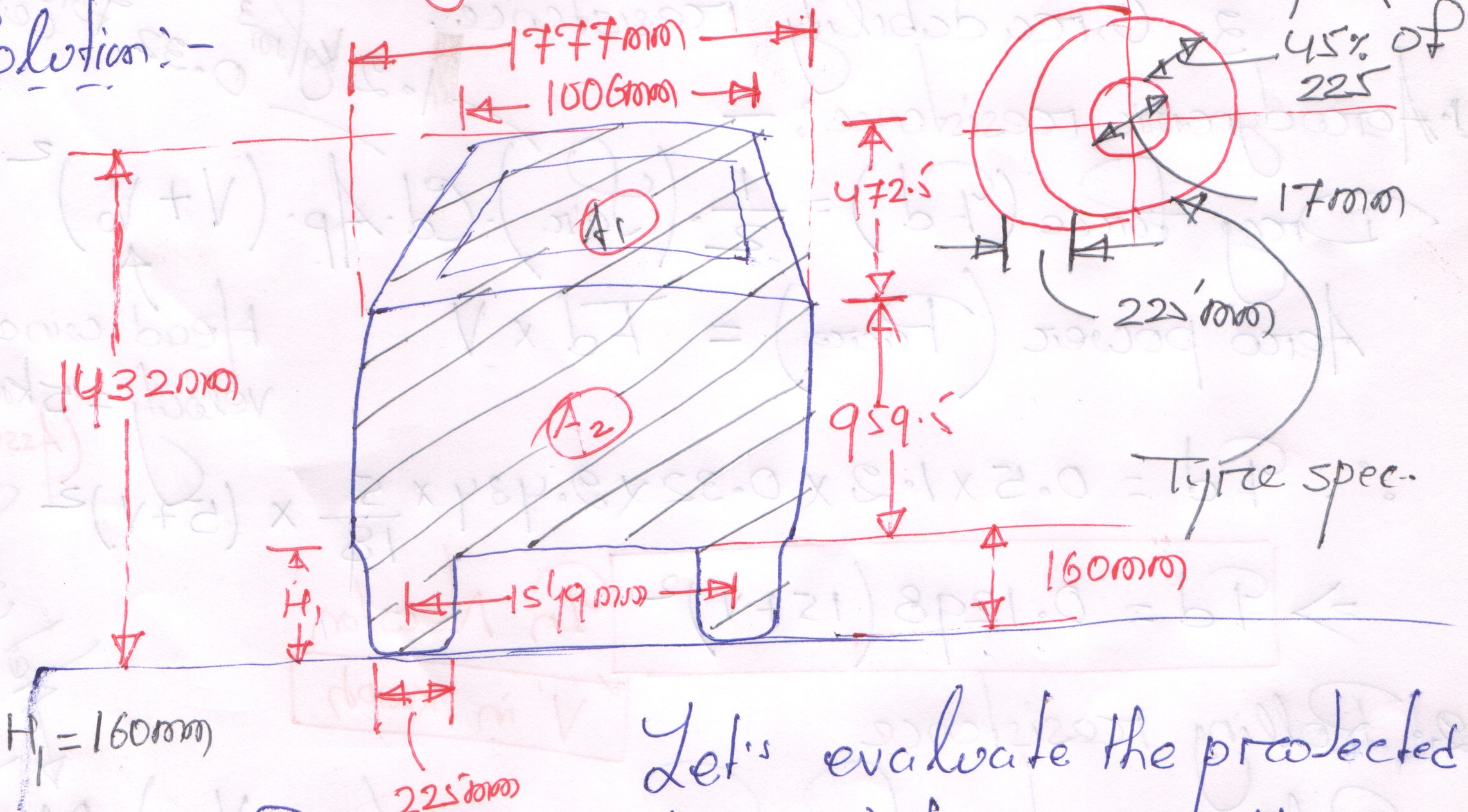
#1

Q.1 A Mercedes-Benz CLA 200 CDI style has the following dimensions & specifications.

