Development and Implementation of Multi Element Aerodynamic Devices with Drag Reduction System for a Formula Student Vehicle

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Abstract- **The design, manufacturing and validation process of an aerodynamic package for a formula student vehicle is described.A review of a formula SAE rules to develop realistic parameters to produce maximum downforce within the stated acceptable limits of drag and speed.Designing and implementation of sidepods in order to increase aerodynamic efficiency and assist engine cooling is stated.The net effect of this package on the performance of the vehicle is predicted using various softwares and then validated in actual testing with DAQ devices.The underbody is introduced to produce efficient downforce with minimal drag. An effort has been made in order to reduce wheel drag by appropriate flow over the racecar.**

Keywords- Aerodynamics, Wings, Underbody, Sidepod, Downforce, Drag, Validation.

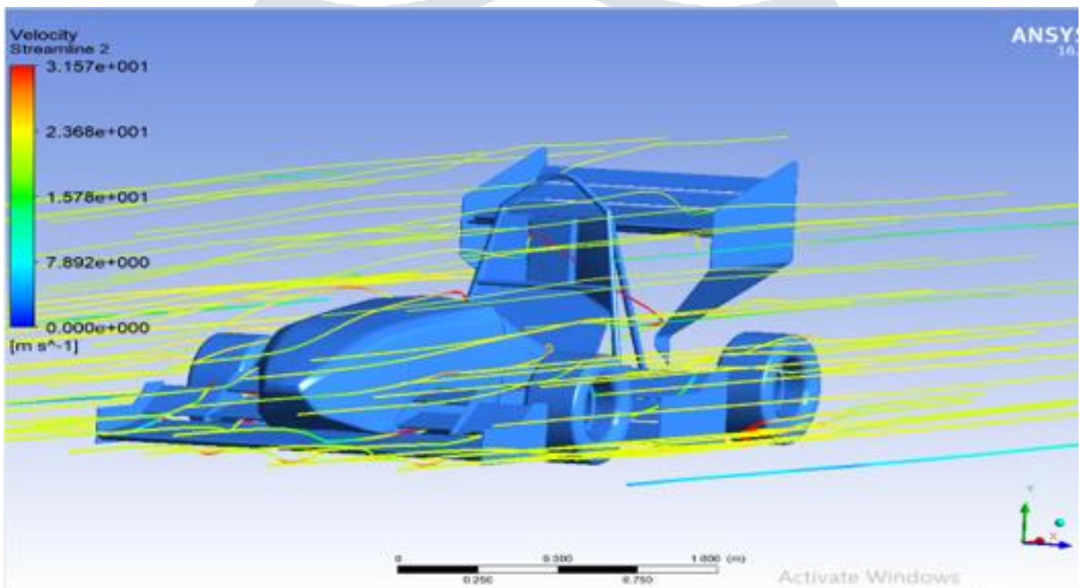


Fig.1. CFD of Formula Style Vehicle

I. INTRODUCTION

Formula Student is the biggest student competition in the world, around 1000 universities around the world boast of a functional formula student team. FS competitions are held across the globe, which attract a host of students from various domains such as Mechanical, Electrical, Electronics and Production. To compete in formula student competitions students must develop a small Formula-style, prototype racecar that must be an open-wheeled racecar with the prospect target buyers being an average weekend racer. Each student team must follow a strict series of rules to encourage fair competition as well as promote astute problem solving skills. This competition prepares university-level engineering students for the automotive industry by exposing and involving the students in research, design, manufacturing, testing, developing, marketing, team management, and financial management. Students involved in this competition are able to actually implement the textbook theories and principles learned in class to real hands-on projects. During the competition, each team is judged on their design as well as the performance of the overall vehicle. Moreover, the team's business structure and organization is judged. We design the components, and then assemble them the most efficient way. All the components and the principle used are explained below. The aerodynamic design is based on the Bernoulli's Equation showing the relation between the pressure and velocity. The flow of air with high velocity below the airfoil and of low velocity above the airfoil induces a downward force called **'**Downforce**'.**

A. Problem Statement: The aim of Team Stallion Motorsport was to frame a formula student race car with high dynamic performance by upholding reliability. The desire of the team to introduce new innovative ideas in the field of race car promotes to install aerodynamic package.
To set maximum performance limit for the aerodynamic package; the sacrificial drag and the required downforce was calculated.

1.Sacrificial drag

It can be explained as the amount of power drop engine can afford in order to compensate for the drag without compromising a lot on a vehicle power performance.

$$\textit{Brake kW absorbed} = \frac{C_D \times A \times v^3}{1{,}633}$$

2.Required Downforce

To excel in the formula student dynamic event, vehicle has to show dynamic performance on straight as well as curved path. In order to corner the vehicle at high speed , downforce is necessary as explained earlier. The amount of downforce required is calculated by targeting a particular lap time for Skid pad event in the competition.

