Introduction to Aerospace Propulsion

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Lecture No - 24

Aircraft Engine Development from Fundamental Considerations: Thermodynamic and Mechanical

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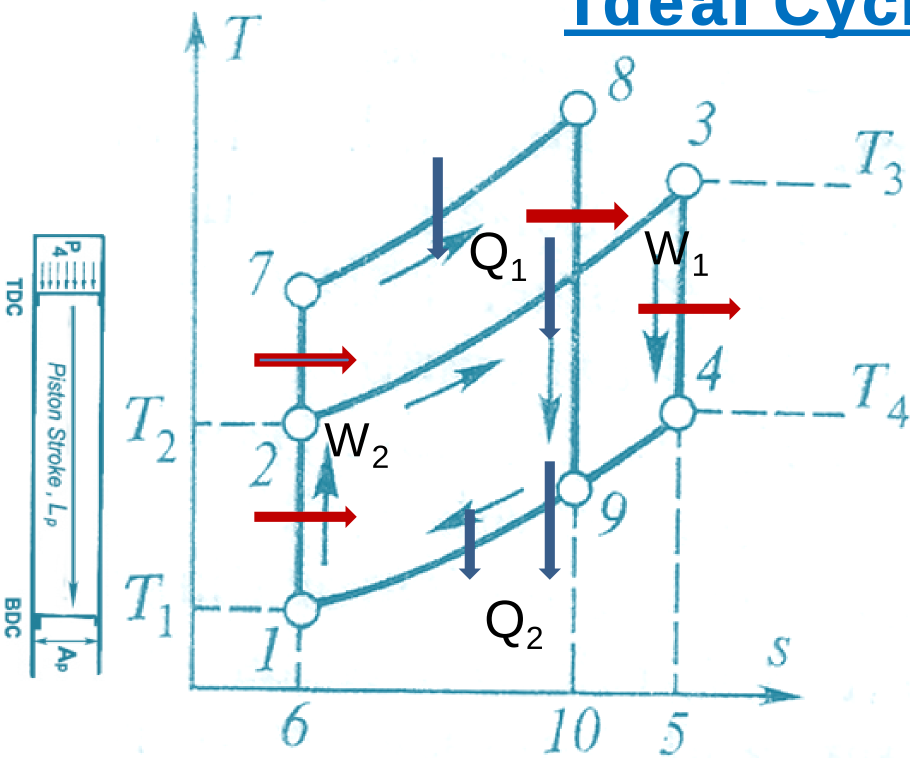
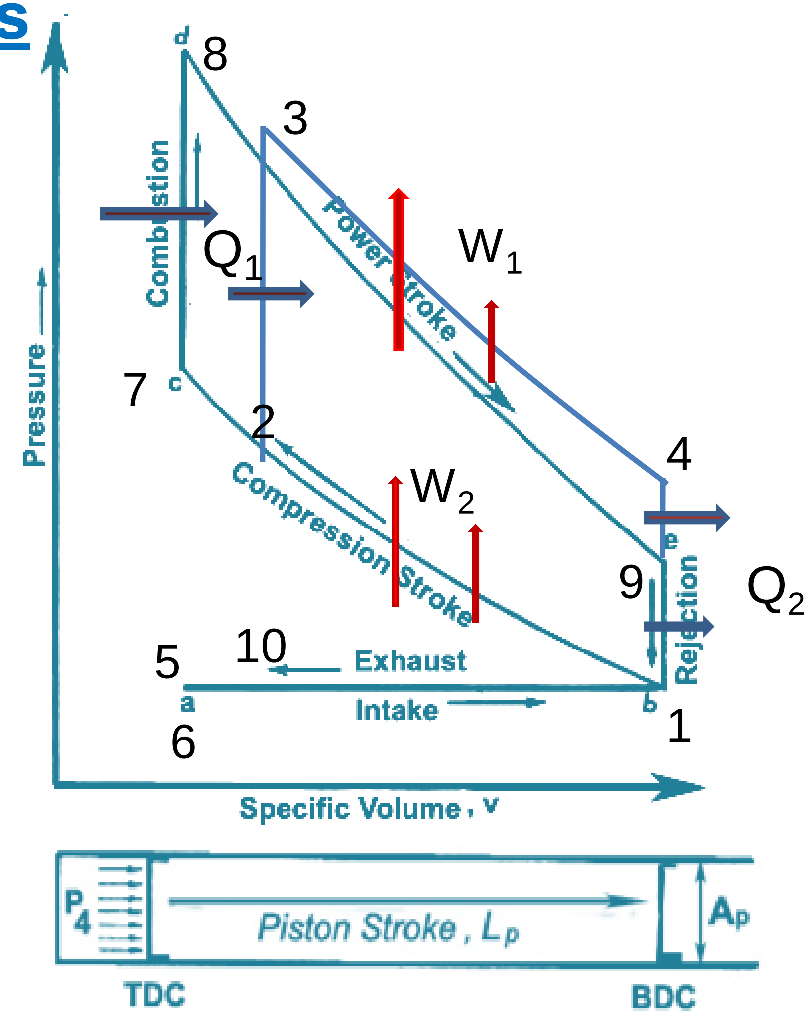
Ideal Cycles





