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Modification of airflow around a FSAE Race car using sidepods to increase the downforce on the car

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Abstract- *Aerodynamics pertaining to vehicles focuses on improving the drive-ability of the vehicle while also reducing losses due to air drag. This paper focuses on maximizing the cornering performance of the formula student race car with slight modifications to the airflow around the vehicle and meagre addition of weight. The undertray produces downloads by altering the velocity of air flowing underneath it. The sidepods act to reduce flow velocity above the undertray, thus increasing the pressure above it. This leads to an increased pressure difference over the surface of the undertray which translates to increase in downforce. The car is able to have a 10% decrease in lap times on a 500m racetrack.*

Keywords- *downforce, drag, aerodynamic efficiency, sidepods, undertray*

I. INTRODUCTION

SPCE Racing is a student organization which designs, manufactures and validates an open wheeled race car. The car is required to maneuver through tracks which have a lot of turns. Due to this car requires maximum grip on the tracks which can be obtained through extra vertical loads. As a part of improvement of performance, the team intends to design, manufacture and validate a downforce producing device. Downforce is the vertical force that is produced from aerodynamic loads[1]. This additional force acts to counter the centrifugal force generated while cornering. It allows car to travel through a corner at a speed due to which it would have otherwise slipped. Drag force is the force generated in the opposite direction the car is moving which acts to retard the car. The tire specification enables evaluation of the benefit of increasing the normal reaction using downforce produced in a way similar to that shown by [2]. A tire's coefficient of friction will increase with added vertical force. Without adding weight to the vehicle, downforce enables faster cornering which causes reduction in lap time.

1.1 Aerodynamics

Aerodynamics plays a crucial role in providing additional performance to a race car. It is the study of forces and moments created by the interaction of air with a solid body. Historically, drag reduction was the only concern in the beginning. Later on, the entire car was designed in order to provide a smooth, streamlined airflow around the car. This led to generation of negative aerodynamic lift i.e. downforce of race cars. In recent years, vehicle aerodynamics pays attention to the utilization of the ground effect principle. Ground Effect is the cause for additional downforce when the underbody of the car is in close proximity to the ground which acts as a fixed body. Aerodynamics parts which utilize the ground effect give large values of the downforce compared to weight added to the vehicle. Lightweight aerodynamic parts can reap big performance gains in reducing lap times.

$$P_1 + \frac{1}{2}\rho V_1{}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2{}^2 + \rho g h_2$$

Figure 1. Bernoulli's Equation

Equation shown in fig 1represents the Bernoulli's Equation, which relates pressure, kinetic and potential energies at two different points in space. We can observe that at any given point, pressure and velocity are in inverse proportion. This means that If velocity increases at any point then the pressure would decrease at that point. This concept is use to generate pressure difference across the aerodynamic difference which effectively generates the required downforce.

1.2 Undertray

Undertray is a downforce producing device which uses ground effect. Undertray is bolted on the chassis of the car. This location of the undertray in vertical direction is important because it is able to take the advantage of the ground effect which helps in lowering the pressure under the vehicle. This ultimately results in increasing the downforce. The undertray consists of three major divisions: Inlet, Throat and the Diffuser. Inlet portion of the undertray determines the mass flow of air through the undertray. The velocity of air entering through the inlet goes on increasing till the throat, which is the portion where maximum velocity is reached. Diffuser of the car helps to slow down the air i.e. it expands the air under the vehicle causing increase in pressure at the outlet. This would help in reducing the drag due to the undertray.

Main goal of the undertray is to provide maximum downforce with the best downforce-drag ratio, also defined as efficiency and to aid in faster cornering of the car. More exploration has been done by [3].

