Air Flow Optimization through an Intake System for a Single Cylinder Formula Student(FSAE) Race Car

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***Abstract*— This paper focuses on design and manufacture of an intake system for FSAE single cylinder race car engine. The rules impose the introduction of a restrictor in the intake system of the engine. The use of restrictor chokes the engine which reduces its performance and power output and hence necessitate its selection and improvisation. The objective of this paper is to optimize the Venturi to maintain a constant mass flow rate and to maximize the delta pressure after passing through the restrictor. The volume of the Plenum and the size of the Runner were determined for efficient working of the intake system. Analysis was done in iterations by changing the converging and diverging angles of the Venturi. Experimentation showed that converging and diverging angles of 12&6 prove to maximize the pressure lost due to the 20mm restrictor. Plenum and Runner were implemented to recover the pressure lost after the restriction through its way to the engine. The overall design is modelled on a 3D modelling software and the analysis is performed on a flow simulation software. Rapid prototyping being the core manufacturing process, fused deposition modelling was done followed by the process of Fiberglass reinforced lining. This overall process was considered due to the final product being light-weight, profile desired design, elimination of finishing processes and increased strength of the product.**

Keywords—FSAE, Single cylinder engine, Intake system, Venturi, Plenum, Runner, Rapidprototyping, Fibreglass Reinforced Lining.

I. INTRODUCTION

The formula SAE is a student design competition organized by SAE international (previously known as the Society Of Automotive Engineers, SAE). The concept of the event is that a fictional company has contracted a student design team to manufacture a formula type racecar which is targeted for non professional weekend racers. Each team designs build and tests the car based on a set of rules. There are varying departments which are to be worked on for manufacturing the vehicle. The intake system for the engine is one of the important departments to be worked on. The rules for intake system state that "*a singular circular restrictor of 20 mm diameter must be placed in between the throttle body and engine*". This rule is in order to limit the power capability from the engine and for safety consideration at which the event is held. The amendment of the restrictor causes the performance of the engine to be affected drastically. This poses a great challenge and emphasizes the need to design the intake system such that the losses due to the restrictor can be covered and used efficiently to increase the performance laid within the constraints. The competition has a variety of engines being used ranging up to

610cc. This paper deals with design of intake system for a KTM duke 390cc engine. The engine is liquid cooled and produces 43 Bhp of power and 35 Nm of torque. The engine comes with a six speed manual gearbox and weighs 35kg.

II. RESEARCH AND DEVELOPMENT

The intake system comprises of 3 parts namely the Restrictor, Intake Manifold and the Runner. The description, design and the manufacturing of all the 3 parts has been given below.

A. Restrictor

The purpose of the restrictor is to reduce the airflow to the engine. There are two types of instruments which can be used as a restrictor i.e. the Orifice plate as well as the Venturi tube. The Orifice plate is a simple rectangular plate with a hole drilled in it. The Venturi tube is a tube having a converging and a diverging section with a throat section of circular shape connecting the both. The choice of restrictor to be used is laid out in the below comparison.

TABLE 1 DIFF BETWN ORIFICE AND VENTURI

Orifice plate	Venturi tube
The coefficient of discharge is between 0.58 to 0.65.	The coefficient of discharge is between 0.95 to 0.975.
The pressure loss is medium on a scale of high to low.	The pressure loss is low on a scale of high to low.
The cost of manufacturing is cheaper.	The cost of manufacturing is high.
The manufacturing is easy as there is just a hole to be drilled on a plate.	The manufacturing is difficult as there is a conical profile to be made.

On considering the above table it can be seen that Venturi tube is much better as compared to the orifice plate in overall terms. As seen from the above table the pressure loss and coefficient of discharge for Venturi tube is much better as compared to orifice plate. According to the restriction on engine, the more efficient design would help for the

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competition. Cost and manufacturing were not taken into account for this part. Comparing the above, Venturi tube was selected as the restrictor. According to the rules the restriction is 20mm in diameter. This will be the throat of the Venturi tube. The diameter of the throttle body for KTM duke 390 engine is 46mm. As the throttle body fits in the inlet face of the Venturi, the diameter of the throttle body would serve as the inlet and outlet diameter of the Venturi tube.

