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Aerodynamic Development of a Formula SAE car: Initial Design Stage

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Abstract

This paper describes the initial design and development of the front and the rear wing of a Formula SAE car.It also reviews in brief the latest Formula SAE rules relating to aerodynamics, which is further used to develop realistic parameters for the specification of the front and the rear wing. The front and the rear wing is designed to generate maximum negative lift (downforce) within the stated acceptable limits of increased drag and reduced top speed. CFD analysis of front and the rear wing is also covered in this paper. The net effect of these wings on a Formula SAE car's performance in the Dynamic Events is then predicted. Wind tunneltesting and on-track testing will be done and setup for tuning of this package is being developed.

Keywords:*Aerodynamics, Downforce, Drag, FSAE, Formula Student, Project, Racecar, Wings, Airfoils, Lift, CFD*

Introduction

1. Vehicle Aerodynamics

Vehicle aerodynamics is a field that describes the forces acting on the vehicle when moving through a fluid. When the vehicle is stationary, the exterior surfaces of it experience one atmospheric pressure; the upper and lower surface as well as the front and rear surfaces all have the same pressures exerted and ultimately achieve equilibrium with the summation of forces being equal to zero. As the vehicle starts to move through the fluid, the pressures exerted on the exterior surfaces change proportional to the square of velocity. These pressure changes create forces acting on the surface of the vehicle which ultimately have an effect on the performance of the vehicle.

2. The Formula SAE/Student Competition

Formula SAE is an engineering design competition organized by SAE international.It is a competition in which students design and build an open wheeled race car. The purpose is to produce a race car prototype to be evaluated for production. The competition started in the USA in 1980. Since its beginning, it has now spread to Europe, Asia, Australia and South America, with hundreds of international teams competing in number of events worldwide [2]. The Indian version of this is organized every year by SAEINDIA and is called as 'Supra'. This event takes place at the Buddh International Circuit or the Madras Motar Racetrack. Also, every year, a similar event is organized by an

Independent governing body. This event is called as 'Formula Student India' or 'Formula Bharat'.Formula Student is the European version of the Formula SAE. Formula Student Germany (FSG) is considered to be the best student engineering design competition in the world.

Teams are awarded points on eight different events, three of which are static and the remaining five are dynamic events. The static events includes Cost, Design presentation and Business presentation. The dynamic events includes Skid-pad/Wet-pad, Acceleration, Autocross, Endurance and Fuel economy. Before qualifying for the dynamic events a team has to clear a series of particular tests which is also called as Mechanical Scrutineering. It consists of Technical Inspection, Tilt test, Noise test and Brake test.

Aerodynamics in Formula SAE/Student Competitions

Aerodynamics has been a major subject in Formula design competitions for almost a decade now. It focuses on different techniques to increase the normal load on tires for improved mechanical grip without the corresponding addition of mass.

The amount of grip available in the tires alongwith aerodynamic drag and engine power set the theoretical limits for the vehicle'svelocity around the track, especially in cornering, and it is thus of particular interestwhen designing a vehicle to increase this grip while keeping drag to a minimum.Nonetheless, the balance of the forces under all circumstances due to speed and acceleration is equally important. [1]Over the years, rules and regulations have been imposed to keep these aerodynamicadvantage on a reasonable scale as technology has improved.

Competition Rules Consideration

The latest and current Formula student rules when compared with most other road racing categories [2, 3] offer some unique challenges and opportunities to the students for the use of aerodynamic devices. These rules are stated below in details, starting with those that influence general vehicle design and performance, and moving onto those more relevant to the use of aerodynamic devices. The broad influence of these rules on the design and performance of a Formula Student car will also be discussed in brief.

Restrictions for Aerodynamic Devices

1. Height restrictions:

• All aerodynamic devices forward of a vertical plane through the rearmost portion of the front face of the driver head restraint support, excluding any padding, set to its most rearward position, must be lower than 500mm from the ground [4].

• All aerodynamic devices in front of the front axle and extending further outboard than the most inboard point of the front tire/wheel must be lower than 250mm from the ground [4].

