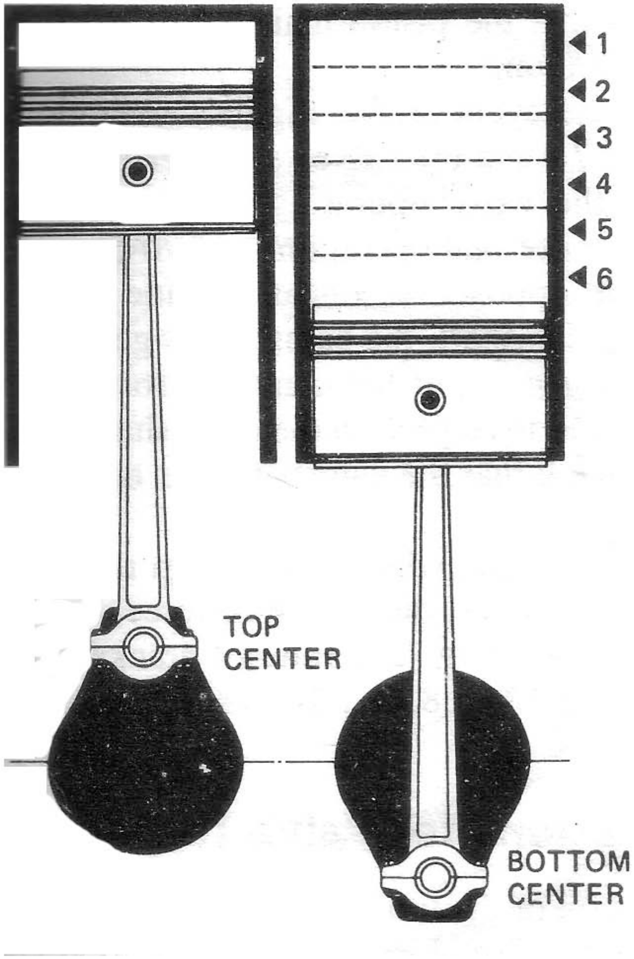
Aircraft Piston Engine Operation Principles and Theory

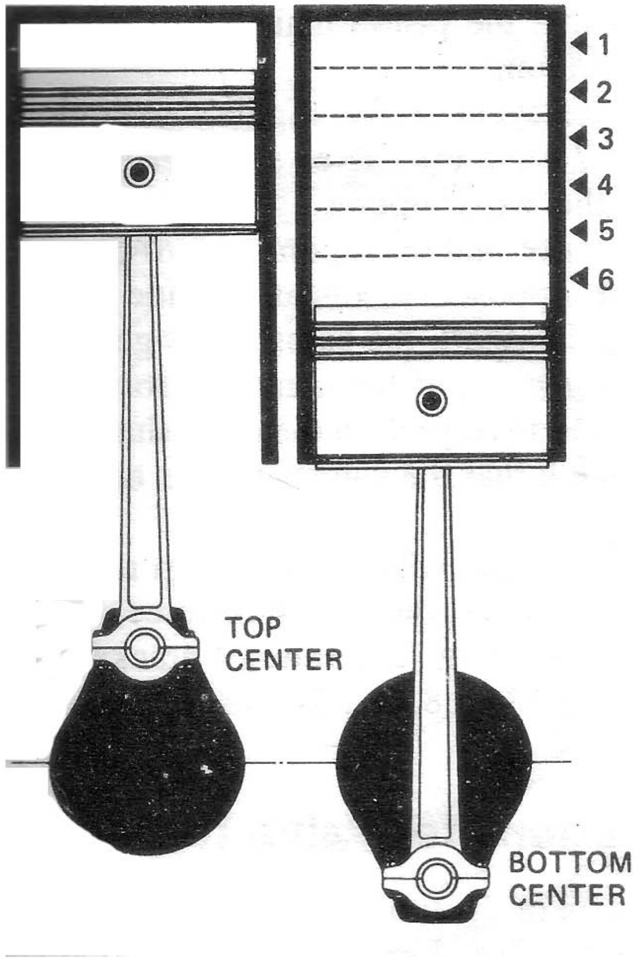
How an IC engine operates-1



- Each piston is inside a cylinder, into which a gas is created -- heated inside the cylinder by ignition of a fuel air mixture at high pressure (internal combustion engine).

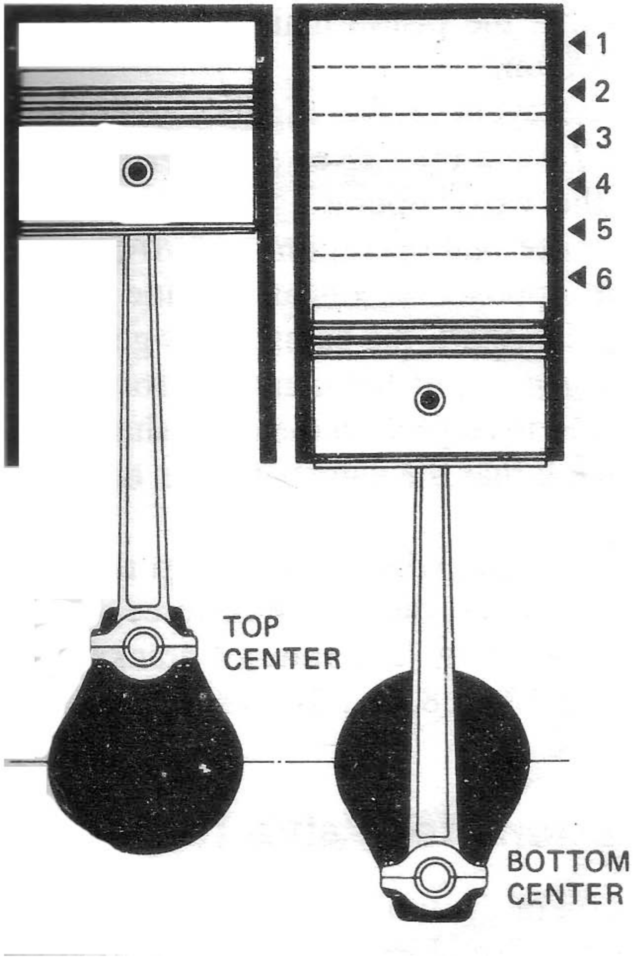
- The hot, high pressure gases expand, pushing the piston to the bottom of the cylinder (BDC) creating Power stroke.

