Introduction to Aerospace Propulsion

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Lecture No - 23

Piston-Prop Powerplants :

Ideal and Real Otto Cycles for basic Piston Engines (Internal Combustion)

- All heat engines are conceptually based on one thermodynamic cycle or the other.
- They all are made up of a number of legs or processes that combine together to make a cycle
- The concept of cycle allows re-use or re-cycle of the same working medium – **air** –freely available in the atmosphere. All aircraft engines are air-breathing engines
- The cycles are made of processes (or legs) – each of which has a path and all of them have to conform to all the thermodynamic laws

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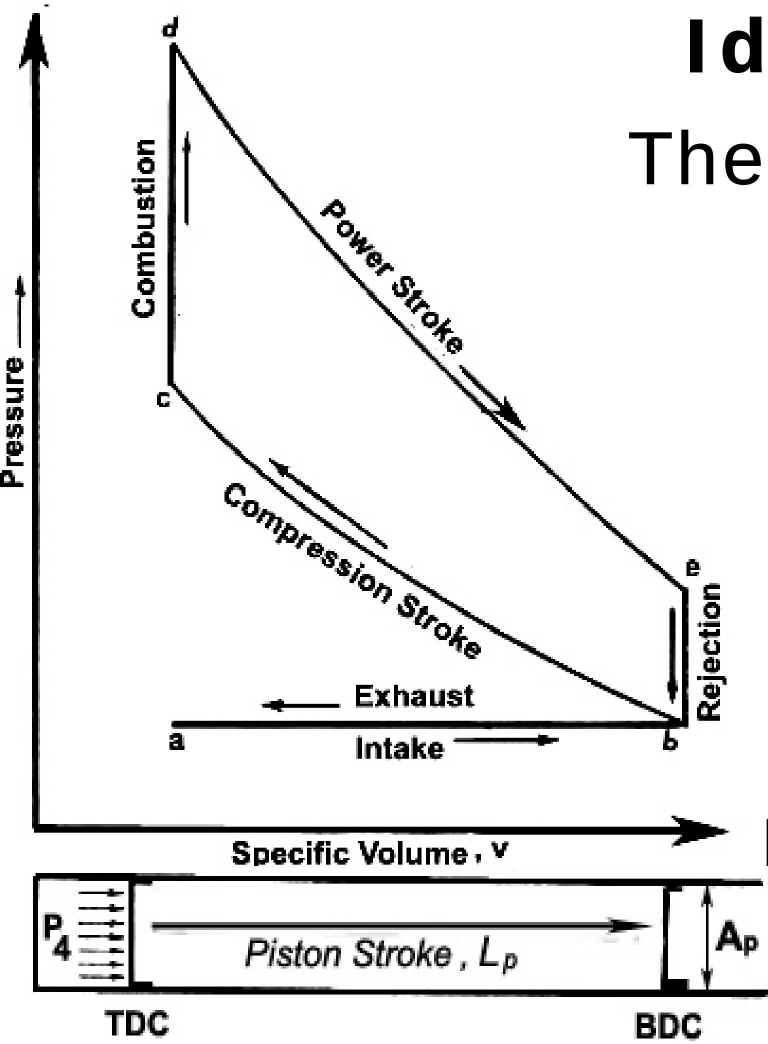
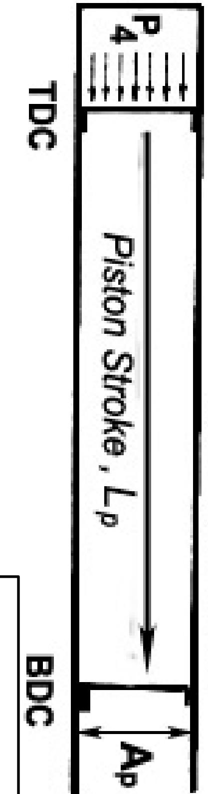
Ideal Otto Cycle



The cycle consists 6 processes

1. a-b – Intake of air
2. b-c – Compression
3. c-d – Combustion
4. d-e – Power stroke
5. e-b – Heat Rejection
6. b-a – exhaust of air

A stroke is the displacement of the piston from *Top dead center* (TDC) to *Bottom dead center* (BDC).



