ESTIMATION OF DRAG AND DOWN FORCES USING AERODYNAMIC PROFILE ON FORMULA STUDENT VEHICLE

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Abstract - *The Formula Society of Automotive Engineering (FSAE) is a competition for undergraduate students to design a high-performance Formula Student car that meets all of the rules. The body and other aerodynamic components are important because they influence the car's drag coefficient and down force. The drag coefficient is a measurement of an object's resistance in a fluid environment; with a lower value indicating less resistance. Down force is a force that pushes an object to the ground, in the car more down force indicates more grip. The objective of the research was to study the comparison between the race vehicle when attached to the wings and without it. As a result, a model of the body structure and its associated ground effects are created, taking into account a variety of elements in order to present the finest model as a result. These factors include but are not limited to weight, wind drag & lift resistance, functionality and aesthetics. These studies were done in three-dimensional (3D) computational fluid dynamic (CFD) simulation method using the Solidworks Simulation. These simulations are being conducted in 5 different velocities.*

Key Words: FSAE, Wings, Drag, Downforce, CFD

1.INTRODUCTION

In the Formula Student competition, all undergraduate students are expected to build a high-performance FSAE car. In FSAE, car's aerodynamic factor is one of the most important factors in achieving high performance. While the engine, suspension, transmission, and tyres are the first structural components to be evaluated when evaluating an automobile's performance, an automobile's efficient performance requires optimal air flow. Commercial manufacturer in most cases aim to reduce aerodynamic drag in order to increase fuel efficiency. This is in contrast to race cars, which use aerodynamic equipment to improve cornering and braking performance.

Moreover, most vital element in aerodynamics is downforce, lift force, drag force and coefficient of drag. Down Force is load from the air that pushes the upper of the car to make more grip on the ground, to decrease the slips between wheels and ground. Higher downforce means higher performance of FSAE car. Downforce is a negative lift. Lift is a force that will lift the car up because of the air that flows in opposite direction of the vehicle at high speed. Commonly the lift in a formula type car occurs from the bottom of the car. This will lift the vehicle from front and cause slip between the wheels and ground, also decrease the dynamic performance of the car. Furthermore, one crucial aspect in aerodynamic is drag force. Drag Force is the force that acts in opposite direction of vehicle movement, so it will resist the movement of vehicle and decreases its velocity.

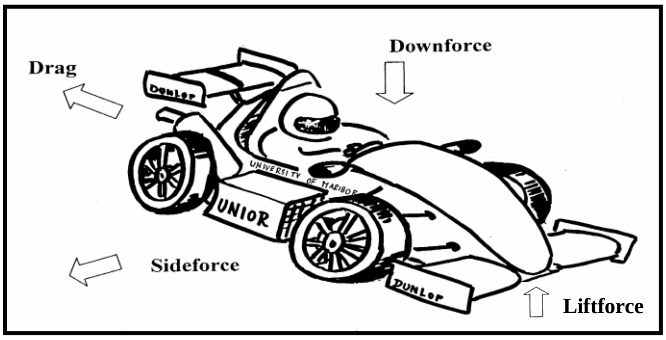


Fig -1: Components of aerodynamic force

1.1 Project Objectives

The objectives of this project are as follows:

- Designing front panel(nose), front wings, rear wings for the selected car model.
- Selection of aerofoil and angle of attack for front and rear wings by referring various research data.
- Performing analysis with and without these devices to calculate parameters like drag and downforce on variable speeds.
- Study the relationship between various factors by analysing the results obtained at various velocities.

2. LITERATURE REVIEW

At very-high speed the experienced driver may have noticed the instability of the car caused by lift, which will usually be larger on the rear wheels than on the front ones. Aerodynamic downforce increases the tires' cornering ability. To demonstrate the positive wings, influence on the car cornering speed, **Katzz 1995 [1]** conducted a study. In this he stated that, there is a huge increase in the cornering capability in the 1979s race cars which seems to be a result of using wings. This trend accelerated towards the end of the 1970s with the introduction of ground effect principle. In addition to improved cornering speeds aerodynamics have dramatically improved vehicle stability and high-speed braking as well, which again lead to faster lap times. This is even more impressive when you consider that aerodynamic drag increase with addition of wings reducing straightway speeds.

