Design & Analysis of Intake Manifold for SAE SUPRA

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Abstract -This research paper aims to optimize the intake manifold of a formula SAE car competition. We are going to discuss about design & manufacturing of intake system for 390CC engine. We have used the 3-D printing technology to manufacture the following parts: -Restrictor, Plenum, Runner As a result, in this approach the geometry has been redesigned to result in reduction of weight. Analytical calculations are done to get maximum mass flow rate and minimum pressure drop across the restrictor. The intake manifold is designed with accordance to the SAE rule book which requires a restrictor of 20mm to be fitted in the intake manifold.

Keywords-Intake manifold, plenum, restrictor, throttle body, air filter, ABS material, 3-D printing.

I. INTRODUCTION

1. About formula SAE

The FSAE (Formula Society of Automobile Engineering) is a interdisciplinary student made, formula car designing competition held at national and international level. In this competition, students from various organizations /institutions design & build a formula car. The driver of the car should be one of the members of the team and therefore it becomes essentialthat the vehicle needs to be manageable and safe for the driver.

The FSAE puts rules and limitation on the car. Event management also provides the rule book. The car should be manufactured according to those rules and satisfy the rules on the parts for example

1. Maximum displacement of the engine should be 610CC
2. Engine should be four stroke, reciprocating piston.
3. A circular 20mm restrictor diameter.

Thus, these conditions have been imposed to the vehicle to optimize at every aspect as much as possible. The further designing is carried on a solidworks software and analysis in done on the ANSYS fluent software. The following are the engine specifications.

Table I: Engine Specifications.

Displacement	373.2cc
Number of cylinders	1
Valves per cylinder	4
Bore / stroke	89mm*60mm
Maximum Power	30.04KW (40.09 HP) @8600 rpm
Maximum Torque	32.92N-m (24.28 ft.lb) @6800rpm
Cooling	Water cooled
Engine Weight	153 KG

II. INTAKE MANIFOLD

The primary function of the intake manifold is to deliver air to engine and this factor makes it a very important aspect to design a quality intake system.

The efficiency of the engine totally depends upon the geometry of the intake design and one must always consider the following points as per the design point of view of a intake manifold.

1. Maximize the air velocity in the engine cylinder.
2. Minimum pressure loss.
3. Minimum bends and curves with sudden changes in geometry.
4. Mass flow rate of air should be near about mach no. 1.
5. Eliminate the sharp corner in design to reduce the vibration in intake manifold.
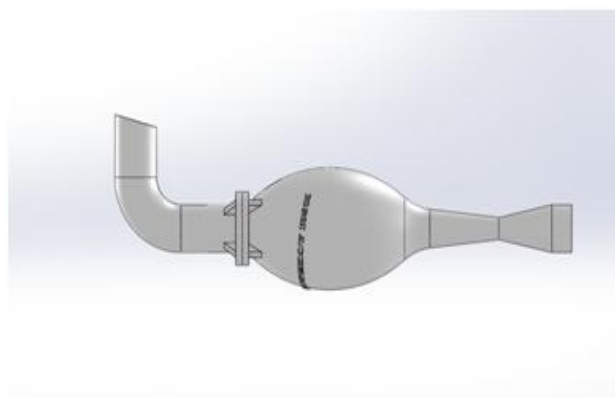

Fig.1. Intake Manifold.

Intake manifold consists of main components such as throttle, restrictor, plenum, runner & air filter.
Arrangement of components is given below:
- Air filter
- Throttle

- Restrictor
- Plenum
- Runner

1. Air filter

Fig.2. Air Filter.

An air filter is usually made of a fibrous or porous material or from pleated paper or cloth enclosed in a cardboard frame. The basic function of air filter is to deliver and provide fresh & clean air. Air filter removes solid particles such as dust, pollen, mud and bacteria from air and those particles that directly affect the engine power & performance.

Disadvantages for vehicles having no air filter
1. Scratches are developed on the piston head and piston rings thus increases wear of the engine components.
2. It disturbs the air fuel mixture.
3. May lead to engine seizure.
4. The dust getting in will eventually lead to poisonous gases.