- ✓ Length - 4630mm
- ✓ Width - 1777mm
- ✓ Height - 1432mm
- ✓ Gross weight - 2005kg
- ✓ Tyre size - 225/45 R17
- ✓ Front head room - 1006mm
- ✓ Rear head room - 905mm
- ✓ Maximum power - 136 BHP @ 3600-4400 RPM
- ✓ Maximum torque - 300 Nm @ 1600 - 3000 RPM
- ✓ Ground clearance - 160mm
- ✓ Wheel base - 2699mm
- ✓ Front tread - 1549mm
- ✓ Rear tread - 1547mm
- ✓ Kerb weight - 1570kg

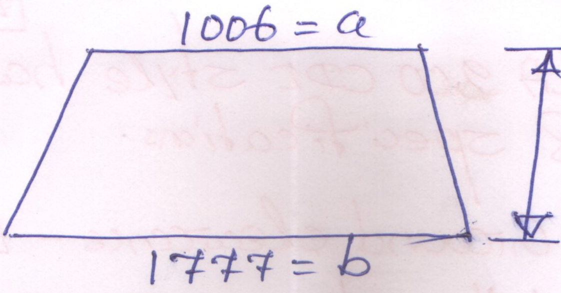
Evaluate the torque & power requirement under steady state between 40kmph to 100kmph and accelerating conditions i.e. 0-100 kmph at 9.8 s.

Solution:-



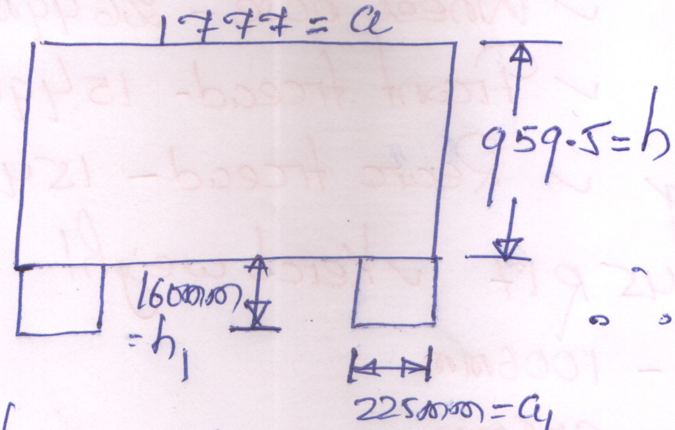
Let's evaluate the projected area of the car $(A_1 + A_2)$ based on the information available

$A_1 = \frac{(a+b)h}{2}$



$\Rightarrow \boxed{A_1 = 0.6574\,m^2}$

$A_2 = (a \times h) + 2(a_1 \times h_1)$



$\boxed{A_2 = 1.777\,m^2}$

$\therefore$ Total projected area perpendicular to vehicle motion

$\boxed{A_p = 2.434\,m^2}$

For steady state power requirement calculation, the governing forces are

1. Aerodynamic resistance
2. Rolling resistance
3. Gradability resistance.

1. Aerodynamic resistance :-

$$\text{Drag force } (F_d) = \frac{1}{2} \cdot \left(\overset{1.2\,kg/m^3}{\rho_{air}}\right) \cdot \overset{0.32 \text{ for luxury car}}{C_d} \cdot A_p \cdot (V + V_0)^2$$

V_0: Head wind velocity = 5 kmph (Assume)

$$\text{Aero power } (P_{aero}) = F_d \times V$$

$$\therefore F_d = 0.5 \times 1.2 \times 0.32 \times 2.434 \times \frac{5}{18} \times (5+V)^2$$

$$\Rightarrow \boxed{F_d = 0.1298(15+V)^2}$$

In Newton

'V' in kmph.

2. Rolling resistance

$$\text{Rolling resistance force } F_{rr} = 0.01\left(1 + \frac{V}{147}\right) \times M \times \left(\frac{9.81}{3600}\right)$$

M ← Net weight normal to surface of travel

#3

$$\Rightarrow \boxed{F_{rrc} = 2.72e{-3} \times \left(0.01\left(1+\frac{V}{147}\right)\right) \times M} \text{ in kN}$$

Rolling resistance power

$$\boxed{P_{rrc} = F_{rrc} \times V}$$

3. Gradability resistance:-

Vehicle net weight

Gradability force $\boxed{F_g = W \tan\theta_g}$

Gradability power $\boxed{P_g = F_g \times V}$

Let's take the $M = 2005 + (5 \times 70) = 2355\,kg$

$\tan\theta_g = 3\% = \frac{3}{100}$

Vehicle speed (kmph)	F_{aero} (N)	F_{rrc} (N)	F_g (N)	F_{tot} (N)	P_{tot} kW
40	387.2	81.48	693.08	1161.8 ~~922.65~~	12.9
60	720	90.20	693.08	1503.5	25.05
80	1155	98.91	693.08	1947.2	43.27
100	1693	107.63	693.08	2493.5	69.264

For 80kmph, the powering engine torque is

$$T_{pe} = \frac{F_{tot} \times r_{tire}}{G_0} = \frac{1947.2 \times 0.05912}{(0.94 \times 0.72)}$$