Heat exchanges are :

$Q_1 \sim c_v(T_3 - T_2) > c_v(T_8 - T_7)$

$Q_2 \sim c_v(T_4 - T_1) > c_v(T_9 - T_1)$

$\eta_{Th\text{-}12341} < \eta_{Th\text{-}17891}$

For both cases, $Q_1 - Q_2 = W_1 - W_2$

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Configuration of Aircraft Engines

- In designing an engine for aircraft the size and weight of the engine are severely restricted.

- Size restriction means that the piston length is limited and the cylinder volume is restricted. That means the work done per cylinder is limited.

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- This prompted use of a large number of cylinders to create requisite amount of aggregate power. Most aircraft engines have 6 or more cylinders. The power of a reciprocating engine is proportional to the volume of the combined pistons' displacement.

- Weight restriction on aircraft prompted the development of high strength aluminum alloys that met the requirements of aircraft engine body e.g. the cylinder, the piston etc.

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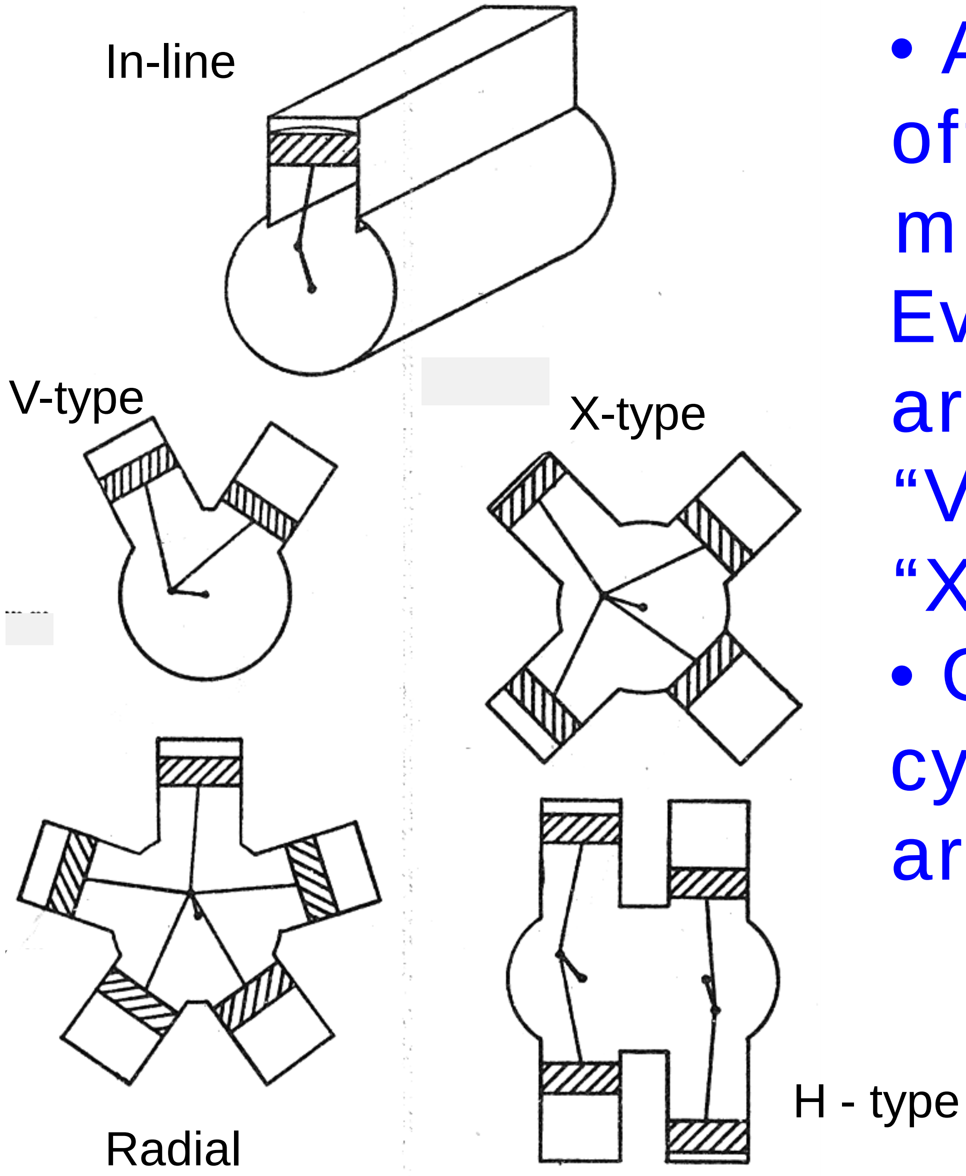