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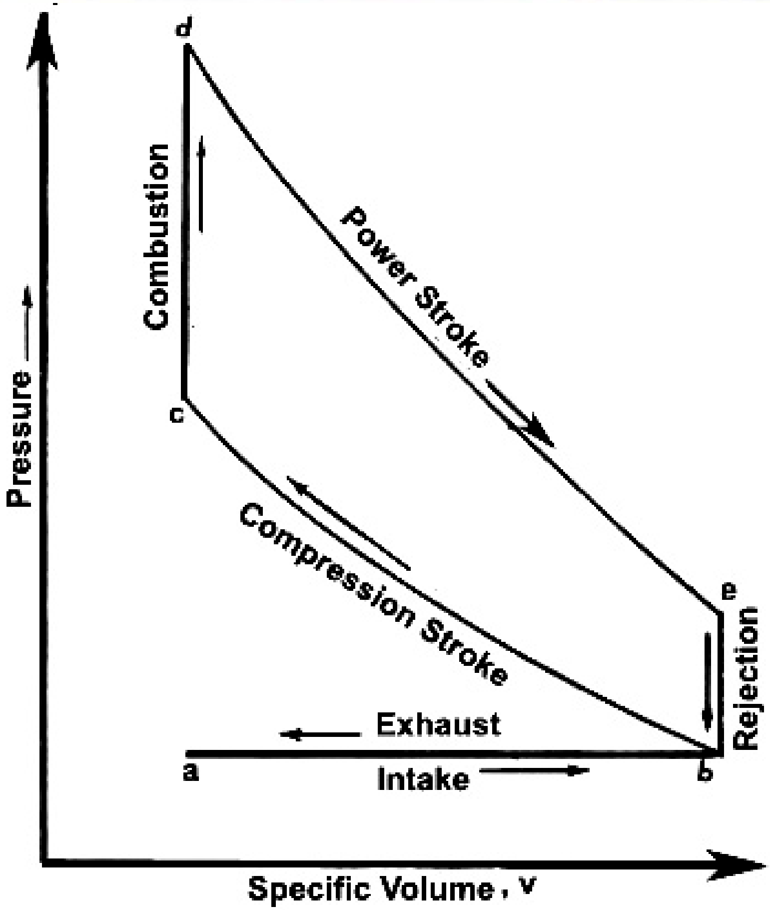

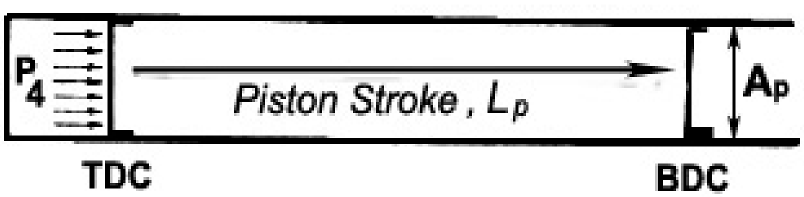

1. a-b – Constant Pressure Intake of air (+fuel)
2. b-c – Isentropic Compression
3. c-d – Constant Volume Combustion (of Fuel)
4. d-e – Isentropic Power stroke of the piston
5. e-b – Constant Volume Heat Rejection (from gas)
6. b-a – Constant Pressure exhaust of burnt gas

A stroke is the displacement of the piston from *Top dead center* (TDC) to *Bottom dead center* (BDC).

- The engine designer has to design a thermodynamic cycle first. In designing it the nett area of the p-v diagram is sought to be increased for maximising the power output.
- The power output would depend thus on the change of specific volume and / or on the increase of pressure / temperature through the cycle
- Large change in volume shall require large sized engines
- Large change in specific volume shall also require large change in pressure – requiring large change in volume
- Large change in temperature shall require large input of fuel or fuel of high heat release capacity

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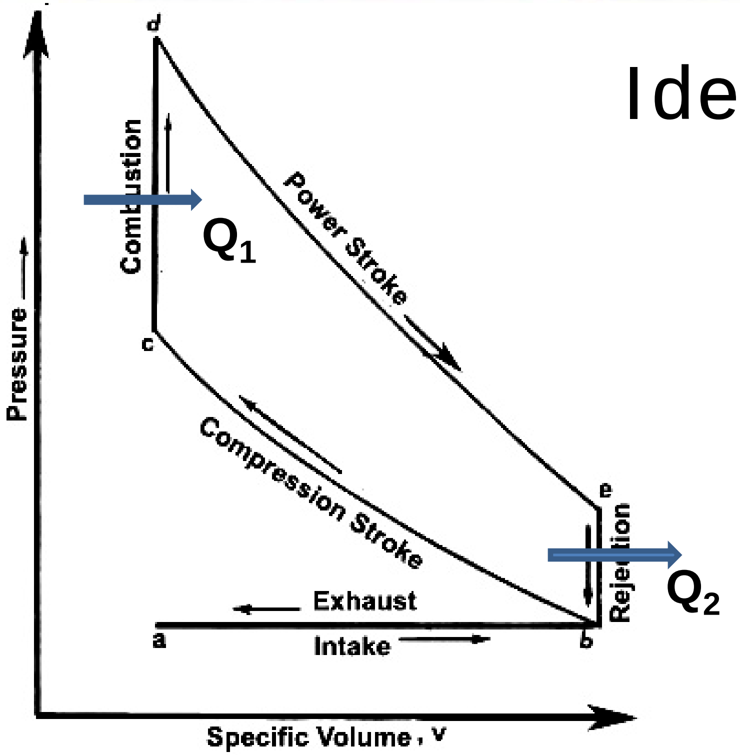


Ideal Otto Cycle Analysis

Energy exchanges are :

