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DOCUMENT TITLE

AIRCRAFT GENERAL KNOWLEDGE

CHAPTER 3 – PISTON ENGINES AND THE FOUR STROKE CYCLE

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PISTON ENGINES AND FOUR STROKE CYCLES

3.1 Engine Performance Terminology

These terms describe the results of the power produced by the engine.

3.1.1 Work

Work is the force multiplied by the distance expressed as foot pounds (ft/lbs) or Newton metre (N-m).

$$W = F \times d$$

> Note: Work is the transfer of energy and energy units are called Joules. Thus, work can also be expressed as Joules.

3.1.2 Power

All engines produce some sort of power, thus power can be determined by measuring the amount of work expended in moving an object a certain distance over a period of time. The basic power formula is:

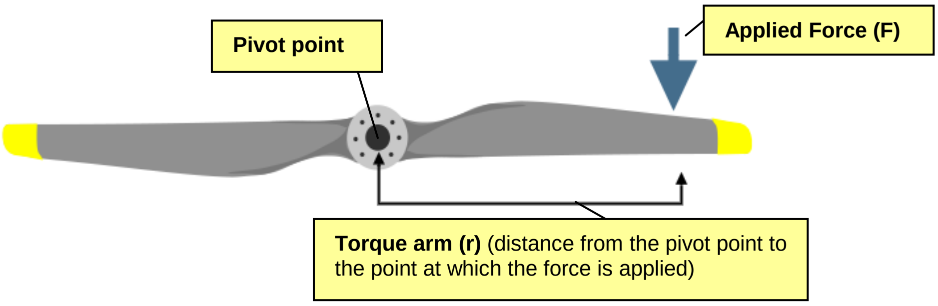
$$\text{POWER} = \frac{\text{Force x Distance}}{\text{Time}}$$

A horsepower is a British unit for power, defined as the force needed to move 550 pounds one foot in one second (550ft/lb per sec), or 33000 foot pounds per minute (33000 ft/lb per min).

> (In the metric system the term for the unit of power is the Watt. One horsepower is equivalent to 760watts or 0.76kilowatts)

3.1.3 Torque

In a rotational system, there is a "twist", which is called torque. Torque is the tendency to produce change in rotational motion; it is equal to the applied force (F) X the length of the torque arm (r). Torque is measured in foot-pounds (ft-lb) in the British System or Newton Metres Nm in the Metric System.



3.1.4 IHP - Indicated Horsepower

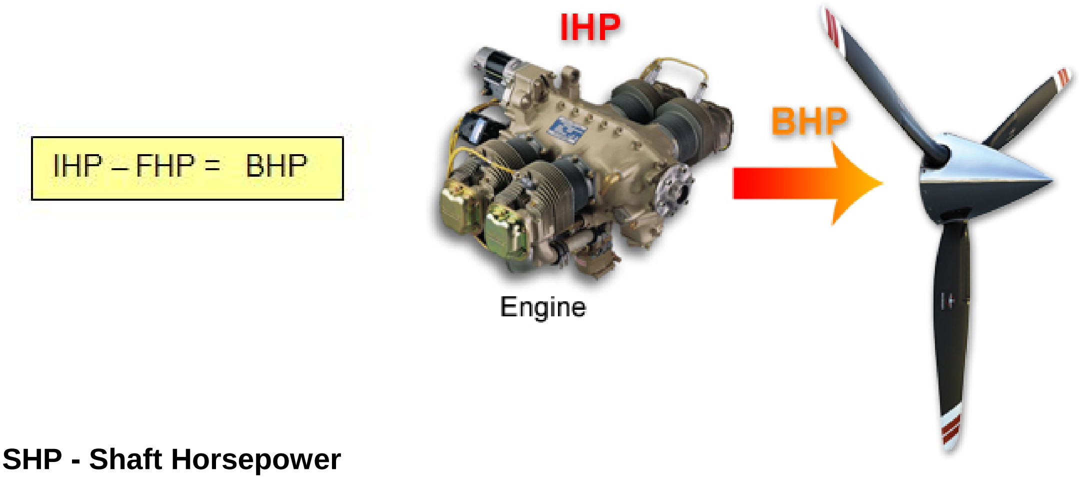
Indicated horsepower is the theoretical power developed in the combustion chamber of a frictionless engine.

