International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 9 Issue 11, November-2020

Design and Analysis of Intake Manifold of Single Cylinder Engine

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***Abstract*:- The performance of an Internal combustion engine is highly determined by the inlet air conditions and air fuel ratio .This paper shall discuss about the role of intake manifold in governing the inlet conditions during the air suction ,the design of intake manifold ,optimization of parameters of design, changing the inlet conditions and predicting the final results. The design and optimization include qualitative use of ANSYS FLUENT for the simulation purpose and predicting the flow properties.**

1. INTRODUCTION

Intake manifold is a component of engine which governs the inlet air flow conditions of the engine. Air enters through the intake manifold comprising of different components and then through a throttle body(in gasoline engines) it enters the engine during the suction stroke .The amount of air entering the engine greatly determines its performance including its volumetric efficiency ,Brake mean effective pressure ,horsepower and specific air fuel consumption.

1.1 Various components of the intake manifold

The various component of intake manifold includes:

1.1.1 ***Diffuser:*** The diffuser or restrictor is the nozzle which is used to accelerate And decelerate the flow of incoming air. The design parameters of diffuser includes the Inlet angle, the outlet angle, throat area, inlet area and outlet area.

1.1.2 ***Plenum:*** Plenum is body that stores the air coming from the diffuser and supply it to the Runner .According the considerations the main designing parameters of the plenum are its Volume and shape .The volume of the plenum is usually taken between the range of 2-2.5

Times the volume of the cylinder .The shape of the plenum is generally of four types:

- Rectangular shape
- Circular shape
- Curved shape
- Elliptical shape.

1.13 ***Runner:*** The final component of the manifold is the runner the basic function of the runner Is to resonate the air flow before entering the engine. Resonating here means that the Maximum Air flow occurs inside the engine when the intake valve opens. The resonance is Based on Helmontz resonating theory discussed later. The design optimization of the runner include the design of the length of runner and its diameter .The length optimization is based on Helmontz equation the diameter optimization on several other factors discussed later.

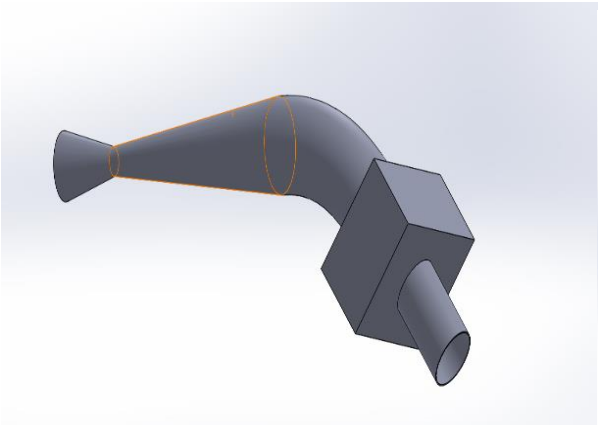

Fig1: Rectangular Plenum

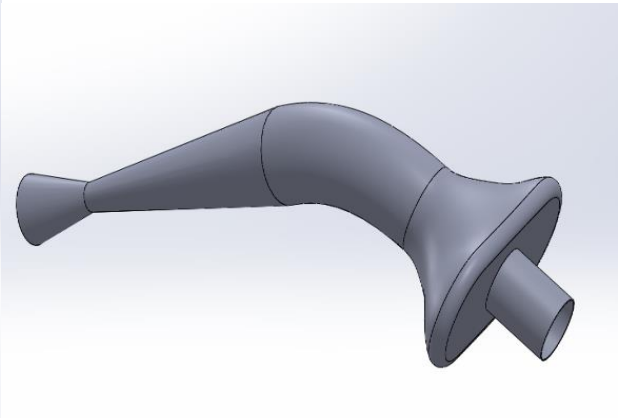

Fig2: Curved plenum

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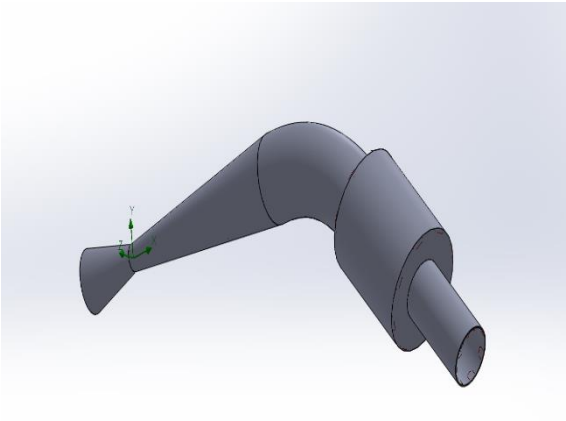

Fig3: Circular Plenum

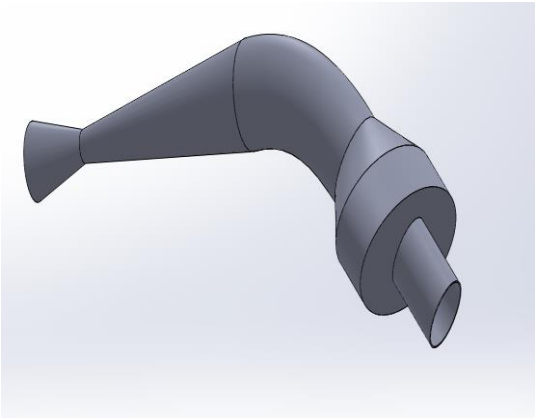

Fig4: Elliptical Plenum

2. ANALYSIS:

2.1 DESIGN OF DIFFUSER OF THE MANIFOLD: The Inlet, Outlet and throat diameter are fixed and optimization include change in nozzle and diffuser angle .Various Nozzle and diffuser angle are used for optimization .

Inlet Diameter: 28mm
Throat Diameter: 19.5mm

Experiment Specification:
Turbulence Model used: Large Eddy Simulation
Turbulence Intensity: 5%
Inlet Temperature: 300K
Inlet Pressure: 100000 N\m^2

2.1.1 12 º - 5 º Diffuser-Nozzle angle

INLET VELOCITY	MAXIMUM MACH NUMBER	MASS FLOW RATE(KG/S)	OUTLET VELOCITY
10	0.068	0.956	19
15	0.105	1.435	27.5
20	0.135	1.91	36
22	0.15	2.11	40
25	0.17	2.405	45

Table1: 12º-5º pair of angles of diffuser nozzle

2.1.2 14º-6º Diffuser -Nozzle angle

INLET VELOCITY	MAXIMUM MACH NUMBER	MASS FLOW RATE(KG/S)	OUTLET VELOCITY
10	0.057	0.955	14
15	0.087	1.434	21
20	0.125	1.937	38
22	0.12	2.106	32
25	0.15	2.395	41

Table2: 14º-6º pair of angles of diffuser nozzle

2.1.3 10º-4º Diffuser – Nozzle angle

INLET VELOCITY	MAXIMUM MACH NUMBER	MASS FLOW RATE(KG/S)	OUTLET VELOCITY
10	0.058	0.955	16
15	0.088	1.432	23.5
20	0.115	1.916	32
22	0.130	2.158	35
25	0.145	2.401	39.5

Table3: 10º-4º pair of angles of diffuser nozzle

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2.1.4 11º - 7º Diffuser- Nozzle angle

INLET VELOCITY	MAXIMUM MACH NUMBER	MASS FLOW RATE(KG/S)	OUTLET VELOCITY
10	0.058	0.955	13
15	0.087	1.4335	19
20	0.115	1.912	26.5
22	0.128	2.104	27.5
25	0.145	2.391	31