Heat input, $Q_1 = c_v(T_3 – T_2)$

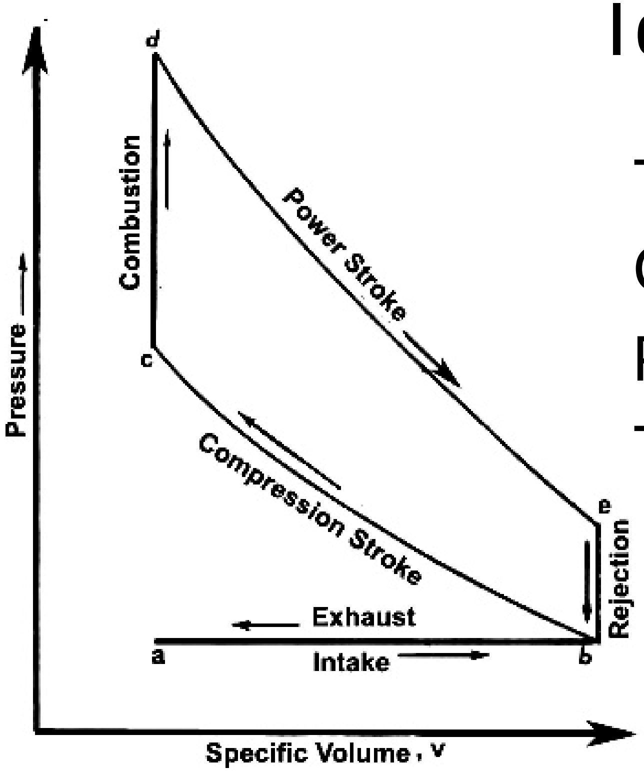
Heat Rejected, $Q_2 = c_v(T_4 – T_1)$

Power stroke converts Heat of energy release by fuel burning) and Pressure (built up by compression stroke) to Mechanical motion

Nett Work Done = $Q_1 - Q_2$

= Work done by power stroke – work done by compression stroke

= Area bcde



Ideal Otto Cycle Analysis

The characteristics of the cycle are :

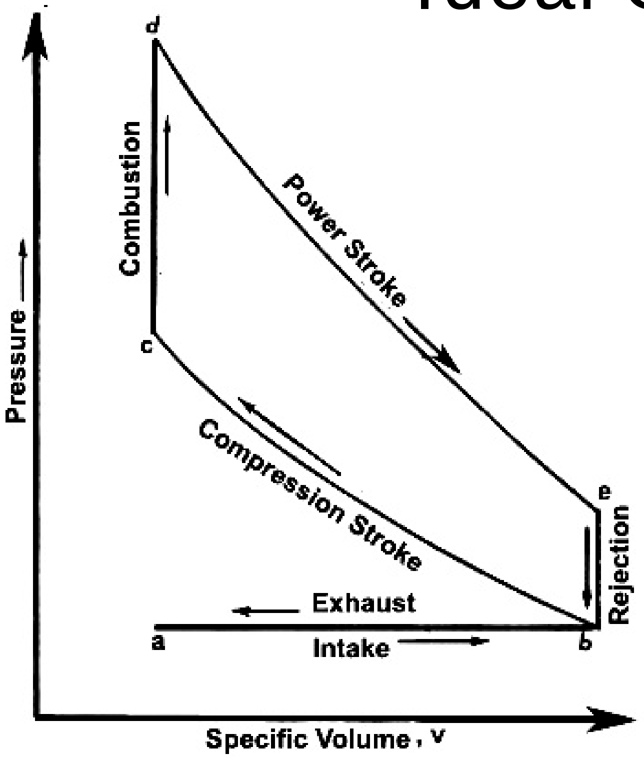
Compression ratio : $\varepsilon = v_b / v_c$

Pressure Ratio : $\pi = p_d / p_c$

Temperature Ratio: $\tau = T_d / T_b$

Every thermodynamic cycle is sensitive to these ratios as they decide the work capacity and the efficiency with which the work is done

Ideal Otto Cycle Analysis



As the compression and expansion processes are isentropic in the ideal cycle, we use the isentropic laws.

And as the combustion and heat rejection are isochoric (constant volume), use the thermodynamic laws

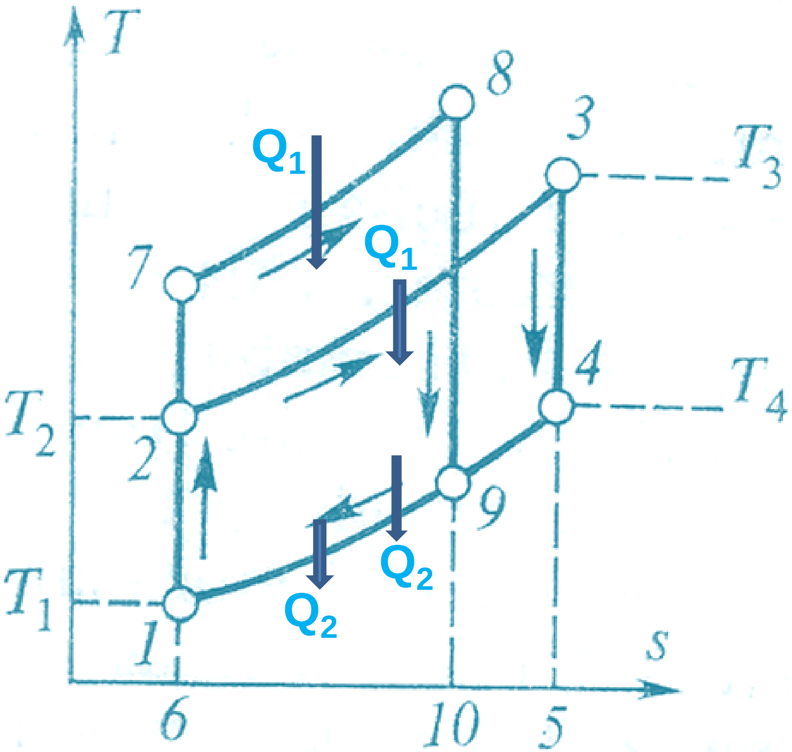
to obtain the cycle efficiency :

$$\eta_{Th} = 1 - \frac{1}{\varepsilon^{k-1}}$$

$$where, k = \frac{c_p}{c_v}$$

Ideal Otto Cycle Analysis

ε	η_{Th} at k = 1.35	η_{Th} at k = 1.40
3	32	36
4	38	43
5	42.5	47.5
6	46.5	51.5
7	49.4	55
8	51.7	57
10	55.2	61.5