McKay and Gopalarathnam [2] did an analytical study to examine the impact of wing aerodynamics on race car performance and its influence on lap times on different kinds of tracks. In this case, downforce is very useful to maintain balance of the car from air pressure, especially when the car wants to turn. With the result that car will grip the ground.

Verhun et al. [3] conducted on study Aerodynamic Modification of CFR Formula SAE Race Car. Good agreement was found between the experimental and numerical data for angles of attack -15°.

Selig and Maughmert [4] suggested a technique for the selection of the different parameters of an air foil such as an air foil maximum thickness ratio, pitching moment, part of the ve1oclty distribution, or boundary layer development.

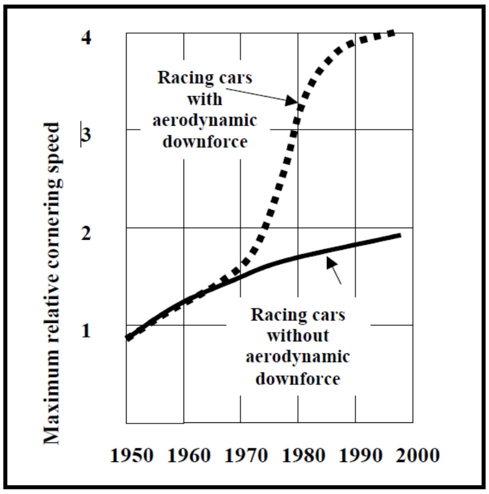


Fig -2: Increase of maximum cornering speed with aerodynamic downforce

Devaiah and Umesh [5] stated that the rear wing is also one of crucial parts of the aerodynamic device. This device contributes approximately a third of the car's total downforce. It is because the rear wing is used to prevent the lift from the machine and turbulent flow from the release flow from the diffuser. The rear wing is constructed by three aerofoils connected to 2 end-points. The aerofoils are divided to be two sides. First are upside aerofoils, which is contain two aerofoils, it is to produce more downforce. The other one is the lower aerofoil, which comprises only one aerofoil to produce downforce too.

3. METHODOLOGY

Design modelling of the Formula SAE race car was done using the software tool Solidworks. The model will be exposed at five different velocities of 40, 60, 80, 100 and 120 km/h in Solidworks Simulation, which was used as a solver of aerodynamic simulation. Figure 3 shows cross-sectional view of the race car model.

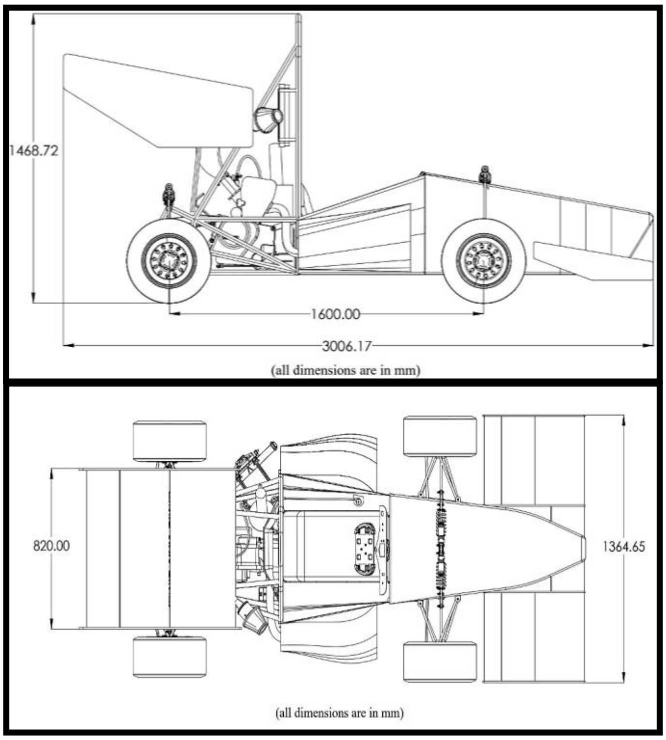


Fig -3: Cross-sectional view of vehicle

3.1 Design Modelling

All the designs are made considering FSAE restrictions referring Formula Bharat and Formula Student Germany rule book **[6]**. The main part of the vehicle, used to streamline the flow of air and channel it towards rear wings is the body panel (nose).