How an IC engine operates-2



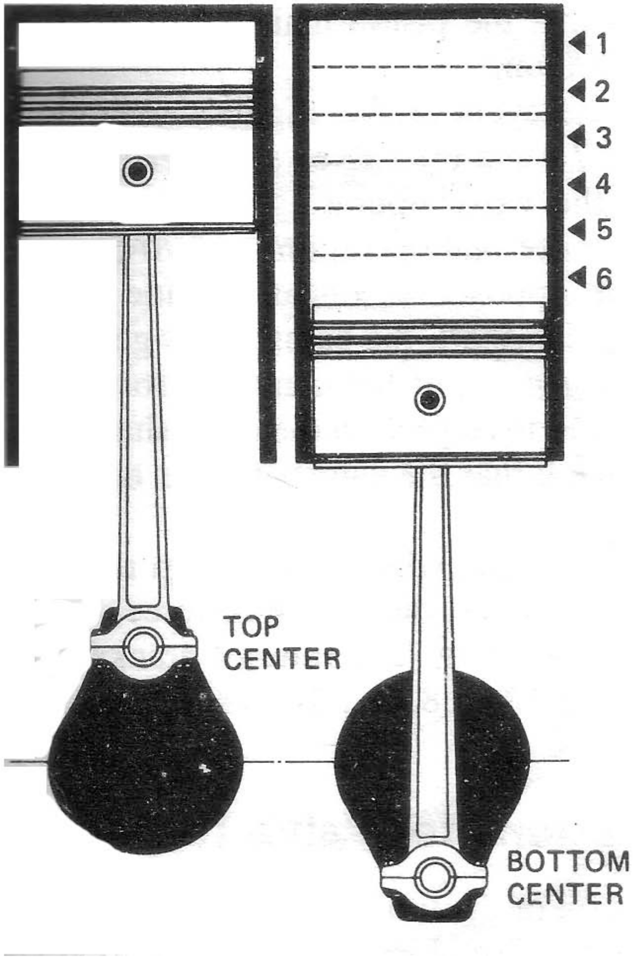
- The piston is returned to the cylinder top (Top Dead Centre) either by a flywheel or the power from other pistons connected to the same shaft.
- In most types the "exhausted" gases are removed from the cylinder by this stroke.
- This completes the four strokes of a 4-stroke engine also representing 4 legs of a cycle

How an IC engine operates-3



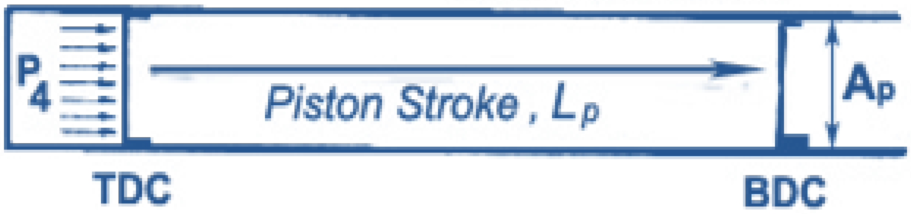
- The linear motion of the piston is converted to a rotational motion via a connecting rod and a crankshaft.
- A flywheel is used to ensure continued smooth rotation (i.e. when there is no power stroke). Multiple cylinder power strokes act as a flywheel.

How an IC engine operates-4



- The more cylinders a reciprocating engine has, generally, the more vibration-free (smoothly) it can operate.
- The aggregate power of a reciprocating engine is proportional to the volume of the combined pistons' displacement.

Reciprocating Engine Performance



Power delivered to the engine by one cylinder is

$$\text{Power} = P_{eff} \times L_p \times A_p \times \frac{n}{2}$$

$$\boxed{P_{eff} \neq P_4}$$

Where A_p = area of piston head

L_p = length of the piston stroke between TDC and BDC

$n/2$ = power strokes per minute, n = rpm

For N_c = number of cylinders, $\text{IHP} = P_{eff} \times L_p \times A_P \times \frac{n}{2} \times N_c$

Total displaced volume, $V_x = A_p.L_p.N_c$ $\text{IHP} = P_{eff} \times V_x \times \frac{n}{2}$

Some of the power developed in the piston-cylinder is lost in the friction of the piston with the inner surface of the cylinder. This is often referred to as *frictional horse power* (FHP).