• All aerodynamic devices rearward of a vertical plane through the rearmost portion of the front face of the driver head restraint support, excluding any padding, set to its most rearward position must be lower than 1.2m from the ground [4].

2. Width restrictions:

• All aerodynamic devices lower than 500mm from the ground and further rearward than the front axle, must not be wider than a vertical plane touching the outboard face of the front and rear wheel/tire [4].

• All aerodynamic devices higher than 500mm from the ground, must not extend outboard of the most inboard point of the rear wheel/tire [4].

3. Length restrictions:

• All aerodynamic devices must not extent further rearward than 250mm from the rearmost part of the rear tires [4].

All restrictions must be fulfilled with the wheels pointing straight and with any suspension setup with or without driver seated in the vehicle [4]. Refer Figure 1.

Minimum Edge Radii of Aerodynamic Devices:

All forward facing edges of aerodynamic devices that could contact a pedestrian must have a minimum radius of 5mm for all horizontal edges and 3mm for vertical edges [4].

Aerodynamic Devices Stability and Strength:

Any aerodynamic device must be able to withstand a force of 200N distributed over a minimum surface of 225 cm2 and not deflect more than 10mm in the load carrying direction.

Any aerodynamic device must be able to withstand a force of 50N applied in any direction at a point and not deflect more than 25 mm [4].

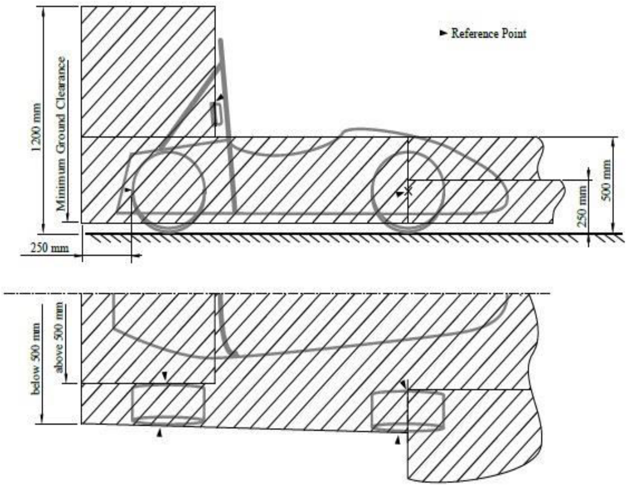

Figure 1.Maximum dimensions and positioning of aerodynamic devices.

It is allowed to adjust the settings of the aerodynamic devices during individual events, but the wholesale removal or addition of a component is not allowed. Therefore, some ability to tune the performance of the aerodynamics package is considered advantageous. This might include a low drag setting for acceleration, a mid to high setting for autocross and endurance, and a maximum downforce setting for wet-pad/skid-pad [4].

Design Process

In the design of an open-wheel formula race car, one is faced with numerous instances of complex geometry, rotating wheels, A-arms and the cockpit with a driver to name a few. This nature of the vehicle make it difficult to approach the problem of aerodynamic design and optimization of the entire car analytically. It is due to these difficulties that methods of simulation such as XFLR5, Optiprof and computational fluid dynamics (CFD) have been developed to aid the research. It is the objective of this paper to develop the front and the rear wing using XFLR5 and CFD for maximum downforce within the acceptable limits of induced drag and reduced top speed. As there is no established method for the theoretical prediction of aerodynamic side forces and their associated yawing moments, this aspect of the aerodynamic design will not be considered at this stage. Figure 2 shows the CAD model of the vehicle with Front and Rear wing.