3.1.5 FHP - Friction Horsepower

Friction horsepower (FHP) is a measure of all the losses which occur within the engine due to friction and auxiliary equipment such as the alternator, fuel and oil pumps. The movement of the pistons up and down, as well as the rotation of the crank and camshafts, all create frictional losses.

3.1.6 BHP - Brake Horsepower

Brake horsepower is the actual power available at the crank shaft, or propeller shaft. It is less than the IHP and is a function of both RPM and torque.



3.1.7 SHP - Shaft Horsepower

Shaft horsepower is the power delivered to the propeller shaft of a turbo shaft engine.

3.1.8 THP – Thrust Horsepower

Thrust horsepower is produced when the propeller converts the engine power in to thrust horsepower. The thrust is a function of the blade pitch of the propeller relative to the velocity of the aircraft. Thrust horsepower is also the equivalent of the thrust produced by a jet engine.

3.1.9 Mechanical Efficiency

Mechanical efficiency is the ratio of the IHP to the actual BHP, generally considered to be about 70% in a piston engine, expressed by the formula:

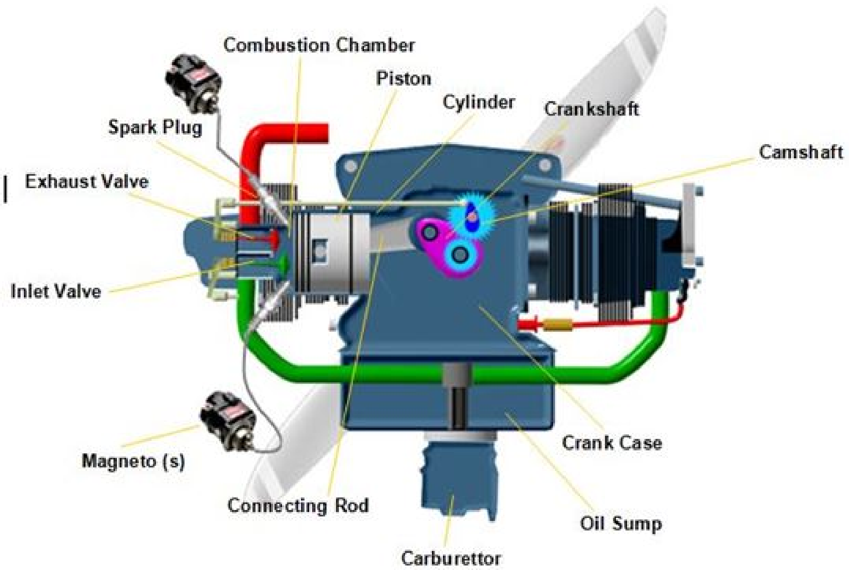
$$\text{Mechanical Efficiency} = \frac{BHP}{IHP}$$

3.2 The Internal Combustion Engine

3.1.10 Introduction

The common piston engine is made up of many different components, mainly metals, which have been cast or forged then machined and assembled together.

