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CFD Analysis of Air Intake Manifold System to Improve Efficiency of Formula SAE Car

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Abstract:*This research paper aims at designing and developing an air intake manifold to be used in FSAE competitions. According to the rule imposed by the FSAE committee, a 20 mm restrictor should be a part of the intake manifold through which only the engine breaths in air for combustion. This rule is imposed to reduce the maximum power produced by an engine. This paper is documented as an introduction on how to design and fabricate an air intake manifold according to FSAE norms. Software tools used designing and developing an air intake manifold are Solidworks (for CADD modeling), Solidworks Flow Simulation (for flow analysis), RICARDO WAVE (for engine simulation). The results from CFD analysis and RICARDO are compared to find the most suitable design of IM for deriving maximum engine performance. The complete study and research of the IM here is done in accordance to the need of a KTM RC390 engine.*

Keywords *- Air intake manifold, FSAE, RICARDO, Restrictor, Solidworks*

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I. Introduction

The Formula SAE series competitions challenge teams of university undergraduate and graduate students to design, fabricate, develop, and compete with small, formula-style vehicles at national level competitions. The engine used must be a four-stroke engine with a displacement not more than 610 cc.

The FSAE committee has imposed a rule of placing a 20 mm restrictor in the air intake manifold if the engine being used is fuel injected and not carbureted may that be a single or multiple cylinder engine. This rule has been imposed so as to curb the maximum power produced by bigger engines. The order in which the components of the IM should be placed are as in air filter, throttle body, restrictor and intake runner. For any engine having more than one cylinder, it has enough suction power to pull the air in through this 20 mm restrictor. But for a single cylinder engine due to lack of suction power, at low RPMs the engine stalls due to insufficient air for combustion. In such a situation, a belly pot has to be placed after the 20 mm restrictor so as to compensate the need of air for combustion. Here on let’s focus on the objective of air intake manifold for a single cylinder engine.

II. Objectives of Work

The objective of the research is to determine the volume, model and fabricate an air intake manifold by abiding the rules put forward by Formula SAE.

Objectives to achieve:

- To control unnecessary rpm spike while throttling.
- To limit noise level to 110 dB at 7500 rpm.
- To find proper orientation by experimentation.

III. Computational Software

As mentioned before the softwares used in the research are Solidworks, Solidworks Flow Simulation and RICARDO WAVE.

Solidworks is used to model the air intake manifold and for CFD analysis, Flow Simulation is used to simulate the flow of air in the manifold.

RICARDO WAVE is an engine simulation software used to simulate the engine performance at various operating conditions of mass flowrate i.e. IM, temperature, A/F ratio etc. After simulation the output given by the engine on various parameters such as power, torque, etc. are obtained. For a standard engine bought from the market, maximum power and torque are known. Simulating the same with the designed IM helps us understand how good the IM is at deriving maximum output.

IV. Modeling &Working

Standard parts used as a part of the assembly are:

4.1 Air Filter

HP 45814 High Performance Bike Air Filter for KTM Duke 200 to filter the air.

Fig.1 Air Filter

4.2 Throttle

For better throttle response suitable throttle body is to be carefully selected.

If using a KTM RC390 engine it is better to use a KTM Duke 200 throttle body since it has lesser diameter. Reason being that at certain point during throttling by 390 TB, at an early point itself the 20 mm restrictor will get saturated with air flow and rest of the throttle travel is of no use, but due to a decrease in diameter of a 200 TB this point shifts to a much later stage increasing the throttle response of the engine.

The fuel injector and air mapping sensor is mounted on the intake runner at the same position as that it was on the bike itself.