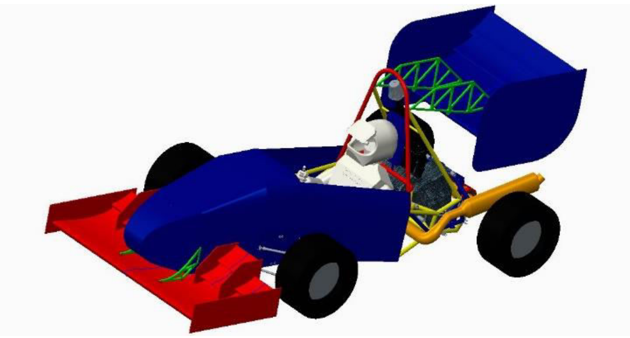

Figure 2. CAD model of the vehicle with Front and Rear Wing

1. Front Wing

The front wing is designed to produce huge amounts of downforce while operating in ground effect and uses a multi-element design. It is designed keeping in mind the competition rules. Endplates are used to minimize tip losses. Its size depends on the rule and its shape and complexity is a design parameter. The front wing is the most important design feature of any vehicle because it sets up the airflow for the entire rear of the vehicle as well as dictates the size and placement of the rear wing to properly balance a car aerodynamically [6]. Since the front wing is the first object to disturb flow around the vehicle, a poorly designed front wing can result in very large drag increases and losses across the entire rear of the car.A number of airfoils were analyzed using the XFLR5 tool to determine a suitable candidate for the front wing. [13, 14] Eventually it was decided to use Selig S1223 airfoil due to its high lift at low Reynolds number characteristic [7]. Figure 3 show the pressure distribution of this airfoil along with it boundary layer. An arrow can also be seen showing the center of pressure. This arrow represents the point where the combined negative lift will be acting. Maximum lift is obtained at angle of attack (α) 12°

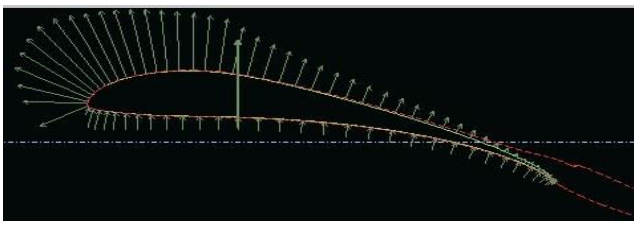

Figure 3. Pressure distribution and Boundary layer of S1223 airfoil

Values defining the airfoil are mentioned in the table 1 below.

Airfoil	S1223
Thickness	12.13%
Max. thickness position	20.21%
Max. camber	8.67%
Max. camber position	49.50%
Number of panels	81

Table 1. Selig S1223 Airfoil Data

The coefficient of lift Cl is 2.270 and coefficient of drag is 0.030 at α=12°. It can be seen from the graph in Figure 4 that maximum lift coefficient occurs at α=12º. The L/D ratio is 76.653. The graph below shows the variation of Cd with Cl. Y-axis represents Cl and X-axis represents Cd.

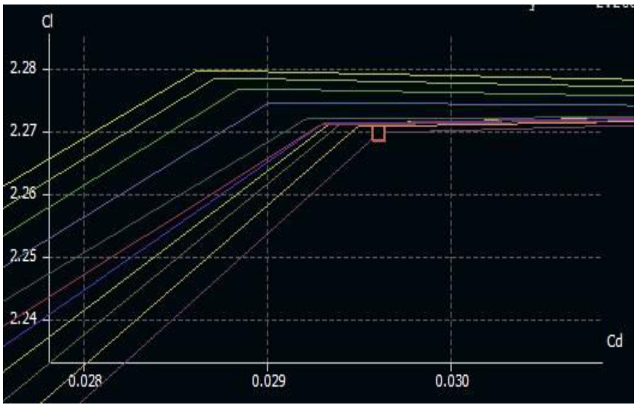

Figure 4. Airfoil S1223 Cl/Cd graph

The graph in Figure 5 show variation of lift coefficient Cl with the change in α.