- A number of pistons are often arranged in a multi-cylinder engine. Even number of cylinders are arranged "in-line", "V-type" , "opposed " , "X-type", H-type".
- Odd number of cylinders (5 or above) are arranged radially.

- Although each cylinder operates on the same thermodynamic cycle the processes in the cycles are time staggered in engine operation.

- The pistons in these cylinders operate in a time staggered manner – so that the main shaft is almost always receiving a power stroke

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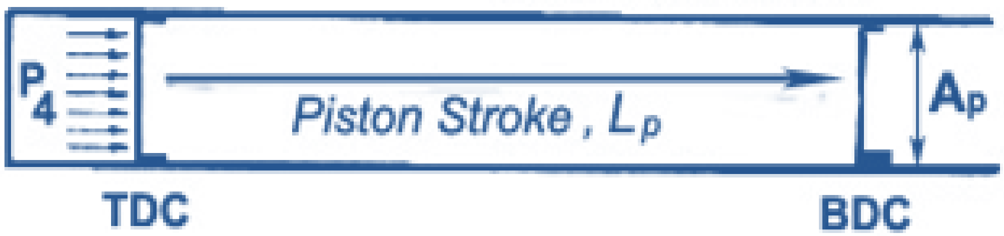
$\text{Power} = P_{eff} \times L_p \times A_p \times \frac{n}{2}$



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

Where P_{eff} is the *mean effective pressure* (MEP) or average pressure on the piston during its strokes
n= rpm, and hence, n/2 = power strokes per minute

Ideal work done by engine $$\text{IHP} = P_{eff} \times L_p \times A_P \times \frac{n}{2} \times N_c = P_{eff} \times V_x \times \frac{n}{2}$$

N_c = number of cylinders, V_x is the total cylinder volume
IHP is the *indicated horsepower* as also determined, from the p-v (*Pressure-volume*) "indicator diagram"