Fig.2 Throttle Body of KTM Duke 390

4.3Nozzle

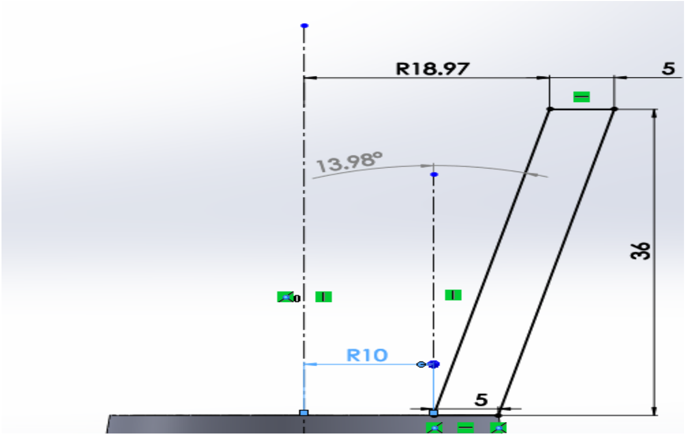


Fig.3 Nozzle Geometric model

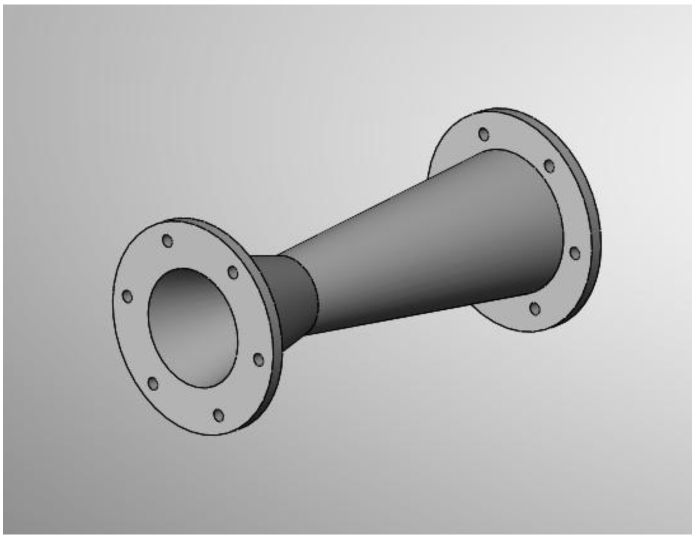


Fig.4 Nozzle Solidworks Model

4.4 Plenum pot

For the plenum pot, the fluid capacity of the same should be varied and analyzed. And the shape of the plenum can be changed as suited to the engine bay's space restrictions.