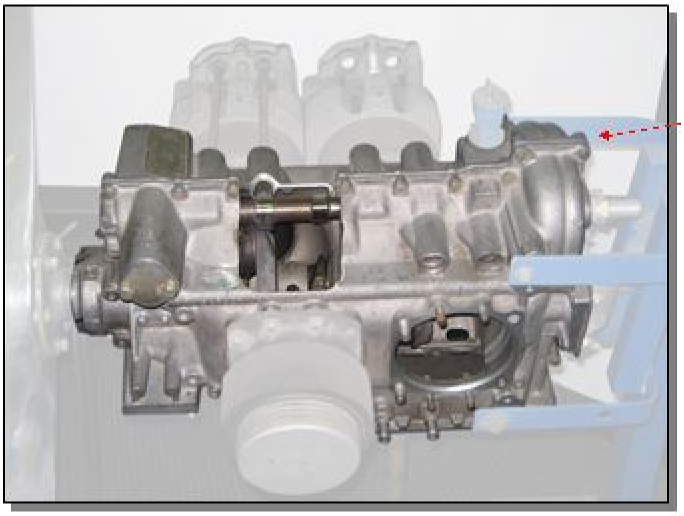
The engine is an energy conversion device operating on a four stroke cycle; it is supplied with aviation gasoline (AVGAS) which is converted into mechanical energy. This mechanical energy is then applied to turn a crankshaft, and in the case of an aircraft, applied to a propeller which produces thrust.



3.1.11 Components

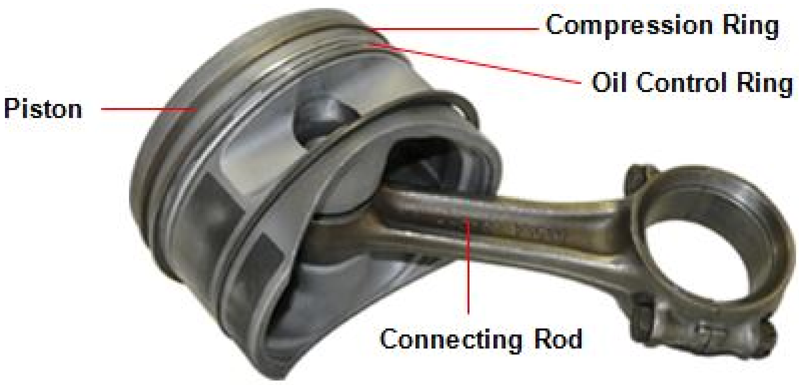
3.1.1.1 Crankcase

The crankcase is the main body of the engine. It is usually made of aluminium alloy and may be forged or cast. It has internal oil passages and is machined to house the crank and cam shafts. It usually carries the engine mounts for fitment to the airframe.



3.1.1.2 Pistons

The piston converts the combustion energy to mechanical energy to drive the crankshaft.



3.1.1.3 Cylinders

The cylinders act as the compression and expansion chambers and provide the bore in which the pistons move.

3.1.1.4 Cylinder Head

The Cylinder Head seals the top of the cylinder to form the Combustion Chamber.

3.1.1.5 Piston Rings

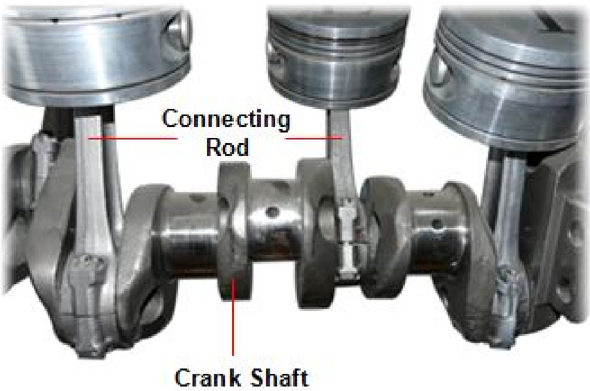
The piston (compression) rings provide a gas tight seal between the piston and cylinder.
Oil control rings, usually fitted below the compression rings, scrape the lubricating oil from the cylinder walls to prevent it from entering the combustion chamber.

3.1.1.6 Crank Shaft

A crankshaft converts the reciprocating motion of the pistons to rotary motion to drive the propeller.

3.1.1.7 Connecting Rod

The connecting rod connects the pistons to the crankshaft.