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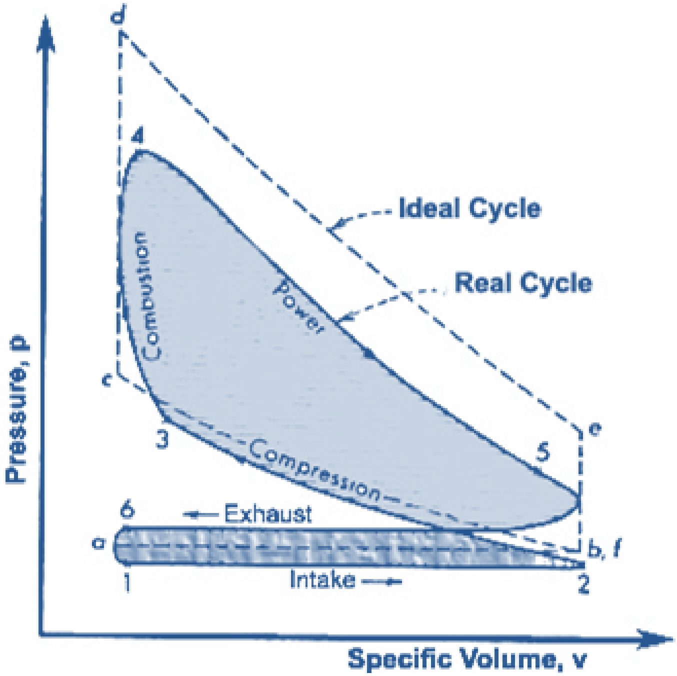
- For a piston engine, increase in mass flow implies that either the rpm or the size of the engine or both should increase and all of them are undesirable for aircraft engines.

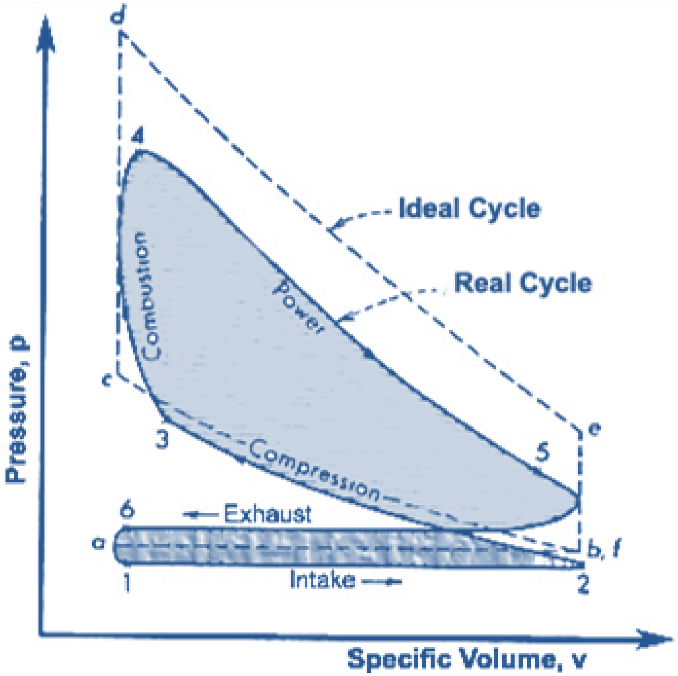
- Suppose the rpm is increased to have large mass flow rate, it will result in high sliding friction and consequently less efficiency.

- Increased engine size implies more drag and less combustion efficiency, more weight etc.