Table4: 11º-7º pair of angles of diffuser nozzle

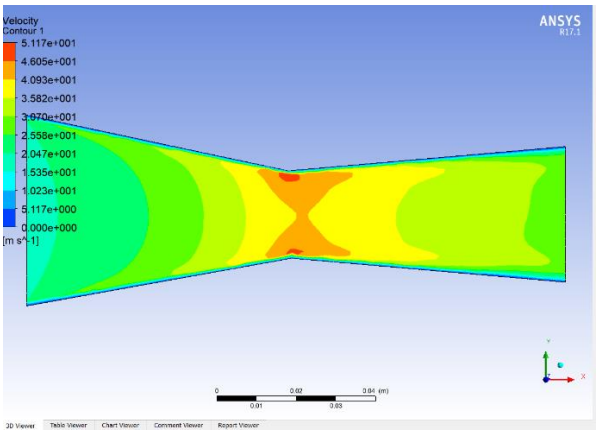

Fig5: Velocity contours at inlet velocity 22m/s

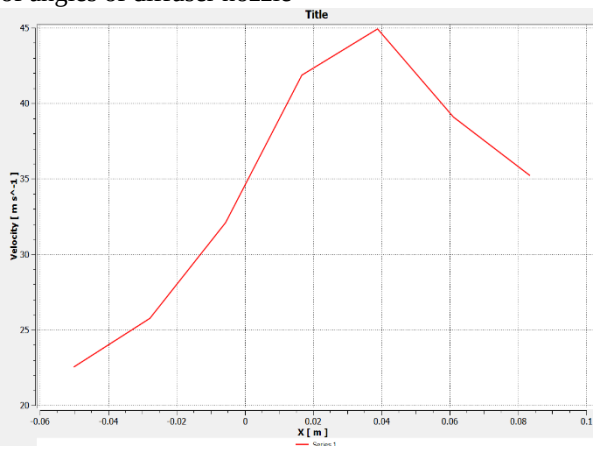

Fig6: Velocity Distribution Along the nozzle at 22m/s

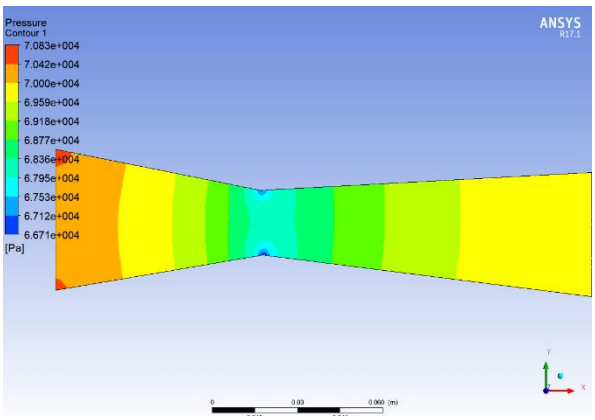

Fig7: Pressure contours at inlet velocity 22m/s

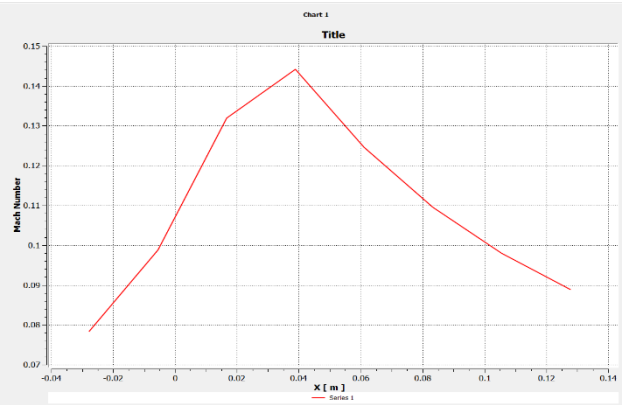

Fig8: Mach number plot along the nozzle

From the experimental validation the pair of 12º-5^0 is used to obtain maximum mass flow rate and outlet velocity as seen from table1. Hence final nozzle parameters are:
Converging angle: 5º
Diverging angle: 12º
Throat Diameter: 19.5mm
Inlet Diameter: 28mm
Outlet Diameter: 48mm

2.2 Design optimization of Plenum of manifold: The design optimization include the optimization of the shape and volume of plenum. 3 cases are considered first at 800cc of plenum volume followed by 600cc and 1000cc of plenum volume.

2.2.1 <u>800cc of Plenum volume</u>

(a) Rectangular Plenum: The mass flow rate and final velocity are calculated for different
Inlet velocities. A bend is introduced in the manifold design for the design and assembly considerations the bend angle is 30º which causes a certain loss in momentum in the bend and hence less bend angle is provided in the design.

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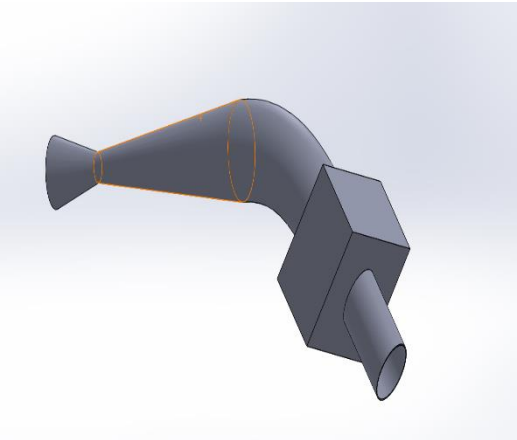

Fig9: Rectangular Plenum

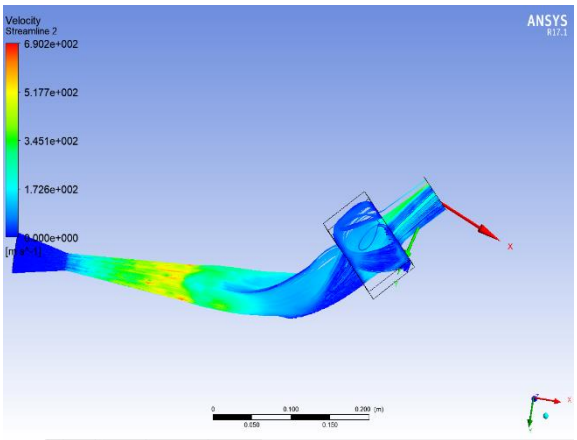

Fig10 : Flow in Rectangular Plenum at high velocities

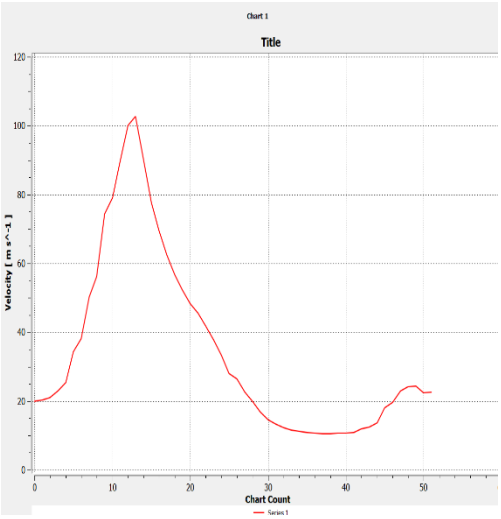

Fig11 : Velocity distribution along the manifold

INLET VELOCITY	MASS FLOW RATE(KG/S)
15	0.053
20	0.071
22	0.079
25	0.098
30	0.081

Table5: Mass flow rate for different inlet velocities

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(b) Elliptical Plenum:

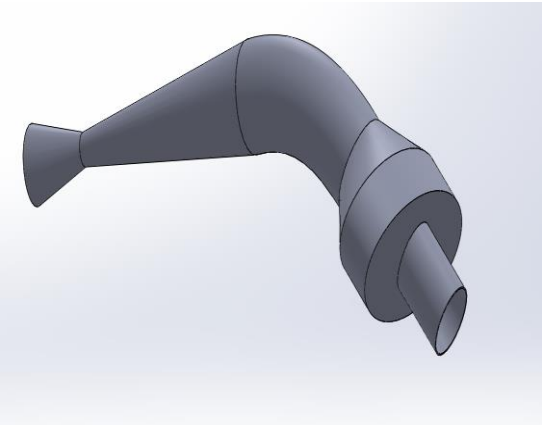

Fig12: Elliptical Plenum

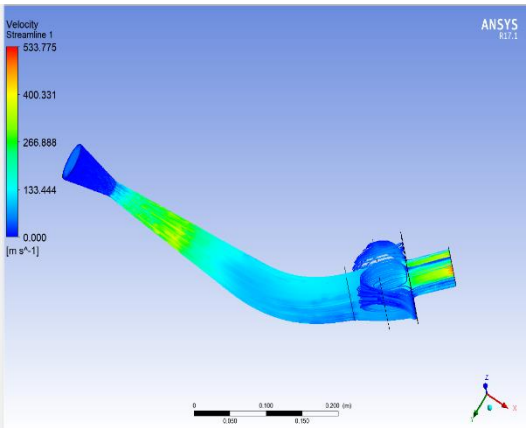

Fig13: Flow in elliptical plenum at high velocities

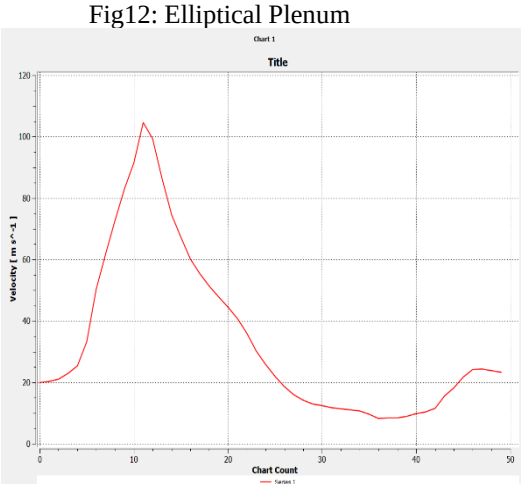

Fig14: Velocity distribution along the manifold

INLET VELOCITY	MASS FLOW RATE(KG/S)
15	0.053
20	0.073
22	0.080
25	0.073
30	0.098

Table6: Mass flow rate for different inlet velocities

(c) Curved Plenum:

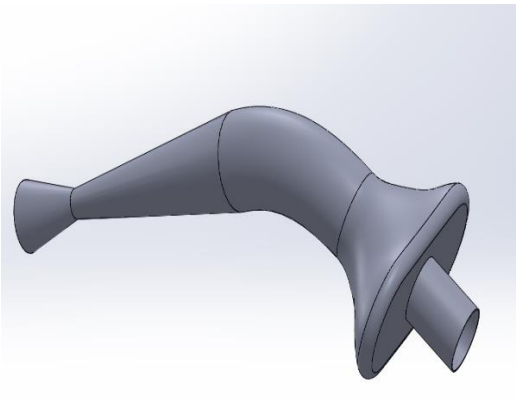

Fig15: Curved Plenum

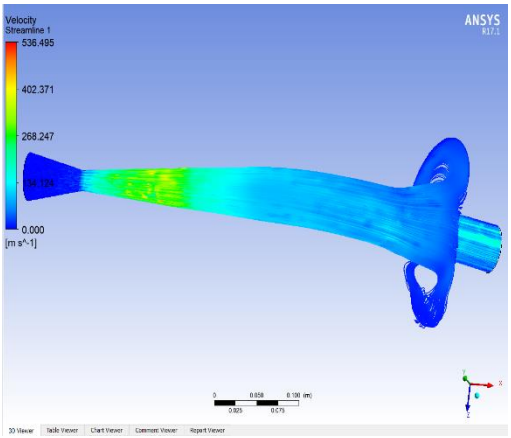

Fig16: Flow in curved Plenum at high velocities

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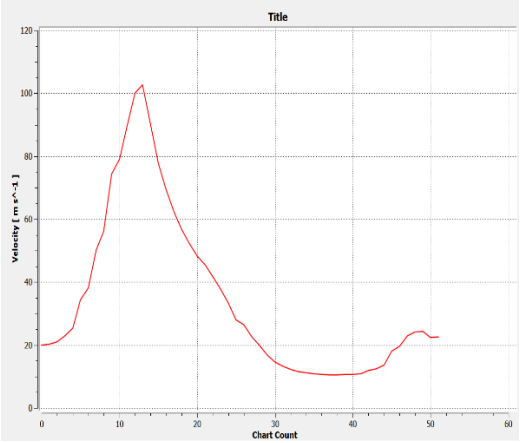

Fig17: Velocity Distribution along the manifold

INLET VELOCITY	MASS FLOW RATE(KG/S)
15	0.053
20	0.072
22	0.067
25	0.113
30	0.109

Table7: Mass flow rate for different inlet velocities

(d) Circular Plenum:

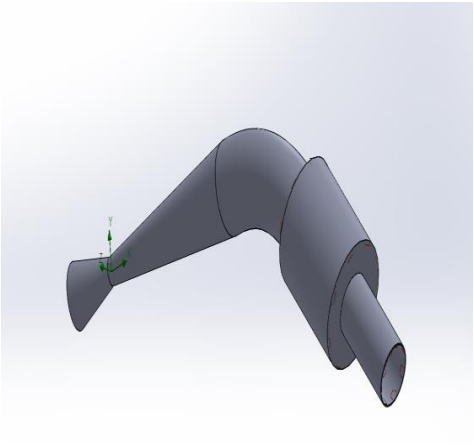

Fig18: Circular Plenum

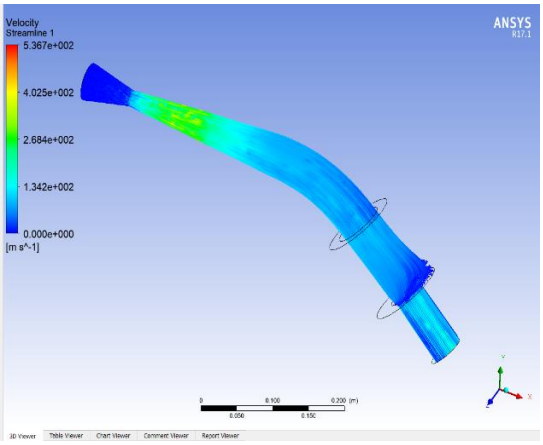

Fig19: Flow in Circular Plenum

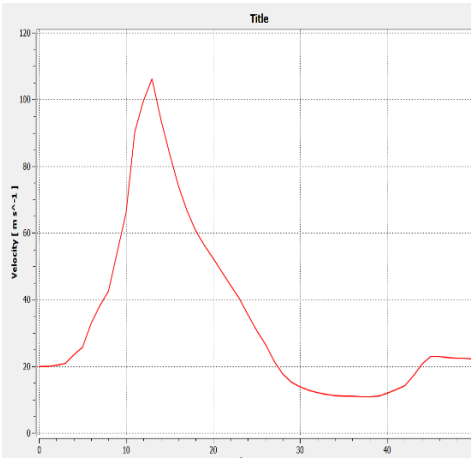

Fig20: Velocity distribution along manifold

INLET VELOCITY	MASS FLOW RATE(KG/S)
15	0.054
20	0.072
22	0.077
25	0.073
30	0.106

Table8: Mass flow rate for different inlet velocities

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From the above simulations it can be seen that at low velocities the curved plenum is less efficient as compared to other shape and as the velocity increases the mass flow late increases and then decreases due to losses in the manifold hence curved plenum is most efficient as vehicle runs at average speed of 25m/s as compared to other shapes (as shown in Table9) as percentage increase in volumetric efficiency is highest.

η_{vol} = Volumetric efficiency
m = Mass flow rate of air
n_r = Number of crankship rotation for a cycle
ρ_a =Density of air
N_e =Engine RPM
V_d =Displacement volume

$$\eta_{vol} = \frac{m * nr}{\rho a * Ne * Vd}$$

Since all the other factors in above relation are constant hence it can said that the volumetric efficiency is directly proportional to the mass flow rate of air entering the cylinder.

