Internal combustion engines

Chapter two

OPERATION IC ENGINES

Section 2.1 ENGINE PARAMETERS

By

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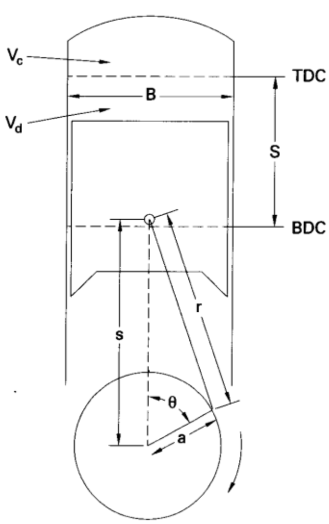

Figure 2-1 Piston and cylinder geometry of reciprocating engine. B = bore; S = stroke; r = connecting rod length; a = crank offset; s = piston position; θ = crank angle; V_c = clearance volume; V_d = displacement volume.

- $S = 2a$
- Average piston speed is:

$$\overline{U}_p = 2(S)(N)$$

- *N is generally given in RPM*
- $5 m/s < U_p < 15 m/s$

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5m/s < Up < 15m/s

- material strength of the engine components
  - ❑Very large engines typically operate in the 200- to 4oo-RPM range
  - ❑smallest engines operate at speeds of 12,000 RPM and higher
- gas flow into and out of the cylinders
  - ❑Higher piston speeds would require larger valves to let the flow enter and exit the combustion chamber rapidly

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TABLE 2-1 TYPICAL ENGINE OPERATING PARAMETERS

	Model Airplane Two-Stroke Cycle	Automobile Four-Stroke Cycle	Large Stationary Two-Stroke Cycle
BORE (cm)	2.00	9.42	50.0
STROKE (cm)	2.04	9.89	161
DISPLACEMENT/cyl (L)	0.0066	0.69	316
SPEED (RPM)	13,000	5200	125
POWER/cyl (kW)	0.72	35	311
AVERAGE PISTON SPEED (m/sec)	8.84	17.1	6.71
POWER/DISPLACEMENT (kW/L)	109	50.7	0.98
bmep (kPa)	503	1170	472

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Bore/stroke ratio : B/S

Small engines: 0.8<B/S<1.2

- B=S
  Square engine
- B<S or B/S<1
  Under-square engine
- B>S or B/S >1
  Over-square engine

Very large engines
B/S = 0.25
Or
S=4B

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$$s = a\cos(\theta) + \sqrt{r^2 - a^2\sin^2(\theta)}$$

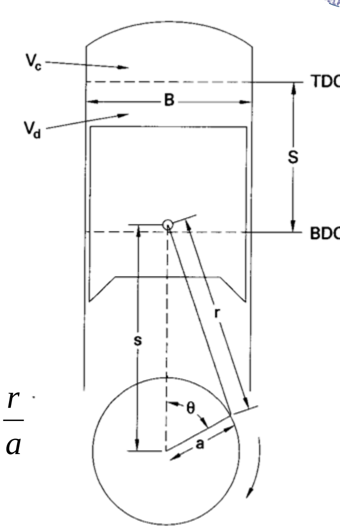
Where:

- **a: crank offset**
- **r: connecting rod length**
- **Ɵ: crank angle**

The instantaneous piston speed Up:

Up = ds/dt

$$\frac{U_p}{\overline{\overline{U}}_p} = \frac{\pi}{2}\sin(\theta)\left[\frac{\cos(\theta)}{\sqrt{R^2 - \sin^2(\theta)}}\right]; R = \frac{r}{a}$$



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R

- 3-4 for small engines
- 5-10 for large engine

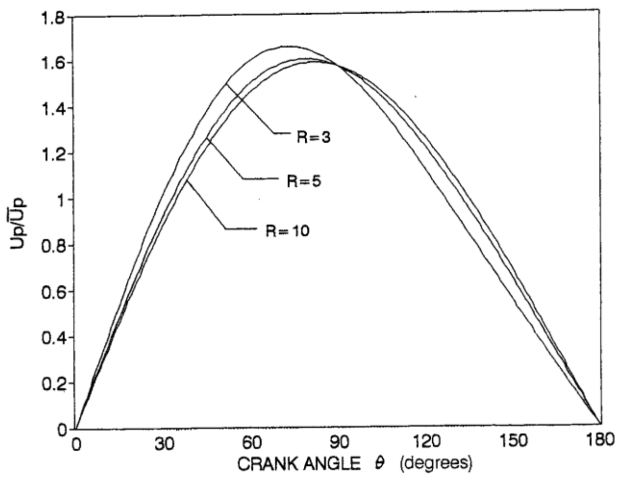

Figure 2-2 Instantaneous piston speed relative to average piston speed as a function of crank angle for various R values, where $R = r/a$, r = connecting rod length, a = crankshaft offset.

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B/S

B/S<1	B>S or B/S >1
1. Higher thermal efficiency	1. Lower thermal efficiency
2. Higher friction	2. Lower friction

Surface area of combustion depends on B/S ratio.
As B/S increases, the combustion chamber surface area increases too.
The increase in combustion chamber surface area means more losses and so bad thermal efficiency. However, it means also decrease in friction between piston and cylinder surface.

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Displacement volume (V_d): $V_d = V_{BDC} - V_{TDC}$

And so: $V_d = \left(\frac{\pi}{4}\right) B^2 S$

For engine with N_C cylinders: $V_d = N_C \left(\frac{\pi}{4}\right) B^2 S$

Clearance volume (V_C): $V_C = V_{TDC} \rightarrow V_{BDC} = V_C + V_D$.