- All the work shown in IHP (from p-v diagram) or from the piston Power (work in power stroke) in slide 9, is not realizable.
- The actual working involves loss of energy in following manner:

1) Incomplete combustion of fuel in the process 3-4 – (Refer to real diagram)
2) Non-uniform combustion of fuel inside the cylinder (process 3-4)
3) Friction loss between the piston and the cylinder – both in the power stroke and in the compression stroke



4) Larger the cylinder size (length or dia) – higher are these losses

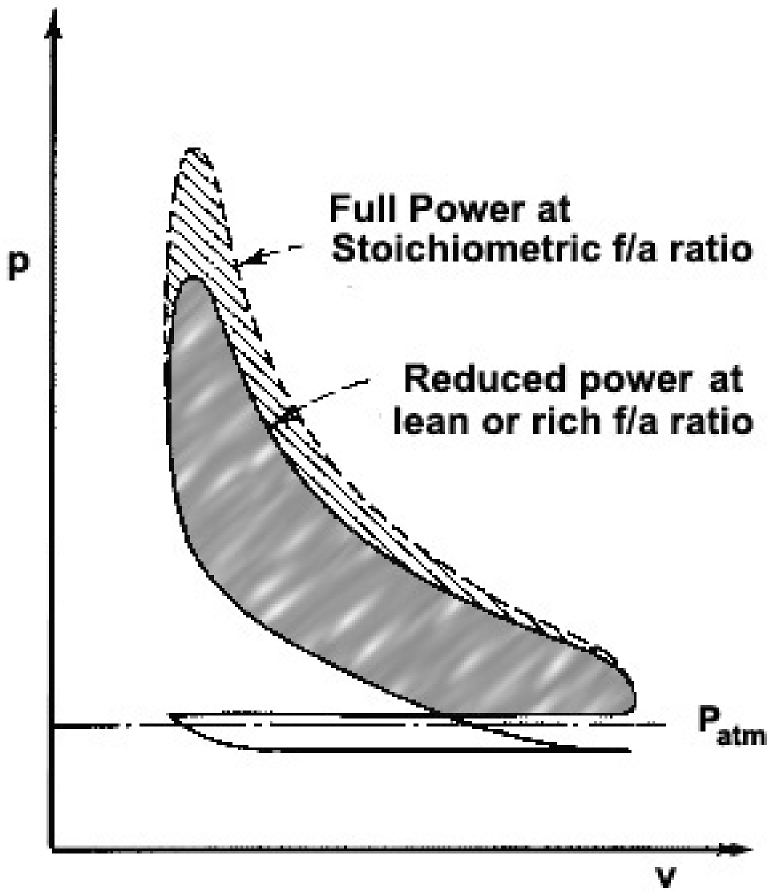
5) Larger the cylinder size more are the heat loss through its surfaces

6) Cycle efficiency is directly influenced by (i) compression ratio, (ii) Pressure ratio, and (iii) Temperature ratio.

7) More the compression ratio or pressure ratio, the cylinders would need to be built of heavier material.

8) All the above are prohibitive in an aircraft engine

Off-design operation



Effect of Fuel - Air Ratio on cycle

(a) Reduction of power

- The power input to the propeller from the main (crank) shaft is the engine brake horsepower (after the gear box)
- The work done and heat transaction of the engine changes with fuel flow into the cylinder.
- Ideal amount of fuel flow is dictated by the Stoichiometric (chemically correct) fuel/air ratio (f/a) .
- A safe f/a zone is identified