The actual power available at the end of the main shaft may be called Brake Horse power (BHP). Thus, BHP= IHP - FHP.

$$\text{BHP} = 2 \times \pi \times \text{RPM} \times \text{torque}$$

$$\text{BHP} = \eta_{\text{mech}}.\text{IHP} = \eta_{\text{mech}}.\text{P}_{\text{eff}} \times \text{V}_x \times \text{RPM} \quad = \text{P}_{\text{eff}}^{\text{Brake}} \times \text{V}_x \times \text{RPM}$$

$\text{P}_{\text{eff}}^{\text{Brake}}$ Is the *brake mean effective pressure* (BMEP)

$$\text{BMEP, } P_{\text{eff}}^{\text{Brake}} = \eta_{\text{mech}}\left(P_{\text{eff}}\right) = \frac{\text{BHP}}{V_x \times n}$$

The BMEP is not a physically active pressure, but is theoretically computed and is an average or mean gas load, through all the strokes and events, on the piston. It has become a widely used index of the engine performance, and is used in setting the allowable limits for gas pressure.

- Since the entire objective of an aircraft engine is conversion of *chemical energy of fuel into propulsive thrust force*, the over-all efficiency thus achieved is of primary importance. An engine fed with $\dot{m}_f$ kg/hr has an equivalent thermal input of $\dot{m}_f.Q_f$ kJ/hr.
- The BHP, normally expressed in kW, may also be expressed in units of kJ/hr. (Q_f = Heating value of fuel, kJ/kg).
- The ratio of these two quantities is defined as the *brake thermal efficiency*

so that

$$\eta_{th}^{brake} = \frac{BHP}{\dot{m}_f \times Q} = \frac{1}{\frac{\dot{m}_f}{BHP} \times Q}$$

This the efficiency of the engine

Now, if we define a parameter called BSFC (*brake specific fuel consumption*)

$$= \dot{m}_f / \text{BHP} \qquad kg/(kW\text{-}Hr)$$

Brake Specific Fuel Consumption *is conceptually based on BHP*. For a selected fuel, BSFC is a good measure of the engine efficiency.

The overall efficiency of a piston-prop engine is

$$\eta_{overall} = \eta_{th}^{brake} . \eta_p$$

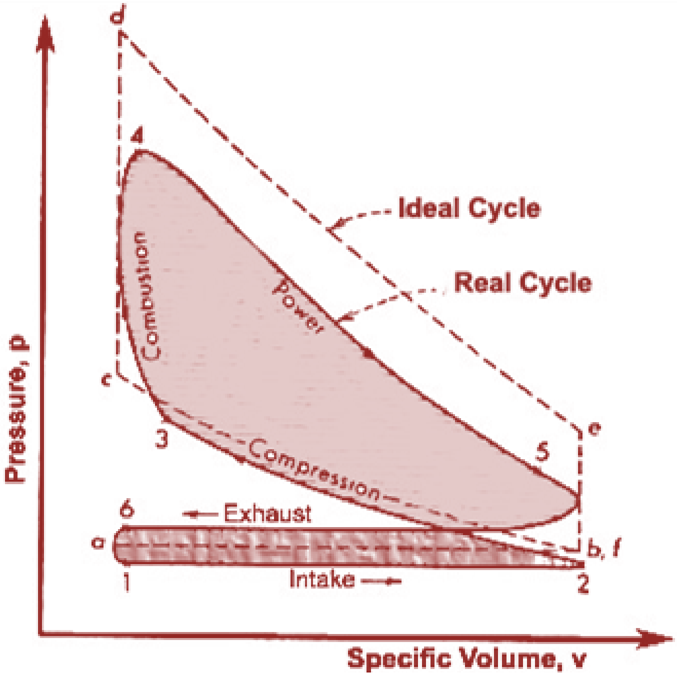
Where, η_p is the propeller efficiency

At typical cruise conditions, η_{th}~30% and η_p~85%, gives an overall engine efficiency of $\eta_{overall}$ ~ 25.5%.

Aircraft reciprocating (piston) engines are typically designed to run on aviation gasoline (petrol), which has a higher octane rating as compared to automotive gasoline (petrol), allowing the use of higher compression ratios, increasing power output and efficiency at higher altitudes. The most common fuel for aircraft engines has a octane rating of 100 octane and low lead content.

Aviation fuel is blended with tetra-ethyl lead (TEL) to achieve these high octane ratings, a practice no longer permitted with road vehicles for pollution.

Augmentation of Power for Aircraft Engines



- Fig. indicates that the exhaust starts (after 5) while the pressure in the cylinder is well above atmospheric. The exhaust stroke ends at near-atmospheric pressure (by virtue of the inertia of piston).

