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Design of Integrated Intake Manifold for Formula Race Car

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Abstract— The paper deals with the design procedure of an integrated intake system, adapted to a racing car engine. The intake manifold must contain the imposed constraint for the airflow in the shape of a single circular restrictor placed between the throttle and the engine to limit its power. The flow and the pressure loss reduction in the engine intake region were investigated with computational fluid dynamics software. Two different materials were integrated in the design and manufacturing of the intake manifold. The paper validates the advantages of integrated intake manifold over other intake manifolds. The paper also investigates the effects of intake runner length on the performance characteristics.

1. INTRODUCTION

Initial research focused on understanding and objectively comparing the wide range of naturally aspirated intake manifold geometries exhibited on Formula SAE cars. In an effort to create a fuel-efficient, lightweight, cost-effective, and fast automobile, students carefully design each component of their vehicle. This paper focuses on the design and manufacture of the intake manifold system by integrating two different materials for a Formula SAE car.

The primary function of the intake manifold system is to deliver combustion air to the engine. Specifically, the primary design goal is to distribute the combustion mixture evenly to each intake port, as doing so improves the engine's ability to efficiently and effectively produce torque and power. The geometric design and material properties of the intake system affects the volumetric efficiency of the engine, and thus directly affects the performance of the vehicle. This paper has a major focus on the selection criteria of materials for intake manifold and integrating different materials in order to achieve their benefits.

The performance of intake manifold widely depends on the material properties, geometric shape and geometric parameters of intake system. The most widely used materials for intake manifold are :

- Aluminium
- Carbon fiber
- FRP
- ABS Plastic
- Mild steel

Depending on the characteristics and advantages, two materials were chosen so as to obtain better thermal efficiency and also considerable weight loss.

1. Carbon fiber (Plenum)
2. Aluminium (Runners)

Advantages of Carbon Fiber:-

- Drawing comparison with different materials of same thickness it has highest stiffness and strength.
- It is very light in weight.
- It has good corrosion resistance.
- It has considerable low coefficient of thermal expansion.
- Due to its low density, it can be easily machined using various tools.

Advantages of Aluminium:-

- heat conductivity.
- When compared with other metals it is very light in weight.
- It shows excellent resistance to corrosion.

Inlet manifold surface finish:

"Smooth internal walls, compared with those with a rough surface finish, produce the least viscous drag on the movement of charge-whether it is pure air or a mixture of air and fuel particles-consequently marginally higher volumetric efficiency can be obtained with smooth induction tracts" .

"Slow moving air-fuel mixtures tend to precipitate fuel particles, in particular the heavier ones, onto the walls of the tract, they then tend to merge into surface films. This effect becomes more pronounced with increased throttle opening. With rough surface finishes the tract offers considerable resistance to the flow of liquid particles suspended in the air stream near the walls, these particles then cling to the walls where they then spread and merge with each other to form films. As these films thicken they become unstable so that they are dragged back into the main air stream and immediately new fuel particles will be thrown onto the tract walls where they again accumulate before repeating the breakaway cycle. This process of build-up and breakaway of liquid fuel from the tract walls produces a continuous and effective mixing mechanism for the charge as it moves towards the inlet port. Conversely, a smooth surface finish reduces the surface flow resistance keeping the film thickness to a minimum, consequently there will be very little mechanical break-up or mixing of the fuel particles with the air stream until the erratically suspended fuel particles impinge on the underside of the inlet valve head."

The following design procedure was implemented to achieve good design of intake system:

1. Design constraints / requirements

2. Design objectives

3. Design methodology

4. Design validations

2. DESIGN AND ANALYSIS

1. Design Constraint:

- Weight is also an important factor for Race car and high-performance car. Use of Turbocharger increases the cost and weight of the vehicle.
- Use of 20 mm restrictor reduce the performance of vehicle
- Spatial constraints as per FSAE rules

2. Design Objectives:

- To provide the smallest possible induction tract diameter that will maintain adequate air velocity at low speed without impeding volumetric efficiency in the
- upper speed range
- To create as little internal surface frictional resistance in each branch pipe as possible
- To provide sufficient pre-heating to the induction manifold for cold starting and warm-up periods
- To provide a means for drainage of the heavier liquid fraction of fuel
- To provide a means to prevent charge flow interference between cylinders as far as possible
- To provide a measure of ram pressure charging

3. Design Methodology:

❖ Design parameters:

a. Restrictor

- To minimize pressure drop across restrictor
- Increase mass flow rate

b. Plenum

- Even distribution of charge
- Reducing losses
- Increasing vaporization

c. Runner length

- Forced induction and obtaining power at high RPM

d. Runner diameter

- Forced induction and obtaining power at high RPM.

❖ Design Calculations

a) Throttle Body

Max .RPM due to mass = 0.0056(CI)- 8.89(CI)+ 11527

where,

CI – Cubic inch. Diameter of Engine

CFM Required= (CI*RPM*Volumetric efficiency) / 3456

Avg. CFM gives size of Throttle Body

b) Restrictor

- Use of DE-LAVAL NOZZLE to minimize the pressure drop.
- Converging angle of 14 degree is used
- Diverging angle of 7 degree is used
- Net pressure drop of 613 Pa is achieved

c) Plenum

- To create as little internal surface frictional resistance in each branch pipe as possible.
- To provide sufficient pre-heating to the induction manifold for cold starting and warm-up periods
- To provide a means to prevent charge flow interference between cylinders as far as possible