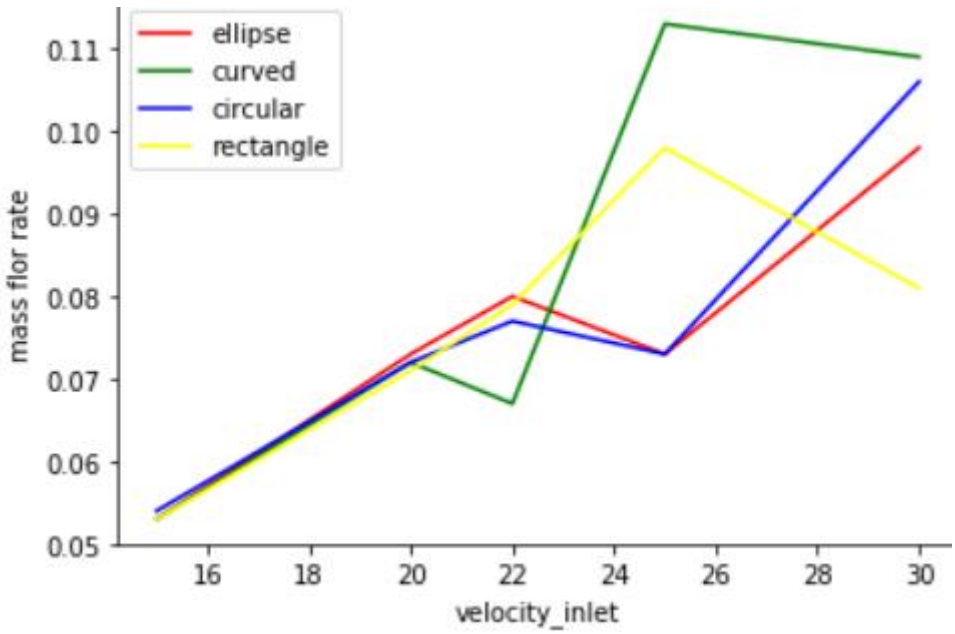

Fig21: Mass flow rate for different plenum (800cc)

2.2.2 <u>1000cc Plenum Volume</u>

Now in the second iteration the volume of Plenum is increased to 1000cc and volumetric efficiency and mass flow rate are calculated for different plenum shapes. The basic design remains same only difference between the manifold is the volume of the plenum.

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(a) Rectangular Plenum:

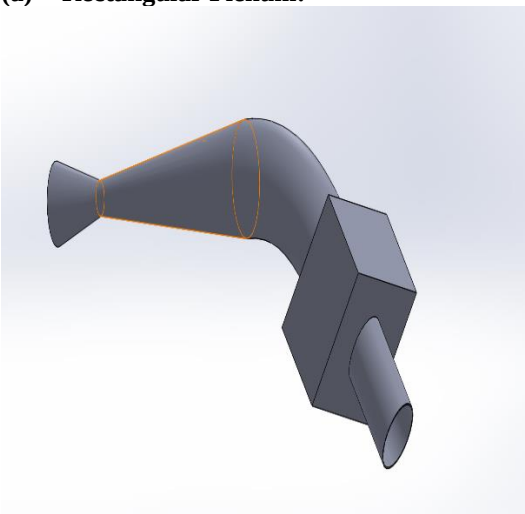

Fig22: Rectangular plenum(1000 cc)

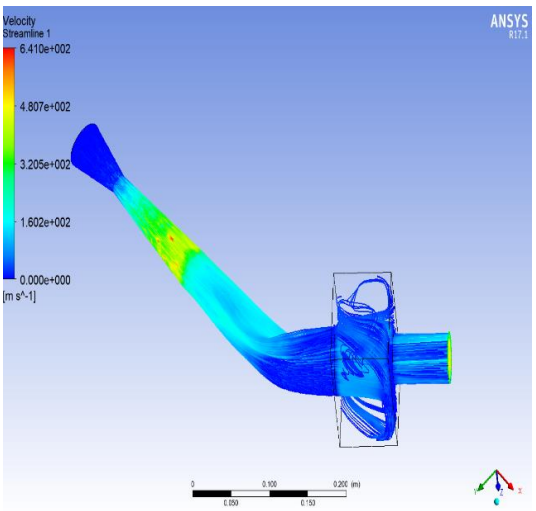

Fig23: Flow in the Rectangular Plenum

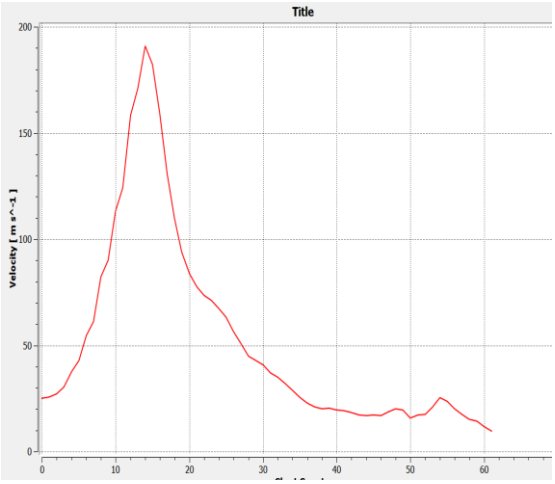

Fig 24: Velocity Distribution of manifold

INLET VELOCITY	MASS FLOW RATE(Kg/S)
15	0.0532
20	0.070
22	0.079
25	0.094
30	0.088

Table8: Mass flow rate at different inlet velocities

(b) Circular Plenum:

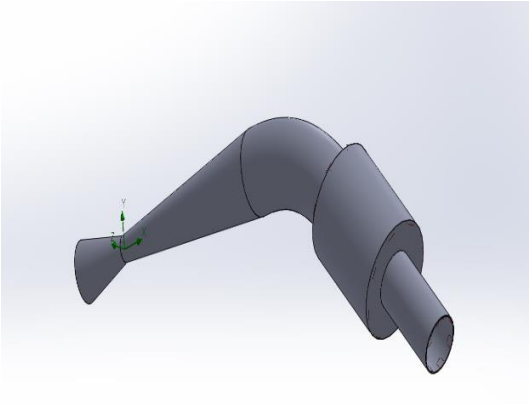

Fig25: Circular Plenum(1000cc)

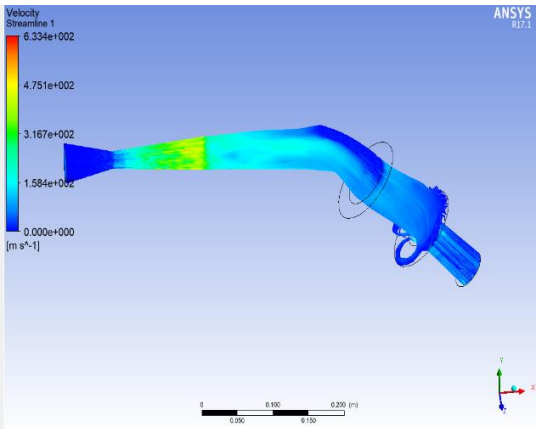

Fig26: Flow in Circular Plenum

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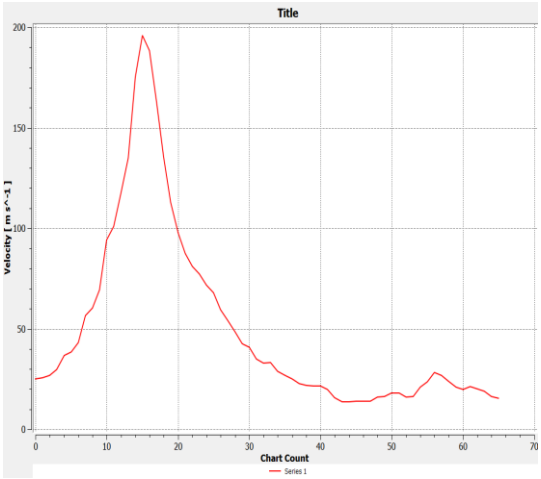