It is important to identify what are the important constant and variables required for designing of Venturi tube. This is for calculating what are the actual flow conditions inside the Venturi tube. These parameters form a rigid base for the experimental and analytical boundary conditions to be used in Flow simulation. As from the above discussion we have three dimension which are fixed i.e. Inlet diameter, outlet diameters, and the throat diameter. We will be requiring the converging and diverging angles of the Venturi. Thus we have defined 3 known and 2 unknown parameters. The pressure at inlet is atmospheric and the temperature at inlet is ambient. The boundary condition at the outlet can either have pressure, velocity and mass flow rate. Calculating the pressure and velocity at the outlet involves complex procedure and can end up being tricky. Mass flow rate at outlet can be easily calculated using the Choked flow equation.

According to the above equation the mass flow rate at outlet was calculated as given below:

M = 1 (choked flow)
A = 0.001256 m^2 (20 mm restriction)
R = 0.286 KJ/Kg-K
$\gamma = 1.4$
Pt = 101325 Pa
T = 300 K

Mass flow rate = 0.0703 kg/s

This the second boundary condition at the outlet of the Venturi. Thus, we have all the boundary conditions required for the CFD analysis of the Venturi. The Aim for the analysis was to minimize the pressure loss at the end of the Venturi. While doing the analysis the converging and the diverging angles were changed and iterations were done to found out which ones provide the minimum pressure loss.

II.A.1 CFD Analysis:-

The Iterations for various angles that were chosen for the analysis were for pressure loss considering the below angles.

Table 2 Converging and diverging angles

Iteration	Converging angle	Diverging angle
1	12	6
2	14	6
3	16	6
4	18	6

The Pressure plots for the above simulations are shown below:-

a) 12 & 6

The below figure shows the flow trajectories for a venturi with converging angle 12 degree and diverging angle 6 degree.

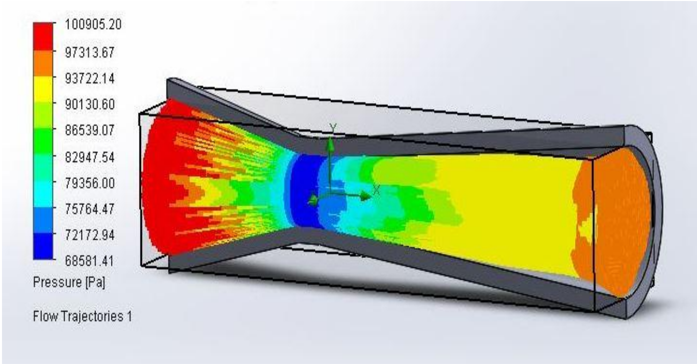

Figure 1 Pressure plot for angles 12&6 degree

b) 14&6

The below figure shows the flow trajectories for a venturi with converging angle 14 degree and diverging angle 6 degree.

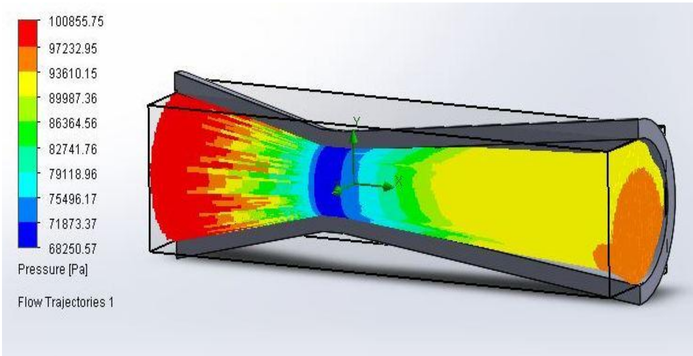

Figure 2 Pressure plot for angles 14&6 degree

c) 16&6

The below figure shows the flow trajectories for a venturi with converging angle 16 degree and diverging angle 6 degree.