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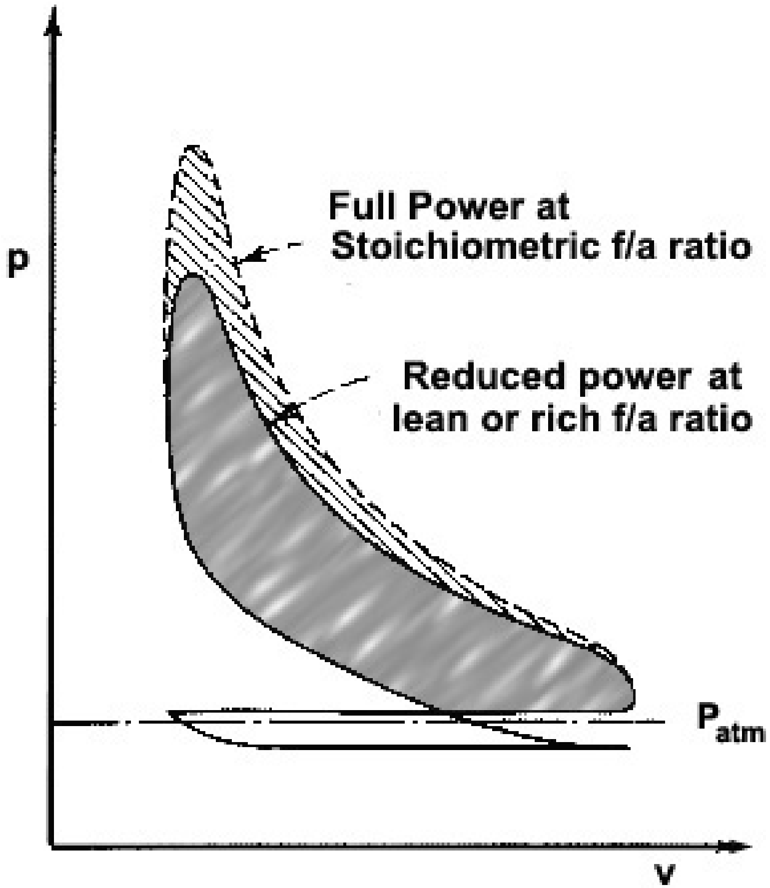

Effect of Fuel - Air Ratio on cycle

(a) Reduction of power

- Less than the ideal (lean f/a ratio) would result in reduced power, till lean blow out.
- More than the ideal (rich f/a) would create more power till it reaches rich blow out.
- An engine is always operates at lean or rich f/a ratio.
- By design it operates longer at lean f/a ratio
- Actual working cycle changes with the f/a ratio.
- An engine essentially operates with variable cycle during a flight.

propeller efficiency is

$$\eta_p = \frac{\text{propeller thrust power}}{\text{engine shaft brake horsepower}}$$

Not all the power developed in the engine cylinder (*ideal power, IHP*) appears as available power (brake horsepower, BHP) for the propeller. There are inevitable losses to friction that are mainly dissipated as heat. Mechanical efficiency, then, may be defined as

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

Some amount of Energy would be lost in the Gear box

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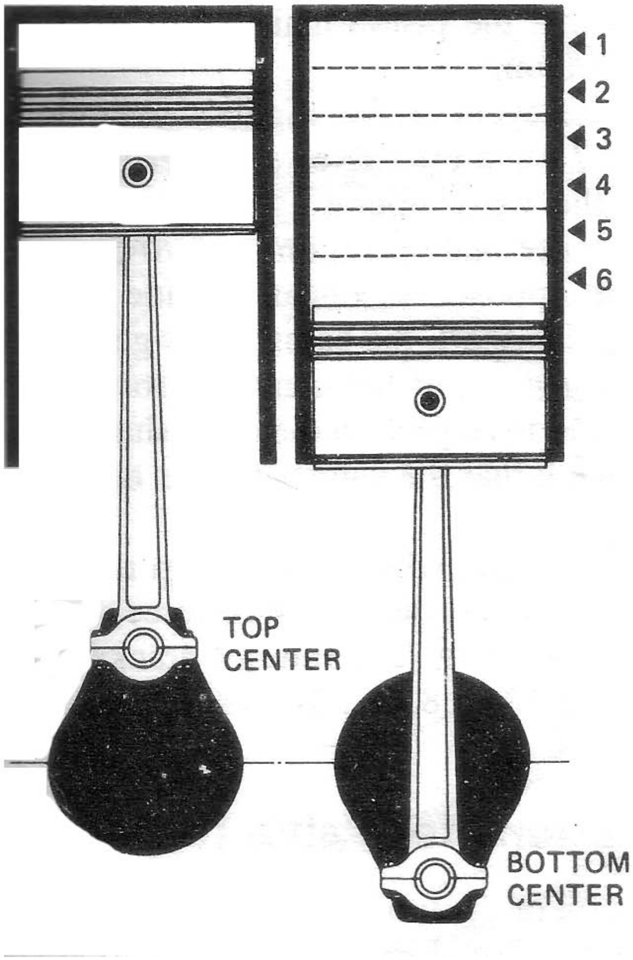