2. Throttle

Throttle body is a device is used to control the amount of air flow into the engine cylinder. Inside the throttle body it consists of throttle plate which is a butterfly valve that regulates the air flow.

Fig.3.Throttle.

3. Restrictor

A restrictor is a device installed at the intake of an engine to limit its power. In FSAE competition the rule is given to limit the power of the engine. The maximum diameter of the restrictor should be 20mm. Mass Flow Rate can be calculated as follows: Mass flow rate Mass flow rate = m= r V A

For an ideal compressible gas:

$$\dot{m} = \frac{Ap_t}{\sqrt{T_t}}\sqrt{\frac{\gamma}{R}}M\left(1 + \frac{\gamma - 1}{2}M^2\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

Mass flow rate is maximum when M = 1
At these conditions, the flow is choked

$$\dot{m} = \frac{A\,p_t}{\sqrt{T_t}}\sqrt{\frac{\gamma}{R}}\left(\frac{\gamma + 1}{2}\right)^{-\frac{\gamma+1}{2(\gamma-1)}}$$

Substituting the values for universal constants
$\dot{m} = 0.532\ \frac{AP_t}{\sqrt{T_t}}$ in lbs/s

Here ,
A = 0.4305564 ft^2
P = 14.6 at 1 atmosphere
T= 540 Rankin = 300 K
$= 0.532 * \frac{0.4305564}{\sqrt{540}} * 14.6$
$= 0.14 lbs/s$
$= 0.0635 kg/s$
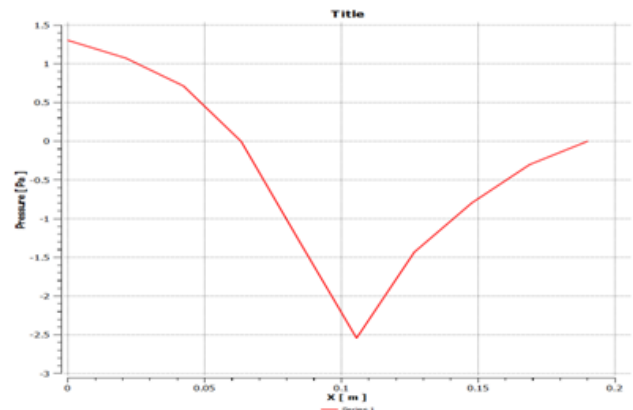$\therefore \dot{m} = 0.0635\ \ kg/s$
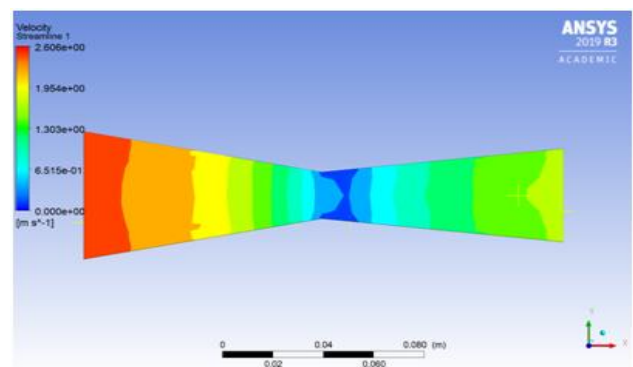

Fig.4. Pressure drop at restriction.

Fig.5. Velocity Streamline.

5. Plenum

Plenum facilitates the distribution of air and fuel mixture into the cylinder. The pressure within the manifold should be greater than that in the cylinders. the basic function of the plenum is to produce the above-mentioned high pressure. Plenum is designed according to RAM theory, which states that a ram air intake is any intake design which uses the dynamic air pressure created by vehicle motion to increase the static air pressure inside of the intake manifold on an internal combustion engine , thus allowing a greater mass flow through the engine and hence increasing engine power. Plenumvolume = 1.7 to 2.7 times the engine displacement Runner The runner is a part which connects the plenum and restrictor with the engine. We can find the runner length using the following theories:

1. Induction wave theory
2. Helmholtz Resonator theory

1. Induction wave theory:

The induction wave theory states that the length of the runner depends on the factors such as EVCD, RPM, Speed of sound, RV, Runner diameter.