3.1.1.8 Inlet Valve

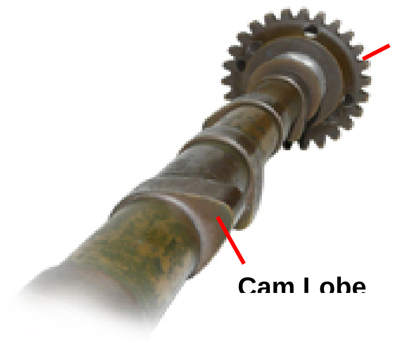
Inlet or intake valves control the air/fuel mixture entering the cylinder. The inlet valves are usually larger than the exhaust valve to improve the gas volume inflow to the cylinders.

3.1.1.9 Exhaust Valve

Exhaust valves control the flow of burned gases from the cylinder. Because hot gases are present on both sides of the exhaust valves they get very hot. Smaller than inlet valves, exhaust valves are sometimes Sodium filled to help dissipate heat.

3.1.1.10 Cam Shaft

The camshaft is driven by the crankshaft at half crankshaft speed and controls the opening and closing of the inlet and exhaust valves (valve timing).

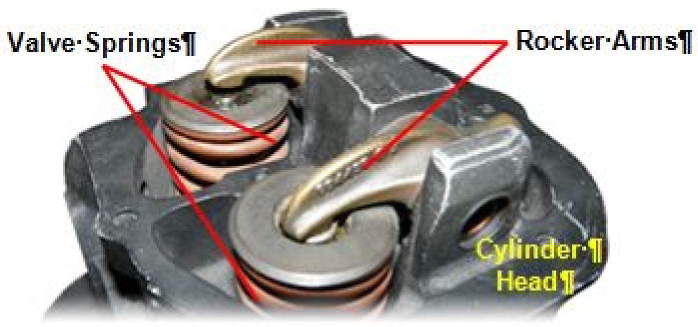


3.1.1.11 Push Rod

A push rod is a hollow metal tube (for light weight and rocker lubrication supply), which is pushed by a cam follower and in turn pushes on the rocker arm.

3.1.1.12 Rocker Arm

The rocker arm is a pivot device mounted on the cylinder head which when pushed by the Push Rod causes a valve to open against spring tension.



3.1.1.13 Valve Spring

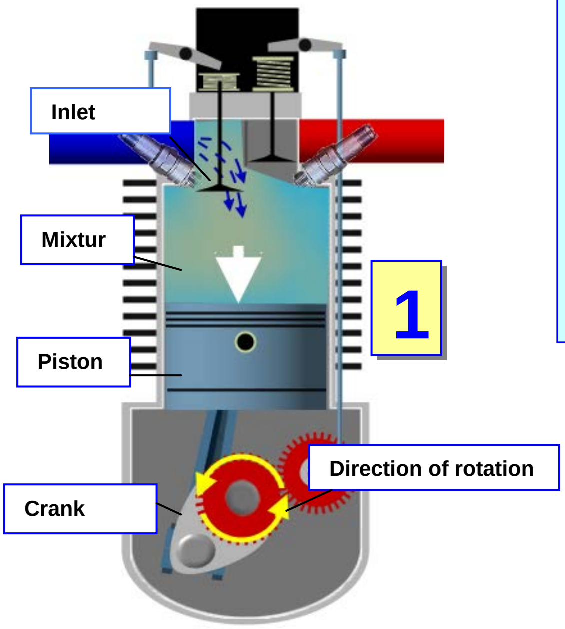
The push rod and rocker assembly open each valve. The valves are closed by strong valve springs when the cam rotates off its lobe. Often double valve springs are used to provide more rapid and positive valve closing as well as eliminating valve bounce.

3.1.1.14 Spark Plugs

Spark plugs are used to ignite the air/fuel mixture in the combustion chamber. In aircraft engines there are always two spark plugs per cylinder to promote complete combustion and provide a safety factor should a plug fail.

