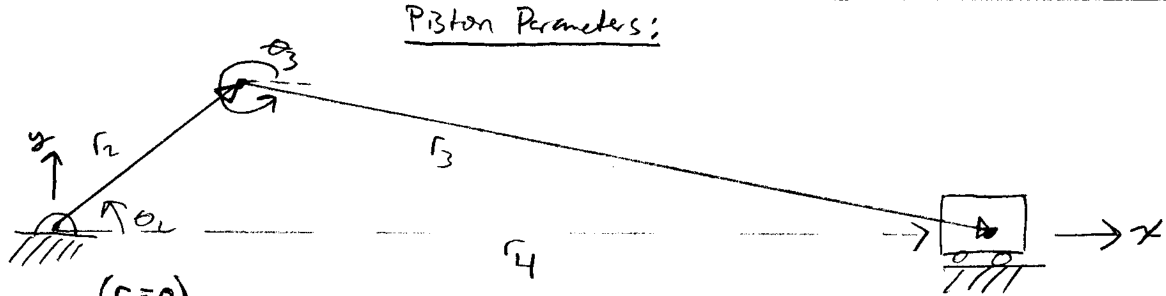
Assume:

- Assume 3900 RPM for engine at 120" MAP
- 13" dia. prop x 117.5" pitch
- Prop shaft speed = 13,000 RPM
- Fuel ≈ 6 lb/gal
- Air @ STP ∴ 0.075 lb_m/ft^3
- 3800 HP
- Blower gears: 6.390:1 ; Gearbox 3:1

Piston Parameters:



$(r_1 = 0)$

$r_2 = 3''$

$r_3 = 10''$

$\dot{\theta}_2 = 3900 \frac{rev}{min} \times \frac{2\pi}{rev} \times \frac{1 min}{60 s} = \underline{\underline{408\ rad/sec}}$

$\ddot{\theta}_2 = 0$

Vector-loop Sol'n:

From Hull's Text, Purdue Univ. Mech. Engr.

eq.7 pg 1.17 → $r_4 = r_2\cos\theta_2 \pm \sqrt{r_2^2\cos^2\theta_2 - r_1^2 - r_2^2 + r_3^2 - 2r_1r_2\sin\theta_2}$ (1)

eq 11 pg 1.17 → $\sin\theta_3 = (-r_2\sin\theta_2 - r_1)/r_3$ (2)

] Pos

eq 5 pg 1.19 → $(-r_3\sin\theta_3)\dot{\theta}_3 - \dot{r}_4 = r_2\dot{\theta}_2\sin\theta_2$ (3)

eq 6 pg 1.19 → $(r_3\cos\theta_3)\dot{\theta}_3 = -r_2\dot{\theta}_2\cos\theta_2$ (4)

] Vel

⇒

eq. 9 pg 1.20 → $(-r_3 \sin\theta_3)\ddot{\theta}_3 - \ddot{r}_4 = r_2 \ddot{\theta}_2 \sin\theta_2 + r_2 \dot{\theta}_2^2 \cos\theta_2 + r_3 \dot{\theta}_3^2 \cos\theta_3$ (5)

eq 10 pg 1.20 → $(r_3 \cos\theta_3)\ddot{\theta}_3 = -r_2 \ddot{\theta}_2 \cos\theta_2 + r_2 \dot{\theta}_2^2 \sin\theta_2 + r_3 \dot{\theta}_3^2 \sin\theta_3$ (6)

∴ from (1), (2)

$$r_4 = r_2 \cos\theta_2 + \sqrt{r_2^2 \cos^2\theta_2 - r_1^2 - r_2^2 + r_3^2 - 2 r_1 r_2 \sin\theta_2} \quad (7)$$

$$\theta_3 = \sin^{-1}\left(\frac{-(r_2 \sin\theta_2 - r_1)}{r_3} \right) \quad (8)$$

