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CFD Analysis of A FSAE Car Equipped with Front and Rear Wings

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ABSTRACT:In motorsport car racing, there are various aspects of the car that determines how fast it can go around the race track. One such aspect is the aerodynamics of the car. The aerodynamics of the race car is largely influenced by aerodynamic devices such as front wings, rear wings and undertrays amongst others. These devices generate considerably increased downforce on the car, which improves the cornering speeds of the race car, which in turn improves lap timings. This paper focuses on incorporating front and rear wings to a Formula SAE car and comparison of aerodynamic performance of the car with and without the front and rear wings through commercial Computational Fluid Dynamic software. The Selig s1223 aerofoil profile was chosen for the design of the front and rear wings with a two-element set up for both. The 3D CFD analysis of the FSAE car was performed without the wings followed by the analysis of the FSAE car with the wings using Solid Works Flow Simulation 2014 package. The results showed the FSAE car with the wings had a better aerodynamic performance than the car without the wings.

KEYWORDS: Aerodynamics, aerofoil, front and rear wings, downforce, Formula SAE, Computational Fluid Dynamics (CFD).

I. INTRODUCTION

Fuel consumption by an automobile is one of the most important issues facing the automotive industry. Growing fuel prices and the need for controlling emission levels in an automobile has forced the governments of World nations to come up with stringent emission norms and fuel efficiency. So the automotive companies have been investing a lot of money in research and development to come up with ways to increase fuel efficiency and lower emission levels. The emission levels and fuel consumption could be lowered by improving the engine, transmission, exhaust systems and aerodynamics of the car amongst others.

Aerodynamics has become one of the most important aspects of motorsport racing for a long time now. Teams invest a lot of money to improve the aerodynamics of the car by building exclusive wind tunnels. Improving aerodynamics in race cars include incorporating devices such as front wings, rear wings, barge boards, undertray with diffusers to increase the downforce on the car which increases the cornering speed and traction of the car. Wings are aerofoils that are used in airplanes to generate lift force enough for taking off, but with an inverted profile when used in a race car. The wings generate substantial amount of downforce on the car with an increase in drag force on the car. Wings use aerofoils in inverted position which generates downforce as opposed to lift force produced by upright aerofoils. There are a wide variety of aerofoil profiles available. In Formula SAE competition, the speeds are relatively low (average

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maximum speed of about 100 kmph). So, the aerofoil should be carefully chosen to have a considerable effect on the performance of the car.

The implementation of aerodynamic devices in a FSAE car is limited by the rule book and should meet all the requirements imposed by it. In order to design the front and rear wings, a FSAE car body was modeled using Solid Works 2014 package and the CFD analysis was carried out throughout using that model using Solid Works Flow Simulation 2014 package. This paper mainly concentrates on comparing the downforce gains when the FSAE car is equipped with front and rear wings to the FSAE car without the wings.

II. RELATED WORK

Initially, the body work for the FSAE car was developed using Solid Works 2014 CAD package. Even though the body of the car is a surface with certain thickness, a solid body was modeled. The reason for this is that the solid model is closed and doesn't have unexpected openings and gaps in the body. So, it is easier during the analysis part. The body has to conform to certain requirements posed by the FSAE rule book. The body is not supposed to have sharp edges in critical areas of the car and edges should have minimum radii as specified by the rule book. For simplicity during the analysis of the car, the rear end of the car was closed. As the driver present in the cockpit also has a considerable effect in the air flow around the car, a 95th percentile male body in the driving position was also modeled. Tires and axles were also modeled. In order to design the front and rear wings for FSAE car, the first and foremost process is the selection of aerofoil profile for the wings. University of Illinois at Urbana Champaign (UIUC) and the National Advisory Committee for Aeronautics (NACA) databases provides the co-ordinates for all the aerofoils. In the FSAE event, the average maximum speed of the vehicle is limited to 100 kmph. So, an aerofoil profile with a relatively low Reynolds number should be chosen. After looking into a number of aerofoil profiles, it was found that the Selig S1223 aerofoil was apt for the FSAE application owing to its high downforce and low Reynolds number. The next process was to determine the number of elements for the wings. Although, the single element set up is simple to design, a two-element wing set up was chosen because of its ability to produce higher downforce with a relatively small increase in drag force on the car. Then, the position of the front and rear wing with respect to the car is determined and the same is constrained by the stipulations in the rule book. Finally, the analysis part was carried out using Solid Works Flow Simulation 2014 package first with the FSAE car without the wings and then with the front and rear wings. The results of the analysis are compared to investigate the advantages of using wings in the FSAE car. The figure.1 shows the methodology in form of a flowchart.