Fig27: Velocity distribution in manifold

INLET VELOCITY	MASS FLOW RATE(Kg/S)
15	0.0536
20	0.071
22	0.077
25	0.098
30	0.084

Table10: Mass flow rate at different inlet velocities

(c) Curved Plenum:

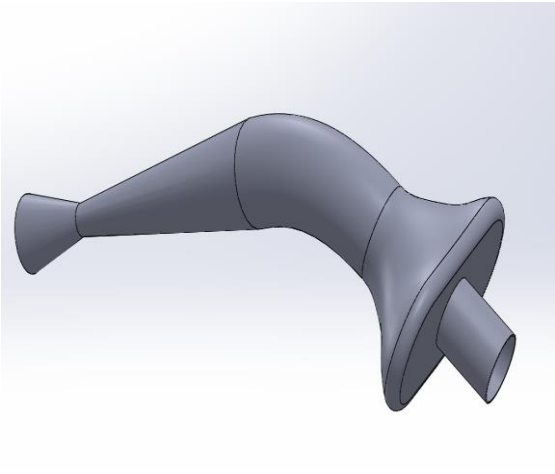

Fig28: Curved Plenum(1000cc)

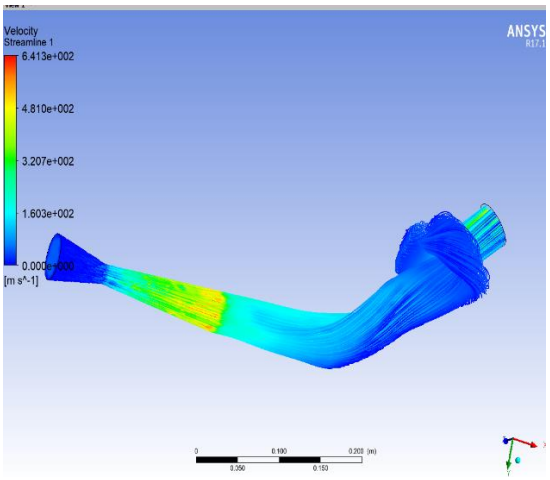

Fig29: Flow in the curved plenum

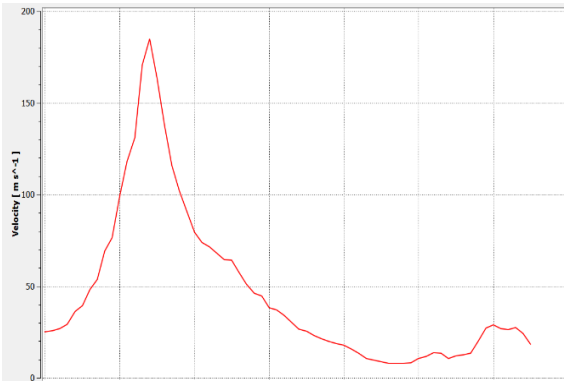

Fig 30: Velocity Distribution along the manifold

INLET VELOCITY	MASS FLOW RATE (Kg/S)
15	0.0536
20	0.071
22	0.077
25	0.074
30	0.090

Table11: Mass flow rate at different inlet velocities

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(d) Elliptical Plenum:

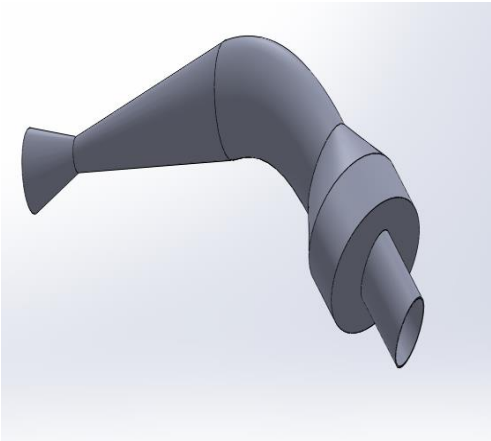

Fig31: Elliptical Plenum (1000cc)

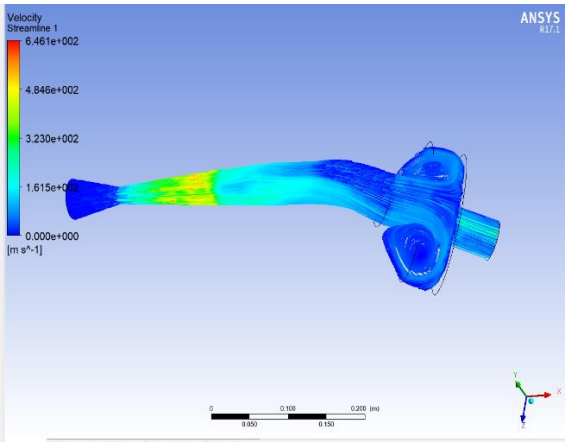

Fig32 : Flow in elliptical plenum

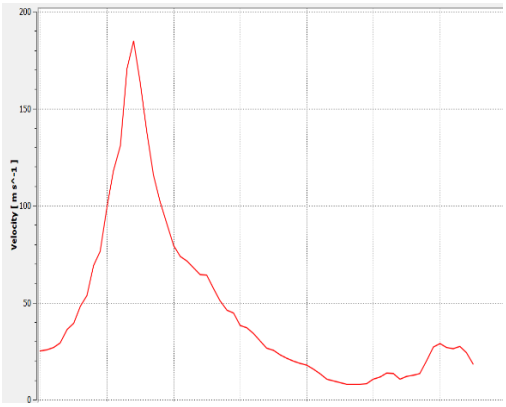

Fig33: Velocity Distribution in manifold

INLET VELOCITY	MASS FLOW RATE (Kg/S)
15	0.053
20	0.070
22	0.084
25	0.067
30	0.098

Table12: Mass flow rate at different inlet velocities

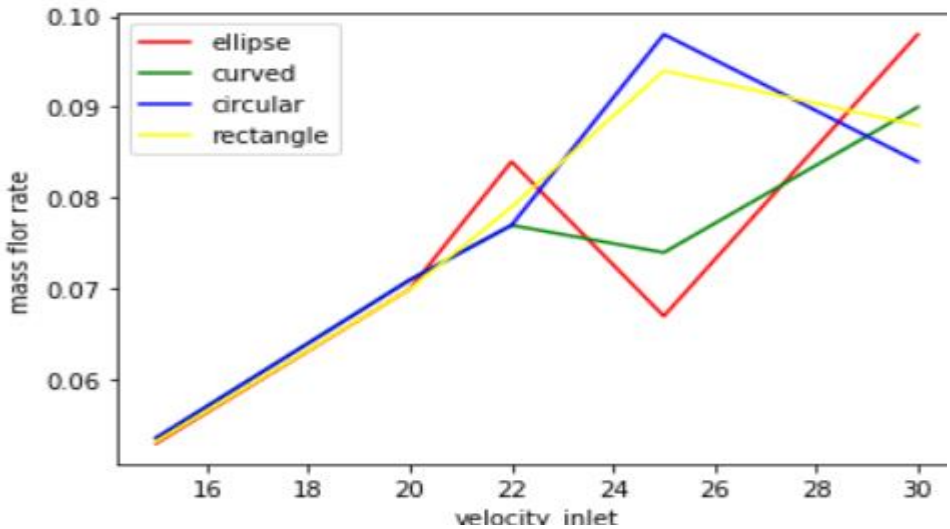

Fig34: Comparison of Mass flow rate for different plenum shapes

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2.2.3 600cc Plenum Volume:

Now in third Iteration the volume of plenum is decreased to 600cc with all other parameters same.