From (4):

$$\dot{\theta}_3 = \frac{-r_2 \dot{\theta}_2 \cos\theta_2}{r_3 \cos\theta_3} \quad (9)$$

from (3):

$$\dot{r}_4 = -r_3 \sin\theta_3 - r_2 \dot{\theta}_2 \sin\theta_2 \quad (10)$$

from (6)

$$\ddot{\theta}_3 = \frac{-r_2 \ddot{\theta}_2 \cos\theta_2 + r_2 \dot{\theta}_2^2 \sin\theta_2 + r_3 \dot{\theta}_3^2 \sin\theta_3}{r_3 \cos\theta_3} \quad (11)$$

from (5)

$$r_4 = -\left[r_3 \sin\theta_3 + r_2 \ddot{\theta}_2 \sin\theta_2 + r_2 \dot{\theta}_2^2 \cos\theta_2 + r_3 \dot{\theta}_3^2 \cos\theta_3 \right] \quad (12)$$

eq 7-12 → Matlab for sol'n

Max velocity = 70 MPH
max accel ≈ 1500 g @ 0°   900 g @ 180°
Avg. velocity = 44 MPH

Revolutions:

$3900 \frac{rev}{min} \times \frac{1 min}{60 sec} = \boxed{65 rev}$

Valves:

Each valve → every other revolution ∴ $\frac{65}{2} \approx \boxed{33 \text{ openings}}$

All valves: $32.5 \times 48 = \boxed{1560 \text{ openings}}$

Sparkplugs

Every other rev ∴ $\frac{65}{2} \times 24 = \boxed{780 \times}$

↑ # plugs

– or –

Each plug fires $\boxed{33 \text{ times}}$

Piston Travel

$65 \text{ rev} \times (6 \times 2) \frac{in}{rev} = 780 \text{ in} \times \frac{1 ft}{12 in} = \boxed{65 \text{ Ft}}$

Direction reversals/rev = 2 ∴ Δ dir → $\boxed{130 \text{ times}}$ (every 6")

Acceleration about 1,000 g's

Power Pulses

$\frac{1}{2}$ Cylinders fire on each revolution

∴ 12 cyl. of 65 rev → $6 \times 65 = \boxed{390 \text{ Pulses}}$

Blower Tip Speed:

$3900 \text{ RPM} \times 6.39 = 24{,}921 \frac{rev}{min}$

$Circ = \pi D = \pi (12'') = 37.7 \frac{in}{sec} = \pi \frac{ft}{sec}$ For 1st Stage

⇒

$V_t = \omega r$

ω = RPM ⇒ $\frac{rev}{sec}$: $24921 \frac{rev}{min} \times \frac{2\pi}{60} = 830.7\pi \frac{rev}{sec}$

$V_t = \underbrace{(830.7\pi)\left(\frac{12}{2}\right)}_{\frac{in}{sec}} \cdot \frac{1}{12} = \underline{\underline{1305 \frac{ft}{sec}}} = 890$ MPH ≈

C = 761 MPH @ STP ⇒ $M = \frac{V}{C} = \frac{890}{761} = \boxed{1.17\ M}$

<u>Blower revs / Tip travel</u>

$24921 \frac{rev}{min} \times \frac{1m}{60s} = \boxed{415\ rev}$

Circ = π ft/rev ∴ $415\pi \frac{ft}{rev} = \boxed{1304\ ft \approx 4\tfrac{1}{3}\ \text{football fields}}$

<u>Air Flow</u>

120 "Hg = $\boxed{4x\ \text{atmospheric}}$

$23{,}500 \frac{lb}{hr} \times \frac{1hr}{3600sec} \times \frac{1ft^3}{0.075lb} = \boxed{86\ ft^3}$

Average human inhalation ≈ 0.5 L = 0.02 ft^3 ∴ ⇒ 4870 human breaths

Average human ≈ 20 breaths / minute ⇒ 244 minutes ≈ <u>4 hrs</u>

∴ IN 1 sec, Merlin breathes as much air as a human in 4 hrs

$23{,}500 \frac{lb}{hr} \times \frac{1hr}{3600s} = \boxed{6.5\ lb\ Air}$

<u>Fuel flow:</u>

Assume F/A = 0.085 ⇒ $6.5 \frac{lb}{sec} \times 0.085 = \boxed{0.555\ lb\ Fuel}$

@ 6 $\frac{lb}{gal}$ ⇒ $\boxed{0.09\ gal}$ or $\boxed{11.5\ fl\ oz}$ or 0.35 liter ≈ $\boxed{1\ \text{can of pop}}$

Assume $125{,}000 \frac{BTU}{gal} \times 0.09\ gal = 11{,}250$ BTU = 3.3 kW-hr

⇒

Assume Avg US household uses ~ 9,000 kw·hr /yr

=> 1.03 kw-hr / hr

[∴ In 1 sec Merlin uses same engy (in fuel) to run an average US house for 3 hrs!]