These obtained target values are used for designing of aerodynamic elements.

B.Objective

We require maximum downforce (force in vertical direction) with optimum drag (force in horizontal direction) limits. By this years design calculations we have as our car body (without aero devices) drag. By subtracting it from our allowable drag 464 N, we have as a allowable drag for aero devices.

As downforce increases traction and it leads to stability, we keep it as maximum as possible

C. Constraints :

In plain view, no parts of any aerodynamic device wings, undertray or splitter can:

Max span allowed :- 1300 mm for front and 1080 mm for rear wings.

Max length allowed:- 762 furthermost from front tyre and 305 mm back from rearmost of rear tyre.

Max height allowed :- 250 mm for front and 1200 mm for rear wings.

Radii of edges of Aerodynamics devices :All edges including wings, endplates & undertray that could contact a pedestrian must have a minimum radius of 1.5 mm

Keep out zone:-

No part of the vehicle may enter a keep-out-zone defined by two lines extending vertically from positions 75mm in front of and 75mm behind, the outer diameter of the front and rear tires in the side view elevation of the vehicle, with tires steered straight ahead. This keep out zone will extend laterally from the outside plane of the wheel/tire to the inboard plane of the wheel/tire.

D. Scope:

1. Determination of most efficient aerodynamic configuration and geometry.
2. Determination of optimal values of Cl, Cd and frontal area as well as angle of attack.
3. Determination of attachment points at chassis interface
4. Design synthesis and real time simulation of complete and functional aerodynamic system.
5. Maintain high level of adjustability for tuning of aerodynamic system.

E. Methodology:

1. Designing of components and selection of materials:

After identifying the problems related to the projects, the project work was embarked by designing the parts, analyzing the forces acting on them. The plan was to pick the material with high rigidity, high strength to weight ratio, and with less cost.

2. Manufacturing of components:

The manufacturing was done with accepted production targets such as :

1. Minimization of manufacturing errors
2. Optimum usage of material
3. To trivialize the cost of production.
4. To downplay the compliances.

3. Organization of Dissertation:

To enhance the performance of car in the dynamic field by diminishing the previous fault was the reason for the selection of project in the area of aerodynamics. To satisfy this aim, intense study in the dynamic arena and regarding up gradation of suspension geometry were accomplished. The scrutiny was done regarding the problems faced by FSAE teams. The cross examination was carried out with the help of mentors. Immense testing of components were carried out to know practically problem faced in assembly. Data Acquisition System was used to validate the dynamic results.

II.THEORETICAL BACKGROUND

All the components and the principle used are explained below.
The aerodynamic design is based on the Bernoulli's Equation showing the relation between the pressure and velocity. The flow of air with high velocity below the airfoil and of low velocity above the airfoil induces a downward force called

'DOWNFORCE'

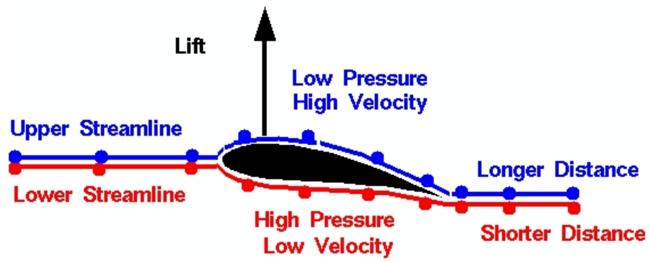


Fig.2. Flow over Aerofoil

AComponents:-

1) **Rear Wings**:-
Rear wings work on Bernoulli principle. They generate downforce which provide traction to tyres and effectively increase stability and cornering performance.

2) **Front wings**:-
Front wings redistribute total downforce level between the front and the rear tyres permitting the race engineers to correct understeer or oversteer to desire aero balance. The intention is also to maximise the quality of flow to the undertray and diffuser.

3) **Undertray with Diffuser:-**
Undertray covers lower body of car. It also contains diffuser at rear end. Diffuser generates downforce using Bernoulli principleby creating venturi. It utilizes high velocity flow generated below front wing.

4)Sidepods:-
A smooth rounded outer surface at each side of racing car between the front and rear wheels, which provides and aerodynamic cover for the air inlet and radiator.
In some advanced designs downforce is also generated by sidepods by placing airfoils under them.

5) Vortex Generators:-
Vortex generators generates vortices which are high velocity, high energy flow which separates streamlined and turbulent flow.

