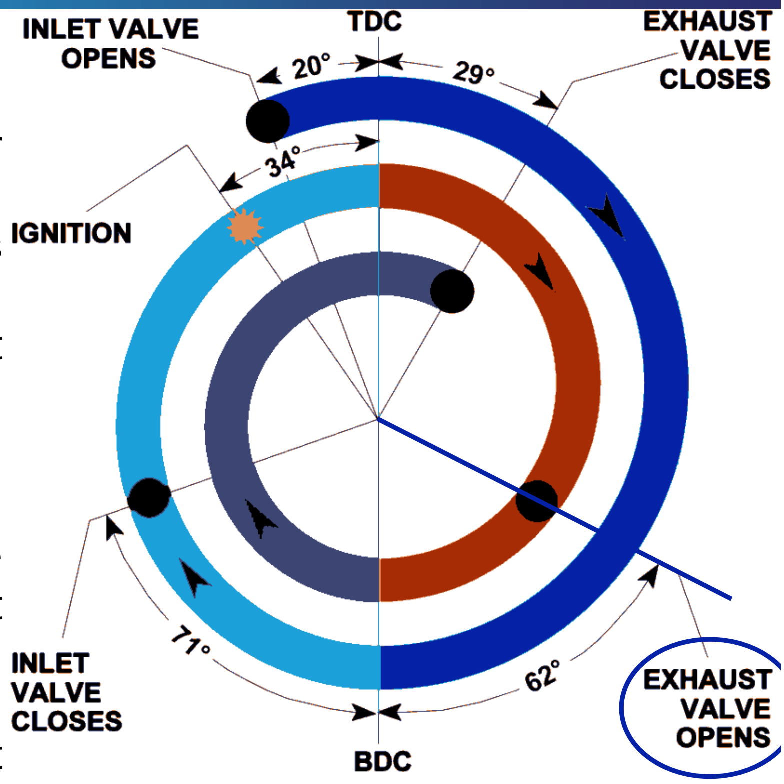


Before the piston reaches TDC on the compression stroke the gas is **ignited by a spark**; the momentum of the moving parts carrying the piston past the TDC whilst the flame is spreading.

As the **flame spreads** through the combustion chamber the intense heat raises the pressure rapidly to a peak value which is reached when combustion is complete, this coincides with the piston being at about 10° past TDC.

If the exhaust valve is not opened until BDC the pressure of the gases remaining in the cylinder would create a back pressure resisting the upward movement of the piston.

Otto cycle - Power

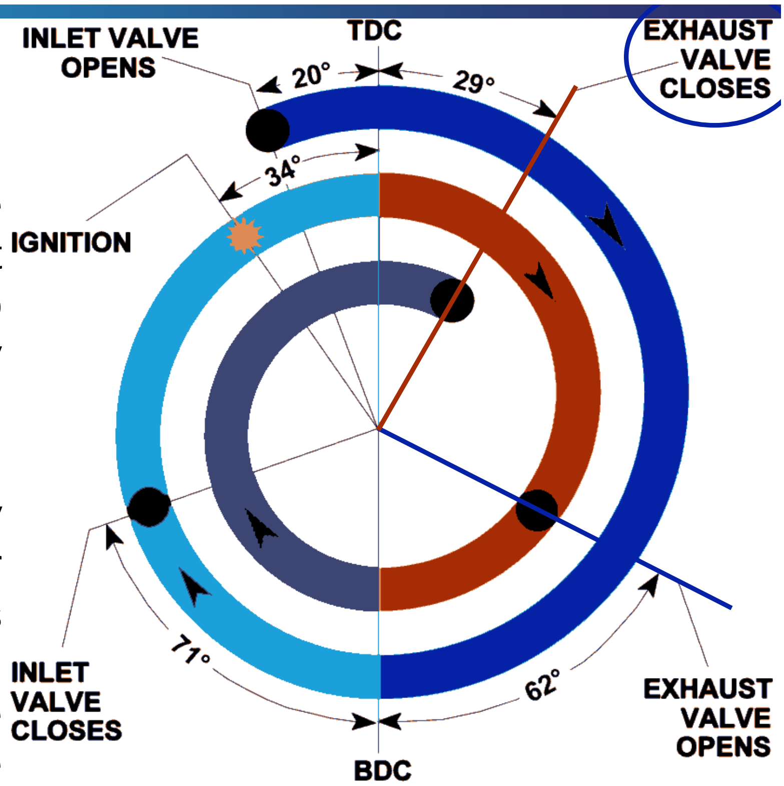


As the piston **descends** on the power stroke, the pressure falls rapidly and by 45° of crank angle after TDC is approximately half its peak value, and by 90° of crank angle after TDC most of the energy in the gases has been converted into mechanical energy.

