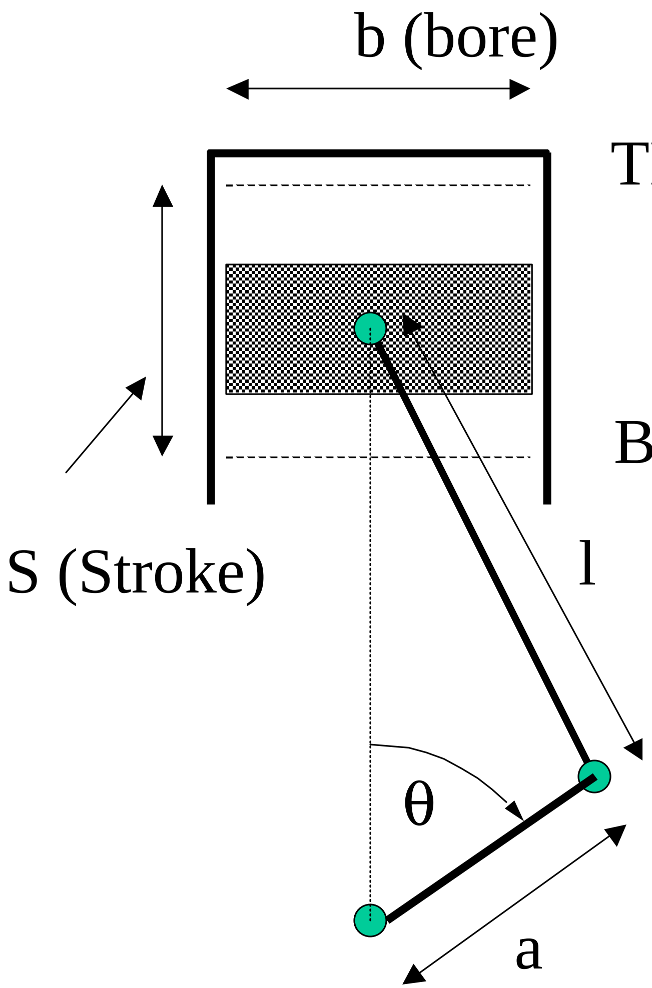
Internal Combustion Engines

- Historical facts: (1st IC engine ~ 1860s (no compression cycle) , prototype Otto engine: 1876. Diesel engine: 1892-1897)

- Engine types:
  - ➢ working cycle (two-stroke, four-stroke)
  - ➢ Fuel type: petrol, diesel, natural gas, hydrogen
  - ➢ Ignition type: Spark or compression ignition
  - ➢ Fuel control: throttling, direct injection

- Engine components (thermal consideration):
  - ➢ cylinders, pistons, valves, intake & exhaust manifolds, combustion chambers

Operating Parameters



TDC (Top Dead Center, $\theta=0^{\circ}$)

BDC (Bottom Dead Center, $\theta=180^{\circ}$)

V_p: piston speed, $\overline{V_P}$: mean piston speed

Show that:

$$\frac{V_P}{\overline{V_P}} = \frac{\pi}{2}\sin\theta\left[1+\frac{\cos\theta}{\left(\left(\frac{l}{a}\right)^2-\sin^2\theta\right)^{1/2}}\right]$$

Operating Parameters

• Piston speed (V_p): 20 m/s represents a practical limit for most engines (choking at the intake valve(s)), V_p=S/(1/2 N)=2NS (note: from now on V_p represents the mean piston speed for simplicity)

• Compression ratio: r = V_{BDC}/V_{TDV}

• Displacement Volume: $V_d=A_pS=(\pi/4)b^2S$

• Fuel/Air ratio: F=(fuel mass flow)/(air mass flow)

• Volumetric efficiency (η_v): the volume flow rate of air into the intake system divided by the rate at which volume is displaced by the piston:

$$\eta_V = \frac{2(\dot{m}_a / \rho_{a,i})}{V_d N} = \frac{m_a}{\rho_{a,i} V_d}$$