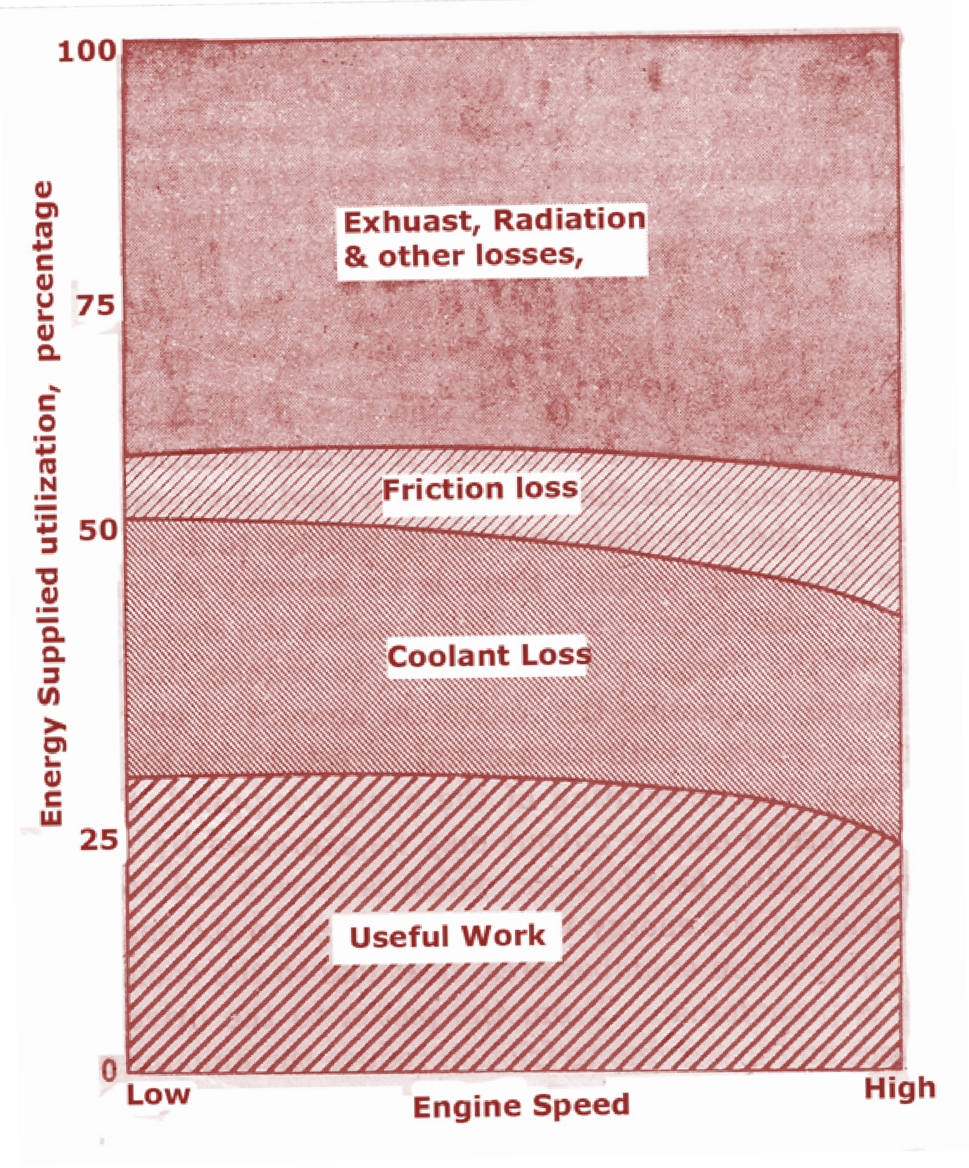
- The internal energy that remains in the burnt exhaust gases, may be utilized for running a device such as *supercharger*, which is then used to hike up the entry gas energy in to the system.

- When the burnt gases inside the cylinder is not fully exhausted, a small amount remains to get mixed with the fresh incoming air/charge. Thus the measure of the piston capacity by volume as discussed earlier becomes erroneous. This error is attempted to be quantified by ***volumetric efficiency*, η_v**.
- Volumteric efficiency is affected by : (i) Density of the fresh charge at the cylinder intake, (ii) The pressure and the temperature of the outgoing burnt gas, (iii) Design of the intake and exhaust manifolds, (iv) The timing of the opening and closing of the intake and exhaust valves. Piston engine designers have to pay sufficient attention to these factors to achieve a high efficiency engine.

Volumetric Efficiency :

$$\eta_{vol} = \frac{\dot{m}_{charge}}{\dot{m}_{theoretical}}$$

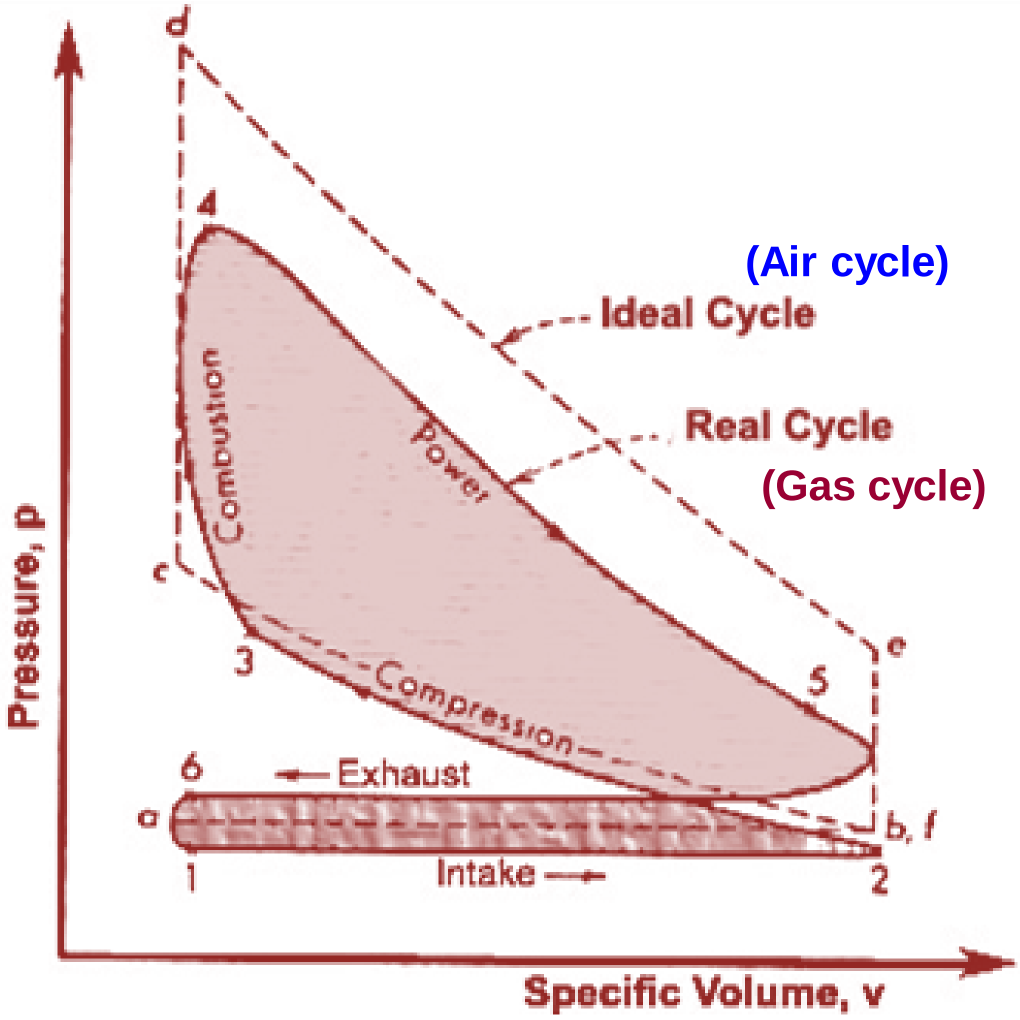
The actual charge mass is a measured quantity and the theoretical mass is estimated from the geometry of the cylinder and number of cylinders, speed of the engine and charge inlet density produced by the operating condition