III. CALCULATIONS, ITERATIONS AND ANALYSIS

1) Rear wing

Objectives for the design of rear wing
1. To act as largest unit producing downforce
2. Decrease the amount of wake generated by flow energising
3. To use Drag Reduction System when necessary to vary drag/downforce ratio
4. To bring net centre of pressure near to the centre of gravity.

Aerofoil Numbers-
A. NACA 6409
B. GOE 448
C. SELIG 1223

A) NACA6409 :

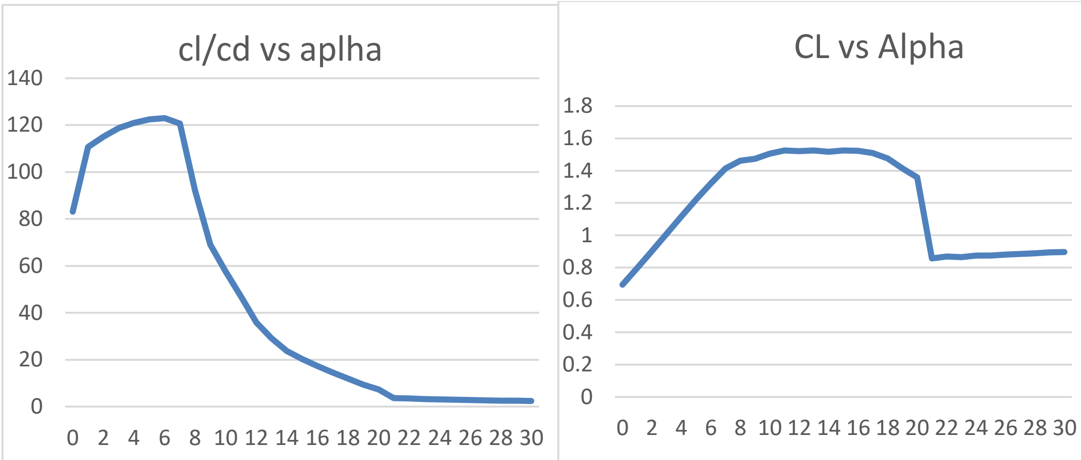


Fig.3. NACA 6409 Characteristic Curves

B) NACA 6412 :