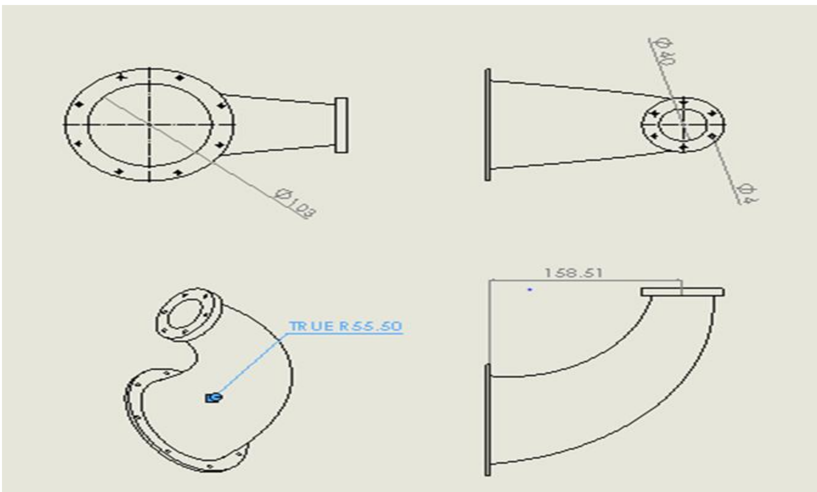


Fig.5 Plenum Geometric Model

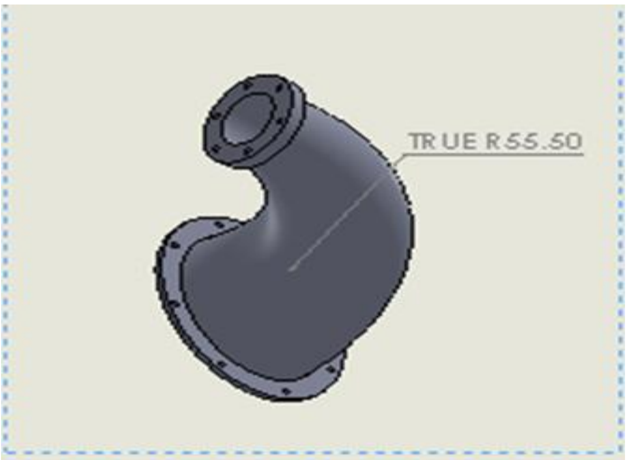


Fig.6 Plenum Solidworks Model

4.5Intake Runner

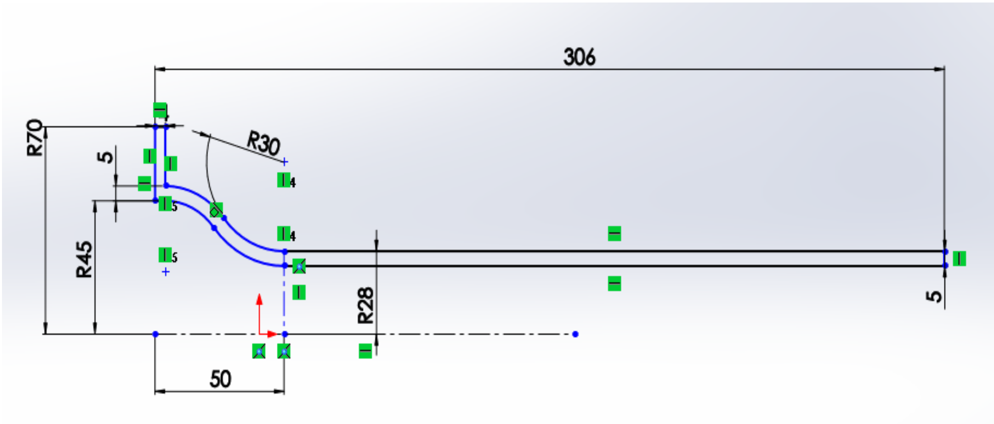


Fig.7 Intake Runner Geometric Model

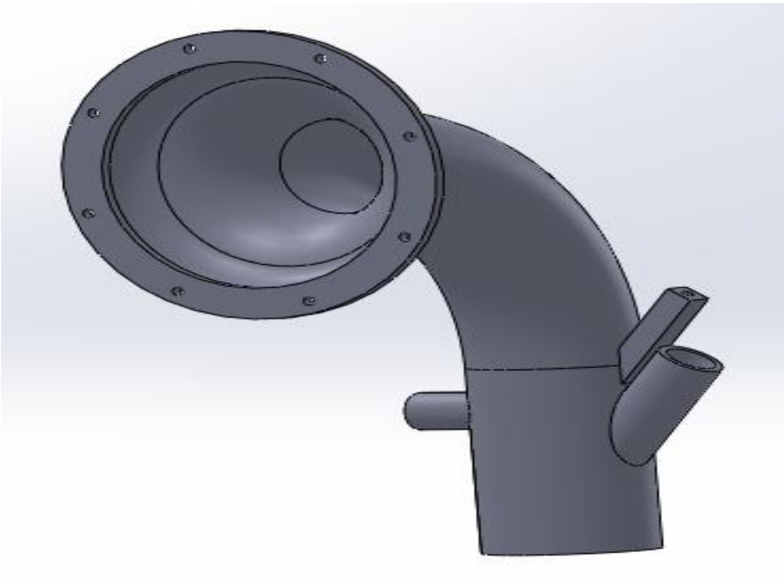


Fig.8 Intake Solidworks Model

4.5.1 Runner Length Calculation

Runner length plays an important role in the plenum efficiency and the proper running of the air intake manifold.

For this we referred many formulas and journals which would help us in calculating the effective length of the runner so as to achieve the best and efficient output of the air intake manifold.