- A typical piston-cylinder arrangement
- The cylinder may be assumed to have, say, 6 equal volumes
- More the volume – more the work capacity

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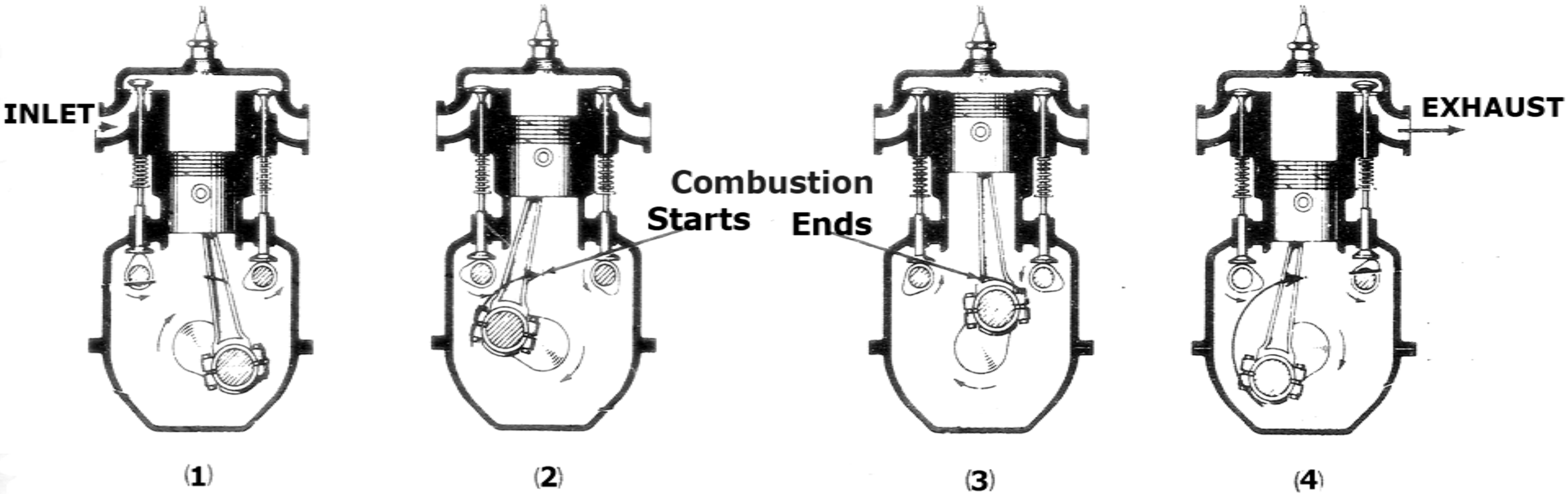
Four Cylinder Arrangement



The arrangement of the engines are such that they operate in a time staggered manner. For example, when cylinder-1 is undergoing a air-intake stroke, Cylinder-2 is undergoing a compression stroke, cylinder-3 is undergoing a power stroke and cylinder-4 is undergoing the exhaust stroke.