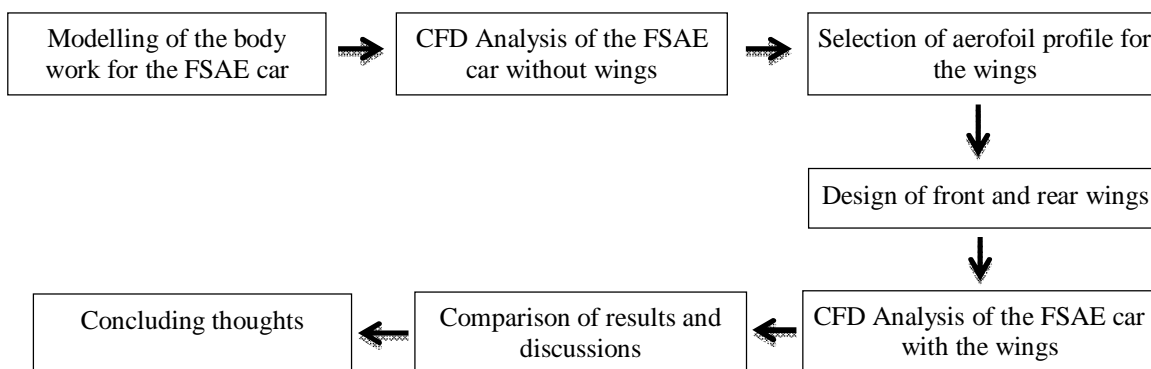


Fig.1 Flow chart with methodology

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2.1. Modelling: The modelling of the body work for the FSAE car was done using Solid Works 2014 package. The SI unit was followed throughout the modelling process. The fig.1 (a) shows the modelled car in isometric view and the figure.2 (b) shows the body work of the car in side view.

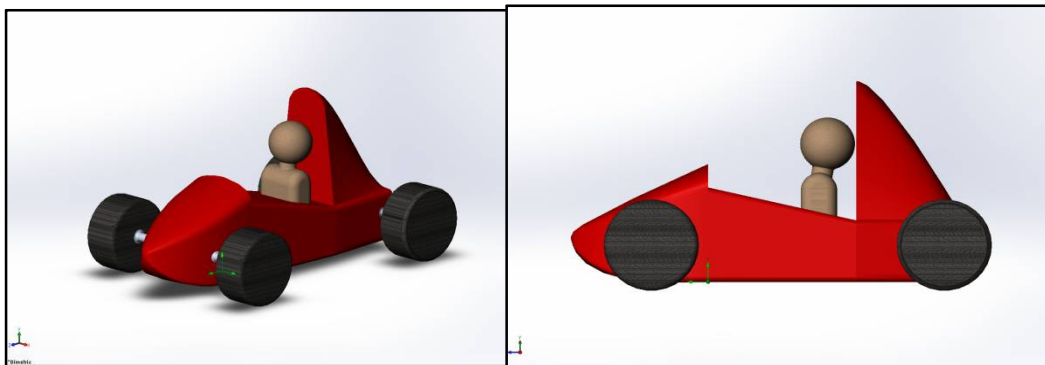


Figure.2 (a) Body work for the FSAE car- isometric view Figure.2 (b) Body work of the FSAE car- side view

2.2 CFD Analysis of the FSAE car without the wings: The FSAE car was analyzed using Solid Works Flow Simulation 2014 package. It is simple to use and gives fair results. Initial settings such as the type of flow, fluid medium and mesh settings are set. A 3D computational domain around the car was set. Ideal wall boundary conditions were given to the ground and the outlet and roof were left as default. The inlet velocity was set at 60 kmph. The goals were set for normal forces parallel to the motion of the car (drag force) and perpendicular to the motion of the car (lift/downforce) The analysis was done and the velocity contours, pressure contours were generated and the lift and drag forces were calculated by the solver and plotted. Figure.3 shows the 3D computational domain set around the FSAE car without the wings inside which the flow analysis is done.