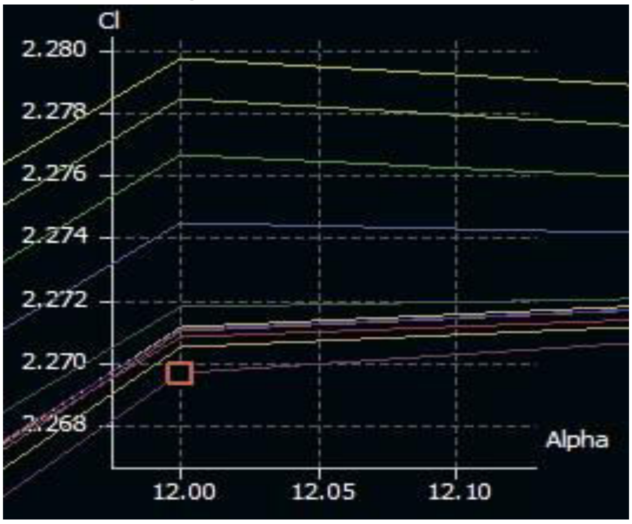

Figure 5. S1223 Cl/α graph

Wing span of the main element of the front wing is 1.338m. And the chord length of this element is .45m. Analysis of this profile at an angle of attack of 12° will give us different parameters like Cp, Lift, Surface velocity, vortex stream. All these parameters are shown in the Figure 6. The table 2 indicates some values from the analysis.

Wing Span	1.338 m
Root chord	0.45 m
Wing Area	.5 m^2
Aspect ratio	2.889
Mesh elements	494
Velocity	15.00 m/s
Alpha	12°
Efficiency	2.998
Cl/Cd	11.677
X_Cp	0.188 m
Ground effect	.05 m

Table 2. Airfoil S1223 Analysis Data

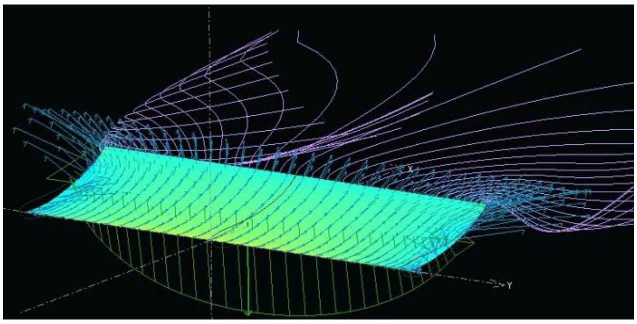

Figure 6. Airfoil S1223 analysis

The purple lines show the vortex stream whereas the blue lines represent the surface velocity. The green arrows represent the magnitude and direction of the negative lift.

To Study the effect of multi-element front wing, CFD analysis on it was done using ANSYS. The results are shown in the Figures 7 and 8.

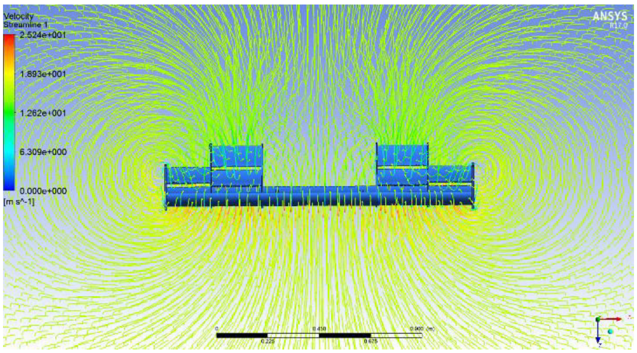

Figure 7. Front wing streamlines

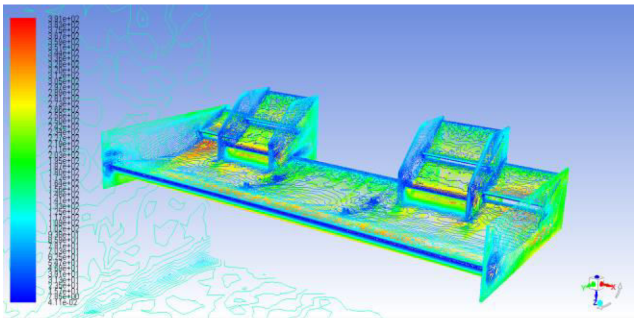

Figure 8. Front wing Dynamic pressure

2. Rear Wing

The rear wing is designed to complement the downforce levels and aerodynamic balance of the front wing. Similar to front wings, a rear wing can use either a single or multi element layout with large endplates to mitigate tip losses. It was decided that a three element rear wing will better suit the design expectations [6]. The airfoil selected for this wing was E423. This airfoil also has a high Cl at low Reynolds number [7]. Figure 9 shows the pressure distribution and the boundary layer of this airfoil along with the center of pressure. Maximum lift is obtained at an angle of 13°.