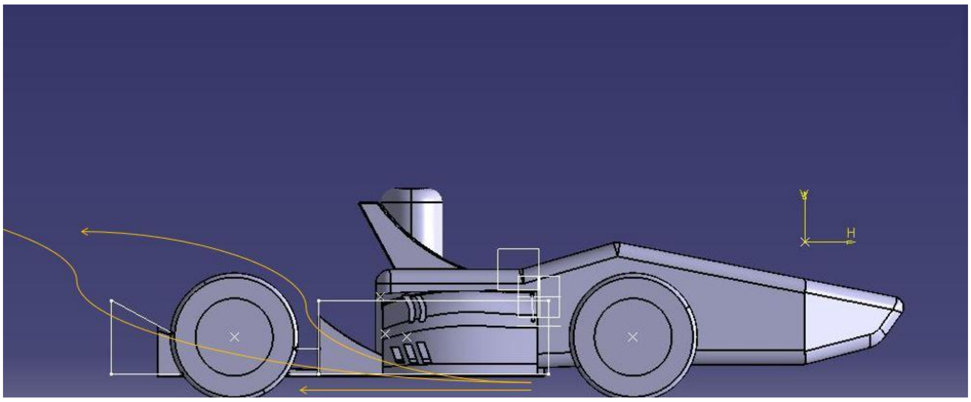

Figure 2. Cad model of 2020 race car

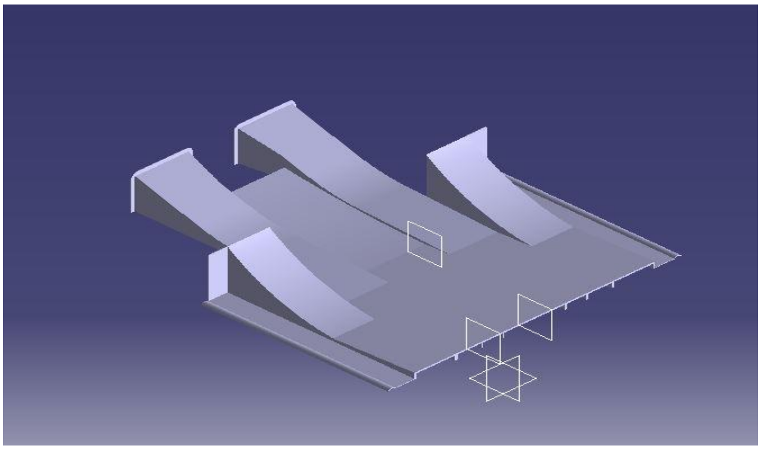

Figure 3. Undertray designed for 2020 race car

1.3 Sidepods

In recent years, engine overheating has been major cause for the breakdown of racing cars in endurance event for many universities. Side-pods play a vital role in control of airflow towards the radiator. Primary goal of the side-pods is to maximize the cooling efficiency of the radiator, by slowing down the air at the position of the radiator and ensuring a laminar flow till the position of the radiator.

II. Methodology

2.1 Visualisation:

We began with the decision making related to the effectiveness and use of the undertray. Tracks used in India do not allow for high speed cornering. Because of this reason there is not much need for aerodynamic elements in India. The goal is to keep minimum drag on the vehicle. We considered all the constraints that include ground clearance, clearances from the wheels and the rear assembly of the car. This also includes accurate positioning of exhaust and radiator. While designing we must focus on the stream lined airflow assuming no flow separation.

Following figure shows the bounds as imposed by the competition rules:

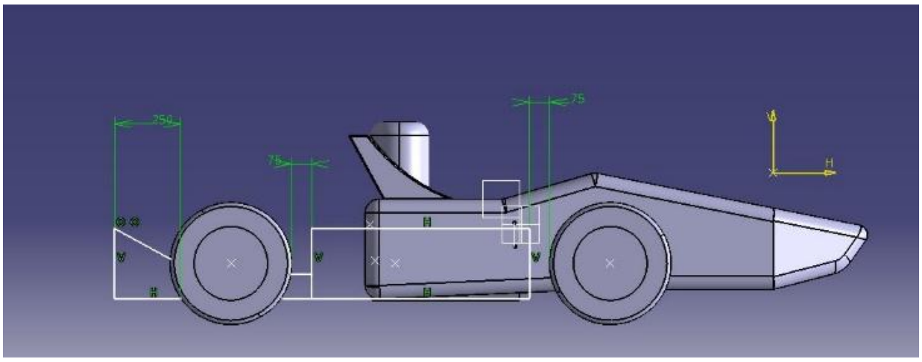

Figure 4. Dimensional constraints for undertray

2.2 Sketching:

We started making sketches while imagining specific targets. We made various sketches on CATIA software. It is a multi-platform software for CAD, CAM and CAE. Later-on 2D considerations related to the aerodynamic elements in the side-view were done on CFD.