(a) Rectangular Plenum:

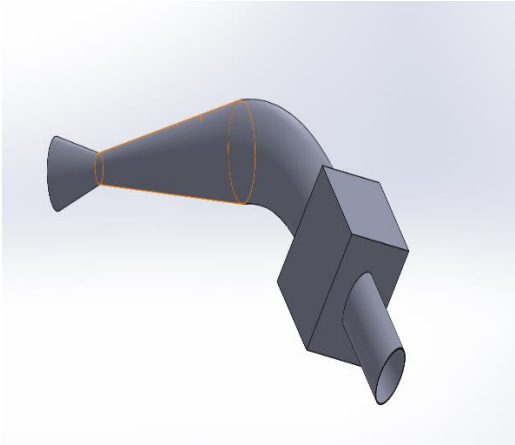

Fig35: Rectangular Plenum (600cc)

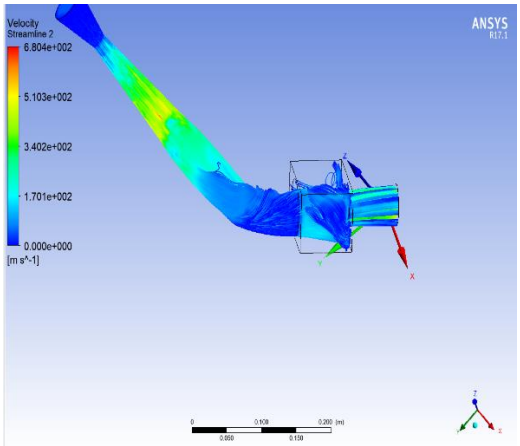

Fig36: Flow in the rectangular Plenum

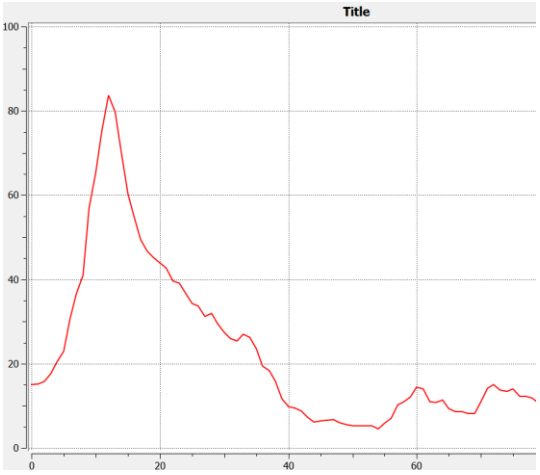

Fig37: Velocity distribution along manifold

INLET VELOCITY	MASSS FLOW RATE (Kg/S)
15	0.053
20	0.073
22	0.078
25	0.069
30	0.118

Table13: Mass flow rate at different velocities

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(b) Curved Plenum:

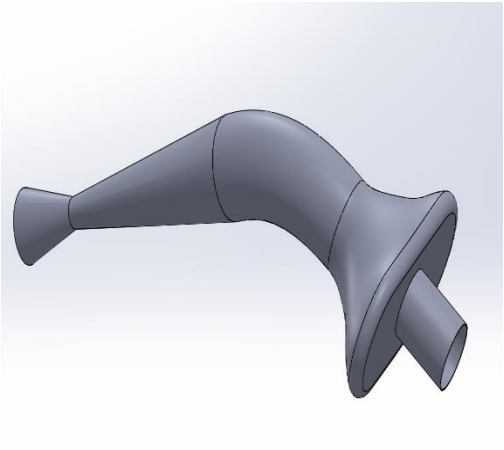

Fig38: Curved Plenum (600cc)

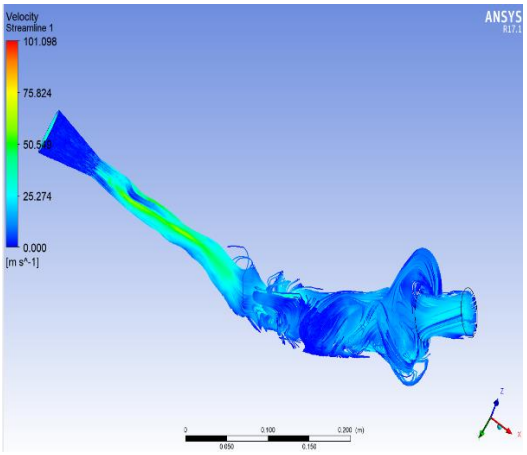

Fig39: Flow in curved plenum

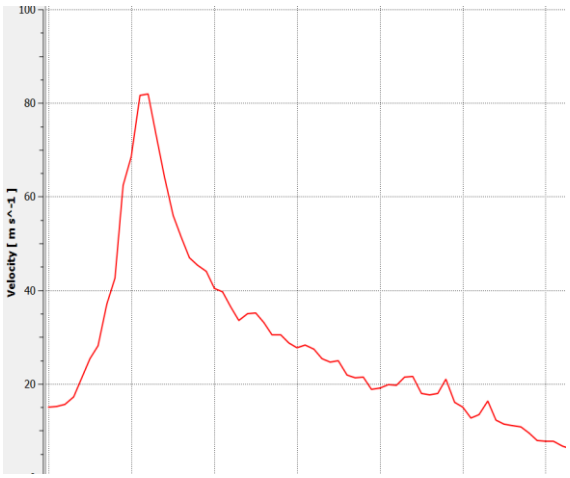

Fig40: Velocity Distribution along manifold

INLET VELOCITY	MASS FLOW RATE (Kg/S)
15	0.0536
20	0.073
22	0.0811
25	0.091
30	0.117

Table14: Mass flow rate at different Velocities

(c) Circular Plenum:

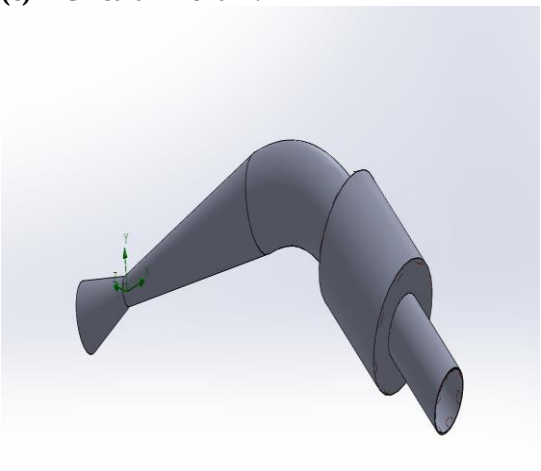

Fig41: Circular Plenum (600cc)

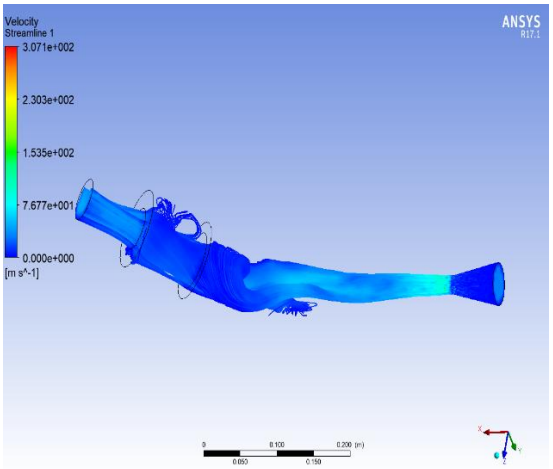

Fig42: Flow in the Circular Plenum

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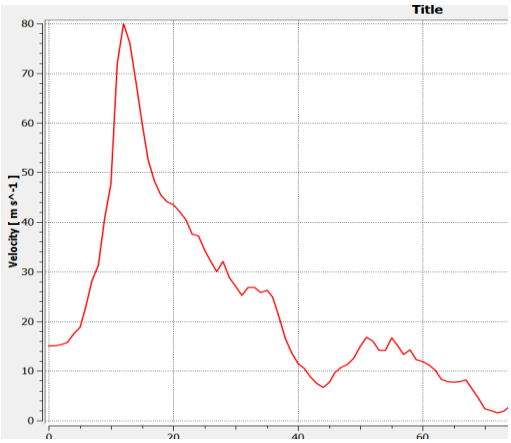

