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AERODYNAMIC STUDY OF FORMULA SAE CAR

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ABSTRACT:

A numerical study of a rear engine SAE racecar is presented. The focus of the study is to investigate the aerodynamics characteristics of a SAE race car with front spoiler, without front spoiler and with firewall vents. Formula SAE is a college level student design competition where every year students of universities all over the world build and compete with open-wheel formula-style race. Society of Automotive Engineers (SAE) INDIA racecar focuses on developing a simple, lightweight, easily operated open chassis vehicle. Compliance with SAE rules is compulsory and governs a significant portion of the objectives. The aerodynamics study of the SAE car is made to reduce the drag force. The study was performed using the CFD package. The main goal of this study is to enhance the stability of the vehicle and reduce the drag. With this the track performance will be increased also the resistance of air to the vehicle gets reduced. The CFD analysis is done on full scale model. The aerodynamic study is conducted in the ANSYS Fluent software to perform a turbulent stimulation (using k - ϵ model) of the air flow on the SAE car. The results are graphically shown with coefficient of drag, velocity contour.

1. INTRODUCTION

1.1. Problem Statement

The goal for Formula Student competition is to produce a car that is designed for performance. The natural progression of the design is to make the car both light and powerful by optimizing the mechanical and structural efficiency of all aspects of the vehicle. This type of design development leads to a contradiction in that a lightweight vehicle is limited in its cornering ability by the weight over wheels, and cannot utilize an increase in power if the traction limits are exceeded. To mitigate these problems, teams turn to aerodynamic features to produce down force as well as to minimize the aerodynamic drag on the car. For the 2019 competition, the design team has been contracted to produce a front aerodynamic package for the team PRAHETI RACING, to be compatible with the 2019 Formula vehicles. The overall objective is to provide a detailed design of a front aerodynamic package for the 2019 for the Vehicle that improves the overall performance of the vehicle and meets the needs of the team.

1.2.Motivation

The FSAE competition offers a challenging environment where engineering students practice and develop various engineering skills. Placing well in the competition occurs as a result of two categories; static testing, where design and engineering practice are judged and scored accordingly and dynamic testing, where the actual performance of the vehicle is judged and scored. Teams that place well attain global recognition for their respective university from both the automotive industry and sponsors. Universities that place well attain an increase in revenues from sponsors/donations and increased relationships with these companies, which lead to an acceleration of the university's programs and an increase in job placement. Thus, the FSAE competition offers a multitude of benefits for both the students that attend and the university as a whole.In order to place well, as previously mentioned, the vehicle must be designed to make the car both light and powerful by optimizing the mechanical and structural efficiency of all aspects of the vehicle. As the design development leads to a contradiction in that a lightweight vehicle is limited in its cornering ability by the weight over wheels, teams turn to aerodynamic features to produce down force as well as to minimize the aerodynamic drag on the car

1.3.Formula Student

Figure 1.1 Formula student logo

Formula Student (FS) is Europe's most established educational engineering competition. Backed by industry and high-profile engineers such Patron, Ross Brawn OBE, the competition aims to develop enterprising and innovative young engineers and encourage more young people to take up a career in engineering.The format of the event is such that it provides an ideal opportunity for the students to test, demonstrate and improve their capabilities to deliver a complex and integrated product in the demanding environment of a motorsport competition.The project usually forms part of a degree-level project and is viewed by the motorsport industry as the standard for engineering graduates to meet, transitioning them from university to the workplace. It is a kite-mark for real-world engineering experience.

1.3.Formula Student Challenge

As a student, taking part in Formula Student gives you the chance to demonstrate your technical, engineering design, and manufacturing skills.You will also learn important lessons on team working, time management, project management, budgeting and presentation: all things that any prospective employer will be looking for. Formula Student graduates also find that the professionalism they gain as practicing engineers means they are well equipped for their future engineering careers.Your team is tasked to produce a prototype for a single-seat race car for autocross or sprint racing, and present it to a hypothetical manufacturing firm. The car must be low in cost, easy to maintain, and reliable, with high performance in terms of its acceleration, braking, and handling qualities. During the competition your team must demonstrate the logic behind your proposal and must be able to demonstrate that it can support a viable business model for both parties.

1.4.Competition

The Formula Student event consists in a series of static and dynamic testing operations that the teams have to complete the engineering project of creating a race car, with its performance, its safety behavior and the ability of the work team to pass all the activities.

- Static Test
  – Technical verification: be sure that the car fulfills all the safety conditions and regulations.
  – Design: the team has to defend the project in front of four judges in a first step, and only fourteen teams go to the final which consist in four hours in front of thirty judges.