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Radial engine powered small aircraft

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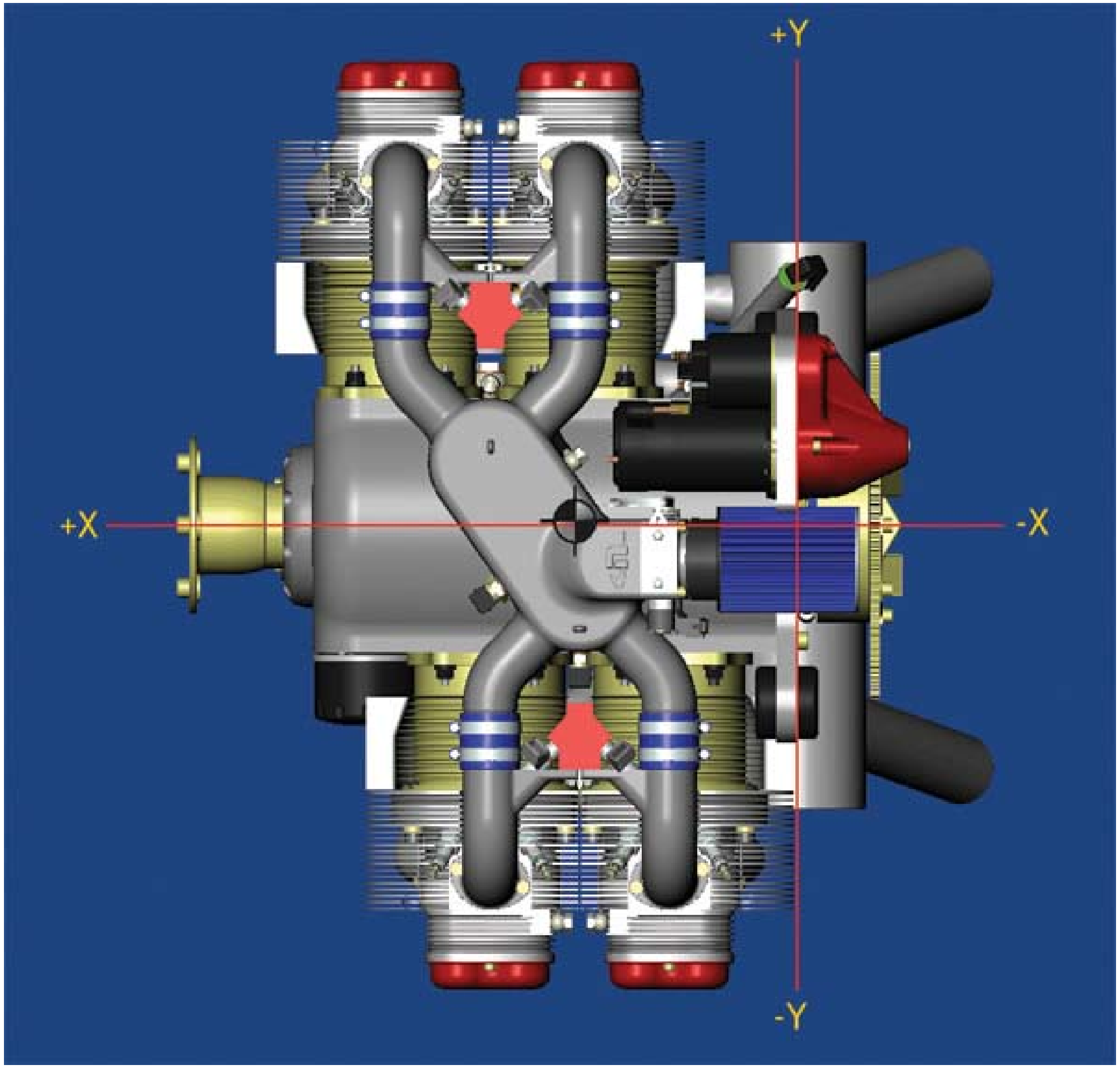
A **Diesel-engine** (SI) powered Piston-Prop - Uses gasoline and made of light alloys



Design of a 4-cylinder opposed IC engine

4-bladed propeller piston-prop

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Spitfire military aircraft – piston-prop

More power requirement finally brought in the **turbo-props** – these are sleeker and more efficient than - a 18 cylinder radial engine piston-prop