3.1.1. Nose

A shark muzzle is considered for nose to get a streamlined air flow to be channeled. The CAD model of nose is shown in figure 4. The flow analysis of nose was carried out using solidworks simulation at mean velocity of 80km/hr. The results of the analysis obtained have been used to calculate forces acting on the nose. The objective of channeling air flow across the nose without creating vortices is clear from the flow analysis shown in figure 5.

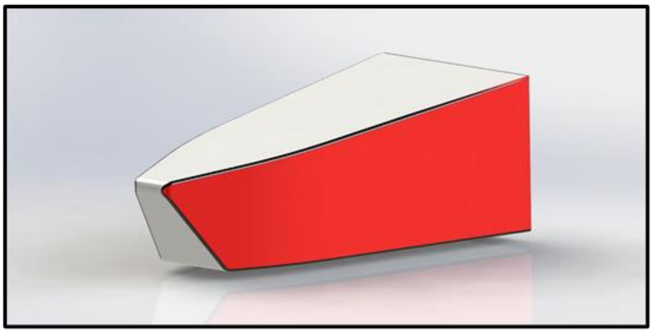


Fig -4: Cad model of nose

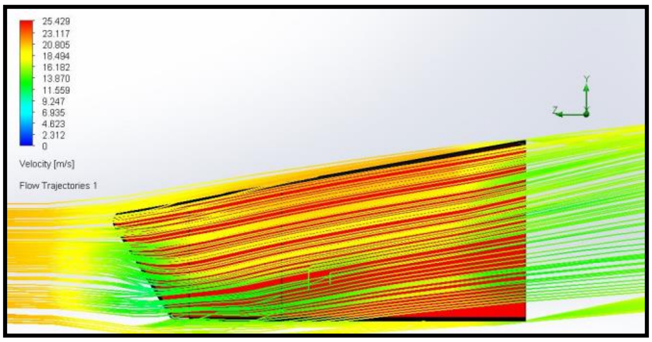


Fig -5: Flow analysis of nose

3.1.2 Front Wing Design

It is the first part of the car to interact with air, therefore, besides creating downforce, its main task is to efficiently guide the air towards the body and rear of the car, as the turbulent flow impacts the efficiency of the rear wing.

I. Selection of Airfoil: The front wing on the car produces about 1/3 of the car's downforce and it has experienced more modifications than rear wing **[7]**. NACA 4-series aerofoils are the most widely used aerofoils for Formula student race cars. NACA 4412 was selected for the front wings, as a thicker aerofoil is useful to obtain higher downforce from the front end of the car, at a given speed.

II. Angle of Attack (α): For front wings design, two sets of angle of attack were considered so are to obtain comparative results between various parameters. The first set of angles is **-6˚, -11˚, -14˚.** And the second set of angles **-6˚, -8˚, -10˚** respectively. A three-element aerofoil was considered for front wing assembly in order to channel the air flow above the wheel, minimize turbulence and maximize downward force without any flow separation. Front wing with three element aerofoil is shown below in figure 6.