The best effective formula used were

1) David Vizzard's Rule
2) Helmhotz Approximation

David Vizzard's Rule:

- The rule states that to begin with the calculations initially take 17.8cm as a length, this initial length will be considered for a max torque of 10,000 RPM.
- Further as we carry and want to lower the RPM, the condition is that for every 1000 RPM we add a total of 4.3 to the runner length.
- For example, we want to find the runner length of RPM=6000i.e. given is 6000RPM

Thus Runner Length L will be given by the formula31
L=initial runner length at 10,000 RPM + (reduction in the RPM from 10000 to 6000*4.3 added to the length)
=17.8 + (4*4.3)
=35cm or 13.7"

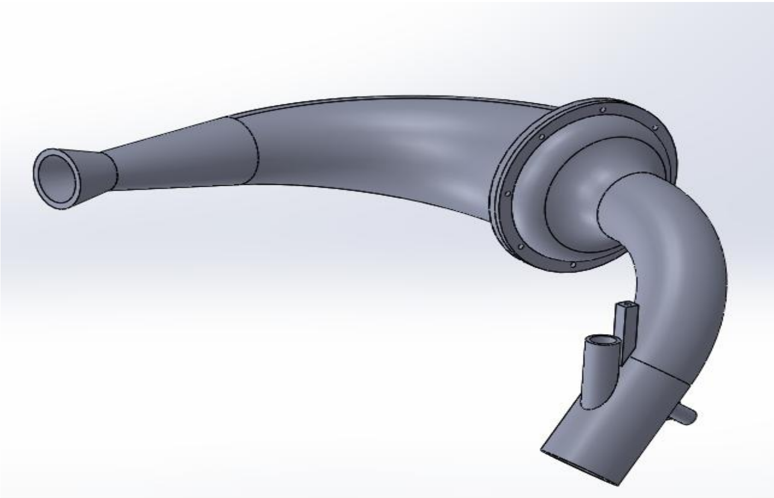


Fig.9 Solidworks Model of Air Intake Assembly

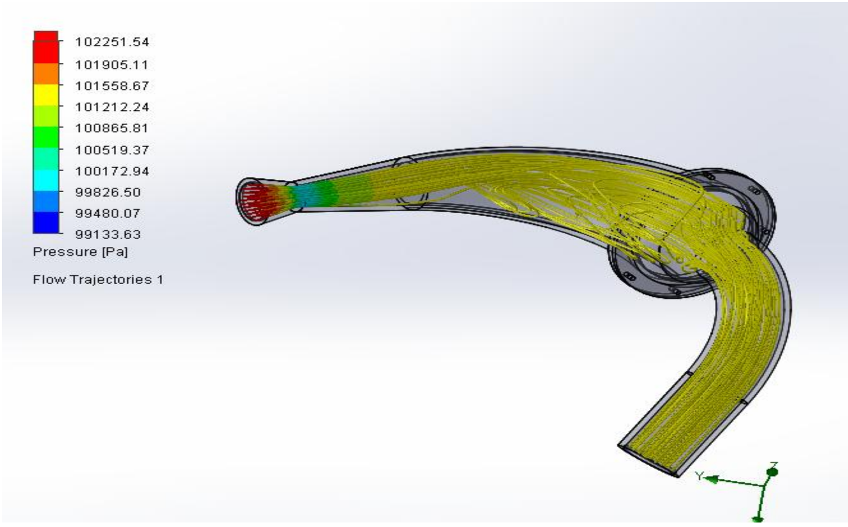
4.6 Working

The volume of the intake manifold needs to suffice the engines requirement and it should derive the best possible output from the engine.

The air chamber of IM is in two part i.e. the nozzle and pot consisting as one and the intake runner. Initially the air will enter through the nozzle where air will lose its pressure energy and gain kinetic energy. But the engine needs to breath at atmospheric pressure and temperature so as to maintain stoichiometric ratio to work efficiently. The kinetic energy gained and the pressure energy lost is normalized with the help of the plenum or belly pot and this normalized air at STP is then delivered to the intake runner. The intake runner is mounted with fuel injector and air mapping sensor. The injector injects fuel i.e. petrol into the stream of air coming from the plenum pot and this charge is then delivered to the combustion chamber. The air mapping sensor keeps a check on the pressure and temperature of the air before entering the combustion chamber. If there is any change in the temperature and pressure of the air the mapping sensor sends this information to the ECU. The ECU, then accordingly changes the fuel discharge. Before modelling the intake manifold the space constrains in the engine bay is to be accounted for.