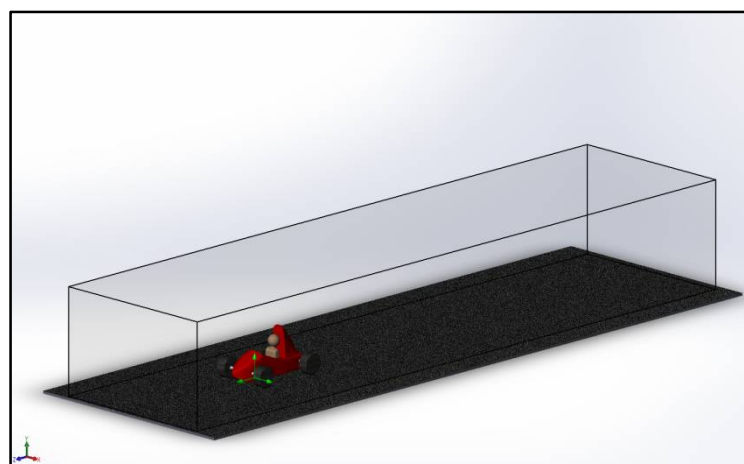


Figure. 3 3D computational domain around the FSAE car (without wings)

2.3 Design of Front and rear wings: Figure.4 shows the profile of Selig s1223 aerofoil which was chosen for the design of both front and rear wings whose coordinates were taken from the UIUC aerofoil database. It can generate a high lift and has low Reynolds number which is apt for FSAE applications.

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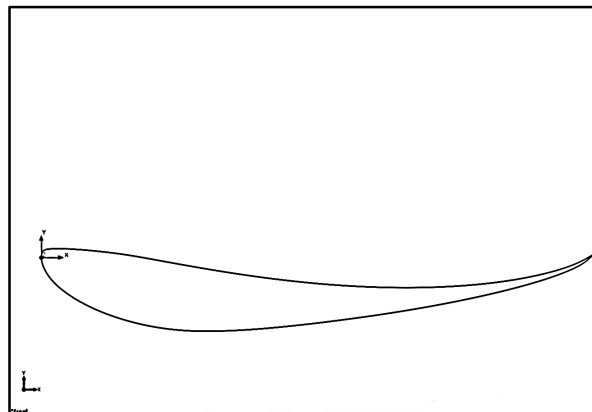


Figure.4 Selig s1223 aerofoil profile

As mentioned earlier, a two-element set up for both front and rear wings were used. The front wing was designed using Solid Works 2014 package. The front wing was split into two parts with a central part which carries only a single element at zero angle of attack and the second part being a two-element set up with a main wing at 12 degree angle of attack and secondary wing at higher angle of attack of 30 degrees. In order to control the vortex formation at the tip of the wings a basic endplate design was employed to control the vortex formation and also to direct the airflow around the front tires. The front wing is located at a distance of 512 mm from the front of the front tires and at a height of 13 mm from the ground. Fig.4 (a) and (b) shows the isometric view of the front wing and the position of the wing with respect to the car respectively.

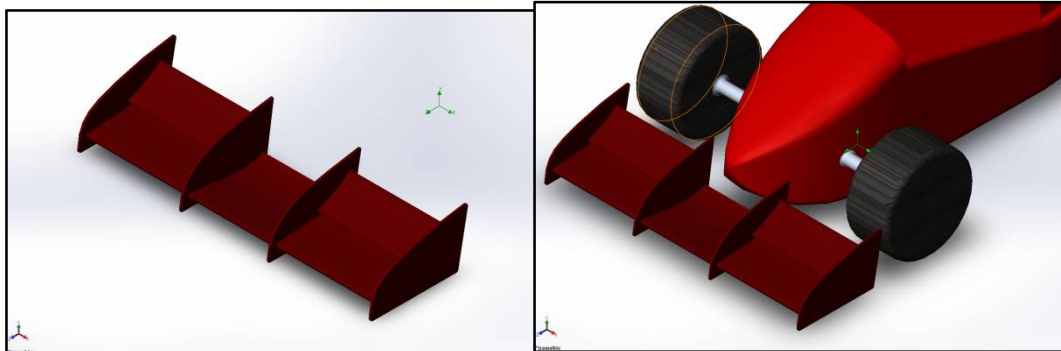


Figure.4 (a) front wing- isometric view

Figure.4 (b) position of the front wing with respect to the car

The rear wing of the car was modeled using Solid Works 2014 package. Unlike the front wing, the rear wing was a unified unit with a two-element set up of its own. The main wing was set at an angle of attack of 11 degrees and the second wing was set at an angle of attack of 24 degrees. The rear wing is located at a distance of 230 mm rearward to the rear of rear tires and at a height of 1648 mm from the ground. The mounting components for the rear wings to the car were not considered for the analysis. The figure.5 (a) and (b) shows the diametric view of the rear wing and the position of the rear wing with respect to the car respectively.