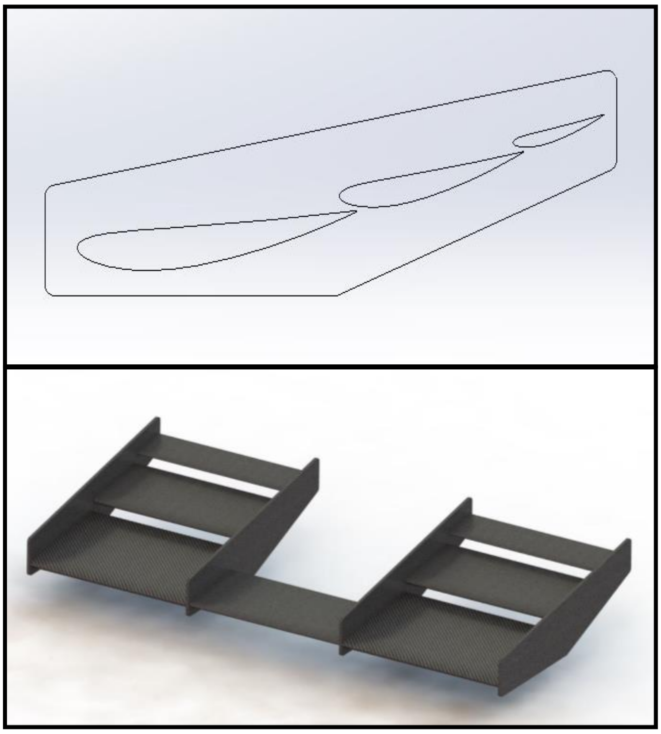


Fig -6: 2D and 3D model of front wings

3.1.3 Rear Wing Design

A rear wing is designed to improve motoring performance and enhance stability during cornering, where car needs to generate a large downforce at a relatively low speed. This downforce helps to stabilize the car at the rear ensuring that the car's rear end does not skid on turns.

I. Selection of Airfoil: Due to location of engine at the rear end of the car, more downforce is generated. Hence, to compensate for minimization of downforce from rear end, a thinner airfoil is used. Thinner airfoil also helps to maintain the continuity of the flow without flow separation. Thus, NACA 6412 is employed at the rear end.

II. Angle of Attack (α): For rear wings design, two sets of angle of attack were considered so are to obtain comparative results between various parameters. The first set of angles is **-15˚, -20˚, -25˚.** And the second set of angles **-9˚, -12˚, -15˚** respectively. A three-element aerofoil instead of a single element aerofoil is considered to achieve maximum down force for a longer length without distortion. Rear wing with three element aerofoil is shown below in figure 7.

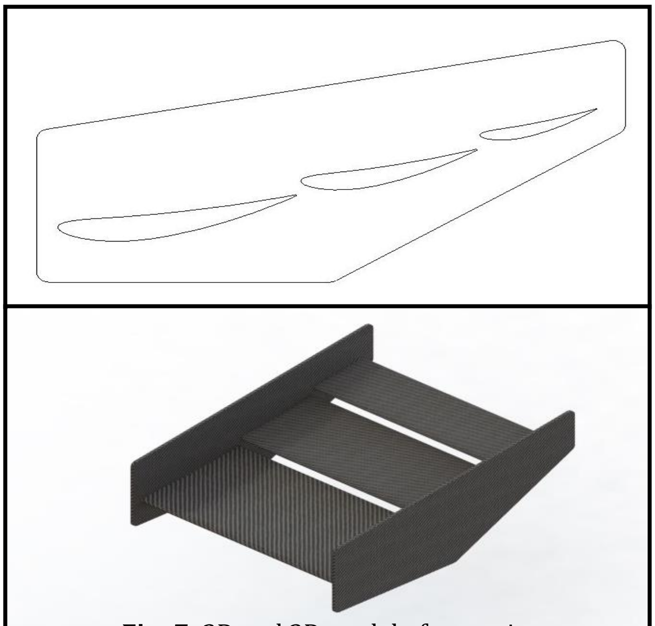


Fig -7: 2D and 3D model of rear wings

3.2 Assembly

Model A: The first step in geometric modelling simulation, excludes both front and rear wings. Figure 8 shows the geometric model of the FSAE car without wings in isometric view. This model aims to compare how aerodynamic aspects of this car without front wings and rear wings.

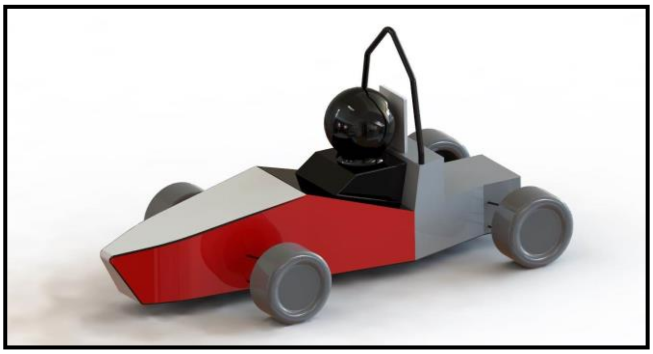


Fig -8: FSAE car model without wings

Model B: In this model front and rear wings are assembled. First set of angle of attack (α) i.e. **-6°, -11°, -14°** for front and **-15°, -20°, -25°** for rear wings is used. The baseline model with wings attached is shown in the figure 9. It is beneficial for finding results compared to the initial model without any aerodynamic device.