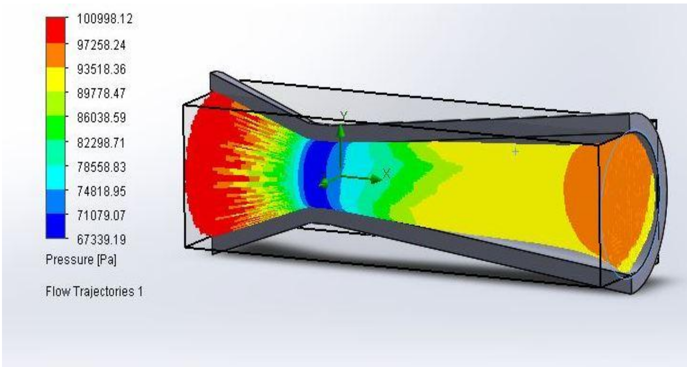

Figure 3 Pressure plot for angles 16&6 degree

d) 18&6

The below figure shows the flow trajectories for a venturi with converging angle 18 degree and diverging angle 6 degree.

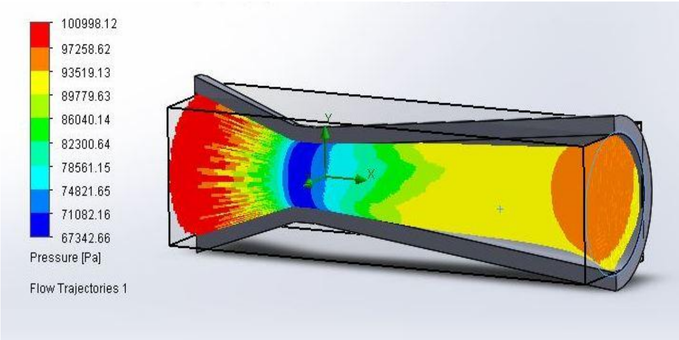

Figure 4 Pressure plot for angles 18&6 degree

II.A.2 CFD Results

The analysis from the above simulation was studied and analyzed to differentiate the flow capabilities for suitable Venturi design. The data acquired from the above analysis was formulated into a table given below. The table gives the iteartions carried out for various combination of converging and diverging angles. The Pressure lost for each set of angles is mentioned in the below table.

Table 3 Delta Pressure

Iteration No	Converging Angle	Diverging Angle	Pressure loss (Pa)
1	12	6	8626.31
2	14	6	8961.82
3	16	6	9234.12
4	18	6	9389.57

From the above figures it is quite clear that the delta pressure is lowest for the angles 12 & 6. The pressure lost is the lowest for these angles of the Venturi and therefore these angles were selected for the manufacturing processes. The Velocity, Density and Temperature plot for the final design with converging and diverging angles are shown.