Figures 5 and 6 show the final iterations for the two different tunnels on the undertray:

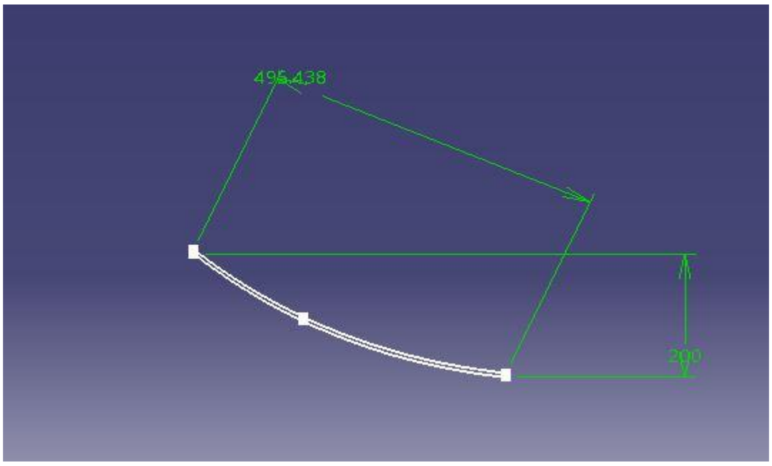

Figure 5. 2D profile for the short tunnel

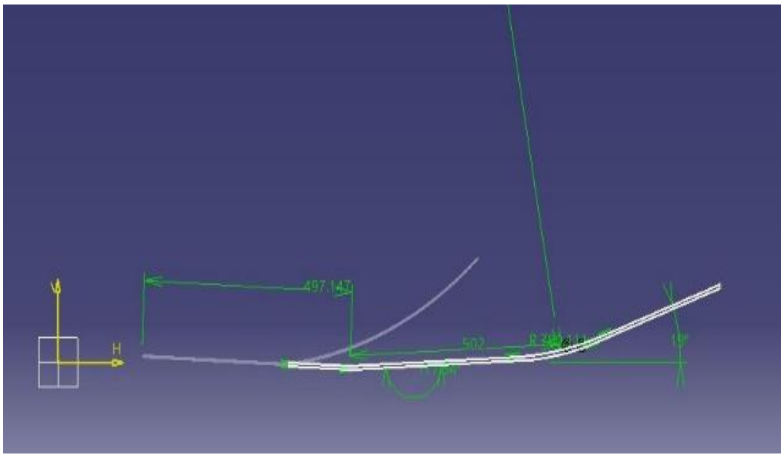

Figure6. 2D profile for the backward extending tunnel

2.3 2D Analysis:

The 2D study was done entirely based on CFD. It is very important to understand about the limitations of the 2D analysis. Method used by [4] was referred for optimizing the analysis approach. We cannot consider effects like vortex generation and effect of 3D shapes here. We tried out variations in the inlet and outlet angle. Then observed the effect on drag and downforce values using 2D analysis. Throat length and inlet outlet lengths were experimented and the best iteration was taken into consideration resulting into the maximum downforce and minimum pressure drag. Plotting the graph between inlet/outlet angle and downforce will lead to the maximum efficiency of the race car.

2.4 3D Analysis:

3D analysis was used for accurate comparisons with real life scenarios. Aerodynamic elements were tested in SIMSCALE software to accurately simulate the flow around the vehicle body. With the help of this softwarevalues of forces and moments acting on the body in all directionswere calculated. After validating the streamlined airflow and pressure distribution on the vehicle body, the final iteration obtained resulting into maximizing the downforce and minimum pressure drag.

The airflow observed around the car is as shown in figures 7 and 8. The streamlines are coloredaccording to the velocity scalar at that point. We can observe the increase in air velocity beneath the undertray, which causes a decrease in pressure under the car.