Compression ratio (r_c): $r_c = \frac{V_{BDC}}{V_{TDC}} = \frac{V_C + V_d}{V_C}$

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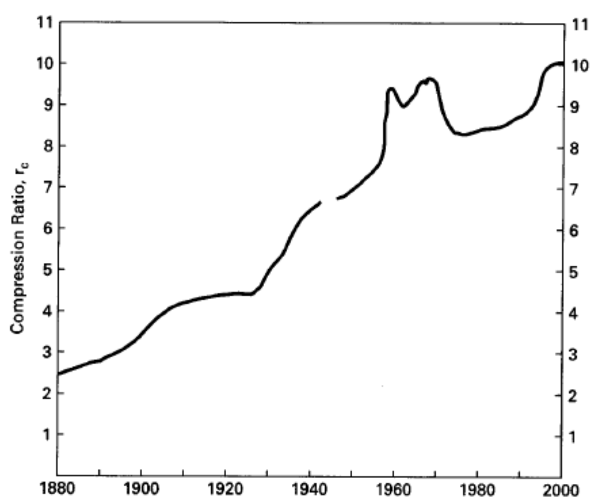
always $r_c > 1$

- spark ignition (SI): 8 to 11
- compression ignition (CI): 12 to 24
- Adding charger reduce r_c.



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The cylinder volume V at any crank angle is:

$$V = V_c + (\pi B^2/4)(r + a - s) \quad (2\text{-}13)$$

where: V_c = clearance volume
B = bore
r = connecting rod length
a = crank offset
s = piston position shown in Fig. 2-1

This can also be written in a non-dimensional form by dividing by V_c, substituting for r, a, and s, and employing the definition of R:

$$V/V_c = 1 + \tfrac{1}{2}(r_c - 1)[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}] \quad (2\text{-}14)$$

where: r_c = compression ratio
$R = r/a$

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The cross-sectional area of a cylinder and the surface area of a flat-topped piston are each given by:

$$A_p = (\pi/4)B^2 \quad (2\text{-}15)$$

The combustion chamber surface area is:

$$A = A_{ch} + A_p + \pi B(r + a - s) \quad (2\text{-}16)$$

where A_{ch} is the cylinder head surface area, which will be somewhat larger than A_p.

Then if the definitions for r, a, s, and R are used, Eq. (2-16) can be rewritten as:

$$A = A_{ch} + A_p + (\pi BS/2)[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}] \quad (2\text{-}17)$$

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EXAMPLE PROBLEM 2-1

John's automobile has a three-liter SI V6 engine that operates on a four-stroke cycle at 3600 RPM. The compression ratio is 9.5, the length of connecting rods is 16.6 cm, and the engine is square ($B = S$). At this speed, combustion ends at 20° aTDC. Calculate:

1. cylinder bore and stroke length
2. average piston speed
3. clearance volume of one cylinder
4. piston speed at the end of combustion
5. distance the piston has traveled from TDC at the end of combustion
6. volume in the combustion chamber at the end of combustion

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1) For one cylinder,

$$V_d = V_{total}/6 = 3\text{L}/6 = 0.5\text{ L} = 0.0005\text{ m}^3 = (\pi/4)B^2S = (\pi/4)B^3$$

$$\underline{B = 0.0860\text{ m} = 8.60\text{ cm} = S}$$

2) $$\bar{U}_p = 2SN = (2\text{ strokes/rev})(0.0860\text{ m/stroke})(3600/60\text{ rev/sec})$$

$$\underline{= 10.32\text{ m/sec}}$$

3) $$r_c = 9.5 = (V_d + V_c)/V_c = (0.0005 + V_c)/V_c$$

$$\underline{V_c = 0.000059\text{ m}^3 = 59\text{ cm}^3}$$

4) Crank offset, $a = S/2 = 0.0430\text{ m} = 4.30\text{ cm}$

$$R = r/a = 16.6\text{ cm}/4.30\text{ cm} = 3.86$$

$$U_p/\bar{U}_p = (\pi/2)\sin\theta[1 + (\cos\theta/\sqrt{R^2 - \sin^2\theta})]$$

$$= (\pi/2)\sin(20°)\{1 + [\cos(20°)/\sqrt{(3.86)^2 - \sin^2(20°)}]\}$$

$$= 0.668$$

$$U_p = 0.668\,\bar{U}_p = (0.668)(10.32\text{ m/sec}) = \underline{6.89\text{ m/sec}}$$

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5) $s = a\cos\theta + \sqrt{r^2 - a^2\sin^2\theta}$

$= (0.0430\text{ m})\cos(20°) + \sqrt{(0.166\text{ m})^2 - (0.0430\text{ m})^2\sin^2(20°)}$

$= 0.206\text{ m}$

Distance from TDC:

$x = r + a - s = (0.166\text{ m}) + (0.043\text{ m}) - (0.206\text{ m})$

$= 0.003\text{ m} = 0.3\text{ cm}$

6) $V/V_c = 1 + \frac{1}{2}(r_c - 1)[R + 1 - \cos\theta - \sqrt{R^2 - \sin^2\theta}]$

$= 1 + \frac{1}{2}(9.5 - 1)[3.86 + 1 - \cos(20°) - \sqrt{(3.86)^2 - \sin^2(20°)}]$

$= 1.32$

$V = 1.32\, V_c = (1.32)(59\text{ cm}^3) = 77.9\text{ cm}^3 = 0.0000779\text{ m}^3$