Engine Operating Parameters

- Mean Effective Pressure (mep, bmep, imep, fmep)
  - bmep (brake) = imep (indicated) - fmep (friction)
  - $P=FV=(mep)(A_p)(n)(S/\Delta t)=(mep)A_p(S)(n)(N/X)$ (S: stroke, n: #cylinders, N: rotational speed of engine, X=2 for four-stroke engine, 2 rotations per power cycle; X=1 for two-stroke engine)

- Efficiencies
  - Air cycle efficiency (Otto efficiency $h_{ac} = 1 - \left(\frac{1}{r}\right)^{k-1}$, r: compression ratio, k: specific heat ratio)
  - Real gas efficiency (η_o), indicated efficiency (η_i) $\eta_i=(\eta_o)(\eta_{ac})$

Operating Parameters

• Torque (T): a measure of the work done per unit rotation (radians) of the crank $\int T d\theta = 4\pi T = \int P dV = (mep)V_d$ (for 4 stroke engines)

• Power (P): the rate at which work is done, $P=(2\pi N)T$ since the engine rotates at a rate of $2\pi N$, N: rotational speed
$P=(mep)V_d\ (N/2)$ (for 4 stroke engines)

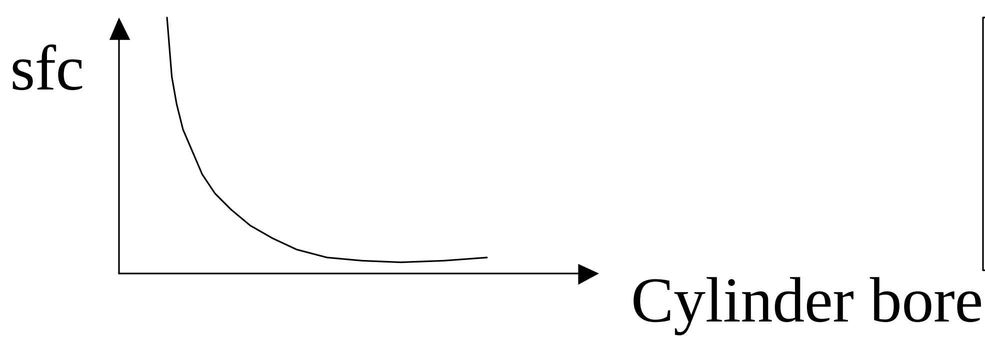
• Specific Power: the power produced per unit piston area
  – $P=(mep)(nA_pS)(N/2)=(mep)(nA_p)(V_p/4)$
  – $P/(nA_p)=(power)/(size)=(mep)(V_p/4)$
  – higher effective pressure and higher piston speed (V_p) lead to higher $P/(nA_p)$ desirable but with technical limitations (knocking, choking, et al.)

Operating Parameters

• Stroke/Bore Ratio (S/b): engine displacement $V_d=A_pnS$
$P=(mep)(nA_p)(V_p/4)=(mep)V_d[V_p/(4S)]$
Power per unit displacement $(P/V_d)=(mep)\ [V_p/(4S)]$: for fixed mep and V_p, a shorter stroke (smaller S) will lead to higher power per unit displacement ➔ it is desirable to reduce the stroke/bore ratio

• Specific fuel consumption (sfc): fuel flow rate divided by the power, a measure of engine efficiency (lower the better)

sfc=(fuel mass flow rate)/power



Larger bore size gives better engine efficiency, lower sfc

Operating Parameters

- Bore size factor:
  - surface area to volume ratio (A/V)~1/b, therefore, less heat loss to surface as the bore increases. (less mechanical friction (relative to its size) also but its influence is at a much lesser extent)
  - rotational speed decrease N ~ (1/b), therefore, more time for effective combustion
  - Large volume means the volume is relatively unaffected by combustion (constant volume assumption is more valid)

Design Considerations

• Volumetric efficiency: dominated by fluid mechanics such as flow separation, viscous losses, Mach number, manifold design. Possible improvements thru valve design (# and shape, and timing), manifold tuning, etc.

• Inlet density: the higher the better. Improved thru supercharging, turbocharging, intercooling, water injection, etc.

• Displacement, stroke/bore ratio: smaller displacement and decreasing S/b.

• Compression ratio: higher compression ratio leads to higher thermal efficiency. (limitations due to structural considerations, knocking, ..)