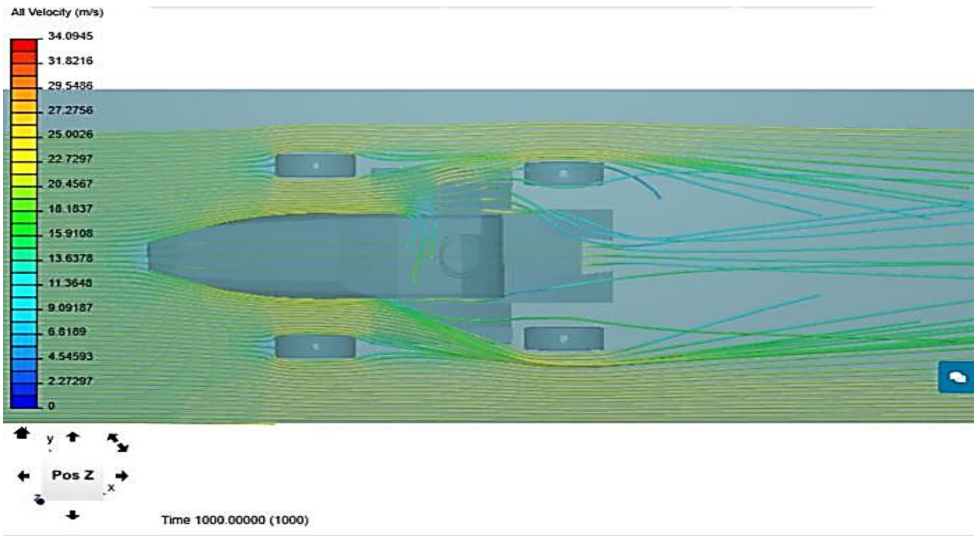

Figure 7. Top View of airflow visualization around the car

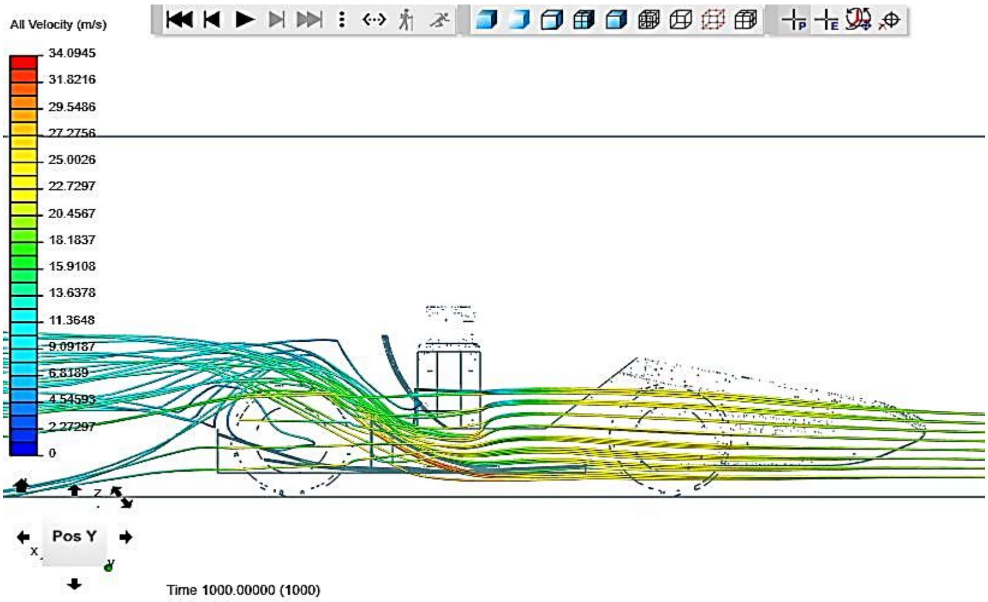

Figure 8. Top View of airflow visualization around the car

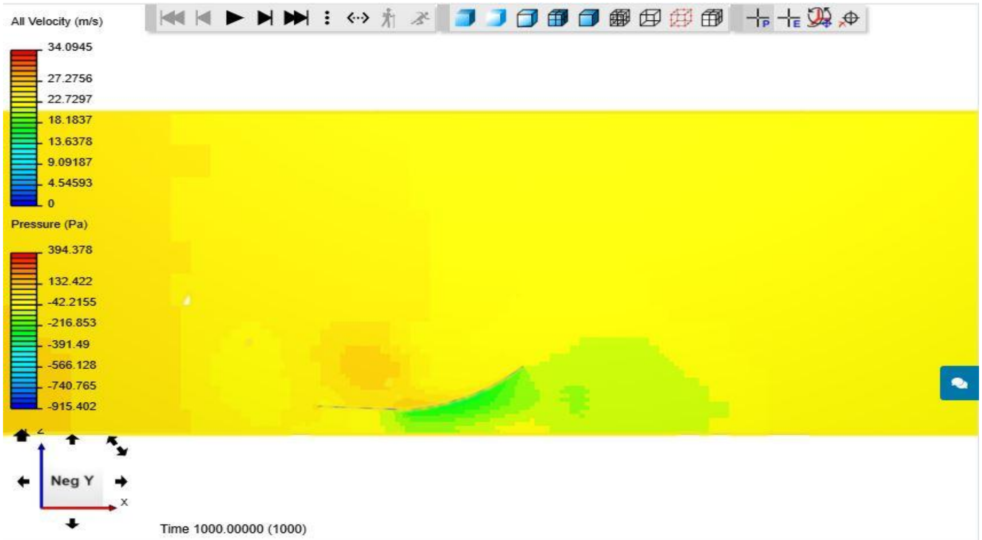

Figure 9. Pressure distribution across undertray

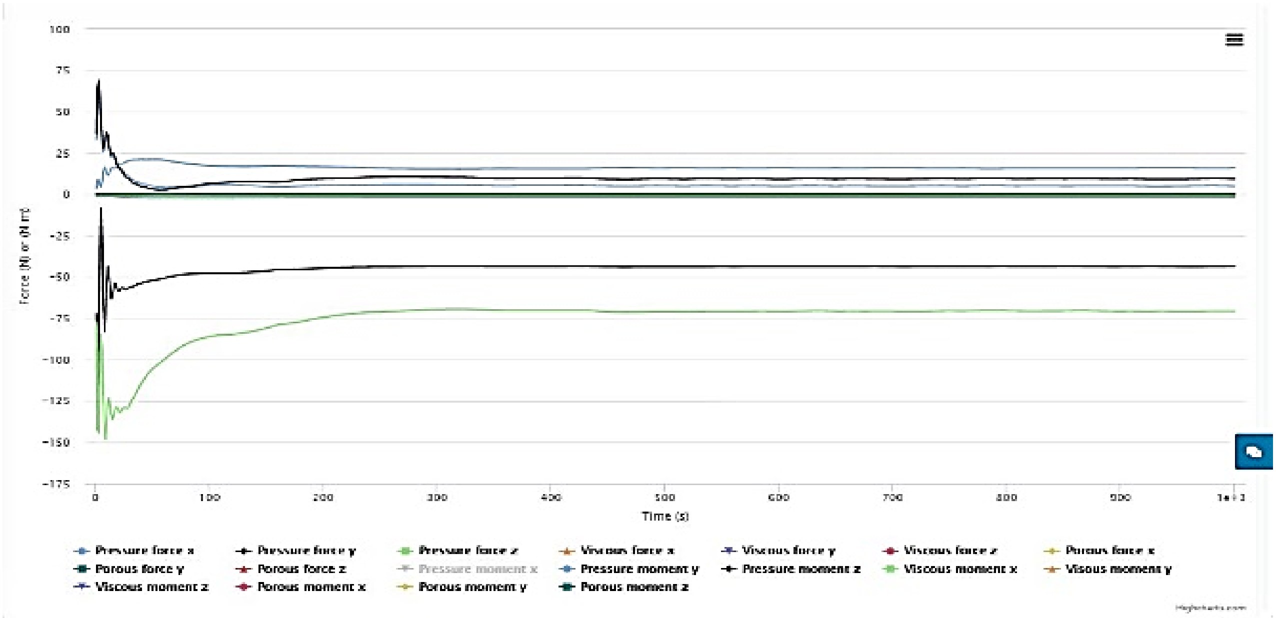

Figure 10. Convergence plot of forces on a symmetric half of vehicle without sidepods

Figure 10 shows that the vertical force (Pressure force Z) on the car is around 148 N after convergence in results is observed.

2.5 Modification:

To add more downforce on the race car, we decided to modify the sidepods. The sidepods have the cross section designed to reduce