3.3 Four Stroke Cycle (Otto Cycle)

3.1.12 Induction



1. Induction

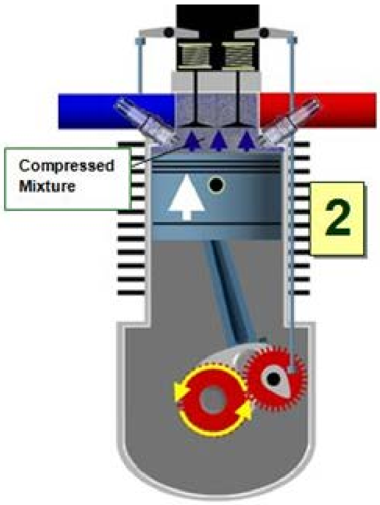
During this stroke, the inlet valve is opened by the camshaft, push rod and rocker arm mechanism and the piston is moving downward. This movement reduces the pressure in the cylinder, and the fuel mixture flows (or sucks) into the cylinder via the inlet valve.

Because the power output of an engine depends on the weight of the mixture induced into the cylinders, as much mixture as possible must be allowed to flow in a very short time. The flow of the mixture is controlled using a throttle.

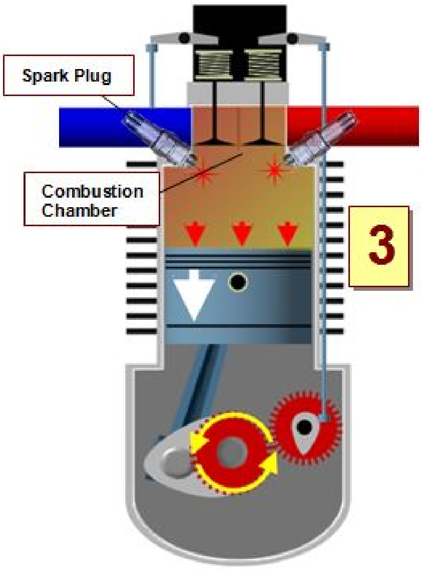
3.1.13 Compression

2. COMPRESSION

Once the induction cycle is completed the inlet valve closes, the piston starts to move upward and the mixture in the cylinder is compressed, due to the compression the mixture temperature also rises. Increasing the pressure of the mixture raises its ability to produce power when ignited.



3.1.14 Power



3. POWER

As the piston reaches the top of the compression stroke, a spark (from the spark plug) ignites the compressed mixture. The mixture then ignites and the intense heat raises the pressure rapidly to a peak value which forces the piston down. As both valves remain closed, the expanding gases continue to move the piston down the cylinder.

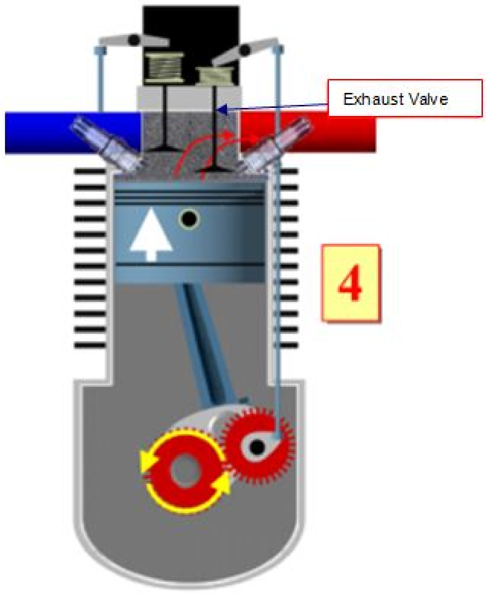
As the piston is forced down, the crankshaft rotates under the influence of the connecting rod and the pressure drops until the piston reaches the end of the power stroke. Combustion is complete and the pressure on the piston is comparatively low.

3.1.15 Exhaust

4. EXHAUST

With the piston now at the bottom of the power stroke, the exhaust valve is opened by the cam pushrod and rocker mechanism. As the piston returns towards the top of the cylinder the gases, (at a much lower pressure), escape past the open exhaust valve into the exhaust manifold and then into the atmosphere.

