1. ENGINE GEOMETRY

Definitions:

TC is top center crank position

BC is bottom center crank position

a = crank radius

B = cylinder bore

l = connecting rod length

L = stroke (= 2a)

$V_c =$ clearance volume

$V_d =$ displaced or swept cylinder volume

$r_c =$ compression ratio

$ = \text{cylinder volume at } BC/\text{cylinder volume at } TC$

$ = (V_c + V_d)/V_c$

$\theta =$ crank angle

$S_p =$ mean piston speed (= 2LN)

$N =$ crankshaft rotational speed in revolutions per second or minute
Torque Versus Crank Angle

At lower engine speeds, the piston and con rod inertia force can be neglected.

Then:

\[ T = a \sin \theta [(p - p_{cc})A_p - F][1 + \frac{a}{\ell} \cos \theta \frac{1}{(1 - \frac{a^2}{\ell^2} \sin^2 \theta)^{1/2}}] \]
Practical parameters:
   Power, Torque
   Specific fuel consumption

Normalized parameters:
   Specific fuel consumption
   Specific emissions
   Mean effective pressure
   Burn rate parameters

Dimensionless parameters:
   Volumetric efficiency
   Fuel conversion (energy conversion) efficiency
   Mechanical efficiency
   Swirl ratio, tumble ratio
Indicated Work Per Cycle

1. For naturally aspirated engines:
   The indicated work per cycle $W_{c,i}$ is the work transferred from the gases in the cylinder to the piston over the compression and expansion strokes. It is found by integrating the area under the cylinder pressure versus cylinder volume curve. It is the maximum work transfer that occurs within the engine. As this work flows through the piston, connecting rod, crankshaft, etc. to the output shaft, it is decreased by the pumping work (in the four-stroke cycle, with naturally aspirated engines), the mechanical rubbing friction and the work to drive the accessories. These three items are called the total friction work. What is left is the brake work per cycle:

$$W_{c,b} = W_{c,i} - W_{c,f}$$

2. For turbocharged engines:
   The indicated work per cycle $W_{c,i}$ is the work transferred from the gases in the cylinder to the piston over the full cycle (all four strokes for the 4-stroke cycle). The definition is changed because, with a turbocharger, the intake manifold pressure is higher than the exhaust manifold pressure so the exhaust and intake strokes contribute positive work. Friction is now defined as the sum of mechanical rubbing friction and the accessory drive requirements. The relation between brake, indicated, and friction quantities remains the same.
Naturally Aspirated Engines

Indicated work

\[ W_{c,i} = \int p dV \]

over compression & expansion strokes

Pumping work

\[ W_p = \int p dV \]

over intake and exhaust strokes

Friction work

\[ W_f = W_p + W_{rf} + W_a \]

\[ W_{rf} = \text{mechanical rubbing friction} \]

\[ W_a = \text{work/cycle to drive accessories} \]
**Actual Performance**

power $P$, torque $T$

$$P = 2\pi N T = W_c N / n_R$$

($n_R = 2$ for 4-stroke and 1 for 2-stroke)

**Normalized Performance**

mean effective pressure

$$\text{mep} = \frac{W_c}{V_d} = \frac{P n_R}{V_d N} = \frac{2\pi n_R T}{V_d}$$

specific fuel consumption

$$\text{sfc} = \frac{\dot{m}_f}{P}$$

specific emissions

$$\text{sHC} = \frac{\dot{m}_{HC}}{P}$$

($N =$ engine speed; $V_d =$ displaced vol.)
Examples of Normalized performance:

<table>
<thead>
<tr>
<th>Engine</th>
<th>bmep(\text{max}) kPa</th>
<th>bmep(\text{p}\max) kPa</th>
<th>(\overline{5})(p\max) m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ford (2V, V-8, S1E)</td>
<td>1000</td>
<td>888</td>
<td>13.8</td>
</tr>
<tr>
<td>Nissan (4V, I4, S1E)</td>
<td>1154</td>
<td>1025</td>
<td>17.6</td>
</tr>
<tr>
<td>Saturn, StarC (2V, I4, S1E)</td>
<td>958</td>
<td>800</td>
<td>15</td>
</tr>
<tr>
<td>Saturn, DottC (4V, I4, S1E)</td>
<td>1090</td>
<td>973</td>
<td>18</td>
</tr>
<tr>
<td>Honda, Form-1 (4V, V-6, TC, S1E)</td>
<td>3615</td>
<td>3277</td>
<td>21</td>
</tr>
<tr>
<td>Isuzu, H, D (4S, NA)</td>
<td>910</td>
<td>856</td>
<td>11.7</td>
</tr>
<tr>
<td>Hino, P11C (4S, TC, I, D)</td>
<td>1640</td>
<td>1298</td>
<td>10.5</td>
</tr>
<tr>
<td>Sulzer, Marine (2S, TC, I, D)</td>
<td>1660</td>
<td></td>
<td>7.2</td>
</tr>
</tbody>
</table>
**Dimensionless performance**

Volumetric efficiency

$$\eta_v = \frac{2\dot{m}_a}{\rho_{a,o}V_dN} = \frac{\dot{m}_a}{\rho_{a,o}V_d}$$

fuel-conversion (thermal) efficiency

$$\eta_f = \frac{W_c}{\dot{m}_fQ_{HV}} = \frac{P}{\dot{m}_fQ_{HV}} = \frac{1}{sfcQ_{HV}}$$

mechanical efficiency

$$\eta_m = \frac{P_b}{P_i} = \frac{\text{bmepe}}{\text{imepe}}$$

Indicated, brake and friction quantities

e.g. \( \text{imepe} = \text{bmepe} + \text{fmepe} \)

Brake mean effective pressure:

$$\text{bmepe} = \eta_v\eta_{f,i}\eta_mQ_{HV}\rho_{a,o}(F/A)$$