  – Business and presentation: it consists in a explanation of how you are selling your car in fifteen minutes in front of marketing professionals.

  – Cost analysis and sustainability: the team discusses with two judges a report of the cost of the car, including pieces and labor.

2. LITERATURE REVIEW

2.1 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.

2.2 The Impact of Aerodynamics on Vehicle Shape

Let us start the discussion on vehicle shape and aerodynamics by comparing the two race cars in Fig. 2.1 and 2.2. Both are aimed at doing the same thing: winning the biggest race of all, the Indy 500. In spite of the fact that the two cars were designed quite a few years apart, the question remains: why do they differ so much in external appearance? One possible answer is the increased importance paid to aerodynamic streamlining details in the later car. But closer examination of the 1916 racecar with its tapering boat-tail reveals that even at the dawn of the century aerodynamic drag reduction was a primary concern.

Figure 2.1: The 1993 Marlboro Penske PC22 Indy car, which won the Indy 500 in 1993. Courtesy of Marlboro Racing.

Figure 2.2: The 1916 Peugeot, winner of that year's Indy 500 race. Courtesy of Peugeot Motors of America.

Streamlining would seem to be important—after all, we want the car to move more easily through the air (less drag = faster)—but the most dominant reason behind the large difference in the appearance of the more recently designed multiwinged race car is the focus on using its body and wings to create aerodynamic dawn force. This raises the question of why aerodynamic down-force is needed. But before answering that question let us convince ourselves that aerodynamic loads are significant and survey some of the terms frequently used when speaking about the aerodynamics of a moving vehicle. It may seem that the loads created by the motion of air are unimportant, especially within the speed range encountered by automobiles. However, you only have to extend your hand out of a car's side window to feel the serious forces exerted by air. And we all have heard about the disastrous effects of the winds in tornadoes or hurricanes. Furthermore, a short glance at the sky reveals that simple airplane wings lift hundreds of tons of cargo and passengers while riding on air alone; those powerful jet engines provide only the thrust needed to overcome the airplane's drag. To understand how such large aerodynamic forces can be created, a typical cross section of a wing is shown in Fig. 2.3. For the sake of the discussion, let us assume that it moves from right to left. Because of the shape and angle of this airfoil section, the air will move faster on the upper surface than on the lower one. As it will be explained later in Chapter 2, this speed difference creates a low pressure (suction) on the upper surface and a higher pressure on the lower one. The result of this pressure difference is the force that lifts an airplane or your neighborhood bird.

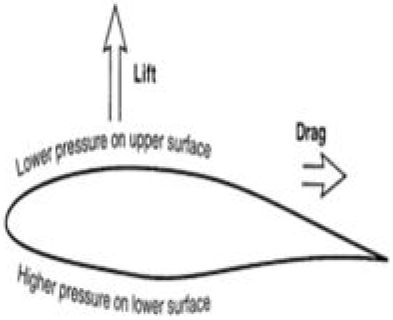


Figure 2.3: The low pressure on the upper side and the higher pressure on the lower side of this airfoil add up to the lift force. Of course when used on a race car, the airfoil is invertedNothing in life comes free, and when wings generate lift they also create drag, which is the force that resists the motion. The drag is usually much smaller than the lift, and it can be reduced by streamlining the vehicle (having smooth external surface). Of course any improvement in a vehicle's drag leads to potential improvements in fuel economy, which is why drag is quite important to the passenger car industry. The effect of streamlining on drag reduction can be demonstrated by using the same visual aid my teachers used many years ago. Fig. 2.4 shows the cross-section of a long circular rod (depicted by the little circle) which has the same drag as a much thicker (up to 10 times) and larger airfoil. (This is the reason why the suspension members (e.g.., A-arms) on many race cars have stream lined

sections and not the more simple circular section.) Fig. 2.3 introduced the lift and drag forces, but in reality a side-force component must be included. Fig. 2.5 depicts these important aerodynamic forces as