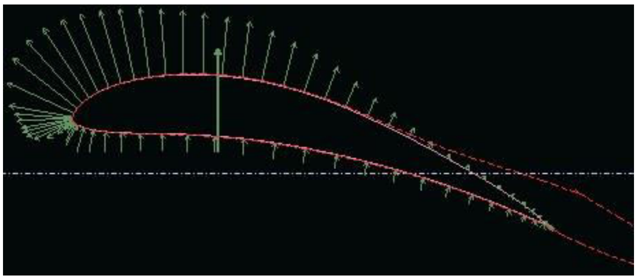

Figure 9. Pressure distribution and Boundary layer of E423 airfoil

The table 3 gives the values defining this airfoil.

Airfoil	E423
Thickness	12.52%
Max. thickness position	24.24%
Max. camber	10.03%
Max. camber position	44.45%
Number of panels	72

Table 3. Eppler E423 Airfoil Data

The coefficient of lift Cl is 2.040and coefficient of drag is 0.034 at α=13º. It can be seen from the graph in Figure10 that maximum lift coefficient occurs at α=13º. The L/D ratio is 59.580. The graph in figure 10 shows the variation of Cd with Cl. Y-axis represents Cl and X-axis represents Cd.

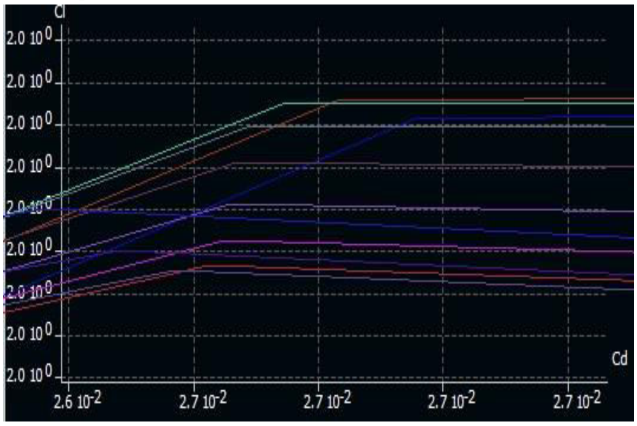

Figure 10. Airfoil E423 Cl/Cd graph

The graph in figure 11 shows variation of lift coefficient with angle of attack α.

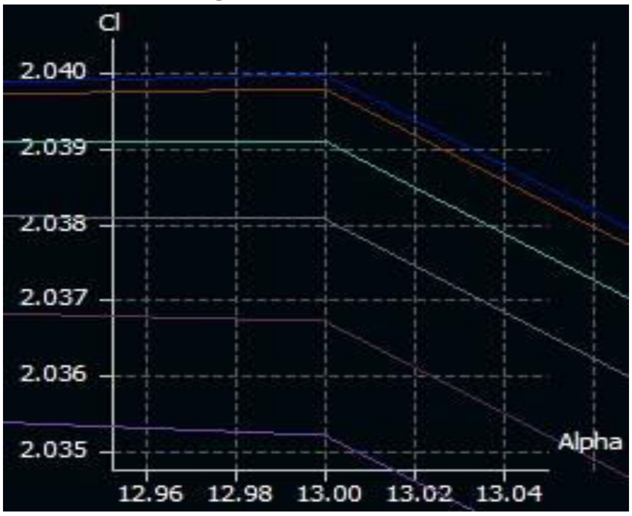

Figure 11. E423 Cl/α graph

Wing span of the main element of the rear wing is 0.890m. And the chord length of this element is 0.50m. Analysis of this profile at an angle of attack of 13° will give us different parameters like Cp, Lift, Surface velocity, vortex stream. All these parameters are shown in Figure12. The table 4 below gives some values from the analysis.