G_0 $r_{gb,7}$

$$\boxed{T_{pe} = 170\,Nm}$$

Engine speed

$$N_e = \frac{1000 \times G_o \times V}{120 \pi r_{tire}} = \frac{1000 \times (0.94 \times 0.72) \times 80}{120 \times \pi \times 0.05912}$$

$$\Rightarrow \boxed{N_e \simeq 2430 \text{ RPM}}$$

If the vehicle accelerates, the inertia resistance come into play. In the present case, the acceleration of the vehicle is 0 - 100 kmph in 9.8s

$$\therefore \text{Acceleration } (a) = \frac{\left(100 \times \frac{5}{18}\right)}{9.8} \Rightarrow \boxed{a = 2.84 \, m/s^2}$$

$$\therefore F_{IR} = M_{eff} \times a$$

Thumb rule

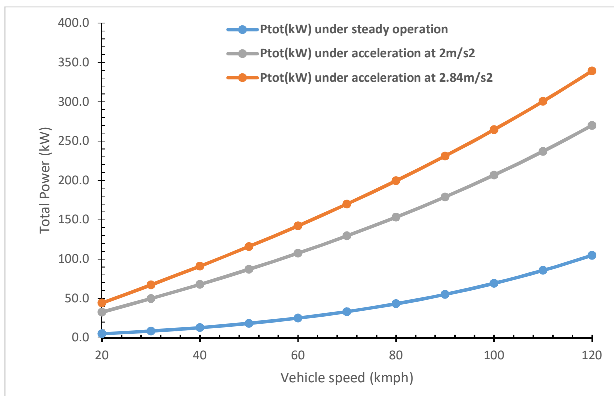
$$\Rightarrow M_{eff} = M \left\{ 1 + 0.04 + 0.0025 \, G_o^2 \right\}$$

$$\Rightarrow M_{eff} = 2355 \left\{ 1.04 + 0.025 \, (0.94 \times 0.72)^2 \right\}$$

$$\Rightarrow \boxed{M_{eff} = 2476.18 \, kg}$$

$$\therefore \boxed{F_{IR} = 7032.3 \, N}$$

			Steady					Acceleratig at a=2.84m/s2			Acceleratig at a=2 m/s2		
Speed (Kmph)	Faero (N)	Frr (N)	Fg (N)	Ftot (N)	Ptot (kW)	Tengine (Nm)	Nengine (RPM)	Fir (N)	Ftot (N)	Ptot (kW)	Fir (N)	Ftot (N)	Ptot (kW)
20	156.8	72.8	693.1	922.6	5.1	80.6	608	7032.35	7955.00	44.19	4952.36	5875.01	32.64
30	259.2	77.1	693.1	1029.4	8.6	89.9	911	7032.35	8061.76	67.18	4952.36	5981.77	49.85
40	387.2	81.5	693.1	1161.8	12.9	101.5	1215	7032.35	8194.11	91.05	4952.36	6114.12	67.93
50	540.8	85.8	693.1	1319.7	18.3	115.3	1519	7032.35	8352.07	116.00	4952.36	6272.08	87.11
60	720.0	90.2	693.1	1503.3	25.1	131.3	1823	7032.35	8535.63	142.26	4952.36	6455.64	107.59
70	924.8	94.6	693.1	1712.4	33.3	149.6	2127	7032.35	8744.79	170.04	4952.36	6664.80	129.59
80	1155.2	98.9	693.1	1947.2	43.3	170.1	2431	7032.35	8979.54	199.55	4952.36	6899.55	153.32
90	1411.2	103.3	693.1	2207.6	55.2	192.8	2734	7032.35	9239.90	231.00	4952.36	7159.91	179.00
100	1692.8	107.6	693.1	2493.5	69.3	217.8	3038	7032.35	9525.86	264.61	4952.36	7445.87	206.83
110	2000.0	112.0	693.1	2805.1	85.7	245.0	3342	7032.35	9837.42	300.59	4952.36	7757.43	237.03
120	2332.8	116.3	693.1	3142.2	104.7	274.5	3646	7032.35	10174.57	339.15	4952.36	8094.58	269.82



#6

Q.2 A 2016 SUZUKI Baleno 1.2 has the following specification.