a) Density

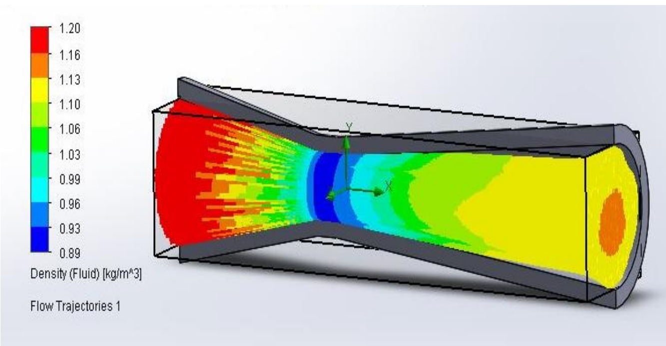

Figure 5 Density Plot

b) Velocity

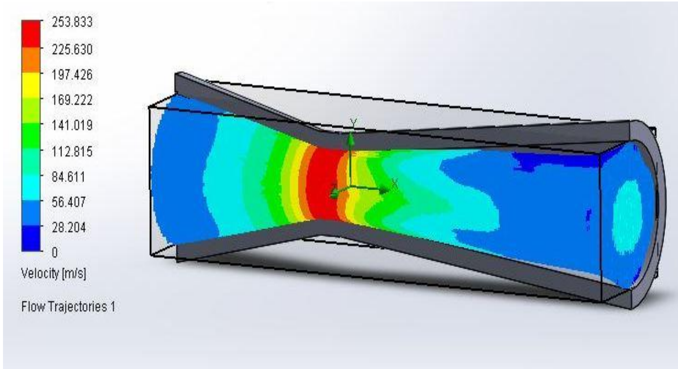

Figure 6 Velocity Plot

c) Temperature

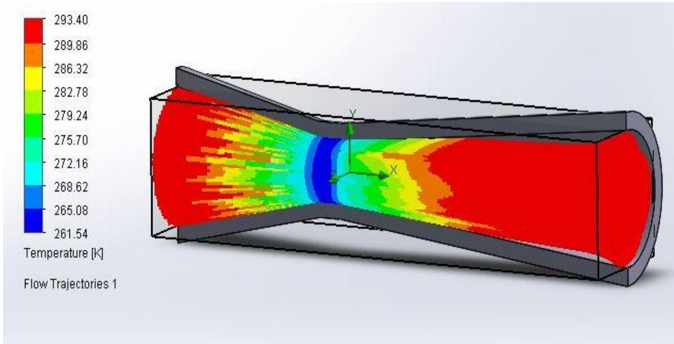

Figure 7 temperature Plot

B. Intake Manifold

The intake manifold aslo known as Plenum is the second part that comes in the assembly of the intake system. It is connected after the Venturi in the whole intake assembly. The intake manifold serves the purpose of air environment which stores the surplus air ready to be sucked by the engine. After the air passes through the venturi there is loss in pressure. This pressure loss occurs as the air passes through a small opening which creates a condition of choked flow, causing the pressure to drop at a remarkable level. This low pressure air is not sufficient for the suction stroke of the engine.

The intake manifold serves as the purpose of pressure recovery. It helps in minimizing the pressure losses that occur after the Venturi as it stores a volume of air in accordance with the engine volume. As the pressure drops after the Venturi, the air is moved into the intake manifold . The first aim for designing the Plenum is to minimize the pressure loss from inlet of the throttle body to the start of the Plenum.

II.B.1 Design consideration:-

There are certain considerations on designing a Plenum according to our requirement. These considerations serve the basis for efficent working of the Plenum. These factors are given below.

a) Position of Plenum*: -*

According to the rules, the vehicle has to be rear wheel drive. This places the engine on the rear of the car after the main hoop and in between the main hoop braces. This positon of the engine gives us 4 positon in which the Plenum and Venturi can be placed.

1) Top facing
2) Besides Left side Main hoop Bracing
3) Besides Right side Main hoop Bracing
4) Towards the Rear end of the car

Figure 8 Top facing

Figure 9 Side facing

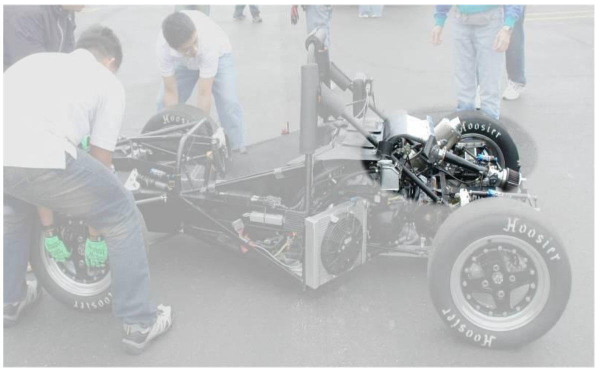

Figure 10 Rear facing

b) Shape of the Plenum

The shape of the plenum plays a vital role in maximizing the pressure loss as this varies the volumetric flow type.This shape houses the air from Venturi and recovers the lost pressure.
There are 2 shapes which can be adopted i.e. Log shaped and Streamlined shaped.