If the **exhaust** valve is opened **before** BDC the residual pressure will start the first stage of exhaust scavenging, so that by BDC there will be no back pressure on the piston. This does not produce a significant loss of mechanical energy because:

- There is only a **short distance** left for downward movement of the piston after the exhaust valve is opened.
- Relatively **little pressure** is still being exerted on the piston by the cooled expanded gases.

Otto cycle - Exhaust



Finally the piston moves upward forcing the remaining gases out of the cylinder. The **exhaust** valve is left open after TDC to permit the gases to scavenge the cylinder as completely as possible by their momentum.

About the position of TDC and BDC, the **distance** the piston moves is very **small** compared to the large angular movement of the crankshaft. This is called the **Ineffective Crank Angle**. As there is little change in the cylinder volume at these times, the weight of charge into the cylinder and the exhaust of the burnt gases can be improved by opening the valves early and closing them late.

These changes to the valve timing are named **Valve Lead**, **Valve Lag** and **Valve Overlap**.

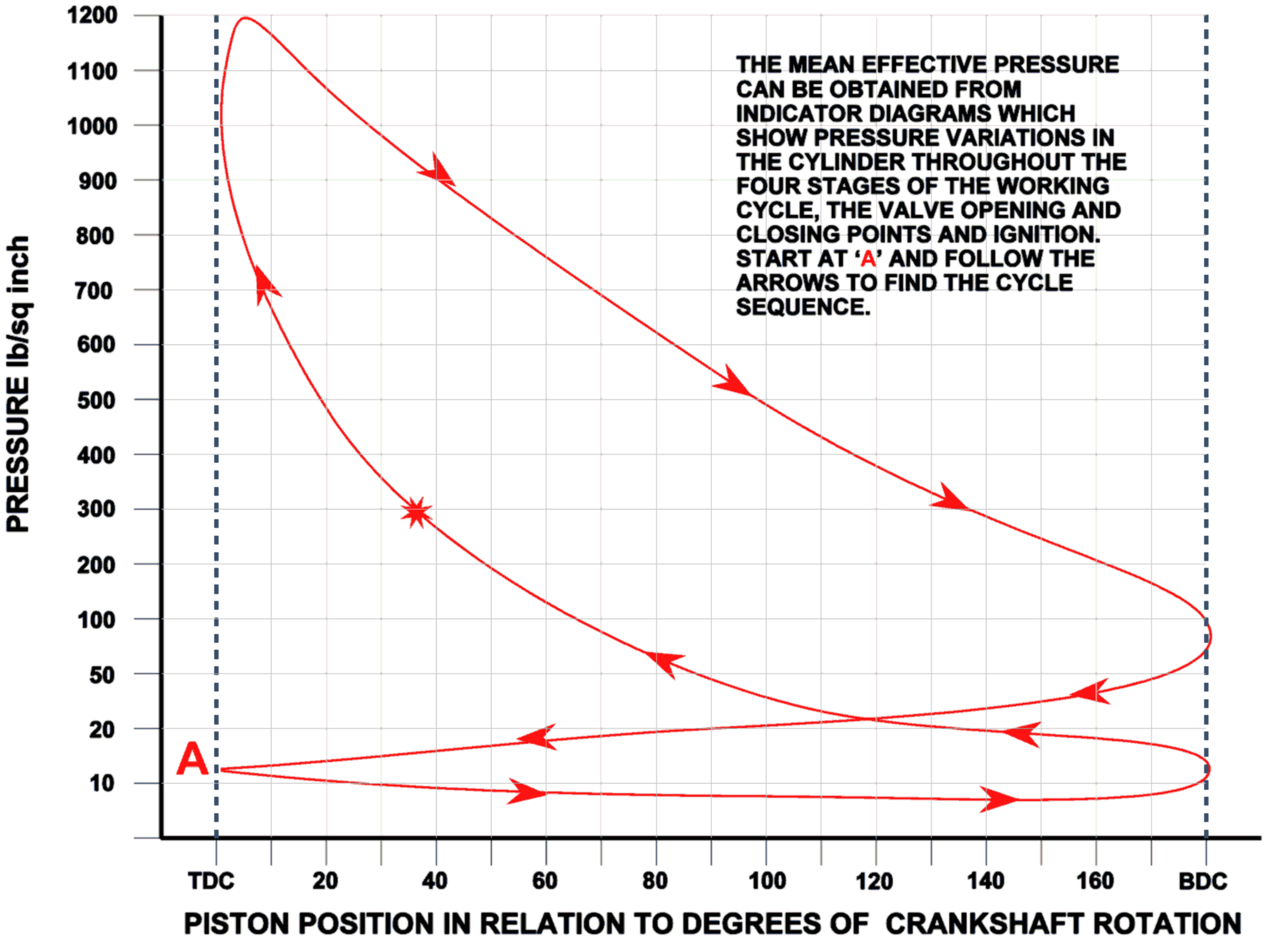
Otto cycle

These changes to the valve timing are named:

- **Valve Lead** is when the valve **opens before** the theoretical opening time. (Inlet valve opens before TDC, exhaust valve opens before BDC).