At the end of the exhaust stroke, the exhaust valve closes, the inlet valve opens and cycle begins again.

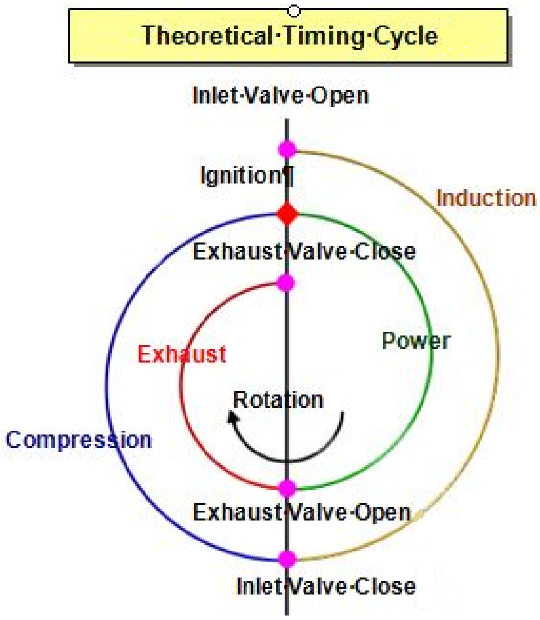


3.4 Associated Principles to the Four Stroke Cycle (Otto Cycle)

3.1.16 Timing

In theory, the opening and the closing of the valves, as well as the supply of the spark should be timed to take place at either Top Dead Centre (TDC) or Bottom Dead Centre (BDC) of each stroke. In practice, however, a number of factors have to be taken into account including:

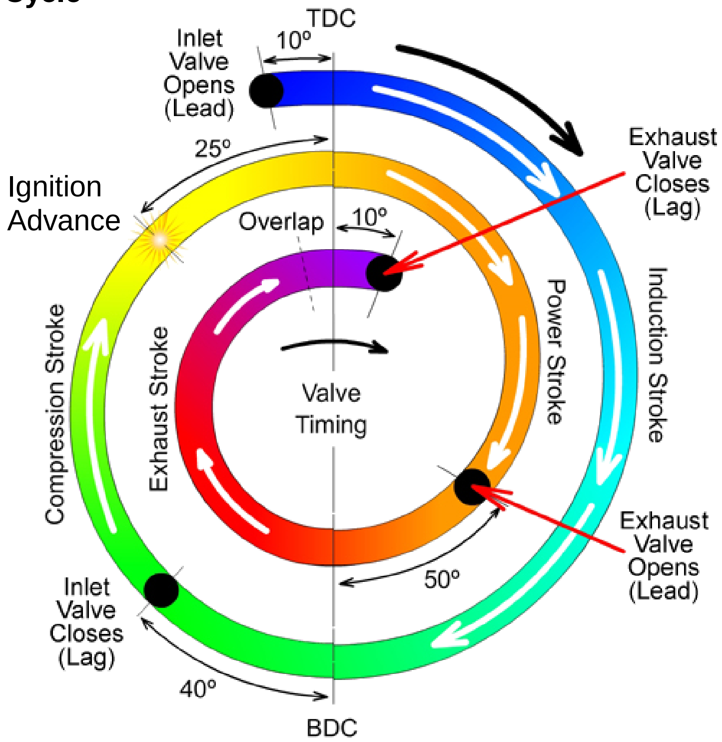
- The period of time the valves are opened and closed
- As a valve is opened there is a period of inertia before the gases begin to flow
- There is a time lag between the ignition of the compressed mixture, and the build up to maximum combustion pressure
- Both the intake and exhaust manifolds impose restrictions on the flow of gases to and from the cylinders.