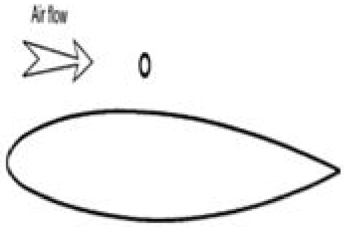


Figure 2.4: This small cylinder and much larger airfoil have the same aerodynamic drag. The cylinder's drag can be reduced almost ten times by covering it with a streamlined shape.They apply to a moving vehicle. The force which resists the motion and points backward is the drag. The second force component, which points upward, is the lift. It is mostly unnoticed by the everyday driver, but those who have experienced very high-speed driving may have noticed that at that speed more attention is needed to keep the car traveling along a straight line. This instability is usually caused by lift, which on passenger vehicles will usually be larger on the rear wheels than on the front ones. The third force, the side force (positive to the right), is important too, but with relatively low levels of side winds this component of the aerodynamic load is usually small. For a race car, the next logical step would be to reduce drag and lift or even create a negative lift (down force). In race car design, drag reduction is secondary. It is the creation of down force by aerodynamic means (such as the use of inverted wings) that is extremely important and leads to major improvements in race car performance, especially on tracks with numerous high-speed, unbanked turns. Aerodynamic down force increases the tires' cornering ability, and the faster a car turns the sooner it will see the checkered flag.

3 METHODOLOGY

The aerodynamic study of the formula SAE car is done in ANSYS Fluent software. The main aim of this aerodynamic study is to reduce the drag and increase the cornering stability of the SAE car. The basic model of SAE car was analyzed in Fluent and it was found that the value for lift and drag co – efficient were on higher. Appropriate design modification in the basic model were incorporated and analyzed separately. This design modification and its subsequent effects are discussed in the later part of this paper.

3.1 Modeling of car

The bodywork design was made with the commercial software SolidWorks that the team got by sponsorship. This program has all the tools to do the complete car design like Computer Fluid Dynamics tool, Finite Element Method tool, motion simulator or electrical circuit simulator. All the calculations have an approximately error of a 10%. When it is designed a new model, it should combine a number of factors including comfort, aerodynamics and security, aimed at obtaining a product that offers significant power with fuel economy. As an example in a sport car habitability is sacrificed in favor of aesthetics and aerodynamics, in a minivan what prevails is the interior layout background instead of aerodynamics. Trying to achieve these objectives are used different strategies:

- Optimize organizational tasks of all divisions involved in the development of the new model allowing a quickly detection of any problem present.
- Application of new concepts and new technologies.
- Capacity for innovation. The strength of a team resides in its ability to innovate faster than competitors.

A typical sequence for a Formula Student new car is developed in the following phases:

- First sketches.
- Design.
- Creating models.
- Building.
- Tests.
- Competition.

First sketches

In this phase, the first designs are made from hand drawings. Then, the technical director working with the team determines the dimensions of the vehicle. For the initial calculation of the exterior body measures usually take into account:

- Aerodynamic requirements.
- Cockpit ergonomics.
- Position and size of the fuel tank.
- Space requirement for wheels.
- Size and arrangement of the suspension.
- Type of position of mechanical parts: engine, radiator, change.

Figure 3.1: open wheel race car

Design of aerodynamics

The main aim of the aerodynamic study is to reduce the drag and increase the stability of SAE car. The reduction in drag will help in increasing the top speed of the SAE car. This is obtained by making the body aerodynamic and air flow should have lesser obstruction in its way. The stability of the SAE car is also very important in the aerodynamic study. The stability is obtained by providing wings or spoilers. In this paper the front wing is installed onto the SAE car to increase the stability. In this report, the aerodynamic study three different solid models are taken.

3.2 Design Modifications

- The first solid model is the basic SAE car model outlining the overall shape with actual dimensions.
- The second solid model is the SAE car model with cut out in the firewall to reduce drag
- The third solid model is the SAE car model with cut out in the firewall and a front wing. This will reduce drag and

increase stability by increasing the down force.

The first model is the basic model of SAE car. All three cars were modelled in SOLIDWORKS2017

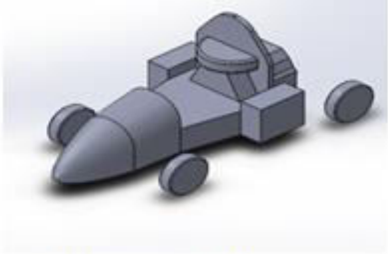


Figure 3.2: Model 1

Figure 3.3: Model 2

Figure 3.4: Model 3

3.3 Meshing For CFD Simulation

A virtual air-box has been created around the 3D CAD model **(Figure 3.5.)**, which represents the wind tunnel in the real life. Since we are more interested in the rear side of vehicle, which is where the "wake of vehicle" phenomenon occurs, more space has been left in the rear side of the vehicle model to capture the flow behavior mostly behind the vehicle.

