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Design and Analysis of Air Intake Manifold for Formula Student Cars

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Abstract - *This paper focuses on making a venturi-type restrictor better for a Formula SAE car engine's intake manifold. The main rule in FSAE is that a 20mm restrictor in the intake manifold is to control the amount of air going to the engine, which helps lower its maximum power. We did some math using standard results to figure out the most air the engine could handle. We also used a tool called CFD to find the smallest pressure drop across the restrictor. We did this by changing the angles of the venturi where the air passes through.*

Key Words: **Runner, Venturi, Plenum, Restrictor, Throttle Body, Air Intake Manifold, CFD, SolidWorks**

1. INTRODUCTION

The goal of this project is to create a special part called an intake manifold for a Formula SAE race car. Formula SAE is a big contest for students who design cars, and it's organized by the Society of Automotive Engineers International.

In this context, there's a rule that limits how much power the car's engine can have. They use a small device called a 20 mm intake restrictor to control the engine's power. The engines used in Formula SAE are only allowed to have 610 cc (cubic centimeters) and can produce 120 horsepower at 15,000 revolutions per minute (RPM). After adding the 20 mm restrictor, the engine's speed is controlled to be between 10,000 and 7,500 RPM.

When the engine is running really fast, it needs a lot of air to burn fuel properly. So, the challenge is to make sure the air flows into the engine at a very high speed to meet its needs. Studies show that the amount of air (called mass flow rate) is a fixed thing when you use a 20 mm restrictor.

Therefore, the main goal of our project is to let in as much air as possible while causing the least amount of pressure drop in the special part we're designing, called the venturi-type restrictor.

2. Air Intake Manifold

The primary role of the intake manifold is to supply air to the engine, making it a crucial element in designing a high-quality intake system. The engine's efficiency is directly influenced by the intake design geometry, and several key considerations should be taken into account in the design of an intake manifold:

1. Enhance air velocity within the engine cylinder.
2. Minimize pressure losses.
3. Aim for a mass flow rate of air close to Mach no. 1
4. Eliminate sharp corners in the design to mitigate vibrations in the intake manifold.

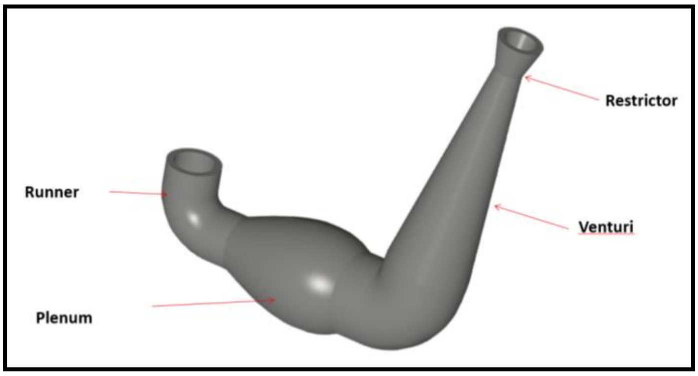

Figure 1 : Air Intake Manifold

The intake manifold comprises key elements, including the throttle, restrictor, plenum, runner, and air filter. The arrangement of these components is as follows:

1. Air filter
2. Throttle
3. Venturi / Restrictor
4. Plenum
5. Runner

2.1 Air Filter

An air filter typically consists of a fibrous or porous material, often pleated paper or cloth enclosed within a cardboard frame. Its primary purpose is to deliver and ensure the circulation of fresh and clean air. The air filter effectively eliminates solid particles like dust, pollen, mud, and bacteria from the air, preventing their direct impact on the engine's power and performance.

Drawbacks of vehicles lacking an air filter:

1. Disruption of the air-fuel mixture.
2. Potential risk of engine seizure.

2.2 Throttle

The throttle body is a mechanism utilized to regulate the quantity of air entering the engine cylinder. Within the throttle body, there is a throttle plate—a butterfly valve responsible for managing the airflow.