- **Valve Lag** is when the valve **remains open after** the theoretical closing time (Inlet valve remains opens after BDC, exhaust valve remains open after TDC).
- **Valve Overlap** is a period when **both valves** are partially **open** together. During this period the action of the exhaust gases flowing out of the cylinder tends to reduce the gas pressure in the cylinder below the gas pressure in the induction manifold. The mixture commences to flow into the area of low pressure and assists in displacing the remaining burnt gases and by doing so improves the volumetric efficiency of the engine by inducing a greater weight of charge into the cylinder.

The **valve timing** for a particular engine is **fixed**, and does not vary with engine speed.

Otto cycle

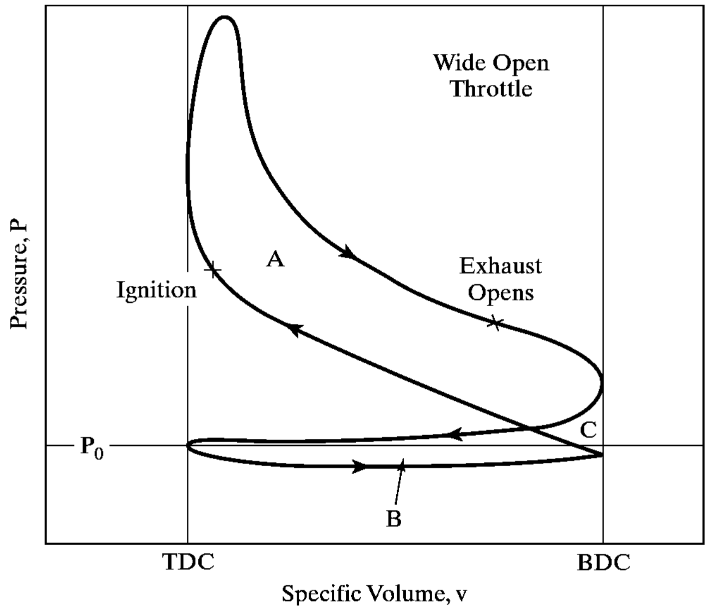


Otto cycle

The **indicated work** is the work inside the combustion chamber.

The work delivered by the crankshaft is **less** than indicated work, due to mechanical friction and parasitic loads of the engine. Parasitic loads include the oil pump, supercharger, air conditioner compressor, alternator, etc. **Actual work** available at the crankshaft is called **brake work**:

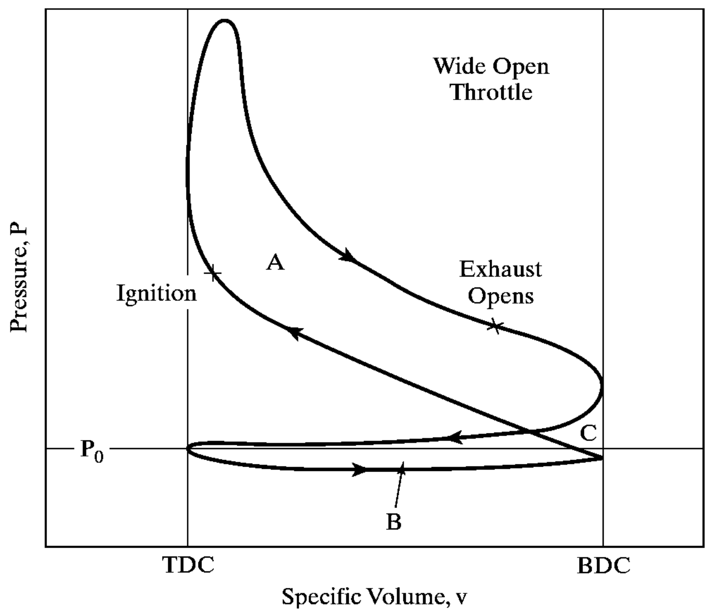
$w_b = w_i - w_f$



Otto cycle

The **upper loop** of the engine cycle consists of the compression and power strokes where output work is generated and is called the **gross indicated work** (Area A). The **lower loop**, which includes the intake and exhaust strokes, is called **pump work** and absorbs work from the engine (Area B). Net indicated work is:

$w_i = w_{gross} + w_{pump}$



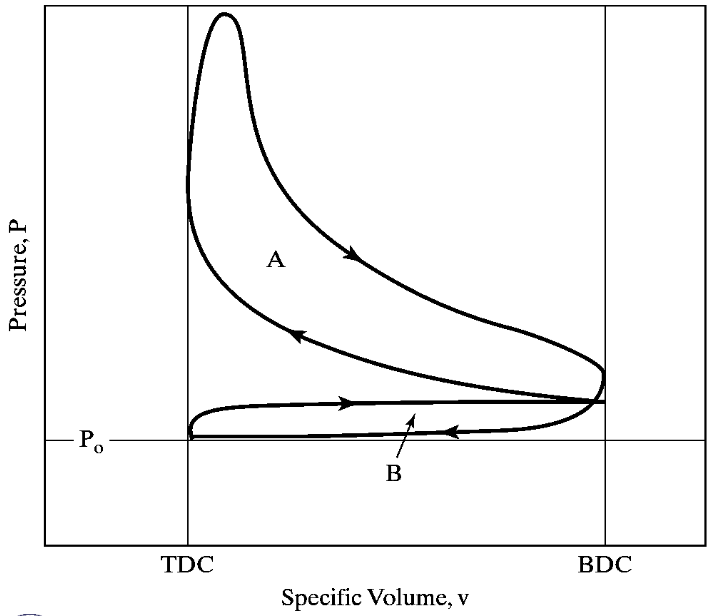
Otto cycle

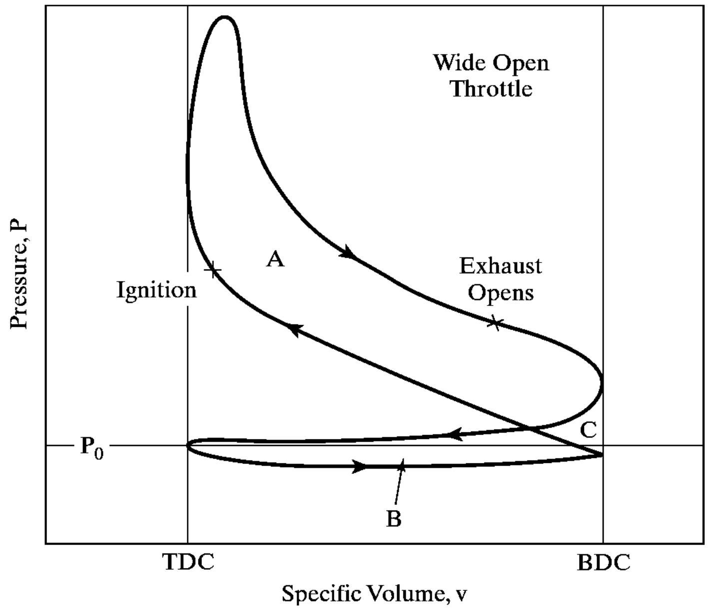
Net indicated work is for engine without super charger (right):

$$w_i = w_{gross} + w_{pump} = A - B$$

Net indicated work is for engine with super charger (left):

$$w_i = w_{gross} + w_{pump} = A + B$$





Otto cycle

An average or **Mean Effective Pressure** (mep) is defined by:

$$MEP = \frac{w}{V_{BDC} - V_{TDC}}$$

Mean effective pressure is a good parameter for comparing engines with regard to design or output because it is **independent** of both engine **size** and **speed**. If torque is used for engine comparison, a larger engine will always look better. If power is used as the comparison, speed becomes very important.

Indicated work gives the **Indicated Mean Effective Pressure**:

$$IMEP = \frac{w_i}{V_{BDC} - V_{TDC}}$$

The **Indicated Horse Power** is:

$$IHP = w_i N E$$

where *N* is the number of cylinder and *E* is the effective (divided by 2 for a 4 strokes engine) working strokes per seconds.