Fig43: Velocity Distribution along manifold

INLET VELOCITY	MASS FLOW RATE (Kg/S)
15	0.0535
20	0.070
22	0.077
25	0.092
30	0.101

Table15 :Maa flow rate at inlet Velocitis

(d) Elliptical Plenum :

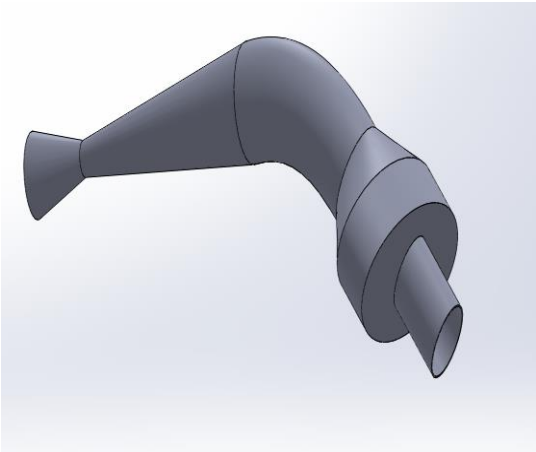

Fig44 : Elliptical Plenum(600cc)

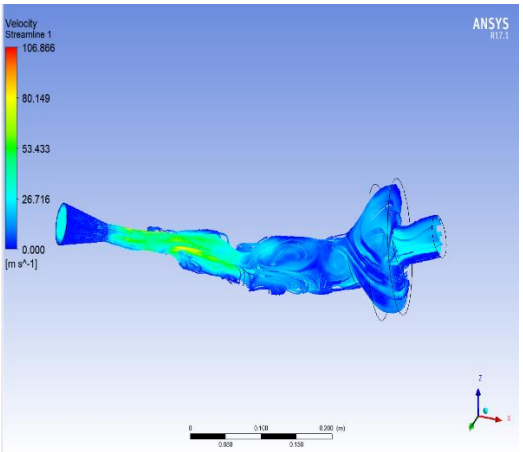

Fig45: Flow in elliptical plenum

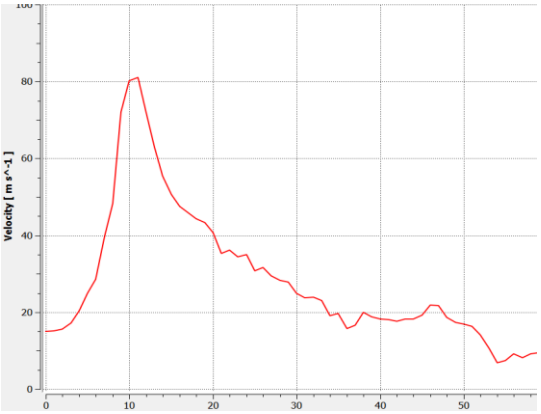

Fig 46: Velocity distribution along manifold

INLET VELOCITY	MASS FLOW RATE (Kg/S)
15	0.535
20	0.070
22	0.074
25	0.076
30	0.095

Table16 : Mass flow rate at different velocitie

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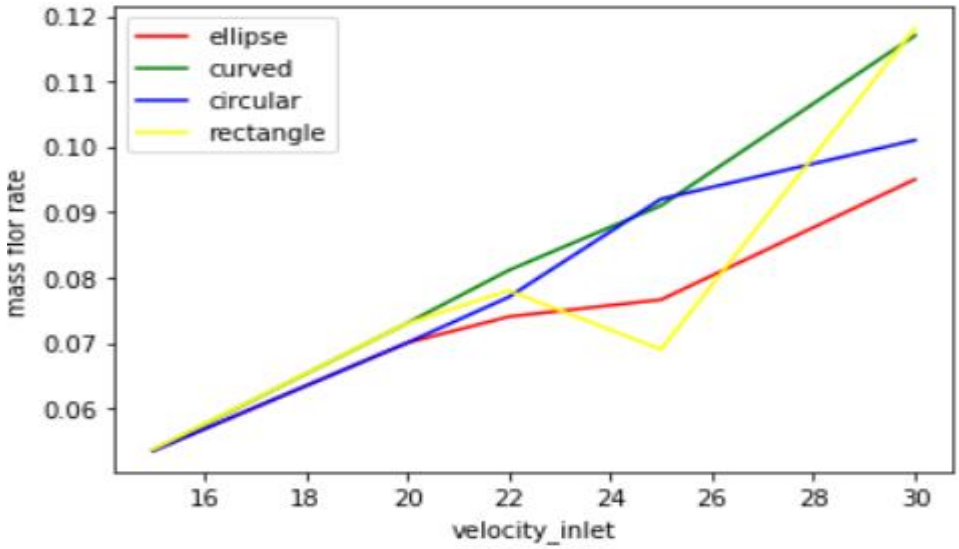