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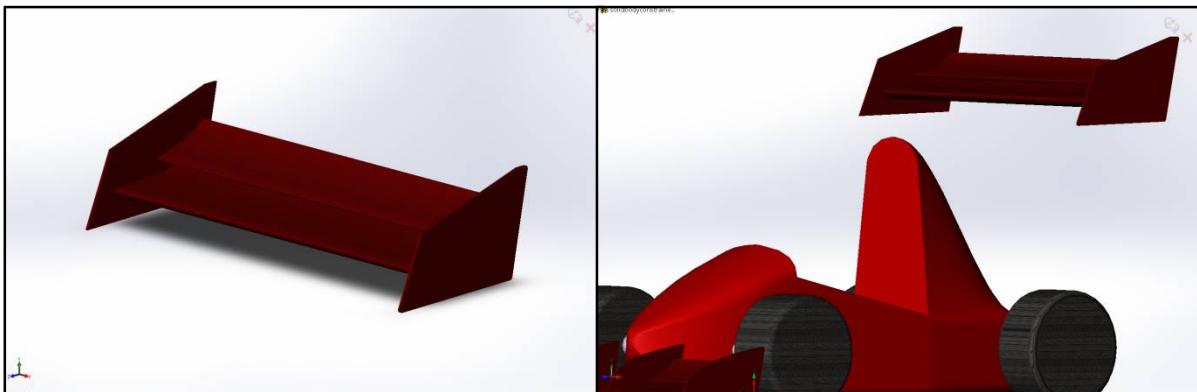


Figure.5 (a) rear wing – diametric view Figure.5 (b) position of the rear wing with respect to the car

2.4 CFD ANALYSIS OF THE FSAE CAR WITH WINGS: The Solid Works Flow Simulation 2014 package was again used for the analysis. The initial conditions were set up with the same conditions as before. The 3D computational domain was set up and the ground was set as an ideal wall and the roof and the outlet were left as defaults. The inlet velocity of the air was again set at 60 kmph. The goal was set for the calculation of the parallel force to the motion of the car (drag force) and the perpendicular force (downforce). The analysis was run and the velocity and pressure contours were generated and the values of drag force and downforce were tabulated. The figure.6 shows the 3D computational domain set up around the FSAE car with the wings.

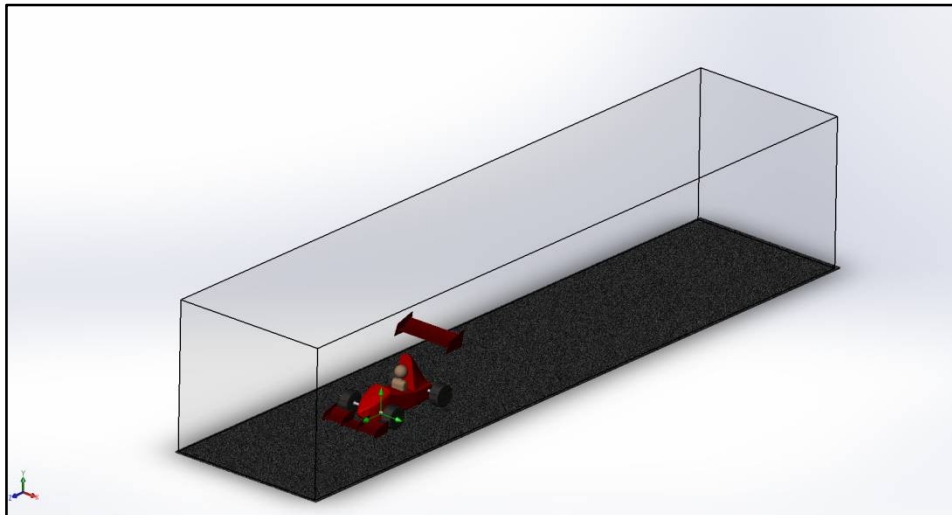


Figure.6 3D computational domain around the FSAE car (with wings)

IV. RESULTS AND DISCUSSIONS

3.1 Velocity Contours: The results of the analysis can be viewed in several ways, one of which is the velocity contours of the airflow around the FSAE car. The comparison of the velocity contours of the air flow around the FSAE car with and without the front and rear wings were made which is shown below in the figure which shows the different

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velocities at different sections of the car. The figure.7 (a) and (b) shows the velocity contours off the air flow around the car with wings and without the wings respectively.