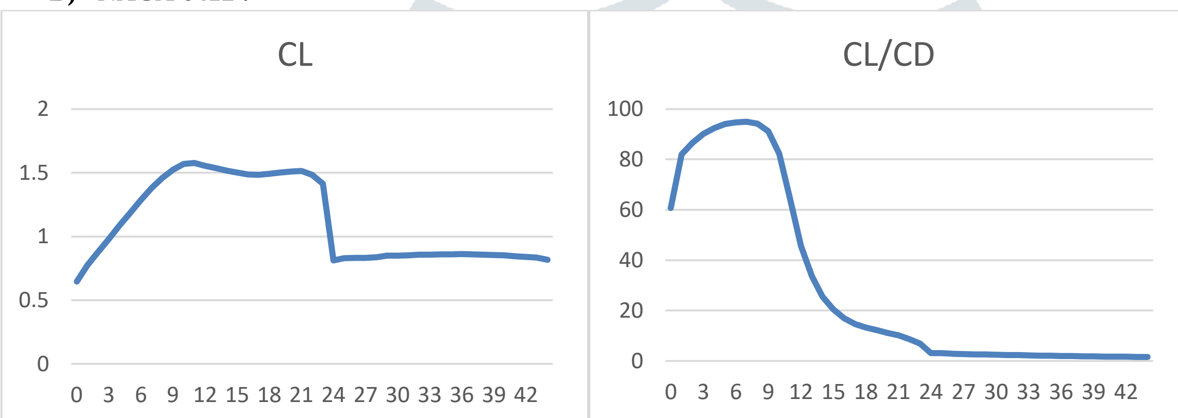


Fig.4. NACA 6412 Characteristic Curves

D) Selig 1223+

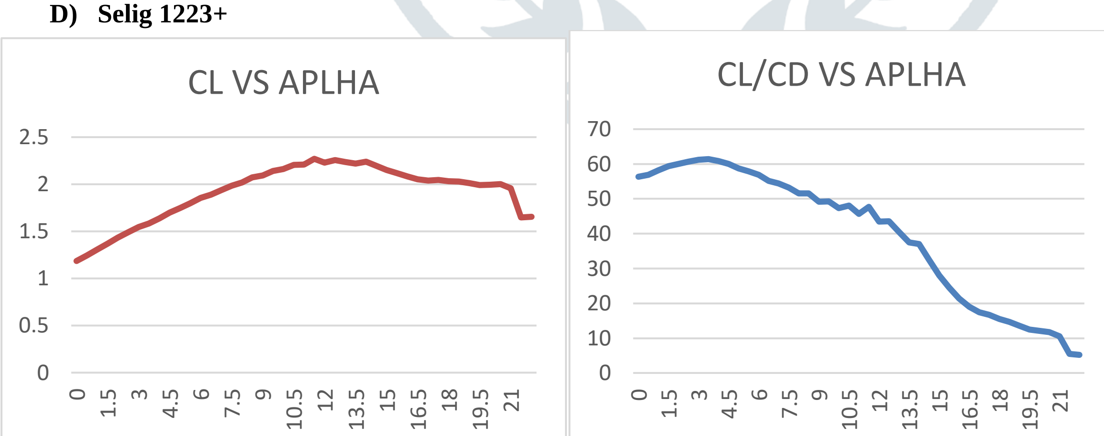


Fig.5. SELIG 1223+ Characteristic Curves

For the criteria of<u>maximum downforce</u>, <u>S1223 is selected as the main wing.</u>

By graphs it can be clearly seen that CL of S1223 is higher than that of any other airfoils. It is selected as, it gives 2.25 lift coefficient which is best for generating downforce.

4.1.2 Secondary flaps

A) LA 5055
B) NACA 6412
C) GOE 464

A) GOE 464

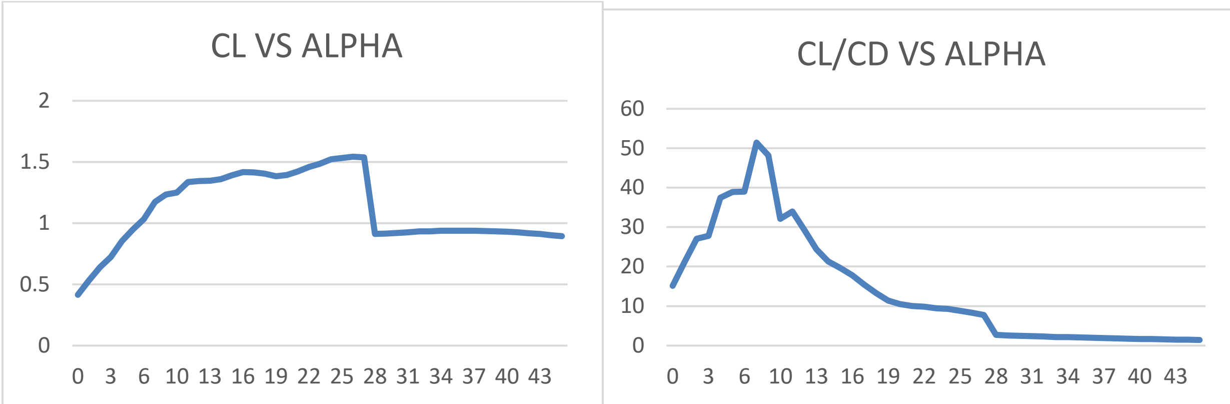
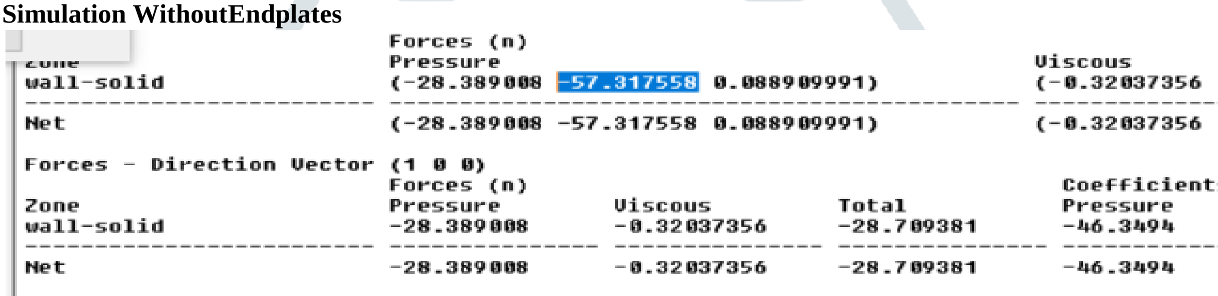


Fig.6.GOE 464 Characteristic Curves

For Flaps to create maximum downforce we selected airfoils which gives us high downforce at a higher angle. So GOE 464 as our secondary flap which gives us about 1.5 CL at 32 degree is selected.