- ✓ Engine capacity - 1242cc ✓ No. of cylinders - 04
- ✓ Bore x stroke - 73x74.2mm ✓ Spark timing - 10° BTDC
- ✓ Max power - 89 BHP @ 6000rpm
- ✓ Max torque - 120Nm @ 4400rpm.
- ✓ Compression ratio - 12.5 : 1 ✓ Connecting rod - 146mm
- ✓ Acceleration - 0-100kmph in 12.3 s
- ✓ Max engine speed - 180kmph ✓ Crank pin radius - 38mm
- ✓ Overall gear ratio - 0.63
- ✓ Fuel consumption - (5.3/3.6/4.2) L per 100 km in urban/extra urban/combined
- ✓ Tyre - 175/65 R15
- ✓ Injection strategy - ~~PFI~~ GDI

If the volumetric efficiency is 92%, determine

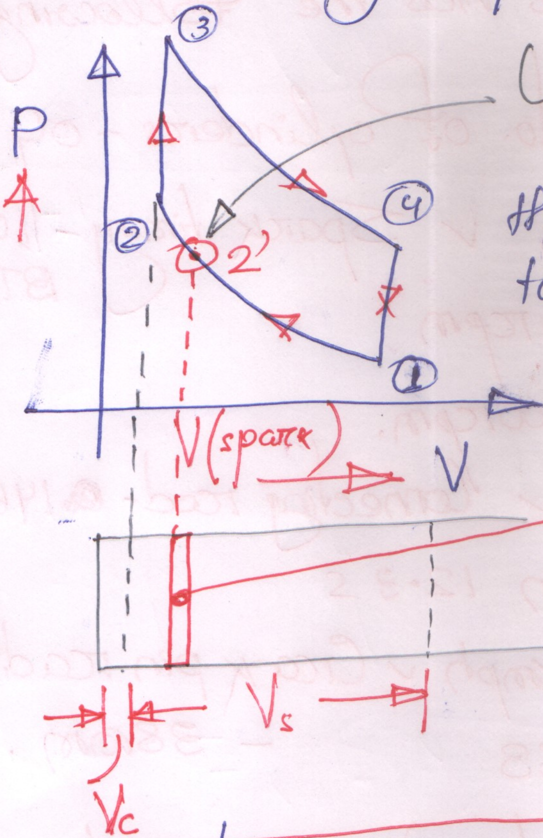
1. Laminar flame speed at max power condition
2. Engine speed corresponding to laminar flame speed
3. Actual flame speed to laminar flame speed ratio. Assume the fuel as iso-octane.

Ans Atmospheric temperature - 310 K

pressure - 96.8 kPa

The first step is to evaluate the polytropic index of the in-cylinder mixture at the point of spark.

In an Otto cycle perspective



Location is 10° BTDC

We are intersted to find out the cylinder volume corresponding to introduction of spark.

$$S(\theta) = R(1-\cos\theta) + L\left\{1 - \sqrt{1-\left(\frac{\sin\theta}{L/R}\right)^2}\right\}$$

Radian

$$\boxed{V(\theta) = V_{cl} + S A_p}$$

Volume

$$\boxed{\therefore V\Big|_{\theta=10^\circ BTDC} = 3.00456e{-5}\ m^3}$$

* You can generate a sub-routine to determine the in-cylinder volume profile easily.

Now determine the air consumption rate — Note

At intake rate of air breathing (Fuel is GDI) in kg/s

$$\Rightarrow \dot{m}_a = \frac{P_1 \times (V_1 \times N_{ps}) \times \eta_v}{R_{air} T_1} \ kg/s$$

$$\Rightarrow \dot{m}_a = \frac{96800 \times \frac{\pi}{4}(0.073)^2(0.0742) \times \frac{6000}{120} \times 0.92}{\frac{8314}{28.97} \times 310}$$

$$\Rightarrow \boxed{\dot{m}_a = 0.0155\ kg/s} \text{ per cylinder basis}$$

For fuel consumption, let's assume the combined mileage 4.2L per 100km

#8

$\rho_{iso\text{-}octane} = 703 \, kg/m^3$

$\therefore \dot{m}_f$ = in $\frac{kg}{s}$ is desired

Tyre 175/65R15

$r_{tire} = \frac{15}{2} + 0.65 \times 175$

$\boxed{r_{tire} = 121.25mm}$

Now Vehicle speed is given by

$$\tilde{V} = \frac{120 \times \pi \times r_{tire} \times N_e}{1000 \times G_0}$$