the velocity of air flowing through its inlet.This velocity is less than the velocity of air in the ambience. This further increases the pressure difference across the surface of the undertray. This would help in increasing the downforce to a great extent.

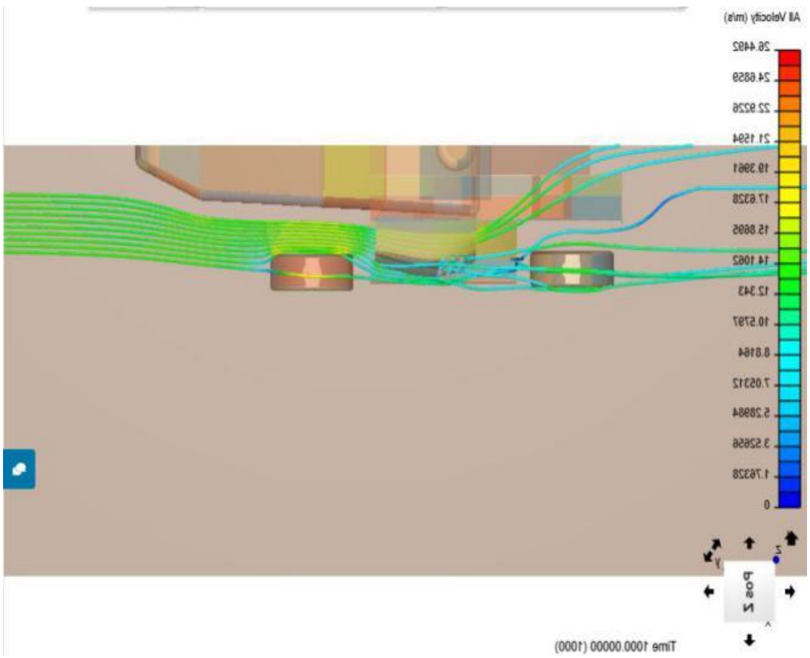

Figure 11. Airflow around the car with sidepods

We could observe from fig 11 that the sidepods could also be used to reduce drag on the rear wheels. The air directed towards the rear of the car's bulk, which could further help in drag reduction. The air is also directed towards the engine which helps in cooling by convection. All this is advantageous and is not observed without the sidepod (Figure 7)