Formula:

Length = (EVCD*0.25*V*2) / (RPM*RV) - (0.5D)
Where,
EVCD = Effective valve close duration.
V = Speed of Sound in feet per second.
RPM = Revolutions per Minute.
RV = Reflective Valve
D = Runner diameter

2. Cam specifications:

Table 2 Cam specifications of 390cc Engine

IVO	2 degrees BTDC
IVC	44 degrees ATDC

$EVCD = 720° – ECD - 20°$
Where,
$ECD = 180° + 2° \, BTDC + 44° \, ATDC$
ECD = Effective Cam Duration.
BTDC = Before Top Dead centre.
ATDC = After Top Dead Centre.
4 strokes = 720°
Therefore,
ECD= 226°
EVCD = 474°
Diameter of Runner = 55mm = 2.1653 inches
Length = (474°*0.25*1125*2) / (4500 * 4) – (0.5 *2.1653)

$\qquad$ = 348.738 mm
$\qquad$ = 13.72985 inches

2. Helmholtz Resonator Theory:

$$F_P = \frac{162}{K} * c \sqrt{\frac{A}{LV}} \sqrt{\frac{R-1}{R+1}}$$

Where ,
Fp= Engine rpm
K=2.0 to 2.5
C= Speed of sound , ft/s .
V= Displacement of cylinder
L= Inlet pipe length
A= Inlet pipe cross sectional area
R= compression ratio
162 is constant incorporating units

III. MANUFACTURING

After all the following considerations the main procedure that arises is that of manufacturing, so the manufacturing can be carried out by following methods

- 3-D printing
- Die Casting
- Injection moulding

Out of these we have chosen 3-D printing method because it was cost efficient and time saving.

1. 3-D Printing:

It is a additive manufacturing process which builds a 3-Dimensional object from a computer aided design (CAD) usually by adding mterial in succesive layers. the most commonly used 3-D printing process is fused deposition modeling (FDM) .

The printing filament material is very crucial as it affects the designing of the intake manifold.

The following factors are considered while choosing the filament: Melting point, Durability, Impact Resistance, Rigidity, Heat resistant, Flame Performance.

The best filament used for 3-D printing are :

1. ABS (Acrylonitrile Butadiene Styrene)
2. Nylon
3. PETG (Polyethylene Terephthalate)
4. PLA (Poly Lactic Acid)
5. TPU (Thermoplastic Polyurethane

Table II: Properties of filament.

	ABS	Nylon	PETG	PLA	TPU
Density (kg/m³)	1010	1150	1270	1240	1235
Durability	High	High	High	Medium	Medium
Strength	Medium	High	Medium	Medium	low
Melting Point (°C)	210-240	220-230	210-260	180-220	190-220
Flexibility	Medium	High	High	Low	High

IV. RESULTS

At the end, Computational fluid dynamics (cfd) of the intake manifold is done using relevant software that is *ANSYS,*by using appropriate boundary conditions.The results from these simulations & tests are given in the figures below. These simulationsarecompared with the 2018 and 2019 intake modelsand we have obtained a greater mass flow rate andminimum pressure drop.
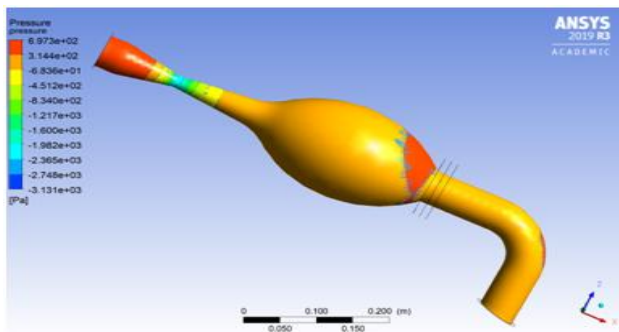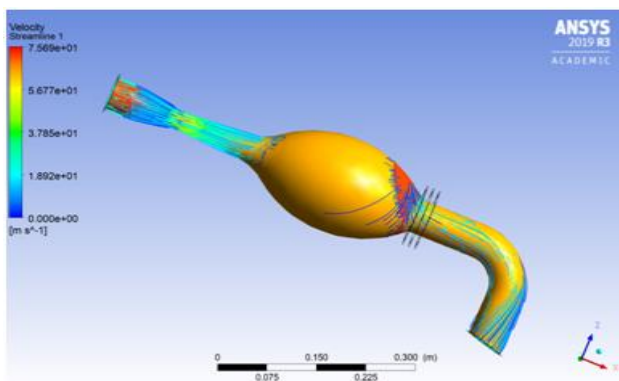