Also consideration can be given to the fact that during one revolution of the crankshaft, there are two periods when the travel of the piston is minimal; these occur as the piston approaches the top and bottom of each stroke. During these periods the piston travel is limited and an opportunity exists for the valves to open either earlier or later, depending on the stroke, thus improving engine efficiency.

Advantage can also be made of reduced piston travel as it approaches the top of the compression stroke. By igniting the mixture before reaching TDC on the compression stroke, the peak gas pressure can be applied to the piston as it begins its downward movement of the power stroke, approximately 30 degrees ATDC. This ensures that the pressure of the expanding gases on the piston apply maximum force to the connecting rod at the most effective crank angle

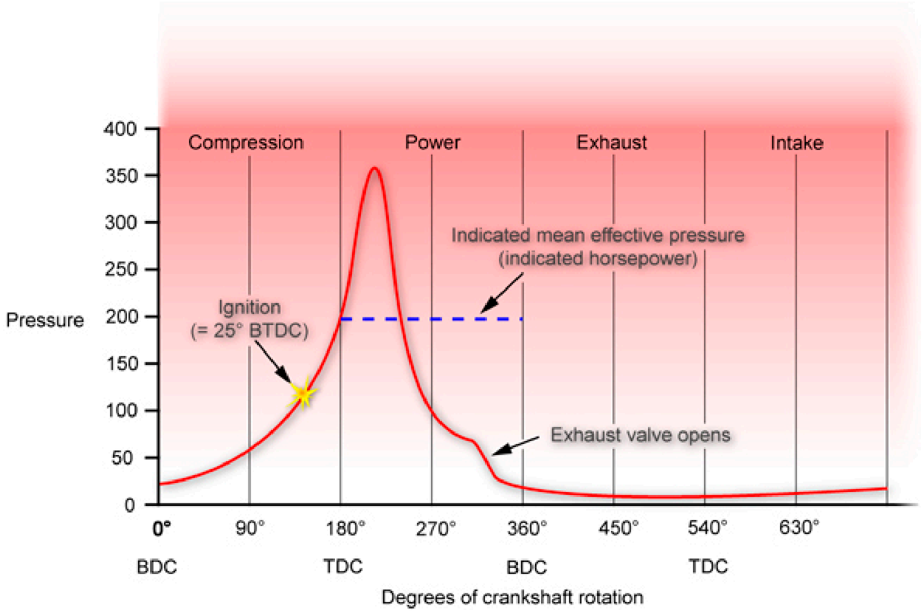
3.1.17 Modified Otto Cycle



The practical timing arrangement (also known as the modified Otto Cycle) is as follows:

- **Induction:** The inlet valve is opened before TDC at the commencement of the induction stroke (valve lead) and remains open past BDC (valve lag). These actions add to the weight of the charge by increasing the time period for the mixture moving into the cylinder, and thus increase the volumetric efficiency.
- **Compression:** During the compression stroke, the spark takes place before TDC, (Ignition advance – 25º) this ensures that the maximum build up of combustion pressure is reached early in the power stroke (approximately 30° after TDC).
- **Power:** The exhaust valve opens before the BDC on the power stroke (valve lead). This means that the exhaust gases begin to flow out of the cylinder before BDC thus ensuring that the cylinder is completely purged of waste gas.
- **Exhaust:** The exhaust stroke continues past TDC (valve lag), overlapping with the induction stroke. Therefore at this point both valves are open (valve overlap). The partial vacuum left in the cylinder with the rapid exit of the exhaust gases induces the fresh charge to enter, and in fact increases the charge weight with an increase in volumetric efficiency.

3.1.18 Modified Otto Cycle Pressure Graph



3.1.19 Volumetric Efficiency (VE)

Volumetric efficiency is the ratio between the charge (air and fuel mixture) that actually enters the cylinder and the amount that could enter under ideal conditions (piston displacement).

An engine would have 100% volumetric efficiency if, at atmospheric pressure and normal temperature, a charge exactly equal to piston displacement could be drawn into the cylinder.