Max power

$$\Rightarrow \tilde{V} = \frac{120 \times \pi \times 6000 \times 0.12125}{1000 \times 0.68}$$

$$\Rightarrow \boxed{\tilde{V} = 403.12 \text{ kmph}}$$ ← This is unusually high speed & not realized

$$\Rightarrow \boxed{\tilde{V} = 111.98 \, m/s}$$ ← Velocity

Now $(4.2 \times 10^{-3} \times 703)$ kg of fuel burned in 100km

$$\therefore \dot{m}_f = 2.953 \frac{kg}{100km}$$

$$\Rightarrow \dot{m}_f = \frac{2.953}{100} \frac{kg}{\cancel{km}} \times 403.12 \frac{\cancel{km}}{hr}$$

For four cylinders

$$\Rightarrow \dot{m}_f = 11.904 \frac{kg}{hr} \Rightarrow \boxed{\dot{m}_f = 3.3e-3 \, kg/s}$$

$\therefore$ Operating A/F ratio for max power condition is

$$\boxed{A/F = \frac{0.0155 \times 4}{3.3e-3} = 18.78}$$

Now, for iso-octane $(A/F)_{st} = 14.7$.

$$\therefore \text{Equivalence ratio } (\phi) = \frac{14.7}{18.78} = 0.783$$

$\therefore$ It may be noted that the fuel consumption at 6000rpm shall be much higher than the rated 5.3/3.6/4.2 L per 100 km

#9

Now, the mixture mass & composition as well as the cylinder volume is known. The exact value of polytropic index can be determined iteratively.

No. of moles of fuel $(N_f) = \dfrac{(3.3e{-3}/4)}{114.22} = 7.23e{-6}$ — 114.22 – Fuel molar weight

No. of moles of air $(N_{air}) = \dfrac{0.0155}{28.97} = 5.35e{-4}$ — 28.97 – Air molar weight

$\therefore\; x_f = 0.0133, \quad x_{air} = 0.9867$

Assume $n = 1.3$

↓ Initialize "epsilon = 1"

while epsilon > 1e-4

↓

$$T_2 = T\Big|_{\theta = 10^\circ BTDC} = T_1 \times \left(\frac{V|_{\theta=10^\circ BTDC}}{V_1}\right)^{n-1}$$

↓

$$C_{p,mix} = x_f\left(C_{p,f}(T_2)\right) + x_a\left(C_{p,air}f(T_2)\right)$$

↓

$$n_1 = C_{p,mix} / (C_{p,mix} - R_{mix})$$

↓

epsilon = $n_1 - n$

if $n_1 > n$
  $n = n + 0.01 \times n$
else
  $n = n - 0.01\, n$

Update n

↓

$\boxed{n = \text{output} = 1.386}$

$$R_{mix} = \frac{8314}{Mklmix}$$

$$Mklmix = x_a Mkla + x_f Mklf = 30.10\ \frac{kg}{kmol}$$

See the MATLAB program —

$$R_{mix} = 276.18\ \frac{kJ}{kg\,K}$$

#10

Now, $T_2' = T\big|_{\theta = 10 BTDC} = 310 \times \left(\dfrac{1}{\dfrac{3.00456e-5}{3.37560e-4}}\right)^{0.386}$

$\boxed{T_2' = 788.64 K}$ $P_2' = 2.76673 \times 10^6$ Pa

Now, we have $\phi = 0.783$, $T_2' = 788.64 K$,

$P_2' = 2.76673 \times 10^6$ Pa

Let's evaluate the Laminar flame speed under these conditions for Iso-octane.

$$\boxed{S_L = S_{L,ref} \times \left(\frac{T_2'}{298}\right)^{\gamma} \left(\frac{P_2'}{1}\right)^{\beta}}$$

in ATM

Values from S. Turns pg-285

$$S_{L,ref} = B_M + B_2(\phi - \phi_M)^2$$

$$= 26.32 + (-84.72)(0.783 - 1.13)^2$$

$$= 16.12 \text{ cm/s}$$

$$\gamma = 2.18 - 0.8(0.783 - 1) = 2.353$$

$$\beta = -0.16 + 0.22(0.783 - 1) = -0.20774$$

Pa to ATM

$$S_L = 16.12 \times \left(\frac{788.64}{298}\right)^{2.353} \times \left(\frac{27.30}{1}\right)^{-0.20774}$$

$$\boxed{S_L = 80.08 \text{ cm/s}}$$

Let's evaluate the feasible engine RPM with this laminar flame speed

The cylinder bore is 73mm & $S_L = 80.08$ cm/s

$$\therefore t_{comb} = \frac{7.3\text{ cm}}{80.08\text{ cm/s}} = 0.09116\text{ s} = 91.16\text{ ms}$$

$$t_{cycle} = t_{comb} \times \frac{720}{N_{cps}}$$ — No. of cycles per second = 50 for 6000 rpm

$$\Rightarrow t_{cycle} = 0.09116 \times \frac{720}{50}$$

$$\Rightarrow t_{cycle} = 1.3127\text{ sec}$$

$$\therefore \boxed{N_{feasible} = \frac{60 \times 2}{1.3127} \simeq 92\text{ RPM}}$$

$\therefore$ With $S_L = 80.08$ cm/s, the maximum feasible engine RPM is 92 RPM.