Model 3: Second set of angle of attack (α) i.e. **-6°, -8°, -10°** for front wings and **-9°, -12°, -15°** for rear wings is used in this model. It helps to study the role of angle of attack in the design of both wings.

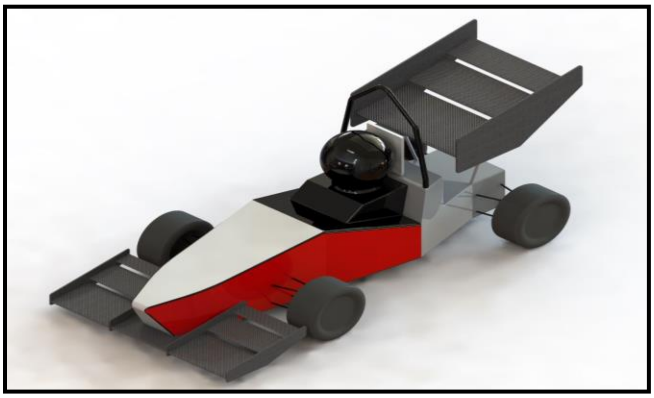


Fig -9: FSAE car model with wings

4. SIMULATION AND ANALYSIS

The simulation of the models is done in Solidworks Simulation. The models will be analysed on 5 different velocities 40km/hr, 60km/hr, 80km/hr, 100km/hr, 120km/hr respectively. The solver settings used for the analysis are listed in the table 1.

Table -1: Solver Settings for Simulation

Solver Settings	
Velocity	Absolute
Flow	Steady
System	3d – Pressure Based

Further there are boundary conditions that are necessary to be applied during the simulation so as to create exact resemblance of actual testing environment. The settings that have to be specified for the simulation are boundary condition listed in the table below.

Table -2: Boundary Conditions for Simulation

Parts	Boundary Conditions
Car body (nose)	Stationary wall, no slip
Front Wing	Stationary wall, no slip
Rear Wing	Stationary wall, no slip
Seat	Stationary wall, no slip
Head Restraint	Stationary wall, no slip
Wheels and Arms	Stationary wall, no slip

5. RESULT

The outcome of this simulation will generate three distinctive results based on all three models respectively. The following tables consists of results on analysis of the model A, B and C with and without aerodynamic devices attached. The readings are with respect to 5 different velocities.

Table -3: Results of model without wings (A)

Srno.	Cd	Velocity	Drag	Cl	Downforce
1	0.51	40	30.39	0.08	5.21
2	0.51	60	68.49	0.08	11.77
3	0.51	80	121.84	0.08	20.09
4	0.52	100	191.41	0.08	30.90
5	0.52	120	276.15	0.08	44.13

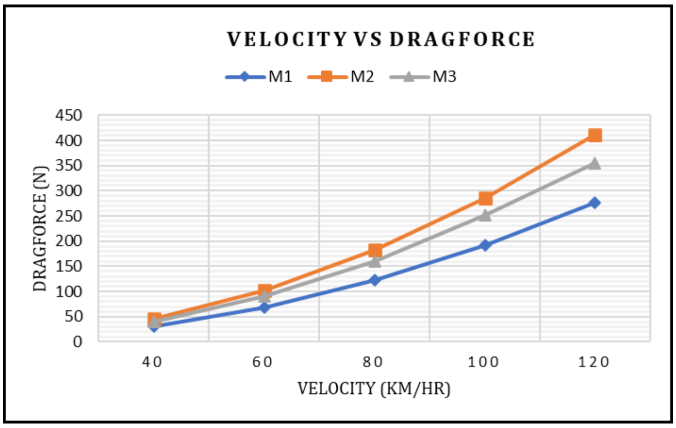
Table -4: Results of model with wings (B)

Srno.	Cd	Velocity	Drag	Cl	Downforce
1	0.58	40	45.26	0.47	35.71
2	0.61	60	102.42	0.47	80.79
3	0.61	80	182.33	0.47	143.05
4	0.61	100	285.35	0.47	223.13
5	0.61	120	410.292	0.47	321.08