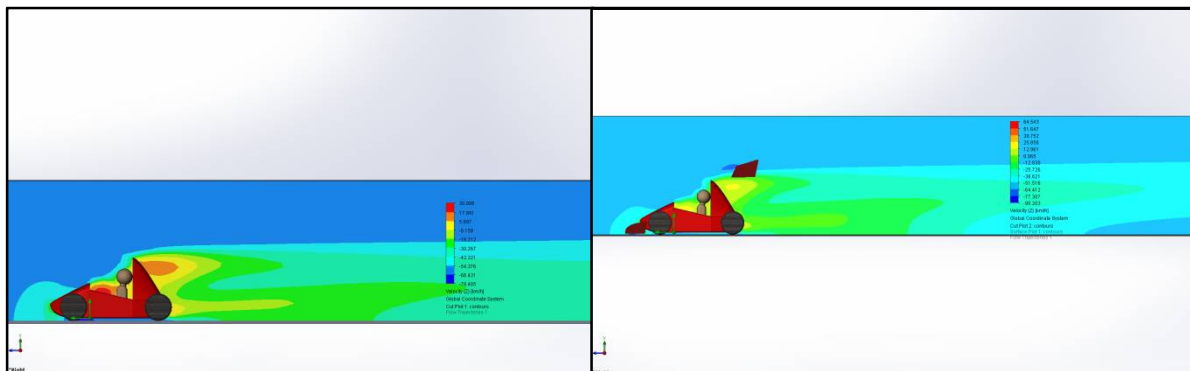


Figure.7 (a) velocity contour around the FSAE car (without wings) Figure.7 (b) velocity contour around the FSAE car (with wings)

3.2 Pressure Contours: The pressure contours at the different sections of the FSAE car with and without the front and rear wings are shown below in figures. The pressure differences because of the different sections of the car influences the amount of drag force and lift forces created on the car. The Figure.8 (a) and (b) shows the pressure contours developed around the car with and without the front and rear wings respectively.

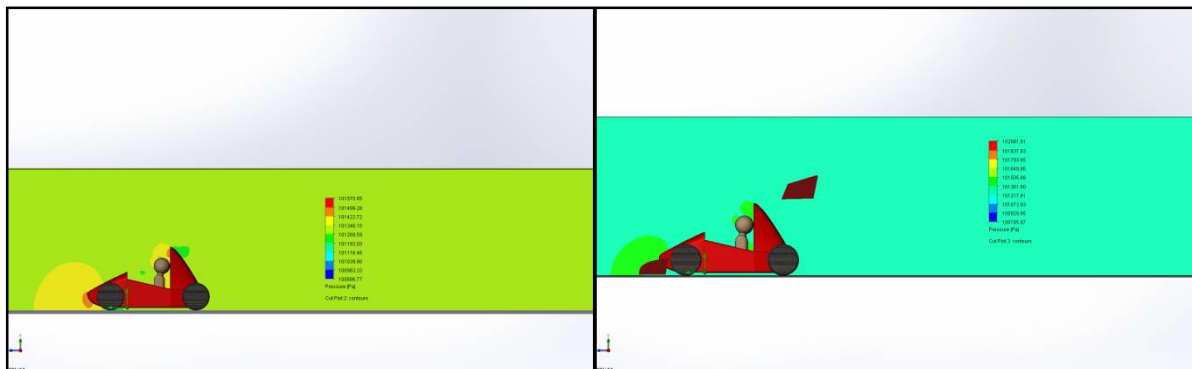


Figure.8 (a) pressure contours around the FSAE car (without wings) Figure.8 (b) pressure contours around the FSAE car (with wings)

3.3 Flow trajectories in velocity: The velocity and pressure variations can also be visualized through flow trajectory of the air flow around the FSAE car. Figure.9 (a) and (b) shows the flow trajectories around the FSAE with and without the wings respectively in terms of velocity.