Let's reverse engineer & see the corresponding actual flame speed for 6000 rpm.

$$6000 = \frac{60 \times 2}{t_{cycle}} \Rightarrow t_{cycle} = 0.02\text{ s}$$

$$t_{comb} = \frac{50 \times 0.02}{720} = 0.00139\text{ s}$$

$$S_{L,a} = \frac{7.3}{0.00139} = 5251.798\text{ cm/s}$$

$$\therefore \boxed{\frac{S_{L,a}}{S_L} = \frac{5251.798}{80.08} = 65.581}$$

$$t_{comb} = \frac{B/2}{S_L}$$ is based on the spark plug positioning.

```
clc;
clear all;

%----Constnats based on gas phase chemistry,Specific Heats  (Values from
http://webbook.nist.gov/)
%-------Gasoline vapour
Cpg0=-24.078;Cpg1=256.63;Cpg2=-201.68;Cpg3=64.750; Cpg4=0.5808;  %---
Cosntants for Gasoline in mass
MWg=114.22;   %----Gasoline molecular weight (Represntative)
%-------Air
Ca0=1.05;Ca1=-0.365;Ca2=0.85;Ca3=-0.39;    %---Cosntants for air in mass
Ca00=3.04473; Ca11=1.33805E-3; Ca22=-4.88256E-7; Ca33=8.55475E-11;Ca44=-
5.70132E-15;%-----Constants for air Crowell
MWair=28.97;                               %---Molecular Wieght of air

B = 0.073;                         %---Engine bore
L = 0.0742;                         %---Engine stroke
r = 12.5;                            %---Engine compression ratio
l = 0.146;                         %---Engine connecting rod length
R = 0.038;                         %---Crank pin radius
N = 6000;                          %---Engine rpm
Vs=(pi/4)*(B^2)*L;                 %---Stroke volume
Vc=Vs/(r-1);                       %---Clearance volume
Vt=Vs+Vc;                          %---Total volume
U=2*L*N/60;                        %---Mean Piston speed
Apd=(pi/4)*(B^2);                  %---Piston Area based upon doameter
Smin=Vc/Apd;                        %---Clearance length
for i=0.25:0.25:720
    k=(i*4);
    j=deg2rad(i);
    S(k)=(R*(1-cos(j))+l*(1-sqrt(1-((sin(j)/(l/R))^2))))+Smin; % Linear
Displacement
    V(k)=(S(k)-Smin)*Apd+Vc;                     % Volume
    Aw(k)=Apd*2+pi*B*S(k);               % Wall Area
end
n=1.4;
T1=310;
P1=96800;
V2=3.00456e-5;
epsilon=1;
xg=0.0133;
xa=0.9867;
MWmix=xg*MWg+xa*MWair;

Rmix=8314/MWmix; count=1;
while epsilon>0.00001
  T2=T1*(Vt/V2)^(n-1);

Cpmix=(xg*Cp(Cpg0,Cpg1,Cpg2,Cpg3,Cpg4,T2/1000)+xa*Cp2(Ca0,Ca1,Ca2,Ca3,T2/1000
))*1000;
  n1=Cpmix/(Cpmix-Rmix);
  epsilon(count)=n1-n;
  if n1>n
      n=n+0.01*n;
  else
      n=n-0.01*n;
  end
  count=count+1;
  end
```

Q. A Maruti-Suzuki Kizashi has the following specification.

- ✓ Displacement - 2393 cc
- ✓ Cylinders - 04 Inline
- ✓ Fuel injection - MPFI
- ✓ Max power - 175 BHP @ 6500 rpm
- ✓ Max torque - 230 Nm @ 4000 rpm
- ✓ Mileage - 12-45 combined
- ✓ Compression ratio - 10.2 : 1
- ✓ Bore to stroke ratio - 0.91

Design a suitable MPFI system.