T-s Diagram of Otto cycle

1) Efficiency of the cycle (12341) may be written down as :

$$\eta_{Th} = \frac{Q_1 - Q_2}{Q_1} = \frac{\text{area 6235 - area 6145}}{\text{area 6235}}$$

$$\eta_{Th} = \frac{\text{area 1234}}{\text{area 6235}}$$

2) For two cycles with same nett areas i.e area1234 = area 1789, the 2nd cycle 17891 has a higher efficiency as area61910<area6145 and area67810<area6235.

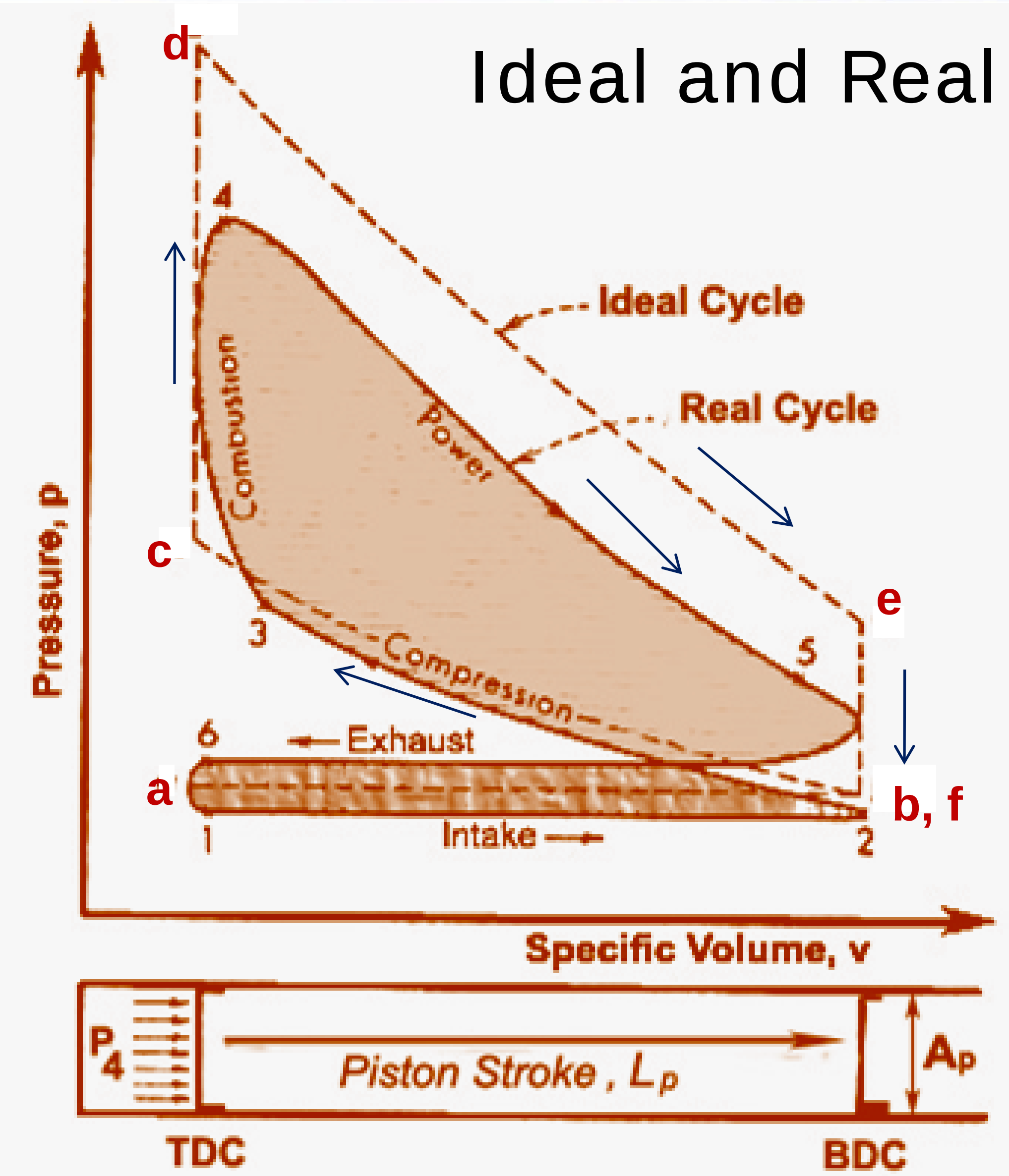
Both Q_1 and Q_2 for the 2nd cycle are lesser, but the cycle efficiency is higher than the 1st cycle