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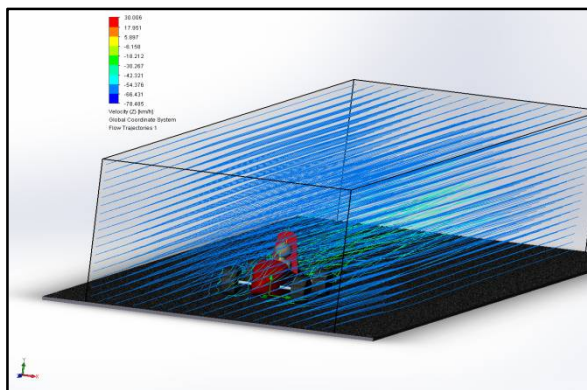


Figure.9 (a) flow trajectory around the FSAE car in terms of velocity (Without wings)

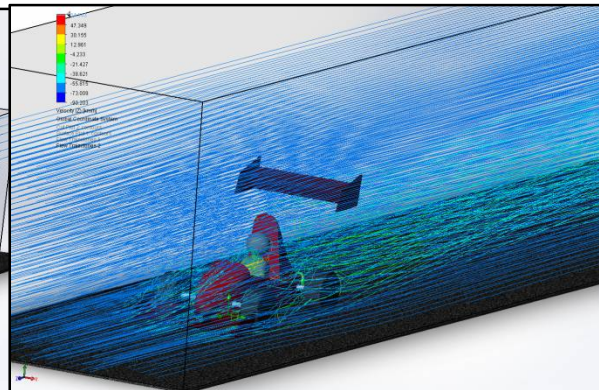


Figure.9 (a) flow trajectory around the FSAE car in terms of velocity (With wings)

3.4 Goal parameters: The CFD results show that the lift force on the car when it is equipped with front and rear wings is -223 N and the lift force on the car when it is not equipped with front and rear wings is 34 N when the car travels at 60 kmph. The difference in value of the downforce is considerably high when the wings are used on the FSAE car. The car is pushed to the ground by the wings with a downforce of 223 N. This helps the FSAE car to maneuver the corners with more traction at higher speeds. The drag force, however, is 107 N when the wings are not used and about 166 N when the wings are used. This may affect the top speed of the vehicle when it is accelerating on straight lines. The average top speed of the car is limited to 100 kmph and the extra power available from the engine would compensate for the increased drag force and the desired top speed might still be achieved. The tables 1 and 2 show the values of drag and lift forces on the car when it is equipped with the wings and when it is not equipped with the wings.

Table.1 goal parameters (without wings)

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Lift force	N	34.9290	34.0815	31.4573	34.9408	100	Yes	2.3564	2.4248
Drag force	N	-107.4593	-107.0170	-107.4935	-105.8868	100	Yes	1.6067	5.5445

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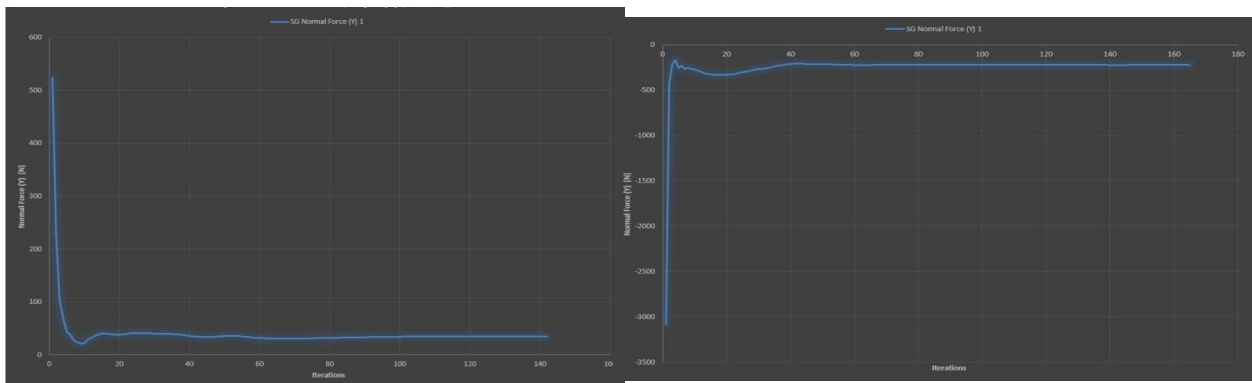
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Table.2 goal parameters (with wings)