Losses in a piston engine

1) Losses due to cooling of the cylinder body to enhance its life
2) Friction losses due to motion of the piston inside the cylinder
3) Loss due to energy carried by the exhaust gas on its way out
4) Loss due to radiation of heat
5) Losses due to improper inlet and exhaust valve operation

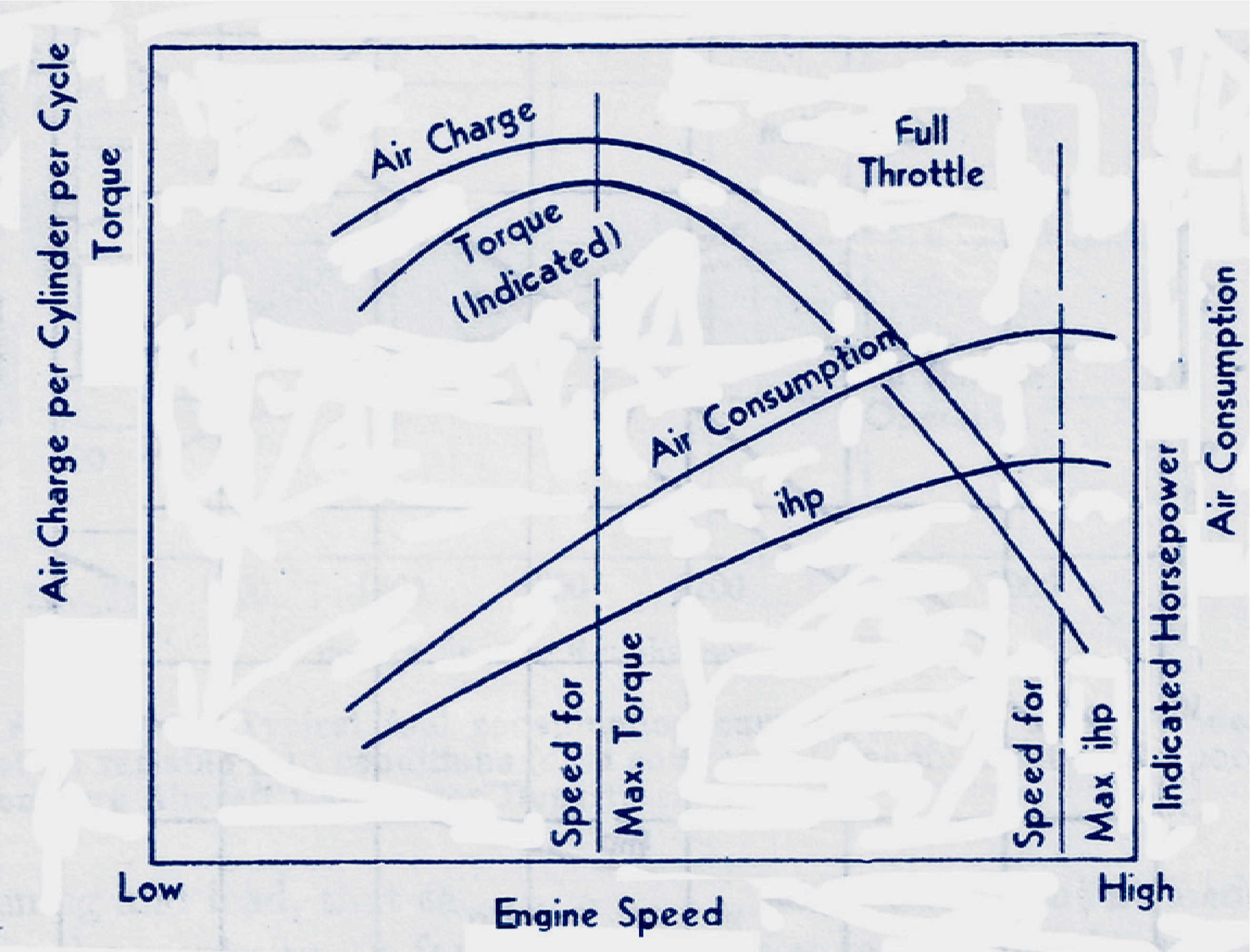
Useful work is done with the remainder of the energy available. This goes down with the speed of operation of the engine. Thus, at high speed more work is possible but at lower efficiency