ADI flow

$1500 \frac{lb}{1hr}$

$\times \frac{1 gpm}{450 lb/hr} = 3.3$ gpm $\times \frac{1m}{60s} = 0.056 \frac{gal}{sec}$ => 7.1 Fl oz

$\times \frac{1hr}{3600 sec}$ => 0.42 lb

Nitrous flow

~~Assume 0.2 N/A ratio for NACA~~

~~∴ 6.5 lb/sec × 0.2 = 1.3 lb NO_2~~

$1200 \frac{lb}{hr} \times \frac{1h}{3600} = 0.3$ lb

Total fluids:

- Assume NO_2 to be in fluid form @ time of injection

Fuel = 0.56

ADI = 0.42

NO_2 = 1.30

2.28 lb/sec fluids

- excluding NO_2 → 0.95 lb/sec => 1 lb fluid /sec

Oil Consumption

$$0.010 \frac{lb}{hp\,hr} \times 3300\,hp \times \frac{1\,hr}{3600\,sec} = \underline{0.009\ lb} \times \frac{1\,gal}{7.4} \Rightarrow \underline{\underline{0.159\ fl\,oz}}$$

Work:

$$3300\,hp \Rightarrow 1.815 \times 10^6\ \frac{ft \cdot lb}{sec}$$

VW bug ≈ 1800 lb ⇒ 1008 ft can lift   E.T = 1000'

∴ lift VW bug to top of Eiffel Tower in 1 sec. (~75 stories)

Prop Rev:

Given: $65 \frac{rev}{sec} \times \frac{3}{1} = \boxed{195 \frac{rev}{sec}}$

Prop Tip Speed

$V_t = \omega r$

$$= \left(195 \frac{rev}{sec} \times \frac{2\pi}{rev}\right) 6.5\ in = 7964 \frac{in}{sec} \Rightarrow \boxed{664 \frac{ft}{sec}\ \text{-or-}\ 453\ mph}$$

Prop Tip Dist

$C = \pi D = 13\pi$

Dist. Rev × C → $195 \frac{rev}{sec} \times 13\pi'' =$ 7964 in ⇒ 664 ft ⇒ 2.2 Football Fields

Blade Cycles

Each blade enters and leaves the center 1/rev

∴ each blade → 195 entrances and exits or a total 390 for 2 blades

Assumes 2 bladed prop

Boat Dist travel:

Assume Zero-Slip Pitch = 17.5"

195 rev x 17.5"/rev = 3413 in → 284 ft = 95 yards

= 0.05 mi ≈ 2.2% of race course

90 sec (Scaled from 1 sec)

Assumes - 3 mi lap
- Full throttle / Full power all lap
- 120"
- 3900 RPM
- 3300 HP

5850 rev

2970 each valve open

140,400 all valves open

70,200 total spark plug fires

2970 each plug fire

70,200 in ⇒ 5850 ft → 19.5 football fields

11,700 Direction changes w/ 1000s acceleration

35,100 power pulses

890 MPH = 1.17 M blower tip speed

37,350 rev. for blower

117,338 in = 9778 ft = 33 football fields blower tip travel

4x atmosphere

7740 cu ft air = 585 pounds

= 18,600 ... → 13 days

50 lb fuel = 8.3 gal

= 304 kw-hr ⇒ 11 days for Avg. US household

5 gal ADI = 38 lb

30 lb NO_2

585 + 50 + 38 + 30 = 703 lb Throughput in 90 sec

14.3 fl oz oil ≈ 1 1/4 cans of pop

$1.815 \times 10^6 \times 90 = 163 \times 10^6$ ft-lb

⇒ 73 UW buses to top of Empire State build
⇒ Bardahl to top of Mt McKinley

17,550 prop rev.

6641 ft/sec = 453 MPH tip speed

716,754" = 59,729' = 200 Football Fields

17,550 Cycles/blade -or- 35,100 total blade cycles

307,125" = 25,594' = 4.8 mi

-or-

Know went 3 mi

∴ 10.8" Actual pitch (36% slip)