Figure 2 : Throttle Body

2.3 Venturi / Restrictor

A restrictor is a mechanism positioned at the engine intake to control its power output. In FSAE competitions, a regulation is enforced to restrict the engine's power, specifying a maximum allowable diameter for the restrictor at 20mm.

Mass flow rate can be calculated as follows:

m=r.V.A

For an ideal compressible gas:

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

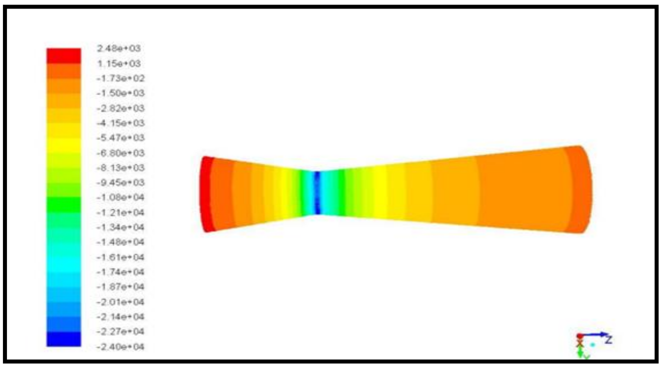

Figure 3: Pressure Contour

The mass flow rate from above equation is calculated using the following data values:

M= 1
A = 0.001256 m^2 (20 mm restriction)
R = 0.286 KJ/Kg-K
ϒ = 1.4
P_t= 101325 Pa
T_t = 300 K
Max. Mass flow rate = 0.0703 kg/sec

We conducted simulations at various convergent and divergent angles. The restrictor operates on the principle of minimizing pressure differences. Following the SolidWorks simulation, we obtained results indicating a convergent angle of **10.5 degrees** and a divergent angle of **6 degrees**, as they resulted in the minimum pressure drop**.**

2.4 Plenum

The plenum facilitates the introduction of an air and fuel mixture into the cylinder by ensuring that the pressure within the manifold surpasses that in the cylinders. The plenum adheres to the RAM theory, asserting that a ram air intake is an intake design utilizing dynamic air pressure generated by vehicle motion. This design aims to elevate the static air pressure within the intake manifold of an internal combustion engine, thereby enabling a greater mass flow through the engine and consequently boosting engine power.

The plenum volume is designed to be 1.5 to 3 times the engine displacement.

Calculations:
Engine Capacity = 373.2 cc
i.e. 373.2 x 3 = 1119.690 cc
1119.690 cc ≅ 1.11969 Ltr
i.e. Volume of Plenum =1.119 ltr

The volume of the plenum is 1.19 liter, which is almost 3 times the engine displacement.

2.5 Runner

The runner, connecting the plenum and restrictor with the engine, plays a crucial role. Determining the runner length can be achieved through any of the two theories:

1. The Induction Wave theory
2. The Helmholtz Resonator theory

2.5.1. Induction wave theory:

The induction wave theory states that the length of the runner depends on factors such as EVCD, RPM, Speed of sound, RV, and 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
Cam specifications:
IVO 2 degrees BTDC
IVC 44 degrees ATDC
} (Cam specifications of 390cc Engine)
EVCD = 720° – ECD - 20°

Where,
ECD= 180° +2° BTDC + 44° ATDC
ECD = Effective Cam Duration.
BTDC = Before Top Dead center.
ATDC = After Top Dead Centre.
4 strokes = 720°
Therefore,
ECD= 226°
EVCD = 474°
Diameter of Runner = 56mm = 2.2047 inches
Length = (474°*0.25*1125*2) / (4500 * 4) – (0.5*2.2047)
= 348.23 mm
∴ **Length = 13.71015 inches**

2.5.2 Helmholtz Resonator theory

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

Where,
F_p= 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 constant incorporating units.

