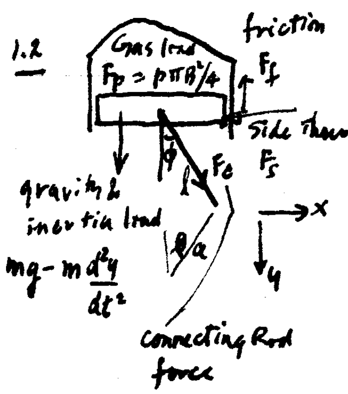
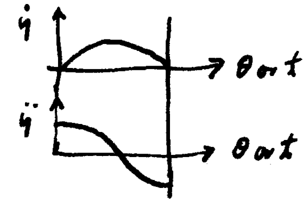
2.615 Solution to HW #1

1.2





Note: 1) The inertia load term changes direction during the piston descend

2) The side thrust F_s is a normal reaction to balance the x component of the connecting rod force F_c.

$$m\ddot{y} = mg + F_c\cos\phi + p\frac{\pi B^2}{4} - F_f$$

$$F_s = F_c \sin\phi$$

and the frictional force F_f is

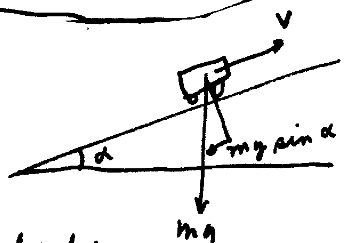
$F_f = fF_s$ where f is the frictional coeff.

ϕ and θ are related by $\phi = \sin^{-1}(a\sin\theta/l)$

at $\theta = 45°$, for $l/a = 3.5$, $\phi = 11.7°$

	SI engine		DI engine	
	N	lb	N	lb
F_p	1.13×10^4	2.50×10^3	1.77×10^5	3.97×10^4
F_c	1.15×10^4	2.58×10^3	1.81×10^5	4.0×10^4
$F_c\sin\phi$	2.34×10^3	5.15×10^2	3.67×10^4	8.07×10^3

2-5



$$P_{required} = P_{gravity} + P_{drag} + P_{friction}$$

$$= \left[\underbrace{mg\sin\alpha} + \underbrace{\tfrac{1}{2}\rho_a C_D A_v V^2} + \underbrace{C_R\, mg\cos\theta}\right]V$$

$$= \left[1500\times9.81\times\sin15° + \tfrac{1}{2}\,1.2\times0.4\times2\times22.4^2 + .013\times1500\times9.81\times\cos15\right]\times22.4$$

$$= [\,3808.5 \quad + \quad 240.8 \quad + \quad 184.8\,]\times22.4$$

$$= \underline{\underline{95\,kW}}$$

typical values

$C_D = 0.4$ $\quad A_v$ (frontal area) $= 2\,m^2$

$C_R = 0.013$ $\quad V = 50$ mph $= 22.4$ m/s

$m = 1500$ kg $\quad \alpha = 15°$

Av. accel for 40 to 60 mph in 5 sec: (1 mph = .447 m/s)
$a = \Delta V/t = (20\times.447/5) = 1.79\,m/s^2$;
$ma = 2680\,N$

Note: The drag and friction components are roughly equal. The power to propel against gravity is much higher.

2.8

$\eta_{f(brake)} = 0.3$

$$bsfc = \frac{\dot{m}_f}{\dot{m}_f Q_{HV}\eta_f} = \frac{1}{Q_{HV}\eta_f};$$ Put in conversion factors $$bsfc\left[\frac{kg}{kWhr}\right] = \frac{1}{Q_{HV}(J/kg)\,\eta_f}\times3.6\times10^6$$

Fuel	Isooctane	Gasoline	Methanol	H_2
Q_{HV} (lower) (J/kg)	44.3×10^6	44.0×10^6	20.0×10^6	120×10^6
Bsfc (kg/kWhr)	0.271	0.273	0.600	0.100

2.11 Design requirement: 300 kW Full Power

Say max piston speed $= 12$ m/s, max mep 10 bar (stress limited)

For number of cylinders $= C$: $\frac{1}{2} C\, V_D\, \text{mep}\, N = \text{Power}$

(factor of 1/2 for 4 stroke)

$$\text{Thus Power} = \frac{1}{4}C\left(\frac{\pi B^2}{4}\right)\underbrace{(2NL)}_{\text{fixed}}\underbrace{\text{mep}}_{\text{fixed}}$$

The trade off between C & B has to do with other considerations. (knock, packaging, heat transfer etc.) Will pick a 8 cylinder engine and do the numbers to see whether they are reasonable.