The Log shaped is quite useful for 1st and 4th positon mentioned above as not much design profiles and curves are required. The log shaped are used in simpler shape and not much complexion. Those are beneficial for small plenums as all the air collected can be use at once for the suction stroke and engine does not have to strive hard.

The streamlined shape is useful for the 2nd and 3rd position as these positions demand curved plenums , so that the overall CG of the vehicle can be balanced. These provide an even flow when the air has to pass through a curved section.

c) Volume of Plenum

The volume of plenum has to be such that the engine does not strive for air during its suction stroke. As the plenum has to serve the purpose of air environment it has to have a volume which is bigger than the cubic capacity of the engine. Some literature suggest it should be 2-2.5 times the cubic capacity of the engine. While some literature suggest it should be quite more than that. The volume of plenum is an important factor for the type of performance needed from the vehicle. The less time required for air to be sucked in to the combustion chamber the more the throttle response on the other side bigger the size of plenum more time required for getting in fresh air hence reduing the throttle response. As is also the case that less the volume more work required for grabing in fresh air and filling the plenum. Alternatively bigger the size more air being stored in the plenum at once so less work required for sucking in fresh air.

C. Runner

The runners are the third member of the intake system. They are the connection members which connect the plenum to the engine. The runner is a tube which can have varying diameter and lenght. Air from the plenum is feed to the engine depending to the stroke cycle. The runners apart from being the transporting members they also serve the purpose of tuning the engine according to the RPM range. The runners can be tuned for Low-End Torque as well as for High-End Horsepower. The shape and size of the runner determine what purpose is it going to serve.

The lenght of the runners determines which RPM range will it benefit. The shorter sized runner are used for High end Horsepower as the suction is quite small and the stroke can be completed as fast as possible, tending to give more power at the Higher end. On the other side the bigger length runner are used for lower end torque, as the passage being long the air has to travel longer than required giving that extra space at the bottom end. The whole analogy has a understanding that air is in form of waves that travel from the plenum to the engine as per the stroke. As the air is being sucked during the suction stroke the air waves try to rush into the combustion chamber and during the closing of the valves these waves are reflected back which causes them to revert back to plenum side. As soon as the waves reach the far end of the runner they are met with a new boundary which reflect them back toward the valves. However the valves being closed and no place being available for the waves to go, the stack upon themselves. Creating a higher pressure wave behind the valves. This creation of altering compression and decompression, an acoustic waves is formed. This alternating waves can be utilized for the stacking in more air into the combustion chamber which would increse its volumetric effeciency. This serves as the purpose of natural turbocharger which can be used only at a specfic RPM range. This phenomenon is always present irrespective of which RPM range the engine is running on. The optimum design would be

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to tune this alternating acoustic wave at the peak torque RPM range.

III. MANUFACTURING

The whole intake assembly had to be light weight along with the geometrical shape that was implemented. The selection was done on the base of two available methods which were the simpliest and easiest.

1) Metals forming

The whole assembly could be crafted with metal, using mild steel or stainless steel. The implemented design was not feasible with metal crafting as the design had curves as well attachments which was not possible by giving profilic shapes to the part. Apart from this there would have been difficulties in welding the parts to one another and to fit in the desried position.

2) Rapid prototyping

Rapid prototyping is the process of using a synthetic material for the creation and modelling of CAD model without any manufacturing errors. The process was quite sufficient as it fulfilled all the criteria for the manufacturing process.