a) Simulation WithoutEndplates



```
                            Forces (n)
zone                        Pressure                                          Viscous
wall-solid                  (-28.389008 -57.317558 0.088909991)               (-0.32037356
--------------------------  ------------------------------------------------  ------------
Net                         (-28.389008 -57.317558 0.088909991)               (-0.32037356

Forces - Direction Vector   (1 0 0)
                            Forces (n)                                          Coefficient
Zone                        Pressure        Viscous         Total             Pressure
wall-solid                  -28.389008      -0.32037356     -28.709381        -46.3494
--------------------------  --------------  --------------  --------------    ------------
Net                         -28.389008      -0.32037356     -28.709381        -46.3494
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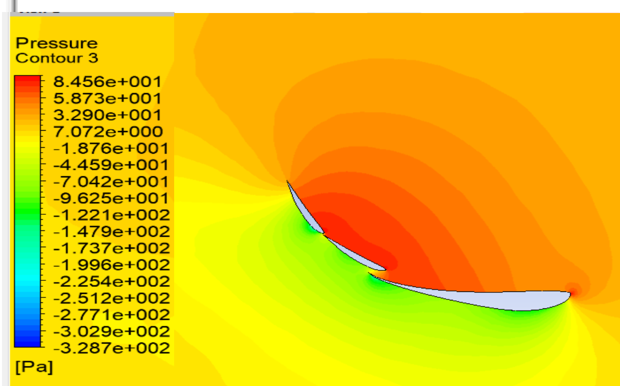

Fig7 -Rear wings pressure contour

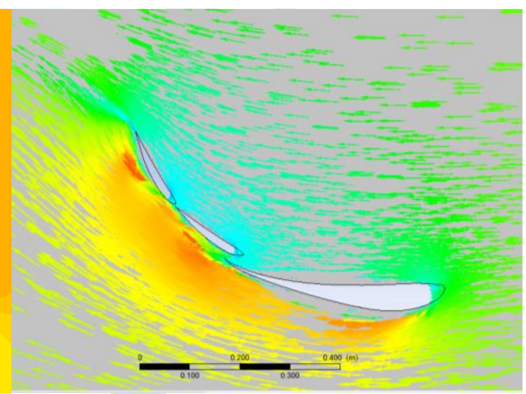

Fig8- Rear wing flow vectors

b) Simulation WithEndplates

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                              Forces (n)
Zone                          Pressure                                      Viscous
wall-solid                    (-32.797005 -92.323868 0.17120296)            (-0.76216638