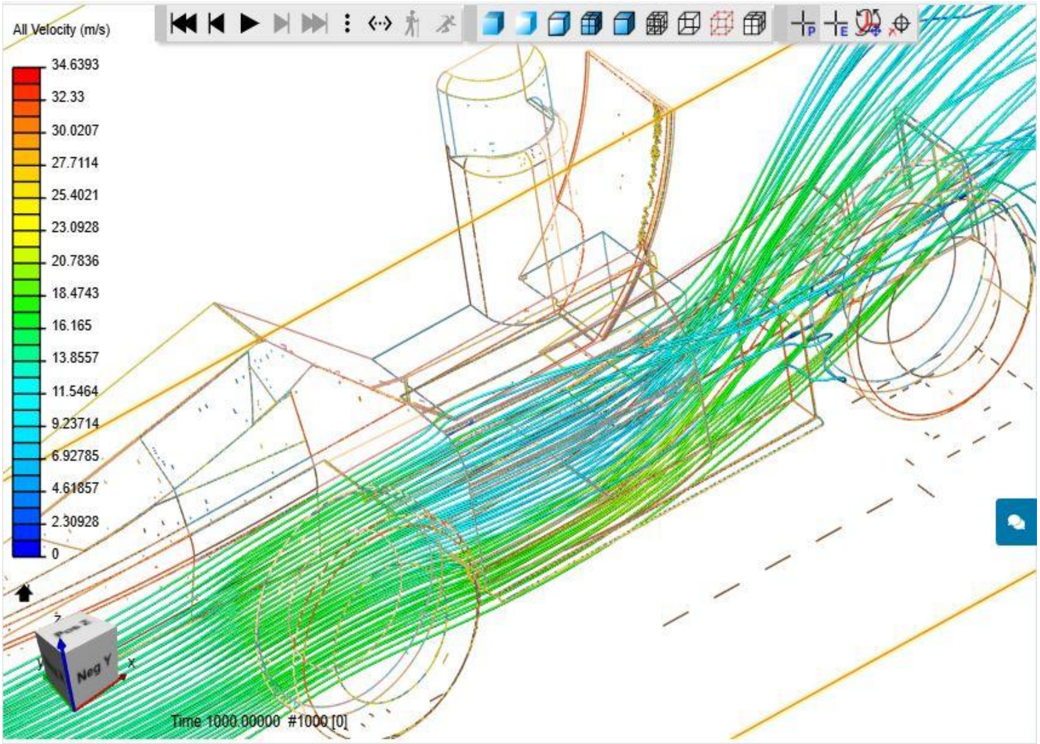

Figure 12. Velocity streamlines across sidepods

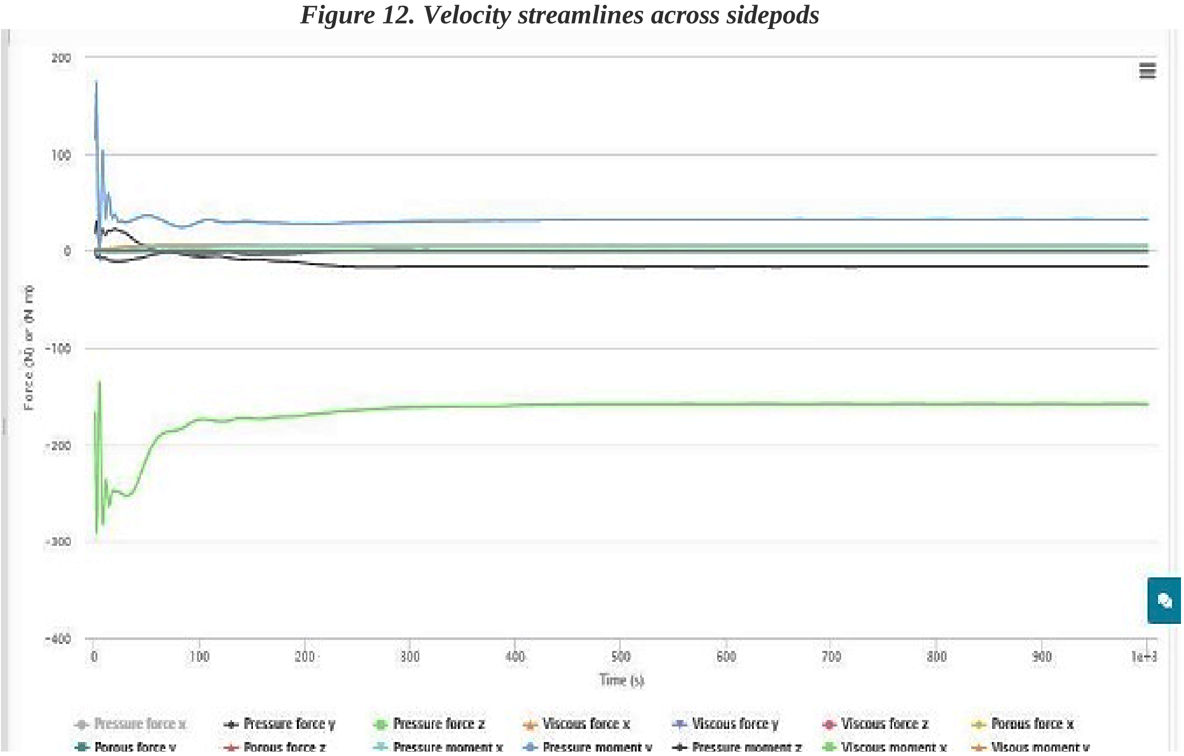

Figure 13. Forces on the car with sidepods

The force plots shown in Fig 10 and 13 show the forces and moments obtained on the car in various directions. The 'pressure force z' represents the downforce on the car. We get a downforce of around 148 N without sidepods and around 165N with the sidepods, that is an increase of 17N.

The sidepods also house the radiator due to which it becomes important to avoid stagnation of air inside the sidepods. The side-pods for the 2020 FSAE car were specially designed