3. Materials & Manufacturing

Upon careful consideration of various factors, the primary approach that emerges is the manufacturing process. The manufacturing can be executed through several methods, including 3-D printing, die casting, and injection molding. Our selection among these options is the 3-D printing method due to its cost-efficiency and time-saving attributes.

3-D Printing is an additive manufacturing process that constructs a three-dimensional object from a computer-aided design (SolidWorks), typically by adding material in successive layers. The most commonly employed 3-D printing process is fused deposition modeling (FDM). Several factors are taken into account when selecting the filament, such as melting point, durability, impact resistance, rigidity, heat resistance, and flame performance.

The optimal filaments for 3-D printing include:
1. ABS (Acrylonitrile Butadiene Styrene)
2. Nylon

Properties	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

Table 1: Properties of Filament

3. PETG (Polyethylene Terephthalate)
4. PLA (Poly Lactic Acid)
5. TPU (Thermoplastic Polyurethane).

The complete air intake system will be manufactured using the 3D printing technique with **ABS plastic material**. Heat Deflection Temperature: 105°C

At the end, the Computational Fluid Dynamics (CFD) analysis for the entire air intake system is also conducted using Ansys Fluent, with the application of suitable boundary conditions after the process.

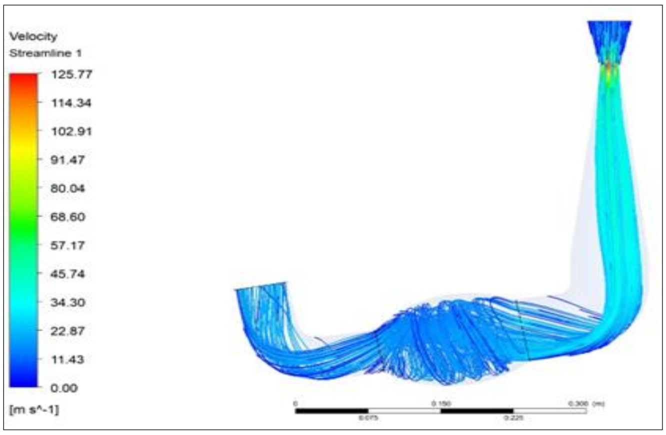

Figure 4: Velocity Streamline for Air Flow in Entire Intake Manifold Consisting of:
1. Venturi
2. Plenum (Curved Central Axis)
3. Runner

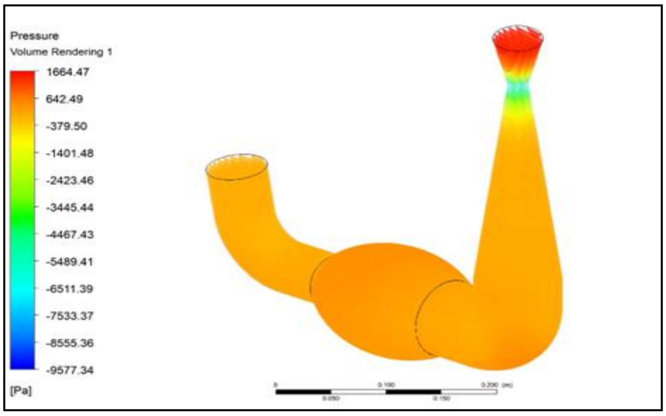

Figure 5: Pressure Contour of walls of Entire Intake Manifold Consisting of:
1. Venturi
2. Plenum (Curved Central Axis)
3. Runner

4. CONCLUSION

Utilizing Computational Fluid Dynamics (CFD) for flow analysis allows for a detailed examination of the intake manifold's flow dynamics. The optimization of the entire intake system is crucial to minimize pressure loss and enhance overall engine performance. A convergent angle of 10.5° and a divergent angle of 6° are chosen for the restrictor, as they result in the least pressure loss through the restrictor. The Plenum Volume is to be 1.119 liter and the entire intake manifold is made of ABS Material.

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