V. Design Analysis

Using Solidworks Flow simulation of Assembly
Boundary conditions:
At inlet we consider a velocity of 20 m/s for air as minimum speed of vehicle
At outlet we consider the air to exit at atmospheric pressure i.e. 1 atm or 101325 Pa(1.01325 bar)



Flow Simulation

Table 1 Result

Goal Name	Unit	Averaged Value	Minimum Value	Maximum Value
Inlet Mass Flow Rate	[kg/s]	0.024852037	0.024846714	0.024860585
Inlet Av Velocity	[m/s]	20	20	20
Outlet Av Total Pressure	[Pa]	101421.2744	101421.2309	101421.3252
Outlet Av Temperature	[K]	293.3149866	293.3077965	293.3173651
Outlet Av Velocity	[m/s]	12.61353901	12.60733529	12.62052453

The results of the Flow Simulation are as tabulated above for the corresponding parameters. The same model was evaluated in Ricardo WAVE to check the output of the engine. The simulation is shown below with its results.

Network Diagram of the System on RICARDO WAVE

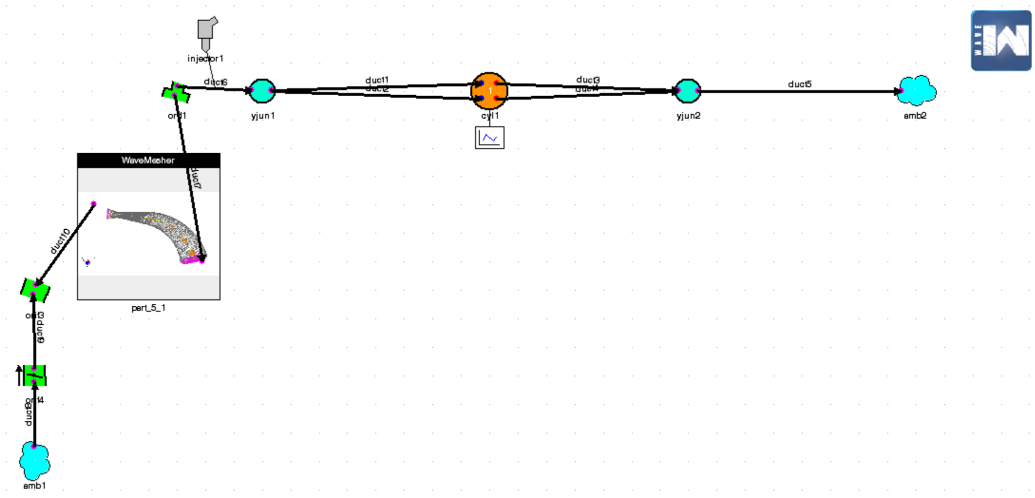


Fig.11 Ricardo Network Diagram

WAVE MESHER is a component of WAVE used to mesh the fluid volume of plenum pot after the fluid volume is converted into the file format of STL (. stl). It is then meshed and imported into the network diagram as shown above in the figure 11.