Ans Let's consider the fuel as "iso-octane". (C_8H_{18})

∴ Stoichiometric air requirement is

$$C_xH_y + \left(x+\frac{y}{4}\right)\left(O_2+3.76N_2\right) = xCO_2 + \frac{y}{2}H_2O + \left(x+\frac{y}{4}\right)\left(3.76N_2\right)$$

For iso-octane

$$\Rightarrow C_8H_{18} + 12.5O_2 + 47N_2 = 8CO_2 + 9H_2O + 47N_2$$

$\frac{114}{1830}$ - 0.0623 $\quad \frac{400}{1830}$ - 0.2186 $\quad \frac{1316}{1830}$ - 0.7191 ← Mass fractions

∴ Air requirement $= \frac{1}{0.0623} - 1 = 15.05$ kg air per kg of iso-octane

Let's assess the air consumption limit per cylinder between 650 RPM to 6500 RPM with 92% volumetric efficiency.

#13

At 650 RPM (Idling)

Cycles per second

Total cylinder volume

$$\dot{m}_a = \frac{P_1 \times V_1 \times N_{cps} \times \eta_v}{R T_1} = \frac{96800 \times 6.63e-4 \times 5.42 \times 0.92}{290 \times 310}$$

Assumption

$\Rightarrow \dot{m}_a = 0.00356 \text{ kg/s} \Rightarrow \boxed{m_a = 6.56642e-4 \frac{kg}{cycle}}$

At 6500 RPM (Max power)

$$\dot{m}_a = \frac{96800 \times 6.63e-4 \times 54.17 \times 0.92}{290 \times 310} = 0.03558 \text{ kg/s}$$

$\boxed{m_a = 6.56765e-4 \text{ kg/cycle}}$

Both are equal

Let's assume a range of 'ϕ' for engine operation - say $\boxed{\phi = 0.7 \text{ to } 1.3}$

This is a critical assumption. The cold-start & max power requirements may vary significantly from this range.

$$\phi = \frac{(A/F)_{st}}{(A/F)_{act}} = \frac{15.05}{(A/F)_{act}} = 0.7 \Rightarrow \boxed{\left(\frac{A}{F}\right)_{\phi=0.7} = 21.5}$$

$\boxed{\left(\frac{A}{F}\right)_{\phi=1.3} = 11.58}$

$$\therefore \left[\begin{array}{l} m_f\Big|_{\phi=0.7} = \dfrac{6.56642e-4}{21.5} = 3.054e-5 \text{ kg/cycle} \\ m_f\Big|_{\phi=1.3} = \dfrac{6.56642e-4}{11.58} = 5.670e-5 \text{ kg/cycle} \end{array}\right.$$

These are the flow of iso-octane per cylinder. Note - If throttle body injector is used, then the flow rates to be multiplied by 4.

#14

Let's cross-check the injected fuel per cycle at $\phi = 1.3$ is capable of generating maximum power

$$m_f = 5.670e{-5}\ \frac{kg}{cycle} \qquad CV_{iso\text{-}octane} = 44.27\ \frac{MJ}{kg}$$

$$\therefore q_{pc,pc} = 5.670e{-5} \times 44.27 \times 10^3 = 2.510\ kJ \text{ per cylinder per cycle}$$

$$\therefore \text{Total } Q = 2.510 \times 54.17 \times 4$$

$$\Rightarrow \boxed{Q = 543.86\ kW}$$ ← Net heat input to the system

Now the rated power = 175 BHP or 130.5 kW

$\therefore \eta_{thermal} = 23.9\%$ (Quite capable to handle max power requirement)

So, now let's design MPFI capable of delivery the flow rates 8.054e-5 to 5.67e-5 kg/cycle

Typical MPFI injectors operate at 3 bar (gauge) up-stream pressure. However, flow rate to fuel pressure calibrations should be referred.

Let's calculate the nozzle exit velocity.

$\rho_{iso\text{-}octane} = 690\ kg/m^3$, $\Delta P = 3 \times 101325\ Pa$, $C_d = 0.6$

$$\therefore V_{nozzle\text{-}exit} = \sqrt{\frac{2 \times 3 \times 101325}{690}} = 29.683\ m/s$$

→ 2 nozzle → 3 nozzle

$$2 \times \frac{\pi}{4} (d_{nozzle})^2 \times 690 \times 29.683 \times 0.6 = 5.67e{-5}$$

#15

$\therefore d_{nozzle} = \sqrt{\left(\dfrac{5.67e-5 \times 4}{\pi \times 690 \times 29.683 \times 0.6}\right)} \times \dfrac{1}{2}$

$\Rightarrow d_{nozzle} = \underbrace{54.2\ \mu m}_{2\ nozzle}$ or $\underbrace{44.04\ \mu m}_{3\ nozzle}$