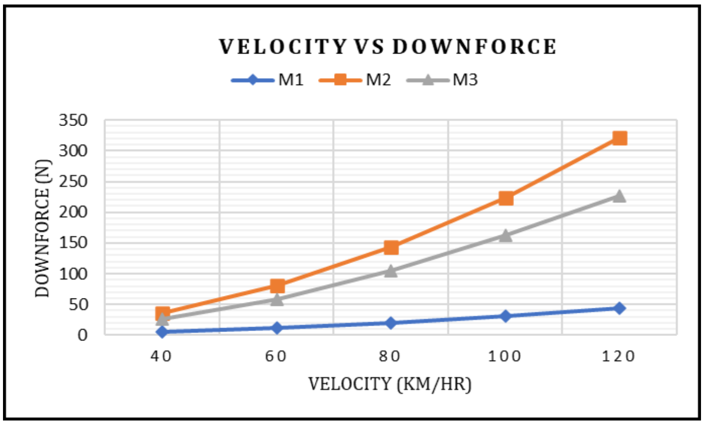
Table -5: Results of model with wings (C)

Srno.	Cd	Velocity	Drag	Cl	Downforce
1	0.55	40	39.97	0.35	25.81
2	0.56	60	90.61	0.36	58.832
3	0.56	80	160.77	0.36	104.70
4	0.56	100	252.05	0.36	162.66
5	0.55	120	355.16	0.35	227.36

All the results of model 1, 2 and 3 shows change in coefficient of drag, coefficient of lift, drag-force and downforce with change in velocity. To further understand the relation between them, graphs have been plotted. Following graph 1 and 2 are based on the results of model 1, 2 and 3. It shows that with increase in velocity, drag and downforce both increases.



Graph -1: Velocity vs Dragforce (M1, M2, M3)



Graph -2: Velocity vs Downforce (M1, M2, M3)

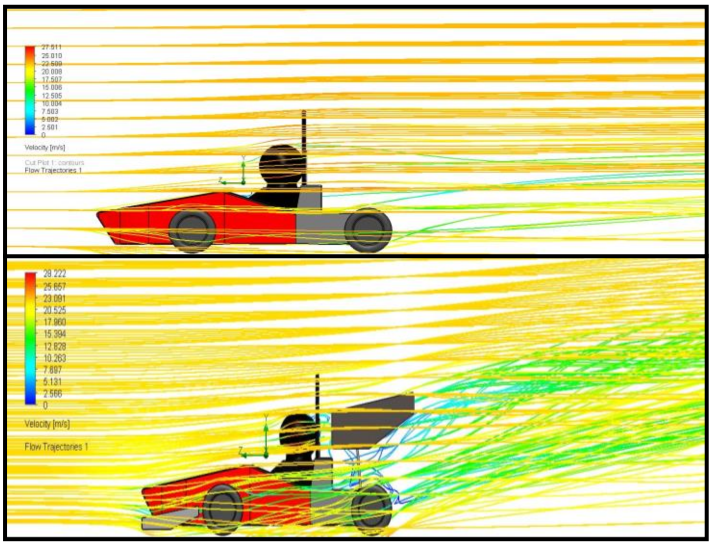


Fig -10: Solidworks simulation of models

6. CONCLUSION

The design and fluid flow analysis of a full-fledged aerodynamic package for a Formula Student vehicle was described. As per the results obtained after the analysis of all 3 models, the key learnings developed in this project are:

- CFD is an extremely useful tool. It can solve a wide range of engineering issues despite computing constraints.
- With the addition of front and rear wings down force increases substantially with increase in velocity.
- As the downforce increases, drag force also increases to some scale. So, we can say that downforce and drag force are proportional to each other.
- Due the addition of front and rear wings the area of the model increases. It is seen that drag force increases with increase in area to model, it states that drag depends upon area of contact.
- The angle of attack of front and rear wings influences forces acting on the vehicle body.
- When the angle of attack is increased, higher downforce and drag force is obtained and with lower angle, the forces obtained are lower for same aerofoil.
- The design and analysis of aerodynamic accessory depends upon number of factors that needs to be taken in consideration for optimum results.
- The process should be meticulously conducted to find the correct or optimum angle of attack which can contribute to maximum downforce and minimum drag force.

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