to help in engine cooling, by providing adequate airflow to maintain stable engine operating temperatures.

Special care has been taken to ensure proper flushing of the heated air which exits the radiator using fins. These fins as observed in fig 14 have been designed to avoid turbulence at the sidepod outlet.[5]

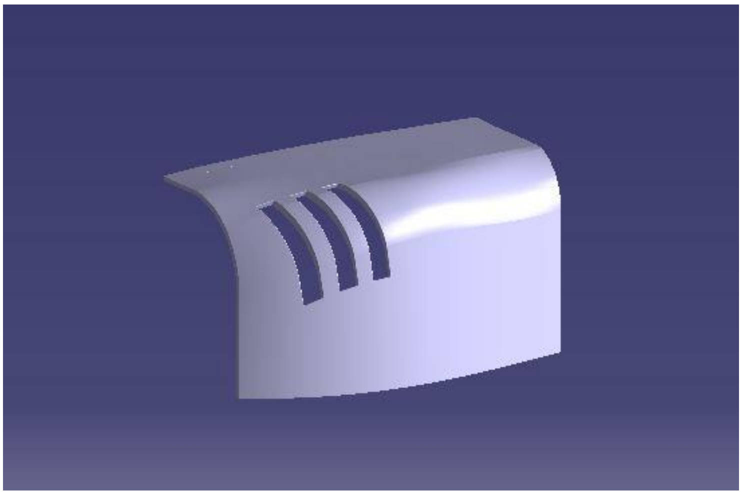

Figure 14. Sidepods with fins to aid in proper airflow

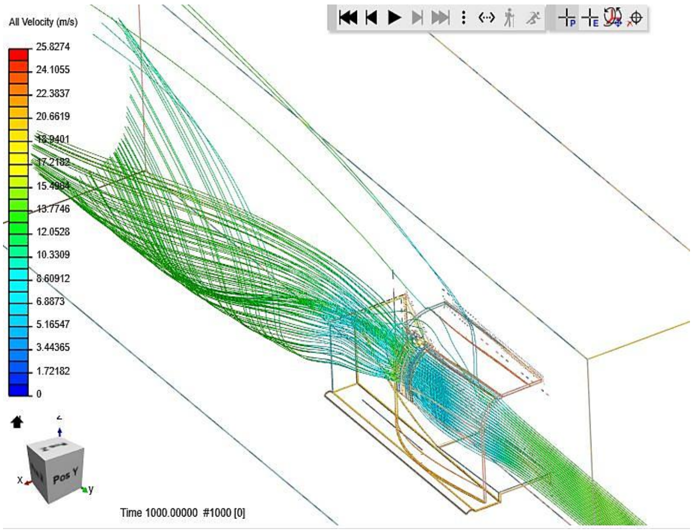

Figure 15. Airflow inside the sidepods with fins

The fins act as vents for the hot air which would be flowing from the radiator to avoid stagnation at the outlet of the sidepod.