---------------------------   -------------------------------------------   ------------
Net                           (-32.797005 -92.323868 0.17120296)            (-0.76216638

Forces - Direction Vector     (1 0 0)
                              Forces (n)                                                 Coefficient:
Zone                          Pressure        Viscous         Total          Pressure
wall-solid                    -32.797005      -0.76216638     -33.559171     -53.54613
---------------------------   ------------    ------------    -----------    -----------
Net                           -32.797005      -0.76216638     -33.559171     -53.54613
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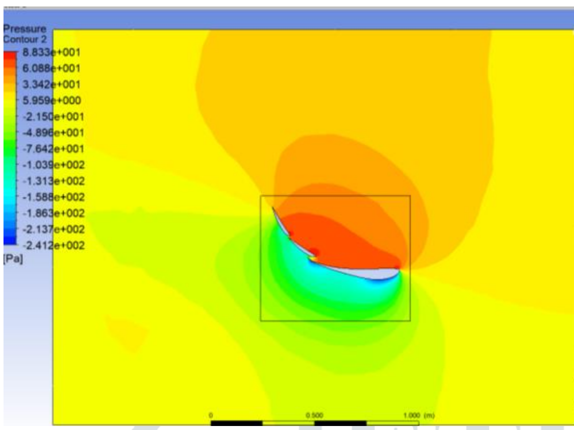

Fig.9.- Rear wings pressure contour

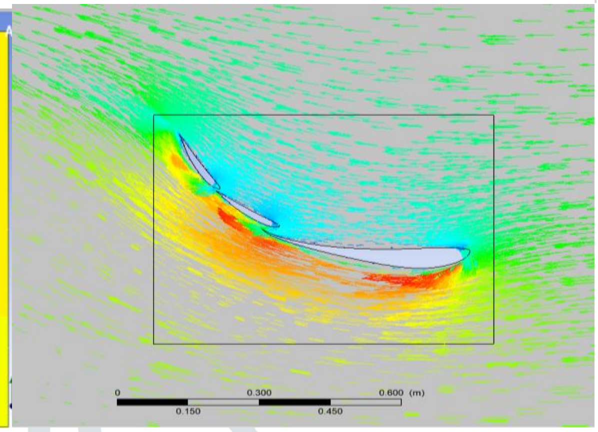

Fig.10. Rear wing flow vectors

2)Front wing:-

Front wing produces downforce to keep the car from taking off. In other words, the airfoil of a frontwing is profiled so that it helps keep the car on the ground and wheels in contact with the surface.

The front wing is designed to produce downforce and guide the air as it moves toward the body and rear of the car. Flaps and winglets may also be used to guide the air past the wheels to the radiator inlets and underbody. Theturbulent air moving toward the rear of the car will impact the efficiency of the rear wing. The efficiency of the wing is based on the following:

Objectives for front wing design-

1. To produce major downforce on the front wheels
2. Guide the air past the wheels towards the radiator fins.
3. To energise the flow moving towards the rear vehicle
4. Reducing turbulence drag due to rotating tire deflecting the airflow.
5. permitting the engineers to correct understeer or oversteer by desire aero balance.

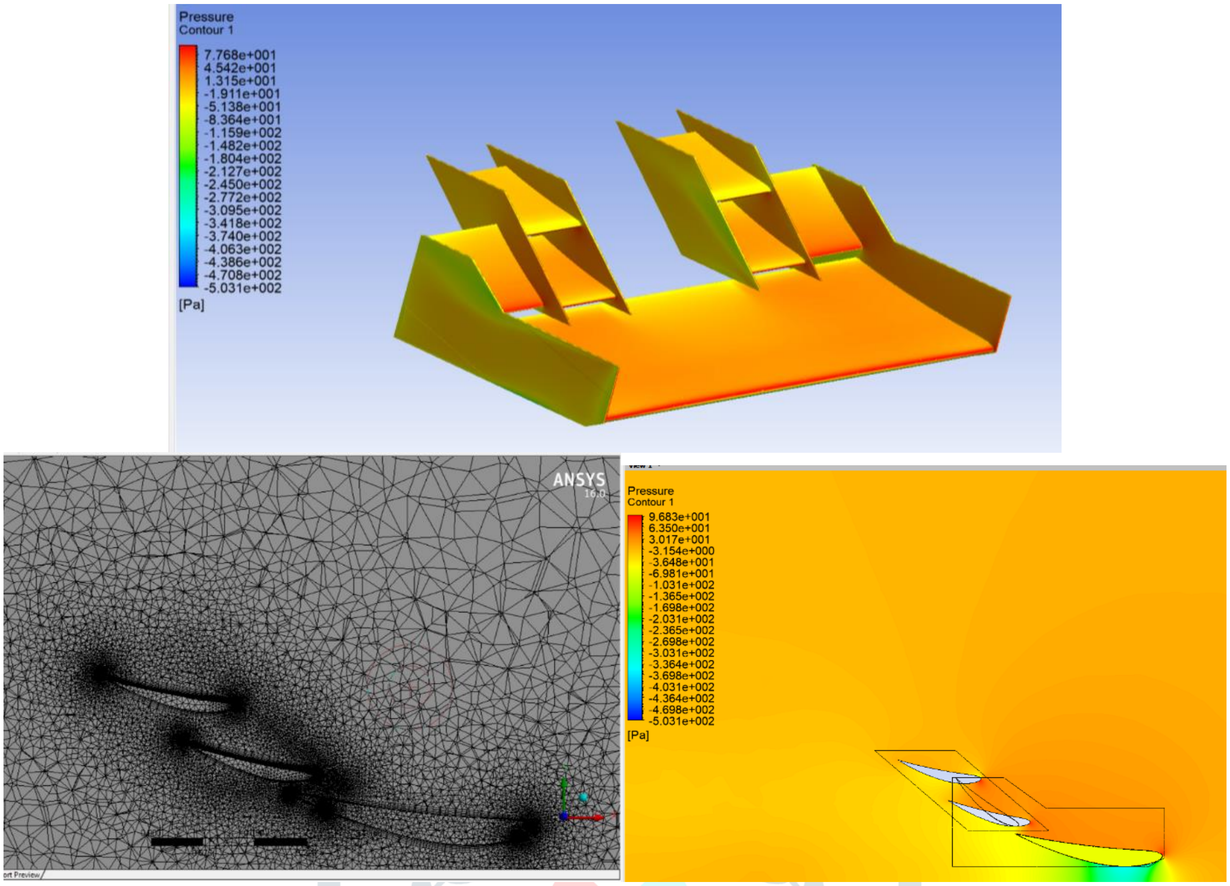

Fig.11. Front wing meshing and pressure contour

3)Undertray:-

The idea behind undertray is to use the close proximity of the vehicle with ground to create ground effect , that is to cause the venturi like effect under the vehicle . like venturi there is a nozzle which increases the velocity of air underneath the vehicle and create low pressure . using this low pressure under the vehicle and high pressure above the vehicle downforce is created.

Objectives for underbody design.

1. To act as major source of downforce
2. To achieve maximum Cl/Cd ratio by diffuser design
3. To keep centre of pressure near the centre of gravity.

Undertray containing diffuser is the most efficient way to generate downforce.

A) 2D Analysis:-

Final Iteratiom

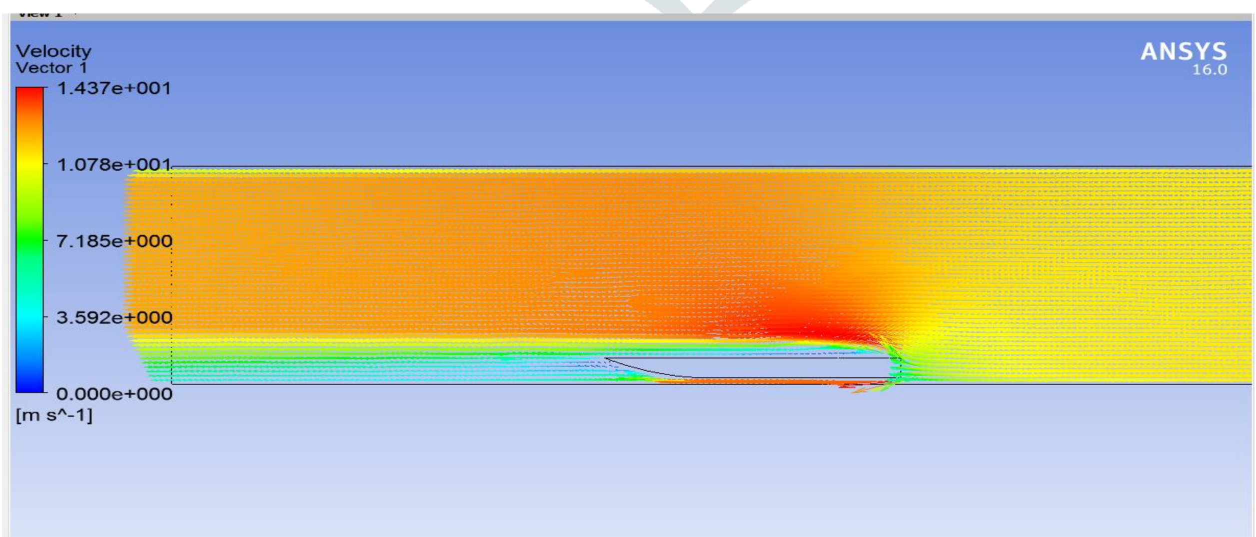

Fig.12. Undertray Iterations (2D)

The above 2Diteration gives best flow separation with high velocity in undertray.

B) 3D analysis

Final iteration