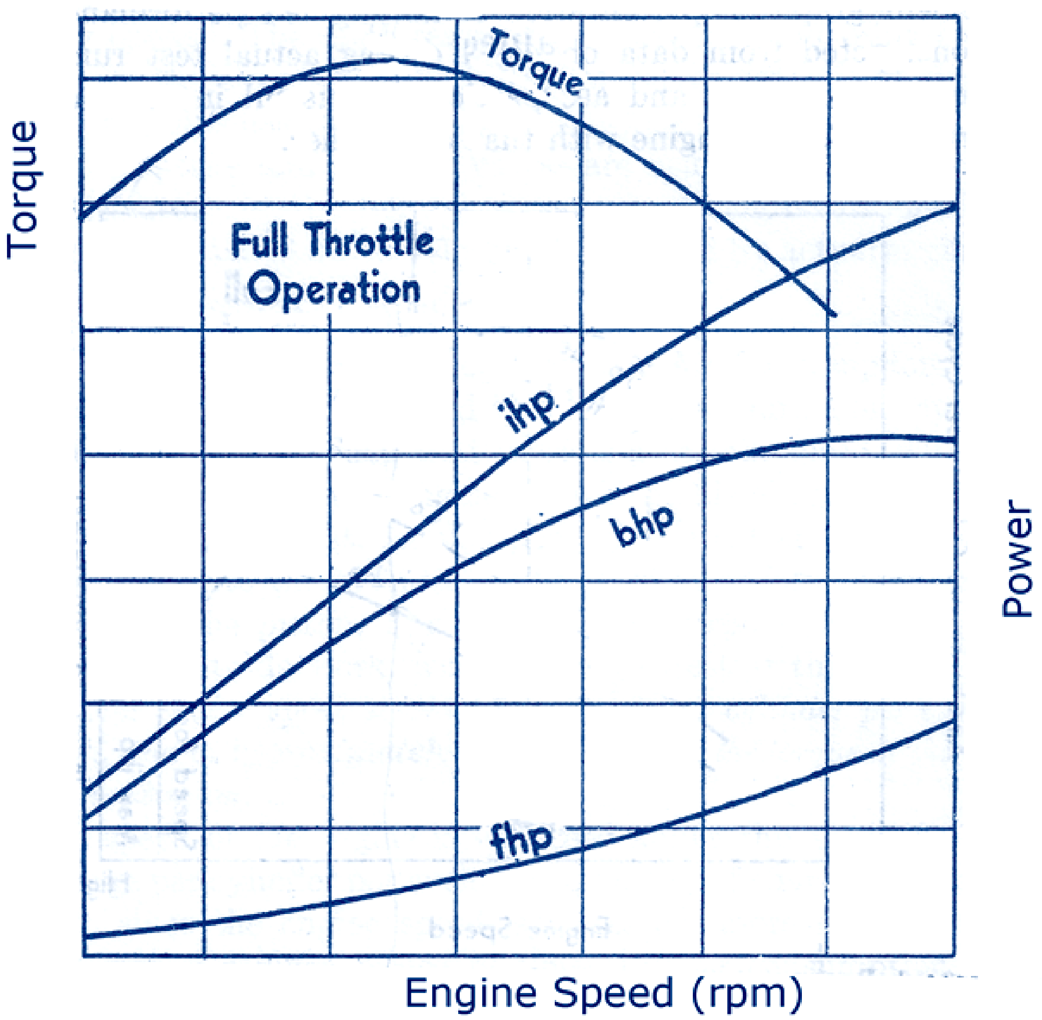
Analysis done with Air as working medium and that with hot burnt gas after the combustion as working medium makes a lot of difference, and is considered as the fundamental reason for the difference between ideal and real cycle.