Fig47 : Comparison of Mass flow rate for different plenum shapes

2.3 RESULTS OF PLENUM OPTIMIZATION:

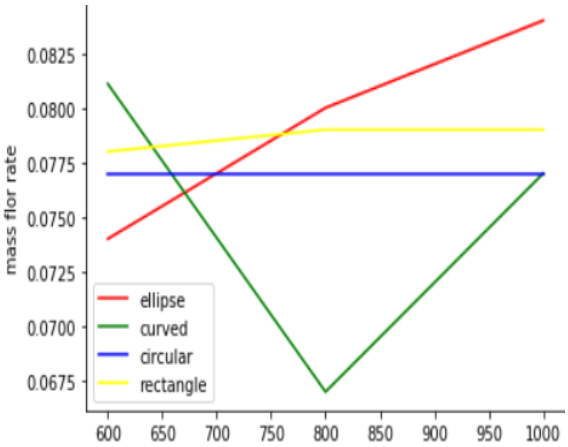

Fig48: mass flow rate vs volume at 22m/s

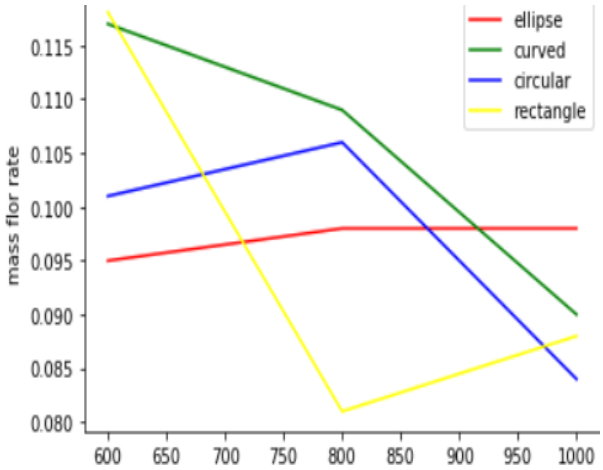

Fig50: mass flow rate vs volume at 30m/s

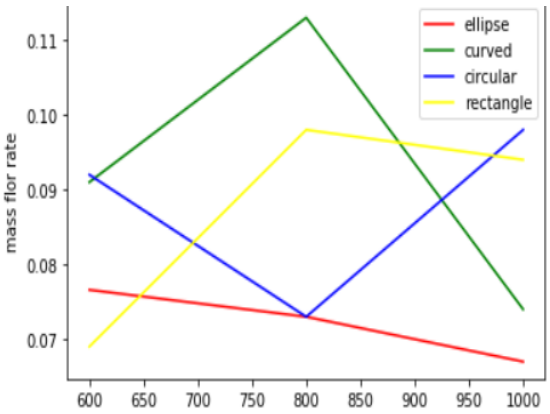

Fig49: mass flow rate vs volume at 25m/s

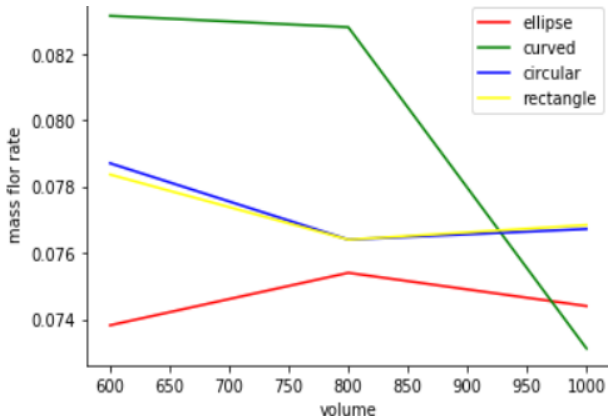

Fig51: Mean mass flow rate vs volume

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From the above graphs it can be seen that mean mass flow rate is maximum at 600cc of plenum volume followed by 800cc and then 1000cc. Curved Plenum is most suitable plenum type of plenum for lower volume of plenum at all velocities and elliptical plenum is most unsuitable type of plenum as mean mass flow rate is minimum for elliptical plenum at all volumes. The performance of curved plenum decreases drastically as volume increases to 1000cc at all velocities,
Hence volume of plenum should be between 600cc to 800cc and curved plenum is most suitable plenum shape.

2.3 RUNNER DESIGN OPTIMIZATION:

2.4.1 Optimization of Length of Runner:

Length of runner is decided based on Resonance Theory that is the peak pressure wave of air enters when the intake valve opens
Let us assume KTM 390 engine, the inlet temperature is 30° C therefore calculating the speed of sound at 30°C

$$c=\sqrt{\gamma RT}$$

R= Gas constant
Calculating the value of speed of sound we get c=349m/s.
Peak RPM of engine is 9000RPM in RPS = 9000/60
Intake value is open for 288° of 720°
Time taken for complete revolution=60/9000
=0.006
Intake valve remain closed for 432° which is 432/720 =1.2 Revolutions
Time it takes between when the valve closes and it open again= 1.2*0.006
=0.0072sec

Distance covered by sound in the time= 0.0096* 349
=3.34 m
Length of the runner =1.92m

Since physically 1.92 m length of runner cannot be assembled so now according to resonance
Theory the peak pressure wave occur at 2n harmonic (acc to helmontz resonance theory)
According to harmonic the length of runner at 3rd harmonic is 0.20.

ENGINE RPM	LENGHT OF RUNNER (M)
1000	2.09
2000	1.02
3000	0.69
4000	0.52
5000	0.41
6000	0.34
7000	0.29
8000	0.26
9000	0.20

Table17: Runner length for different RPM for 3rd harmonic

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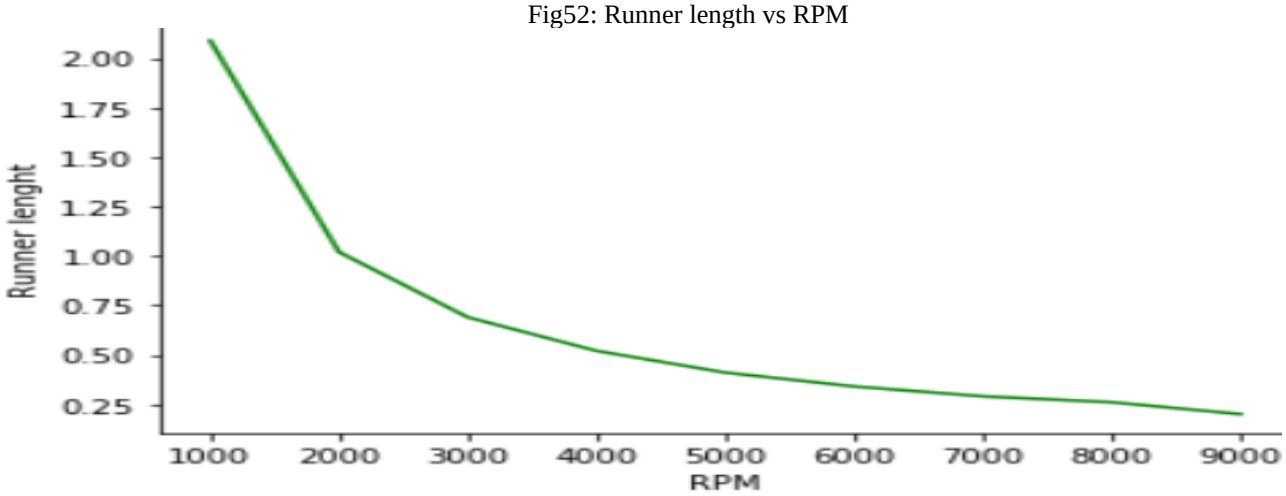
Fig52: Runner length vs RPM



Since from Fig52 it can be seen that runner length varies with RPM so length of runner can be taken as length at 6000RPM because the curve began to flatten at 6000 Rpm and variation is less after 6000RPM.

<u>Length of runner is =34CM</u>

$$\text{Diameter (cm)} = \sqrt{\frac{Displacement(L)*\eta*RPM}{516}}$$

Generally the diameter the is diameter of throttle body in the engine inlet in our case it is 4.9cm

ENGINE RPM	η_{vol} (90%)	η_{vol}(95%)	η_{vol}(100%)
2000	1.3	1.37	1.44
3000	1.95	2.06	2.16
4000	2.60	2.74	2.89
5000	3.25	3.43	3.61
6000	3.9	4.12	4.33
7000	4.55	4.80	5.06
8000	5.20	5.49	5.78

Table18: Runner diameter for different volumetric efficiency

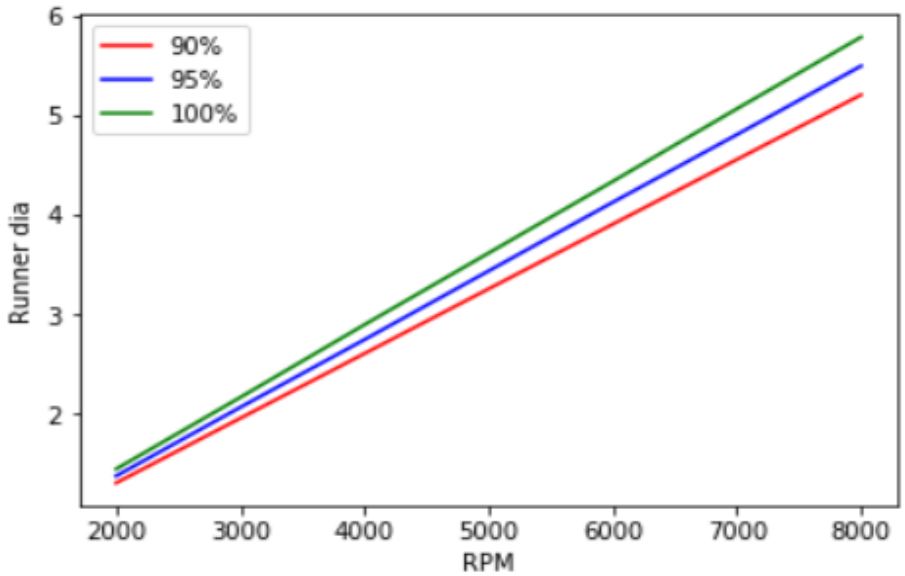


Fig53: Runner diameter at different volumetric efficiency

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3. CONCLUSION:

From the above analysis it can be shown that the effect of nozzle diffuser, the plenum and the runner have important role in improving the performance of the intake manifold and from the analysis it can be concluded that:

Diameter of Nozzle entry =28mm
Throat Diameter of Nozzle =19.5mm
Outlet Diameter of Nozzle =48mm
Nozzle angle=5º
Diffuser angle=12º
Plenum Shape=Curved Plenum
Plenum Volume=Between 600 to 800cc
Runner Length =34Cm
Runner Diameter =4.9Cm

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5. BIOGRAPHIES:

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