Goal Name	Unit	Value	Averaged Value	Minimum Value	Maximum Value	Progress [%]	Use In Convergence	Delta	Criteria
Lift force	N	-223.0728	-222.3326	-221.5257	-221.3252	100	Yes	2.2004	5.0068
Drag force	N	-166.6946	-166.1606	-164.8190	-164.0388	100	Yes	2.7801	7.5917

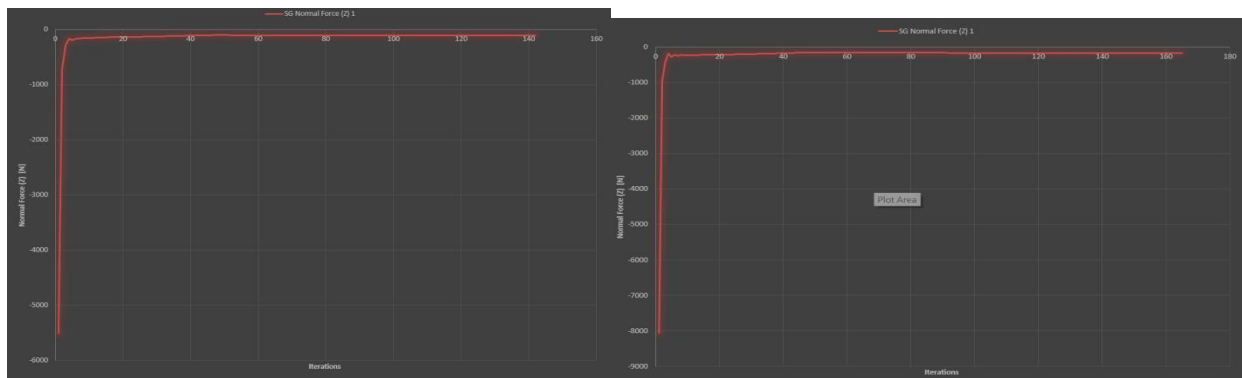
The graphs 1 (a) and (b) show the trend in the convergence of the values of lift forces in a number of iterations when the car is not equipped with front and rear wings.



Graph.1 (a) lift force on the FSAC car (without wings)

Graph.1 (b) lift forces on the FSAC car (with wings)

The graphs 2 (a) and (b) shows the trend in the convergence of drag forces developed on the FSAC car when it is not equipped with the wings and when it is equipped with the wings.



Graph.2 (a) drag forces on the FSAC car (without wings) Graph.2 (b) drag forces on the FSAC car (with wings)

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3.5 Discussions: The verification of the simulated results from the computer software can be done with help of physical testing of a scaled prototype of the FSAE car with help of wind tunnels. Due to time constraints and financial constraints, the physical testing of the FSAE car for the verification of the simulated results was not done. The verification of the results obtained can also be obtained by using a different commercial CFD software and comparing the results obtained from different softwares. Also, there are more advanced CFD softwares available which offer control over a wide range of settings and can produce more accurate results. But these packages are usually expensive and are complex to operate. So, students with limited knowledge in CFD will find it difficult to work with the software. In order to avoid complexity during analysis, the body of the car was closed. Exposed components such as engine, transmission, radiators, inlet manifolds and exhaust not included. The vehicle dynamic characteristics such as pitching moment, yaw moment etc., have a great influence on the handling of the FSAE car. This aspect is not included in this project. This paper doesn't deal with the effects a rotating wheels and its interaction with the wheels which bears an effect on the result of the analysis.

V. CONCLUSION

The main motive of this project was to investigate the effect of incorporating front and rear wings in a FSAE car. The comparison of the CFD analysis results of the FSAE car with and without the front wing and rear wings showed that when the FSAE car is equipped with the front and rear wings, the downforce on the car is significantly increased and this would obviously help the car to traverse through the corners of a race track at higher speeds with increased traction. However, the results also showed that there is an increased drag on the car when the car is equipped with wings which would limit the top speed of the vehicle. So, the use of wings in an FSAE car is very much debatable, but it does have its advantages helping to improve the lap times in dynamic events of the FSAE competition.

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