Work exchanges are :

$Q_1 = c_v(T_3 - T_2) < c_v(T_8 - T_7)$

$Q_2 = c_v(T_4 - T_1) < c_v(T_9 - T_1)$

Ideal and Real cycle Comparison



- The arrowheads indicate the direction of piston/process path
- The real cycle (123456a) differs from the ideal cycle (abcdefa)as shown in the Fig
- Due to loss of energy actual paths differ from the ideal
- The work done is less than the ideal

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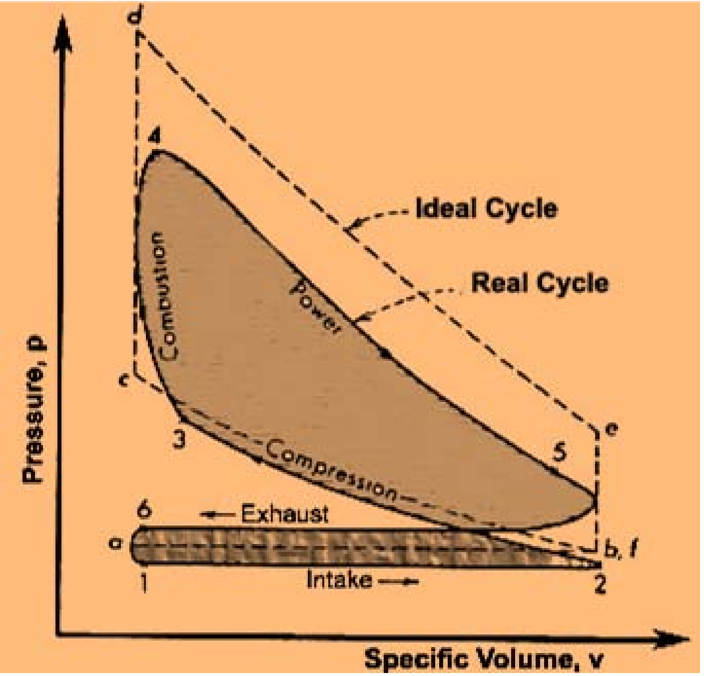
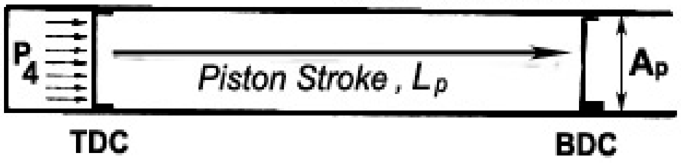
Ideal and Real cycle comparison





1) The Intake of fresh air often happens at a pressure (1-2) lower than that of ideal cycle (a-b)
2) Exhaust often happens at a pressure (5-6) higher than that of ideal cycle (b-a).

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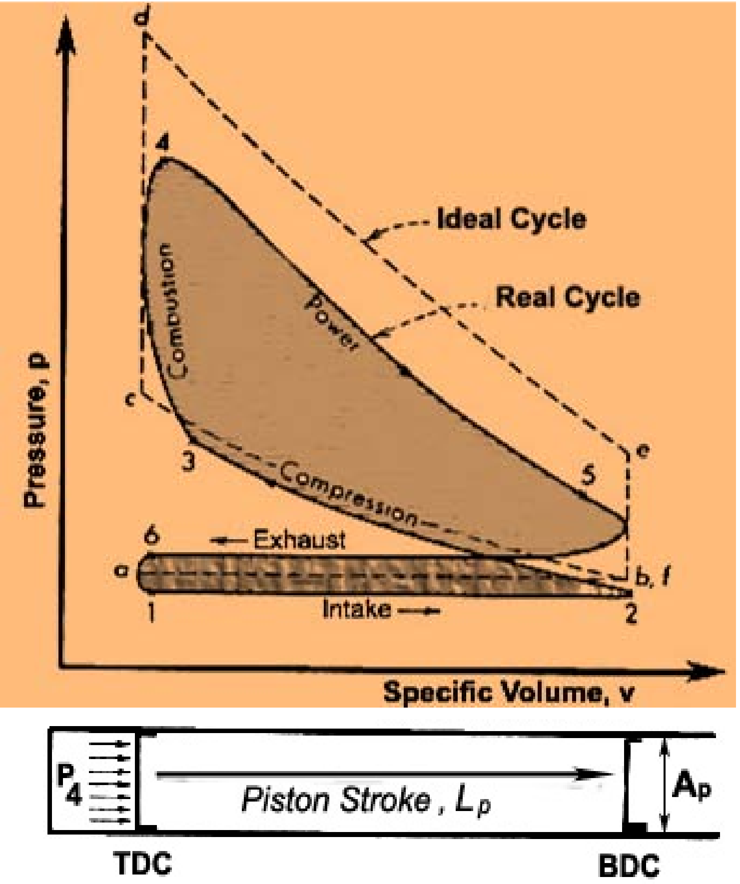
Ideal and Real cycle comparison



3) Compression starts at a pressure lower than the ideal value and proceeds along a path (2-3) lower than the ideal compression path (b-c). As a result the work done for the compression is less than that of the ideal work (area under the curve 2-3)