(2-11 cont.)

Using $c=8$ $\Rightarrow$ $300\times10^3 = \frac{1}{4}\times 8\times\left(\frac{\pi B^2}{4}\right)\times 12\times 10\times10^5 \longrightarrow B = \underline{\underline{13\text{ cm}}}$ (~5 in.)

Say bore to stroke ratio $B/L \simeq 1$ Then $L = 13$ cm and $2NL = 12$ m/s would give $N = 46.15$ c/s or $\underline{2769\text{ rpm}}$.

Torque: $T\,2\pi N = \frac{N}{2} V_D\, mep$ (for 4 stroke) $\Rightarrow T = \left(\frac{1}{4\pi}\right) V_D \cdot mep \cdot c = \frac{1}{4\pi}\times\frac{\pi\cdot 13^3}{4}\times10^6\times 8 = \underline{\underline{1100\text{ N-m}}}$

Fuel flow rate: Say $\eta_f = 0.3$; $P = Q_{HV}\,\eta_f\,\dot{m}_f$

Thus $\dot{m}_f = P/Q_{HV}\eta_f = 3\times10^5/(4.3\times10^7\times0.3) = 2.33\times10^{-2}$ kg/s $= \underline{\underline{84\text{ kg/hr}}} \simeq 28$ gallon/hr.

(These figures are typical for a commercial V-8 truck engine.)

<u>2.13</u> 1.6 litre displacement engine, 4 cylinder, WOT @ 2500 rpm.

Say $B/L = 1$ $\Rightarrow$ $\frac{\pi}{4}L^3 = 400$ cc or $L = 8$ cm

mean piston speed $\bar{S}_p = 2NL = 2\times\frac{2500}{60}\times 0.08 = \underline{6.67\text{ m/s}}$

Max piston speed (see fig. 2.2 of Text) $\simeq 1.6\,\bar{S}_p = \underline{10.7\text{ m/s}}$

Max charge velocity at intake $\simeq$ Max piston speed $\times$ Area ratio $= 10.7\times5 = \underline{\underline{54\text{ m/s}}}$

(The following are estimates of the time taken for the various processes. Refer to figure 1-8 in Text for more precise numbers.)

- Time per cycle @ 2 revolution per cycle $= \left(\frac{60}{2500}\times 2.5\right) = \underline{\underline{48\text{ ms}}}$
- Intake, compression, expansion and exhaust each takes up ~ 1/4 of the cycle time ~ $\underline{\underline{12\text{ ms}}}$
- Combustion: Starts ~ 20° BTC, ends ~ 40° ATC. Duration = 60°

  time $= \frac{60}{720}\times 48\text{ ms} = \underline{\underline{4\text{ ms}}}$
- Flame velocity: Say flame starts at the center (spark plug centrally located). It has to traverse the radius in 4 ms

  Flame velocity $= \frac{.04\text{ m}}{4\times10^{-3}\text{ s}} = \underline{10\text{ m/s}}$
- WOT intake "run length" $= \frac{V_D}{A_{port}} = \frac{V_D}{A_{piston}\times 1/5} = \frac{\text{Stroke}}{1/5} = \underline{\underline{40\text{ cm}}}$
- Exhaust "run length" $= \frac{V_D}{A_{port}}\times$ Temperature ratio $= 40\text{ cm}\times\frac{425+273}{300}$

  $= \underline{\underline{93.07\text{ cm}}}$