Now, let's evaluate the Sauter Mean Diameter (SMD) or the volume to surface area diameter

$$\boxed{SMD = 4.12 (d_{nozzle}) Re^{0.12} We^{-0.75} \left(\frac{\mu_f}{\mu_a}\right)^{0.54} \left(\frac{\rho_f}{\rho_a}\right)^{0.18}}$$

$$Re = \frac{\rho_f V_f d_{nozzle}}{\mu_f} = \frac{690 \times 29.68 \times 5.42 \times 10^{-5}}{0.0006}$$

$\Rightarrow \boxed{Re = 1849.95}$ ← For two nozzle

$\boxed{Re = 1515.46}$ ← For three nozzle

$$We = \frac{\rho V^2 l}{\sigma} \simeq \frac{\rho_f V_f^2 d_{nozzle}}{\sigma_f} = \frac{690 \times 29.68^2 \times 5.42e-5}{0.022}$$

$\Rightarrow We = \underset{02\ nozzle}{1497.45}, \underset{03\ nozzle}{1226.69}$

$$\therefore SMD = 4.12 (5.42 \times 10^{-5}) (1850)^{0.12} \left(\cancel{1515}\ 1497\right)^{-0.75} \left(\frac{0.0006}{1.8e-5}\right)^{0.54} \left(\frac{690}{1.2}\right)^{0.18}$$

$\boxed{SMD = \underset{02\ nozzle}{47.712\ \mu m}, \underset{03\ nozzle}{54.07\ \mu m}}$

Let's evaluate the droplet lifetime, where the generalized droplet diameter is SMD.

As per D^2 law, $\boxed{t_d = \frac{D_o^2}{K}}$ ← Droplet life-time

where D_o = SMD

$$K = \frac{8 k_g}{\rho_l C_{pg}} \ln (B_q + 1)$$

$$B_q = \frac{C_{pg}(T_\infty - T_{boil})}{h_{fg}}$$

Let's evaluate the gas phase temperature first

$$\bar{T} = \frac{T_\infty + T_{boil}}{2}$$

Note- one third rule is also available in some literature

$$\bar{T} = T_{boil} + \frac{T_\infty - T_{boil}}{3}$$

$$\Rightarrow \boxed{\bar{T} = \frac{310 + 398}{2} = 354 K}$$

Note- During manifold injection, ambient temp. is low. However, for in-cylinder injection the gas phase temperature can be quite high.

$$C_{pg}\Big|_{354} = \frac{4.184}{114.23}\Big(\overset{a_1}{-0.55313} + \overset{a_2 t}{181.62\left(\frac{354}{1000}\right)} + \overset{a_3 t^2}{(-97.787)}\left(\frac{354}{1000}\right)^2 + \overset{a_4 t^3}{20.40\left(\frac{354}{1000}\right)^3} - \overset{a_5 t^{-2}}{0.031\left(\frac{354}{1000}\right)^{-2}}\Big) = 1909.9 \ J/kg K$$

Refer - S. Turns
Appendix-B for constants

Similarly, $k_f\big|_{354} = 0.0182 \ W/mK$

$k_\infty\big|_{354} = 0.025 \ W/mK$

Mean thermal conductivity is

$$k_g = 0.4 \times 0.0182 + 0.6 \times 0.025 = 0.02228 \ W/mK$$

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Now $h_{fg} = 300\,kJ/kg$

$\therefore$ Transfer number $B_q = \frac{1909.9(310-398)}{300{,}000}$

$\Rightarrow \boxed{B_q = -0.56}$

$$K = \frac{8 \times 0.02228}{690 \times 1909.9} \ln(1+0.56) = 6.014e{-8}\,\frac{m^2}{s}$$

$$t_d = \frac{(4.77e{-5})^2}{6.014e{-8}} = 0.0378\,s$$ – 2 nozzle

$$= \frac{(5.407e{-5})^2}{6.014e{-8}} = 0.048612\,s$$ – 3 nozzle

It may be seen that the droplet lifetime is 37.8ms for 2-nozzle arrangement.

Now for 6500 RPM – the $N_{eps} = 54.17$

$\therefore$ 720×54.17 in 1 s

$\Rightarrow$ $1°$ in $2.564e{-5}$ s

$\Rightarrow \boxed{180° \text{ in } 2.56\,ms}$ ← Ideal suction stroke

$\therefore$ As the droplet lifetime is higher than suction stroke, let's see if it survives till ignition.

$\Rightarrow \boxed{348° \text{ in } 8.92\,ms}$

↳ Droplet does not survive till start of ignition. – Note – the droplets vapourize at a much faster rate when ambient temp. (310 K) increases due to droplets entering the cylinder