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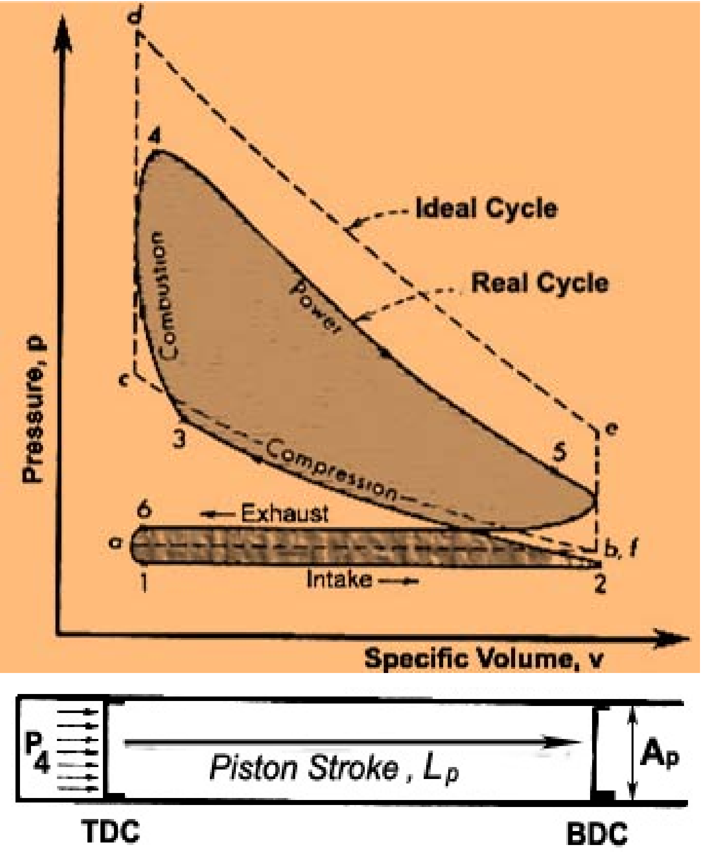
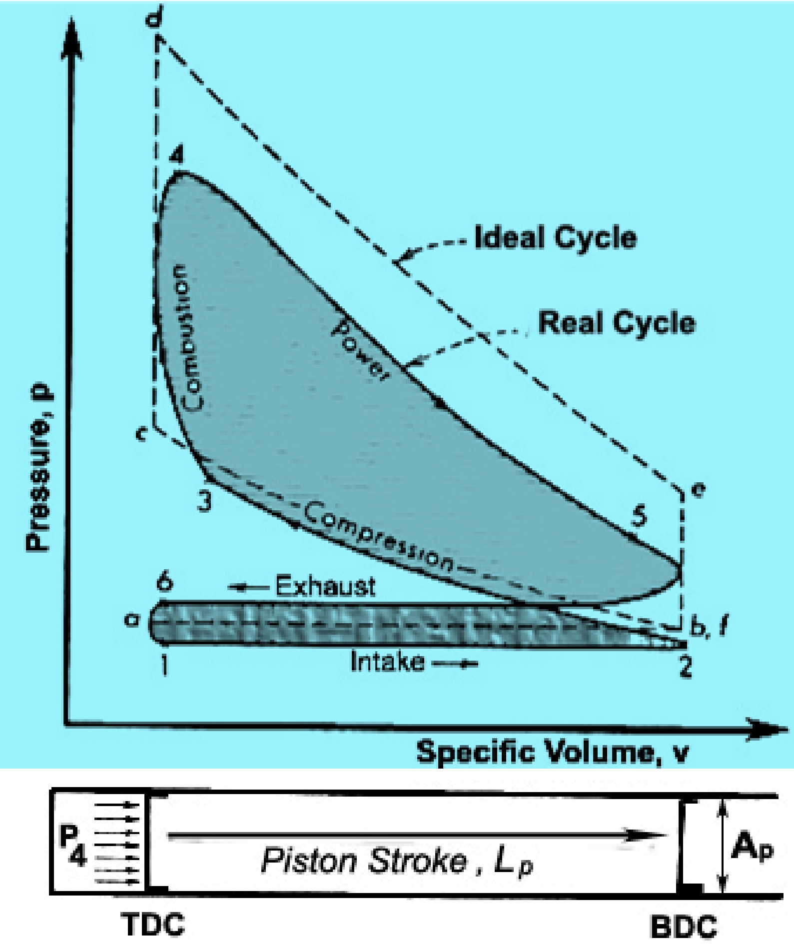
Ideal and Real cycle comparison



4) Combustion (3-4) starts before the compression stroke is completed (3-e). Thus compression end and part of the combustion occur together when the piston reaches TDC