Wing Span	0.89 m
Root chord	0.445 m
Wing Area	.445 m^2
Aspect ratio	1.780
Mesh elements	494
Velocity	15.00 m/s
Alpha	13°
Efficiency	1.163
Cl/Cd	6.210
X_Cp	0.245 m
Ground effect	.8 m

Table 4. Airfoil E423 Analysis Data

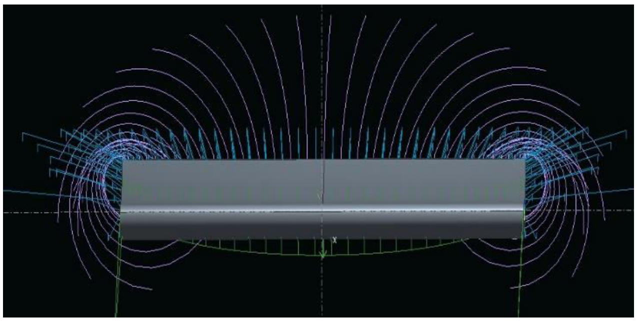

Figure 12. Airfoil E423 analysis

The purple lines show the vortex stream whereas the blue lines represent the surface velocity. The green arrows represent the magnitude and direction of the negative lift. To Study the effect of multi-element rear wing, CFD analysis on it was done using ANSYS. The results are shown in the Figures 13 and 14.

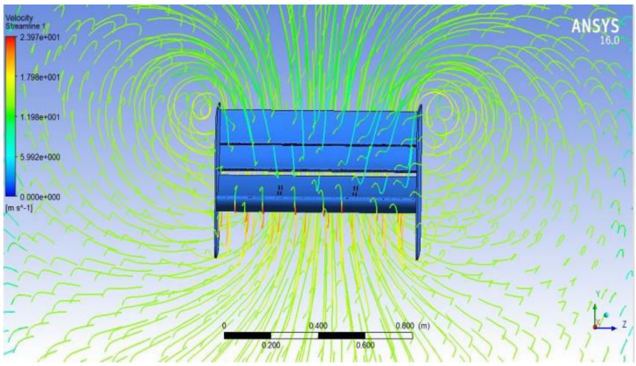

Figure 13. CFD of multi-element rear wing

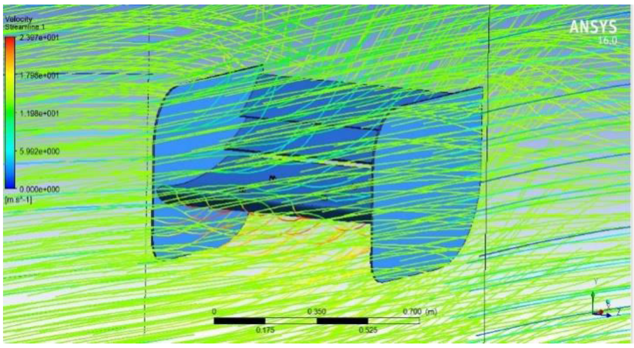

Figure 14. CFD of multi-element rear wing

Aerodynamic Validation

The analysis presented above is one process by which an aerodynamics package can be designed for a race car. There is however, no guarantee that the wings will perform as intended within the near flow field of the race car. It is generally safe to assume that their performance will be adversely affected due to their interaction with the vehicle, and even each other. For this reason a wide range of wind tunnel testing and on track aerodynamic testing will be done. A setup for tuning of this aerodynamics package is being developed. Also, active aerodynamic system is meant to serve as a platform for further development. Currently track testing utilizing aerodynamic anti dive under heavy braking has shown promise in improving the stability of the car. Other stability management control schemes can be experimented with as well such as aerodynamic anti roll.

Conclusion

Using values obtained from analysis of airfoils in XFLR5 and also from CFD analysis, preliminary specifications of a high downforce front and rear wing for a Formula SAE car is developed. The wing profiles were extensively studied to obtain the best possible compromise between downforce and drag. This data was further used to design a multi-element front and a rear wing in Creo 2 software. CFD analysis of these wings was also done individually to study the effects of lift. This analysis overall predictsthat the wing package will significantly benefit the car's performance in the dynamic events and give the team an upper hand over the competitors.

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