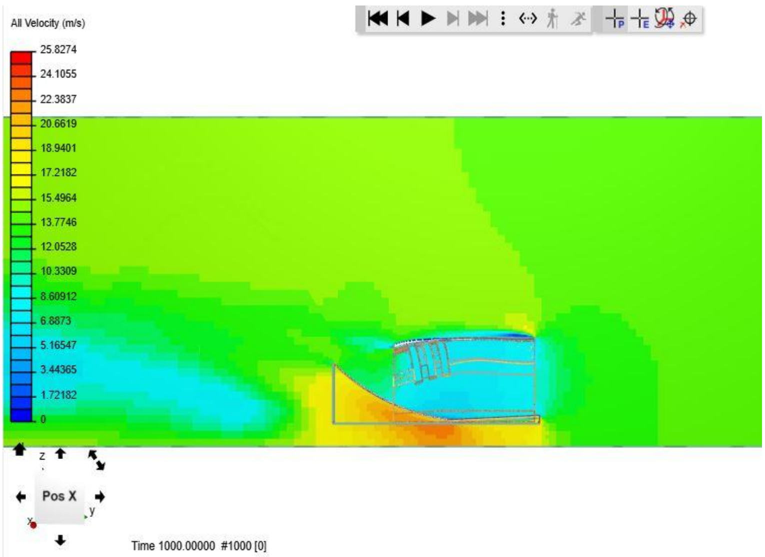

Figure 16. Flow velocity inside the sidepods with fins

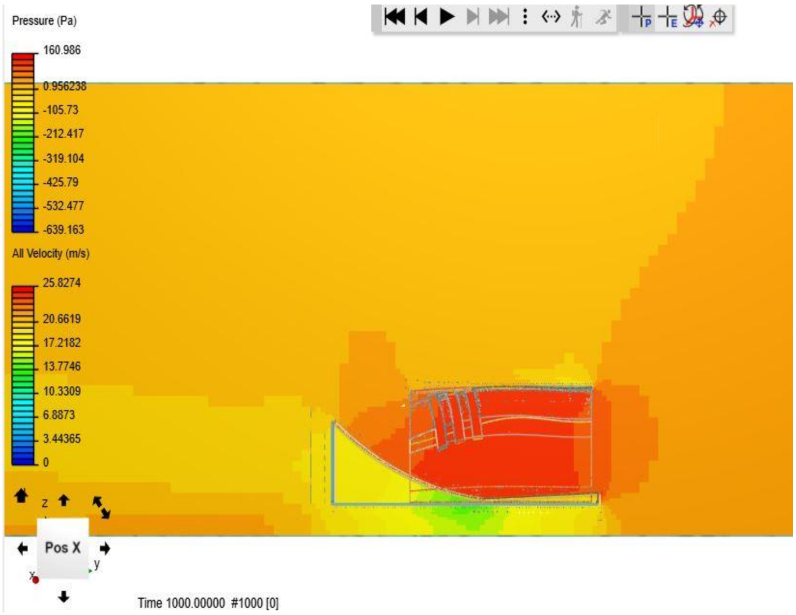

Figure 17. Pressure distribution inside the sidepods with fins

Figures 16 and 17 show the reduction in velocity and the increase of pressure across the sidepod which prove the effectiveness of using this technique of increasing downforce.

III. Validation and Discussion

There was a need to prove the effectiveness of aerodynamic upgrade for the car. Hence, equal importance was placed on validation of the flow observed as well as the downforce produced by the undertray. The airflow around the vehicle was simulated physically using two different methods.

The first involved creating streamlines of smoke using the setup shown. This setup was placed in a room where the air was stagnant to avoid any interference with the initial laminar flow. The velocity of airflow generated by the fans was measured using anemometer and the simulation corresponding to that velocity was validated against the setup flow. The source of the smoke was moved to have a visualization for different areas around the car.

The next method involved the use of a small-scale wind tunnel facility at the institute for flow visualization. The wind tunnel had a throat cross-section of 25cm x 25cm and an operational velocity of 10 m/s. The car was simplified and scale down to one-tenth of its length and printed using 3D printing technique. Using dimensional analysis, the downforce was scaled down and obtained to be 0.7 N. Using a self-designed load cell setup, the downforce was measured to be 0.6 N. This gives an error of 14.28% which is acceptable.

Thus, the flow around the car was validated and useful data for future improvements were obtained.

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