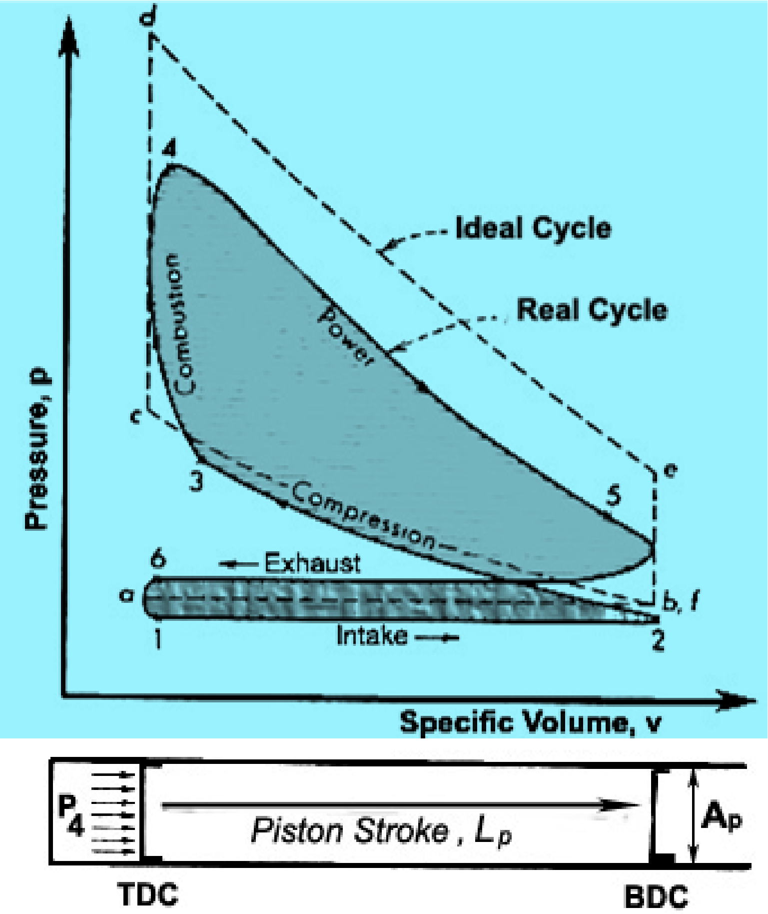
Ideal and Real cycle comparison



5) Expansion or Power stroke actually starts before the combustion is completed

6) The power stroke often starts at a pressure (4) lower than the ideal pressure (d)

Ideal and Real cycle comparison



7) The power stroke (expansion process / path) often occur along a pressure line (4-5) lower than the ideal cycle pressures line (d-e). The diagram shows that a loss of work done by power stroke will occur

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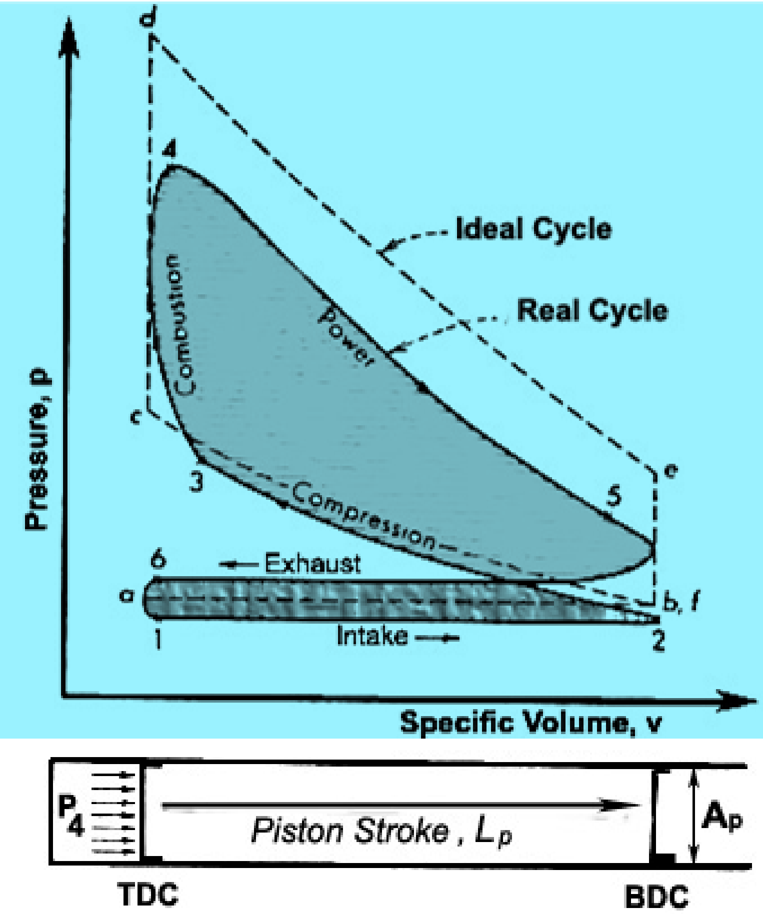
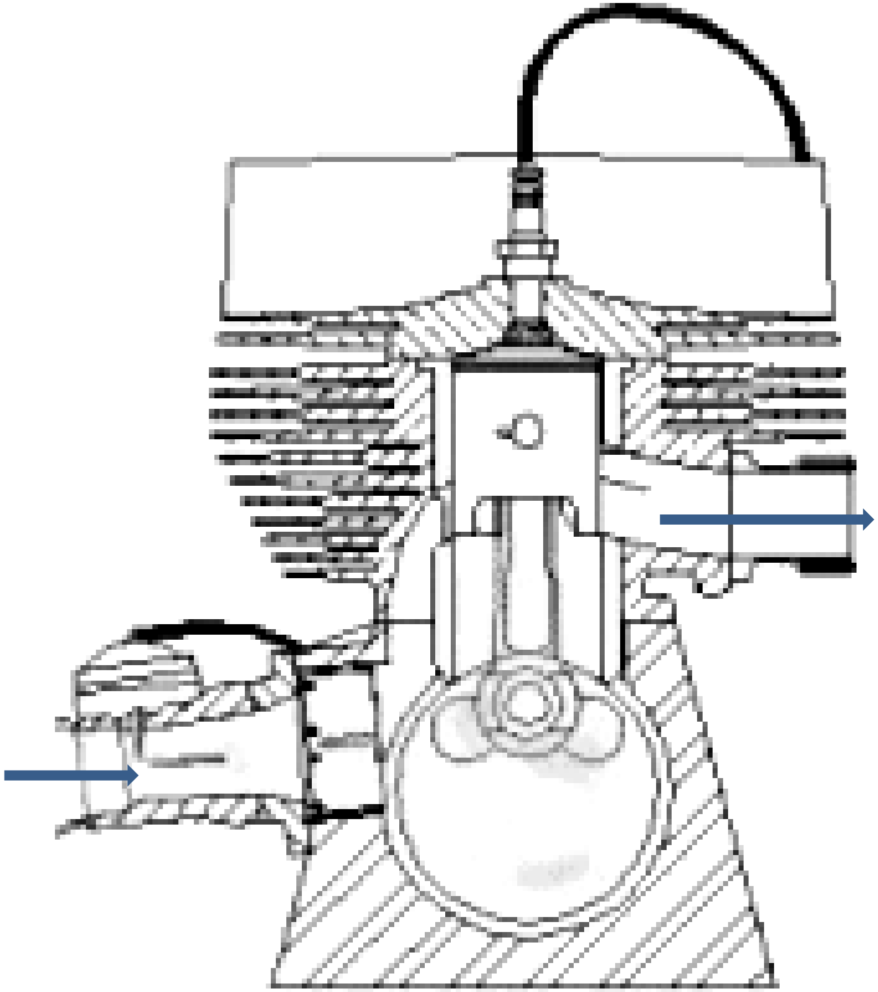