d) Runner Length

Using Steve Magnate Rule,

N * L = 84000

where, N–RPM at peak torque

L–Length of Runner

e) Runner Diameter

Using David Vizard Rule,

D = √(RPM * Displacement * VE) / 3330

where, D-Diameter of Runner

VE-Volumetric Efficiency

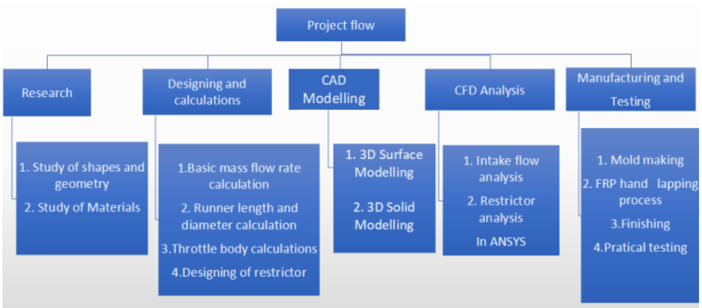


Fig 1 Design Methodology

❖ CAD Modelling:

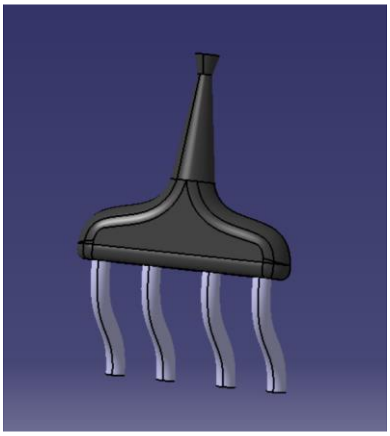


Fig 2 Down draught Intake CAT model

Integrated intake manifold:

The upper plenum is built by using carbon fiber. Carbon fiber provides adequate strength and rigidity to the intake manifold. While using aluminium as upper plenum it leads to following disadvantages :

- It is difficult to manufacture intricate shapes using aluminium
- The inner weld tends to disturb the flow of air fuel charge and eventually leads to pressure losses.
- The weight of aluminium is comparatively greater than carbon fibre.

Due to above disadvantages carbon fibre is selected over aluminium for the upper plenum body .
Carbon fibre provides :

- Better moulding ability and can be used to form any smooth shapes.
- It reduces the surface frictional losses due to smooth inner surface
- Maintains the static pressure distribution in intake plenum.

The lower plenum body is built by using aluminium . Lower plenum must provide optimum vaporization and proper mixing of the air fuel charge. The high thermal conductivity of aluminium makes it the best selection in order to satisfy the design requirements. Therefore, aluminium is selected over carbon fiber for the lower plenum body .

Aluminium provides :

- High thermal conductivity of aluminium provides better vaporization of charge
- Runners have less bends . Hence, it is convenient to use aluminium for runners of intake system
- It avoid the problem of cold start and preheating.

4. Design Validations:

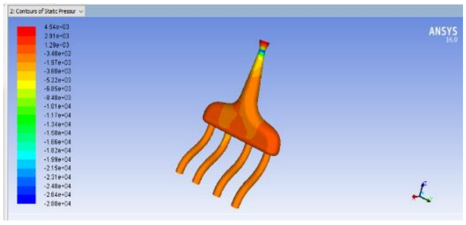


Fig 3 Intake manifold CFD (Static pressure distribution)

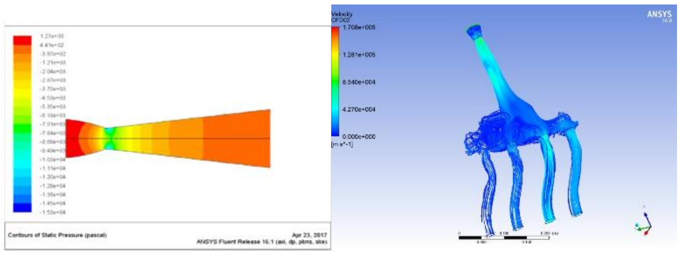
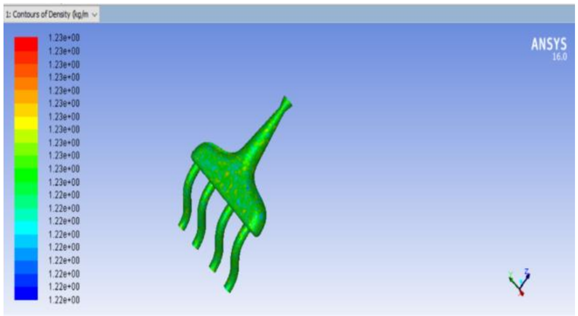


Fig 4 Venture pressure drop CFD



3. CONCLUSION

The reveals the implementation of integrated intake system by keeping parts simple, using best suitable material and keeping manufacturing processes to minimum. Numerical Analysis shows the equal distribution of Static pressure inside the intake. The use of composites and integrated design has lead to better heat conduction & performance of the vehicle. Carbon Fiber Plenum and Aluminium Runner has found out to give maximum power output and optimal heat conduction (Validated using Numerical Analysis). The use of bulky turbocharger and supercharger system was neglected and considerable increase in volumetric efficiency, power and performance was found.

- Numerical Analysis shows the equal distribution of Static pressure inside the intake.
- The pressure drop obtain is minimal at the restrictor, thereby reducing the losses
- The use of composites and integrated design has lead to better heat conduction & performance of the vehicle

- Use of Ram Induction Theory has eliminated the use of turbocharger and reduced the weight & cost of the system
- Carbon Fiber Plenum and Aluminium Runner has found out to give maximum power output and Optimal heat conduction (Validated using Numerical Analysis)

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