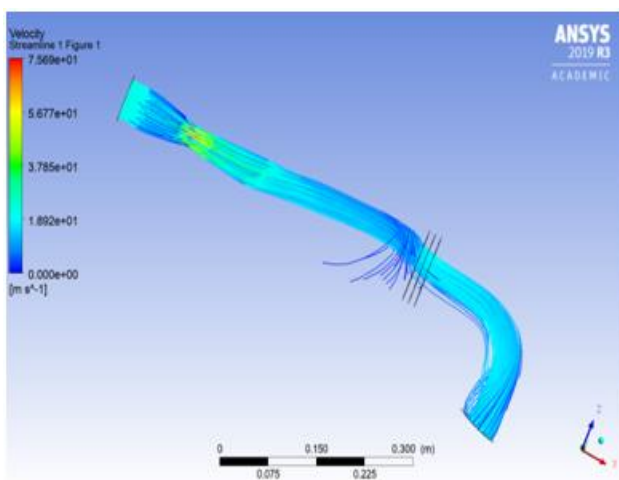Fig.6. Contours of Pressure (Pascal).
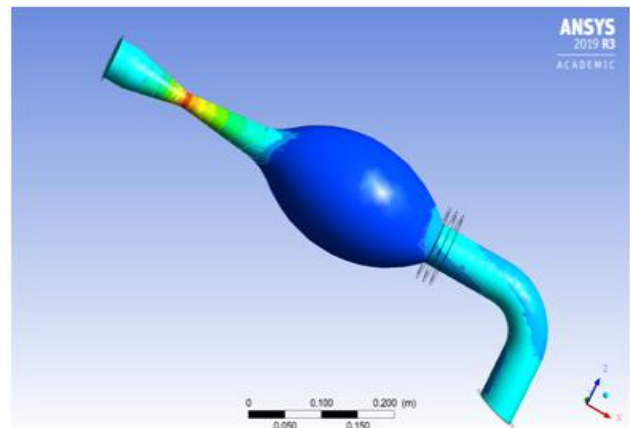

Fig.7. Velocity Streamline.
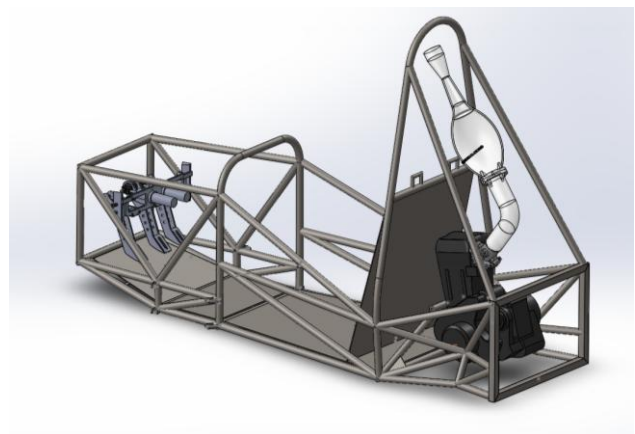

Fig.8. Flow analysis.

Fig.9. Velocity.

Figure.10. Intake mounted on the chasis

V. CONCLUSION

Intake manifold is a very crucial part for the engine as we have seen its importance discussed above, and all the design considerations are made according to the SAE rule book. The design should be fully optimized to get the maximum performance of the engine. And CFD helps to calculate the flow analysis of the intake manifold.

VI. ACKNOWLEDGEMENT

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