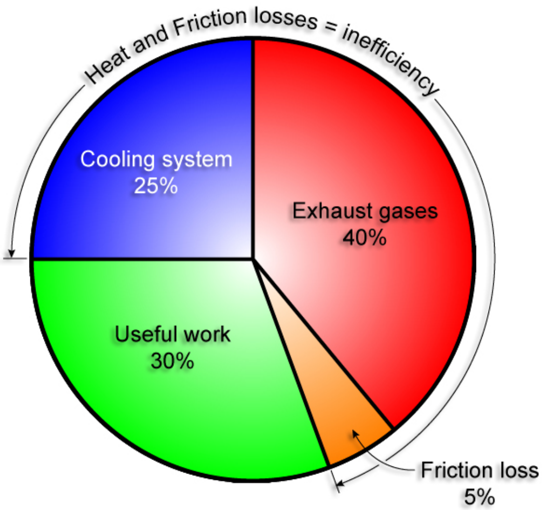
Normally aspirated (non-turbocharged) piston engines have a VE of approximately 70%–80%, while a turbocharged engine is able to achieve 100%+.

Therefore, volumetric efficiency is deter-mined by measuring (with an orifice or venturi type meter) the amount of air taken in by the engine, converting the amount to volume, and comparing this volume to the piston displacement.

$$\text{Volumetric Efficiency} = \frac{\text{Volume of charge admitted into the cylinder}}{\text{Piston displacement Volume}}$$

3.1.20 Thermal Efficiency

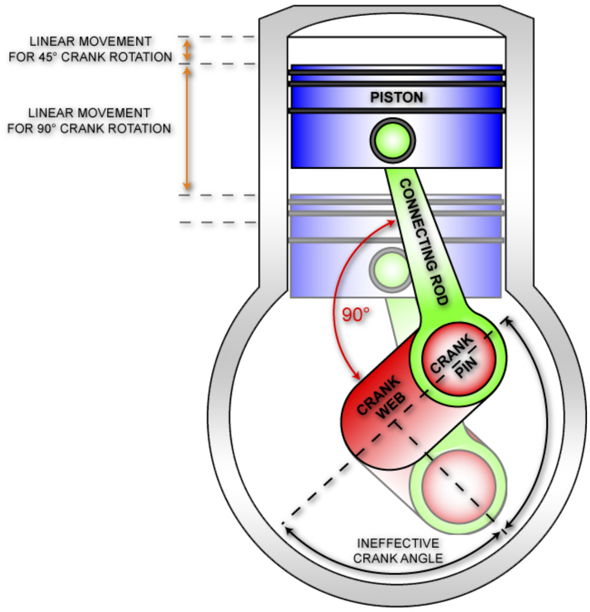
The piston engine is actually a very inefficient power plant, as only about 30% off the power available in the fuel is converted into useful work! During the combustion process, a lot of the heat produced, will be conducted and lost to the engine components and through the exhaust gasses expelled to the atmosphere.



Thermal efficiency (TE) is the ratio of the power actually produced by the engine to the power theoretically available in the fuel; most piston engines operate at approximately 30% thermal efficiency.

3.1.21 Effective Crank Angle

The most effective transmission of power occurs when the angle between the connecting rod and crankshaft is 90°, The thrust in the connecting rod has its greatest leverage at this point. The timing of the ignition spark (25° BTDC) is set to ensure that the maximum combustion pressure released during the combustion process (30° ATDC) coincides with the piston/crank angle being at 90°. Once the crankshaft has turned approximately 120° ATDC, the effective angle has diminished to the point where leverage is lost and the exhaust valve begins to open.



3.1.22 Compression Ratio

The compression ratio of an engine is the ratio of the total cylinder volume compared to the clearance volume. The area swept by the piston in the course of a stroke is known as the swept volume and the unswept volume above the piston is known as the clearance volume. The clearance volume is where the combustion event takes place and is generally considered to be a constant volume area. Raising compression ratios add to engine power output.