```
Forces
                          Forces (n)
Zone                      Pressure                                         Viscous
wall-solid                (0.088563241 -28.21298 -12.586179)               (0.0047034691
s                         (-0.21194449 31.811478 0)                        (-0.002022840
-------------------------  -----------------------------------------------  -------------
Net                       (-0.12338125 3.5984974 -12.586179)               (0.002680629

Forces - Direction Vector (1 0 0)
                          Forces (n)                                         Coefficient:
Zone                      Pressure        Viscous         Total              Pressure
wall-solid                0.088563241     0.0047034691    0.09326671         0.001171437
s                         -0.21194449     -0.0020228401   -0.21396733        -0.00280341
-------------------------  --------------  --------------  ---------------    ------------
Net                       -0.12338125     0.002680629     -0.12070062        -0.00163197
```

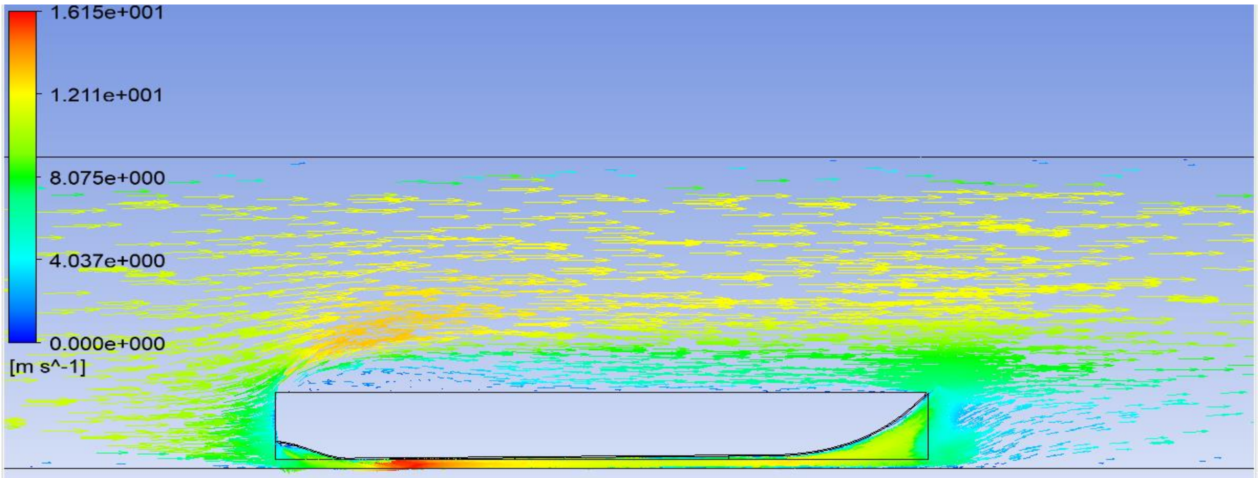

Fig.13. Undertray Iterations (3D)

5. Sidepods

Sidepods are the air ducts provide on the both sides of vehicle with aerodynamic design in order to maximize the airflow.

In the lest sidepod, radiator is to be placed. Exhaust is mounted inside the right sidepod.

The objectives for sidepod design –

1. To maximize the airflow for the cooling of Heat exchanger and the exhaust.
2. To guide the outlet air on the engine for external cooling.
3. To guide and deflect airflow from the rear wheels in order to decrease the parasitic drag.
4. The lower part of sidepod will be in continuation with underbody and will play role in increasing the downforce.

Initial Iterations and analysis-

Iteration 1

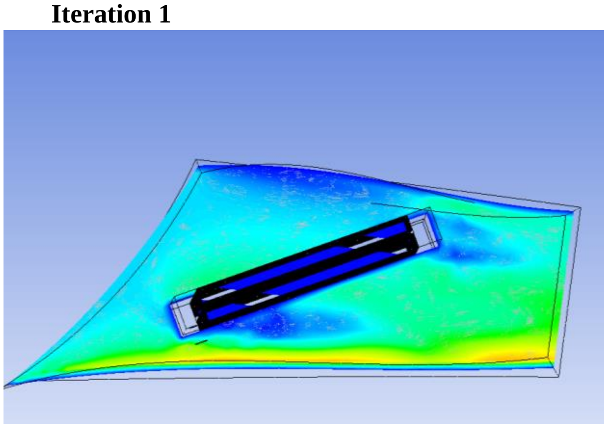

Fig.14.Sidepod velocity Contour

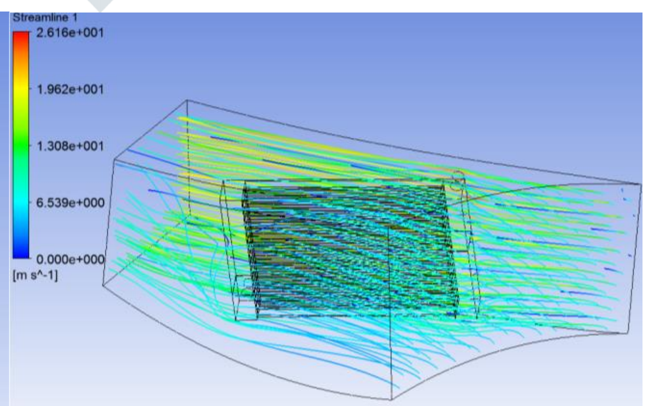

Fig.15. Sidepod Streamlines

IV. Validation

The wings were mounted on a wooden plank which was mounted on load cells. This assembly was rigidly attached to a Commercial four-wheeler and the car was driven with particular speeds which was to be tested. The results from the load cells were plotted and the following results were obtained:

A. Front Wing.
Calculated Downforce : 109 N
Actual Downforce : 101 N

B. Rear Wing
Calculated Downforce : 74 N
Actual Downforce : 68 N

Fig.16. Attachment of Wing on Commercial Vehicle for Validation

V CONCLUSION

The Design, Fluid Flow Analysis, and Validation of a full fledged Aerodynamic package for a Formula Student vehicle was described.The objective of keeping the drag minimum and the downforce was successfully achieved. The advantage to the team design in the ease of adjustment allows thewings to be changed while driving, to compensate for various dynamic loading. The results of CFD Simulations of the whole package and the ones tested in real were validated successfully.

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