$K_{air} = 1.40, K_{gas} = 1.33$

Piston Engine Performance characteristics curves

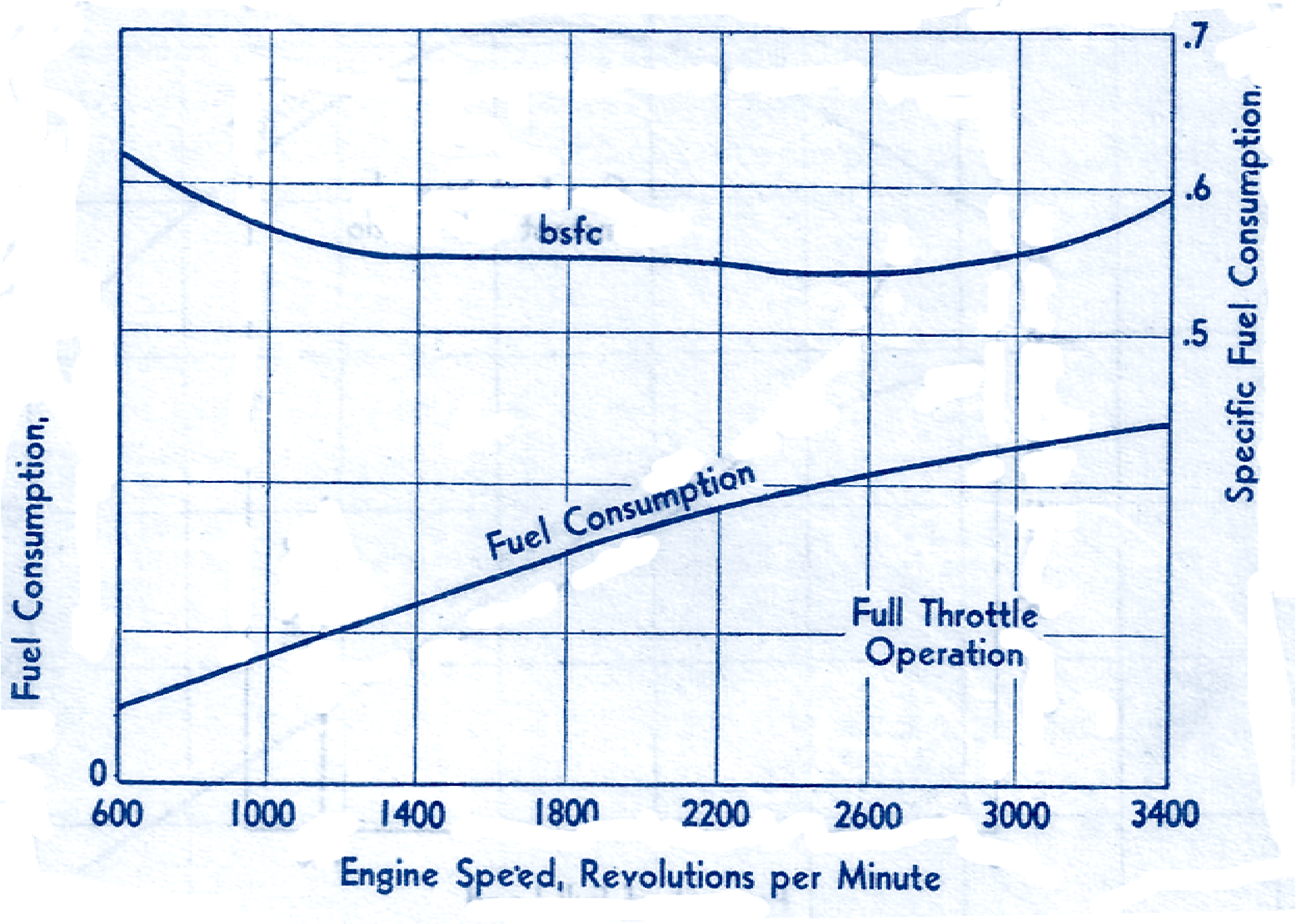


- Air Consumption per cycle peaks at a lower speed, approx along with torque
- Air consumption per unit time (sec or min) peaks along with IHP , when the engine is at full throttle.