Otto cycle

The **Indicated Horse Power** is:

$$IHP = w_i N E$$

where *N* is the number of cylinder and *E* is the effective (divided by 2 for a 4 strokes engine) working strokes per seconds.

IHP is only a **theoretical** value of power. In moving the piston and turning the crankshaft power is used.

This is called **Friction Horse Power**, (FHP), and must be deducted from the IHP.

The power then left to do useful work (for example driving a propeller) is called **Brake Horse Power** (BHP).

Otto cycle

The **Specific Fuel Consumption** is defined as the ratio between the mass flow rate of fuel burnt and the power produced. For example, the **Indicated Specific Fluid Consumption** is:

$$ISFC = \frac{\dot{m}_f}{IHP}$$

Or, the **Brake Specific Fuel Consumption**:

$$BSFC = \frac{\dot{m}_f}{BHP}$$

SFC is affected by engine design and Pilot Operation.

Otto cycle

The **Mechanical efficiency** is defined as:

$$\eta_m = \frac{BHP}{IHP}$$

A typical value of Mechanical efficiency would be in the region of 80-90%.

The efficiency at which the heat energy released by the combustion of the fuel is converted to work done in the engine is known as the **Brake Thermal Efficiency**:

$$\eta_t = \frac{BHP}{\dot{m}_f Q_R}$$

Engine design and the use of correct fuels increase thermal efficiency. A good value for thermal efficiency in an internal combustion engine would be 25-30%.

Otto cycle

The power of the engine is determined by the maximum weight of mixture (charge) induced, and the subsequent rise in pressure during combustion. Due to inertia and factors affecting the density of the mixture, it is **not possible** to **fill** the cylinder completely during the induction stroke.

The ratio of the weight of mixture induced to that which would fill the cylinder under normal temperatures and pressures is called **Volumetric Efficiency**:

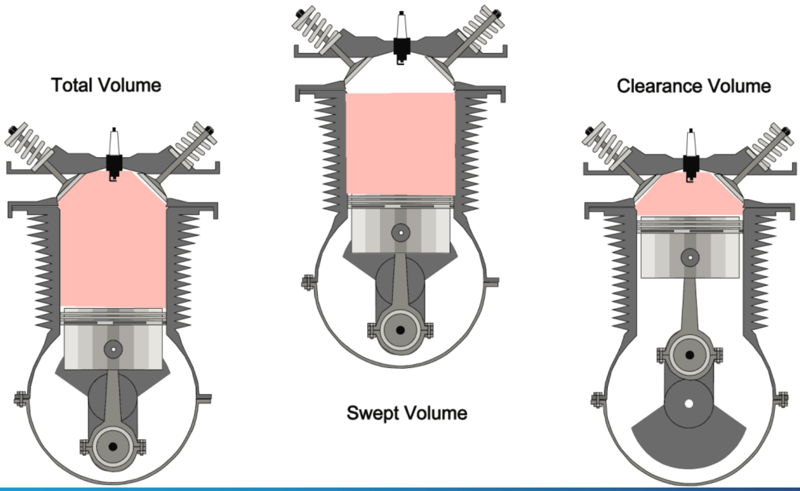
$$\eta_v = \frac{m_i}{\rho V}$$

where ρV is the mass mixture which could fill the cylinder at normal temperatures and pressures. Approximate value 75% for "naturally **aspirated** engines". Could be **greater than 100%** for **supercharged** engines. Volumetric efficiency decreases as RPM increases.

Otto cycle

The work done on the mixture by the piston during the compression stroke depends on the weight of mixture induced and the pressure that it is raised to. The pressure rise will depend on the reduction in volume. There are **three volumes** that need to be considered. They are:

- **Total Volume** is the volume above the piston when the piston is at BDC.
- **Swept Volume** is the volume displaced by the piston during a single stroke.
- **Clearance Volume** is the volume above the piston crown when the piston is at TDC, this form the combustion chamber.



Otto cycle

The increase in pressure is called the **Compression Ratio** of the engine. The Compression Ratio is the ratio of the total volume enclosed in the cylinder with piston at BDC, to the volume at the end of the compression stroke with the piston at TDC.

$$CR = \frac{V_{tot}}{V_{Clearence}}$$

An **increase** in **compression ratio** will result in better fuel utilization (hence greater Thermal Efficiency) and a higher mean effective pressure provided the correct fuel is used. This, however, will be at the expense of higher loading on the moving parts due to an increased working pressure.