In rapid prototyping fused deposition modelling was used. Fused deposition modelling is a process in which the part is divided into 2 segments. The inner core and the outer coating. The base inner core was made up of ABS material (P400). ABS material is a polymer material which has good strength and can be modelled according to our shape. The outer coating was done with fiber reinforced modelling. The coating gives added strength and also gives a leakproof coating which can be cover the pores of the base inner core.

All the parts were manufactured by FDM and the whole assembly was coated by FRP fiber lining. The Rapid prototyped parts are shown below:-

a. Venturi

Figure 11 Rapid Prototyped Venturi

b. Plenum

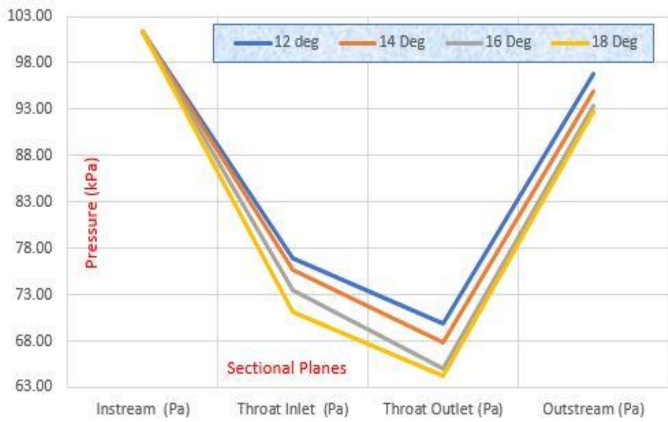
Figure 12 Rapid Prototyped Plenum

c. Runner

Figure 13 Rapid Prototypes Runner

IV. CONCLUSION

The experimentation concludes that Venturi is a more efficient than orifice plate for the intake system. Various iteration were performed on the Venturi considering the various converging and diverging angles states that the angles of 12&6 degree are best for use. The Maximum pressure is being recovered from this set of angles. The graph of Pressure at various sectional planes on the Venturi has been plotted below.



Graph 1 Pressure at sectional planes

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The X axis depicts the various sectional planes where the Pressure was calculated on flow simulation software versus the Y axis which depicts the Pressure range. The angles 12&6 maximizes the delta pressure measured between the inlet and outlet of the Venturi. The Plenum and runner are so designed to match the performance of the Venturi. The assembly is shown below.

IV.A.1 CAD Model & Manufactured Intake system

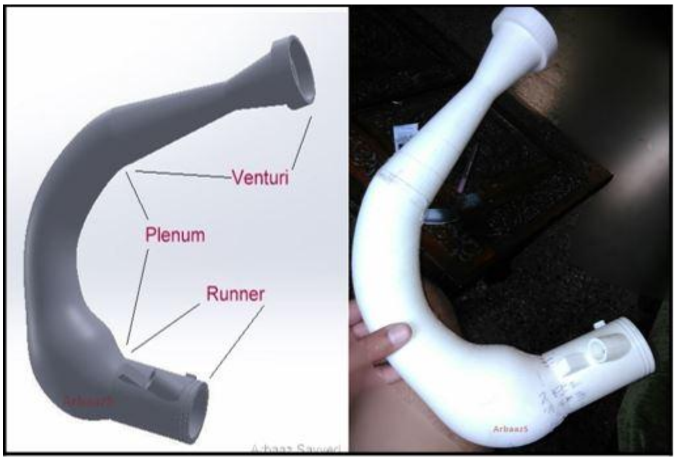

Figure 14 CAD Model and Manufactured Part

The image to the right is the CAD model of the intake from the 3D modelling software and the image to the left is the Rapid prototyped Intake assembly. The below pictures show the rapid prototyped part coated with Fibreglass reinforced lining assembled on the FSAE car engine.

Figure 15 Intake system assembled on FSAE car

Figure 16 Top View of Intake System Assembly

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