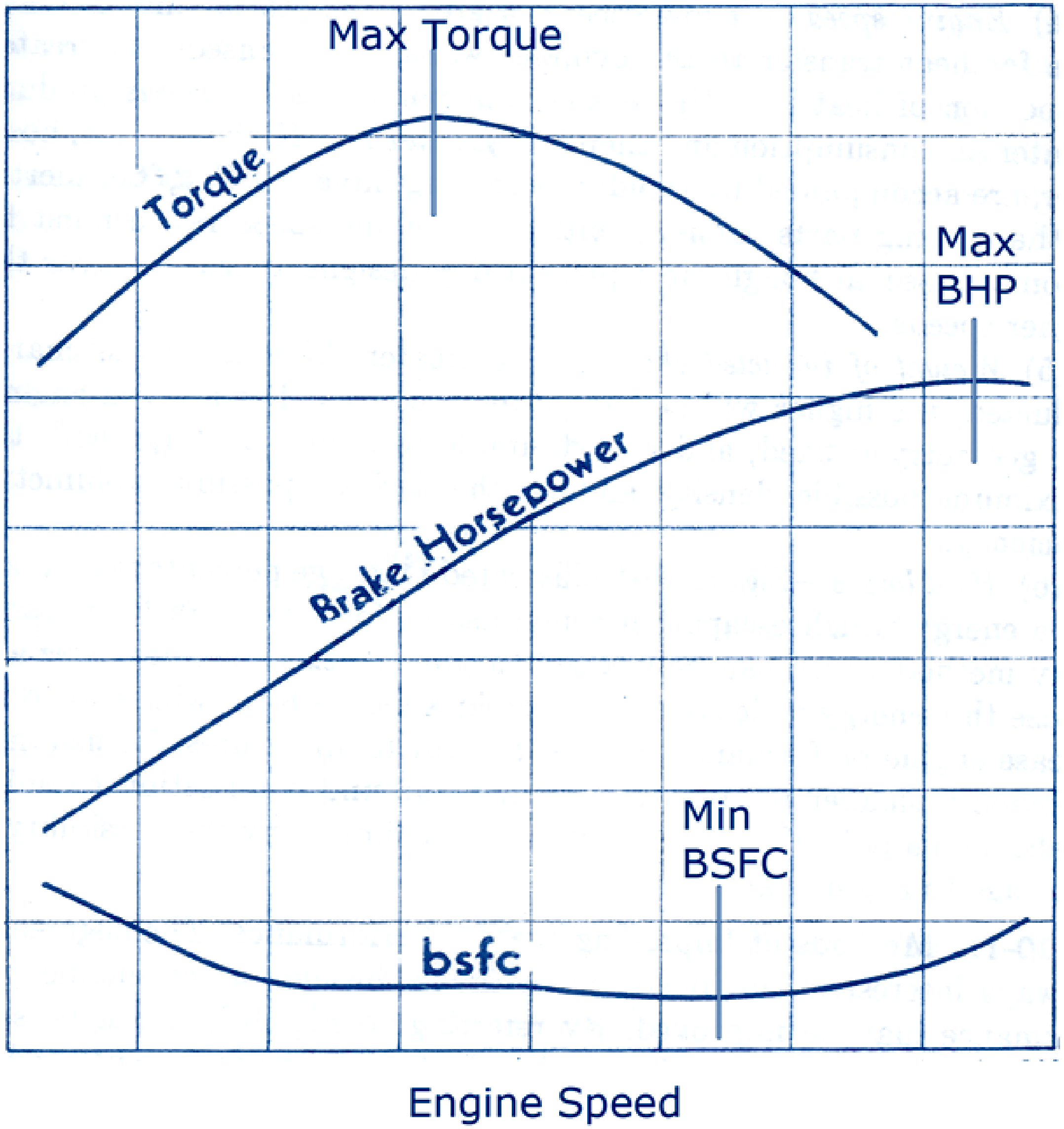


- Maximum torque of the engine occurs at a lower speed

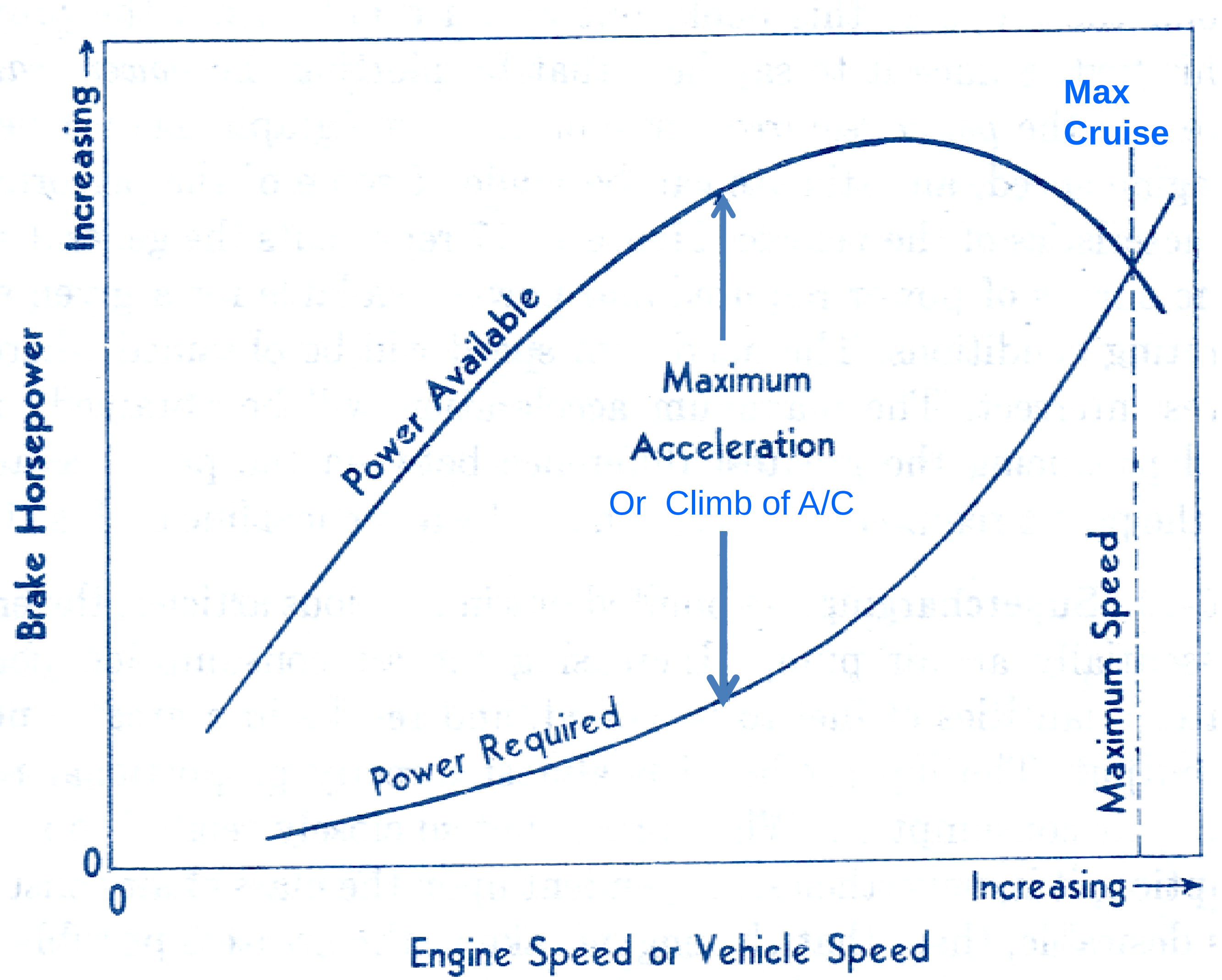
- BHP starts levelling out due to rise in FHP



- Minimum BSFC occurs at lower operating speeds.
- Fuel consumption (per unit time) increases with speed



Maximum Torque Maximum BHP and Minimum BSFC occur at different speeds



Matching of Engine with Aircraft requirements

Next Lecture :

1) Operational Reasons for loss of engine Power
2) Part-load Performances
3) Supercharging of Aircraft Engines