After running the simulation, the following observations were made

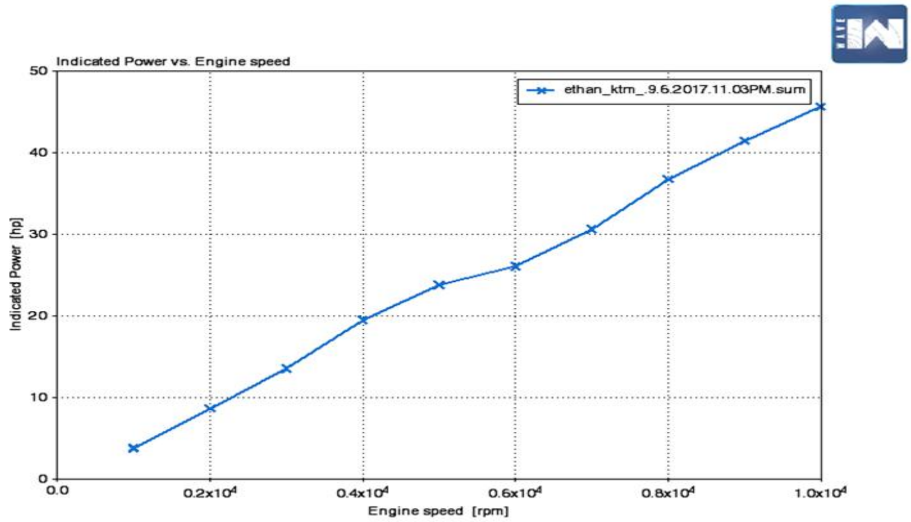


Fig.12 Indicated Power to Engine RPM plot

It was noted that the power produced at 7000 rpm was 31 HP.

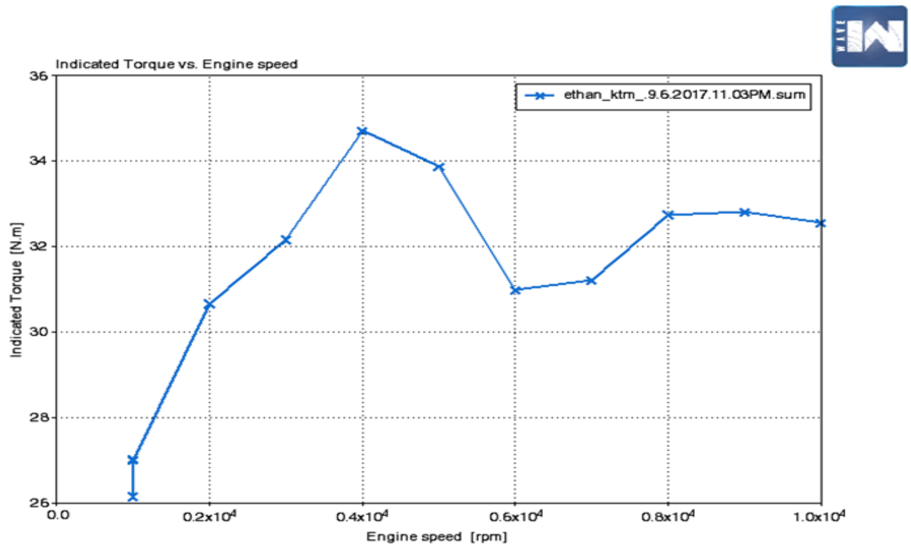


Fig.13 Indicated Torque to Engine RPM plot

As well as for the maximum torque produced by the engine in simulation was 34.6 N.m at 4000 rpm

VI. Conclusion

After conducting analysis on various trails for different volume capacities of the IM, the results that were obtained are as tabulated below;

Table 2 Result

Iterations	1	2	3	4
Inlet Mass Flow Rate	0.024628405	0.024847969	0.024846714	0.024796678
Inlet Av Velocity	20	20	20	20
Outlet Av Total Pressure	101419.7627	101421.2019	101421.2309	101421.6673
Outlet Av Temperature	293.3272036	293.3275637	293.3173651	293.3169982
Outlet Av Velocity	12.52097473	12.59815542	12.60733529	12.66166389
Indicated Power (HP)	31.46	31.22	32	31.5
Indicated Torque (N.m)	34.35	34.5	34.66	34.25

From the tabulated result as above we concluded that the 3rd trial would give out the best performance
Good correlation in terms of flow rate was observed between the simulations and experiments.
Rapid prototyping is the most appropriate way to manufacture the IM, as it gives a very smooth finish to the final object, which in our case is essential. Even rapid prototyping gives accurate dimensions which ensures accuracy in restrictor diameter and uniform angles of converging and diverging cones over its entire length.
Material used for fabricating the IM can be ABS, PLA or Nylon 6,6 based on the strength needed of the IM depending on the orientation and the entire load on the bends, mating faces, etc.

We thank Abhinay Mane from 3D Print Wizard and Imaginarium 3D printers for their support and advice on manufacturing aspects of the intake manifold and helping us neatly fabricate the same as per our design.

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