8) The heat rejection process (5) (at the end of the power stroke) is in reality short and the gas exhaust starts as soon as the power stroke is completed and the piston reaches BDC (5). The exhaust is completed when the process reaches 6.



2-stroke engine

- Intake + Power stroke – Piston going down
- Combustion– piston at TDC
- Compression + Exhaust – piston going up

All Modern aircraft engines use four stroke engines

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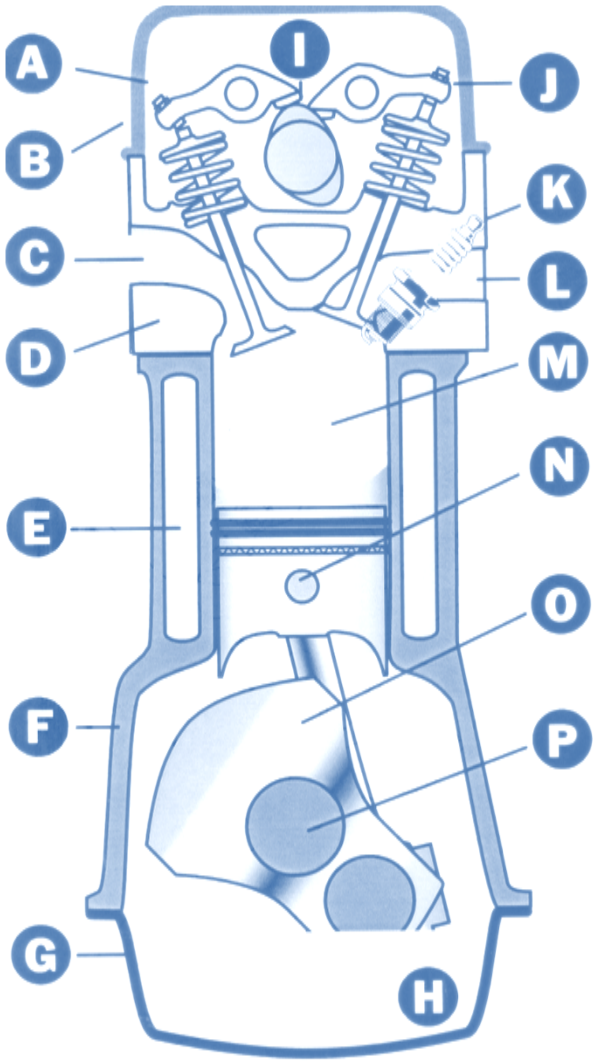

- A Intake Valve, Rocker Arm & Spring
- B Valve Cover
- C Intake port
- D Head
- E Coolant
- F Engine Block
- G Oil Pan
- H Oil Sump
- I Camshaft
- J Exhaust Valve, Rocker Arm & Spring
- K Spark Plug
- L Exhaust Port
- M Piston
- N Connecting Rod
- O Rod Bearing
- P Crankshaft

4-stroke engine

- Intake - Piston going down
- Compression – piston going up
- Combustion- piston at TDC
- Power – piston going down
- Exhaust – piston going up

In the next lecture we will look at various types of piston engines used in aircraft powerplants

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