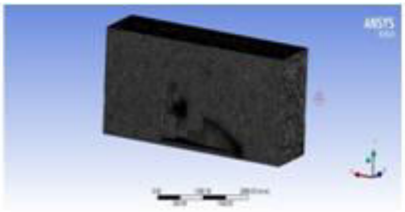


Figure 3.5: Meshing ,

Due to the complexity of the simulation with limited computer resources and time, the complete domain was divided to half using a symmetry plane (YZ plane), which means, the simulation would be calculated for just the one side of the vehicle and since the other side is symmetric and YZ plane has been defined as symmetric boundary in the solver to make the boundary condition as "a slip wall with zero shear forces"; the simulation results would be valid for full model as well. All 5 surfaces of the virtual wind tunnel (air-box) have been named so the numerical solver of ANSYS FLUENT® would recognize them and apply the appropriate boundary conditions automatically. The final meshing can be seen in Figure 3.6. The same procedure to create high resolution meshing has been followed for all cases (model 1: Car with fire wall, model 2: car with cut out in the firewall, model 3: car with front wing).

3.4 Boundary Conditions for Simulations

Analysis has been done to simulate the car model in the wind tunnel. In order to achieve this, the domain around the body is considered as that of actual size of the wind tunnel . Wall of the wind tunnel, the side, top faces of the domain are given boundary conditions of symmetry. The inlet velocity is given 25 m/s. Blue and red faces indicate velocity inlet and pressure outlet respectively. White represents wall whereas yellow represents symmetry conditions.

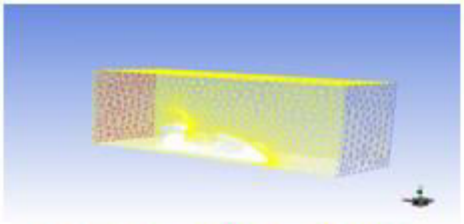
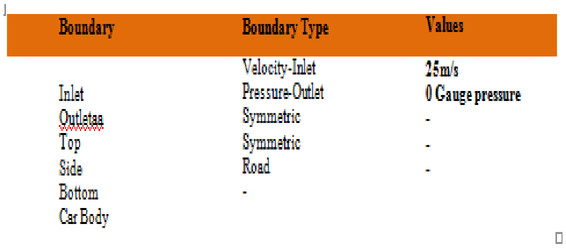


Figure3.6: Boundary conditions



Boundary	Boundary Type	Values
	Velocity-Inlet	25m/s
Inlet	Pressure-Outlet	0 Gauge pressure
Outletaa	Symmetric	-
Top	Symmetric	-
Side	Road	-
Bottom	-	
Car Body		

Table no 1: Boundary condition

3.5. CFD simulations

A CFD simulation is capable of solving the mentioned simulations by dividing the fluid volume in a finite number of blocks (with different possible shapes) called cells. To obtain a finite number of cells, a finite volume around the test object has to be created, making it big enough so the blockage effect1 is minimised. The accuracy of the calculations depends on the size and structure of the cells. As an example of the different cell shapes that can be used:

- Tetrahedral: tetrahedral cell shape based core mesh.
- Polyhedral: arbitrary polyhedral cell shape based core mesh
- Trimmed: trimmed hexahedral cell shape based core mesh.
- Thin mesh: tetrahedral or polyhedral based prismatic thin mesh.

The calculation process consists in the iterative communication of information between the cells in the mesh. Through the different iterations, the software tries to find the balance of forces and mass flows in every cell until the errors (also called residuals) are low enough, and a solution is achieved.

4 RESULTS & DISCUSSIONS

4.1 Drag coefficient

CFD analysis of flow over the car is carried for speed of 25 m/s for all three models. Results are obtained the three models and graphs are plotted.

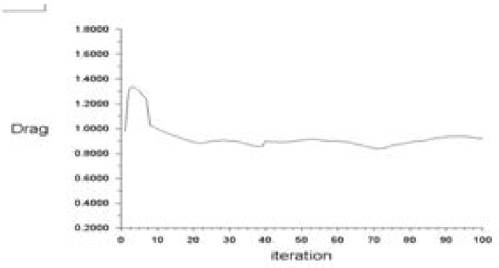


Figure 4.1: Drag coefficient Vs iterations for model 1

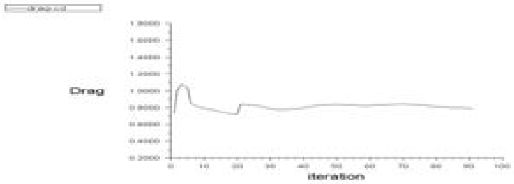


Figure 4.2: Drag coefficient Vs iterations for model 2

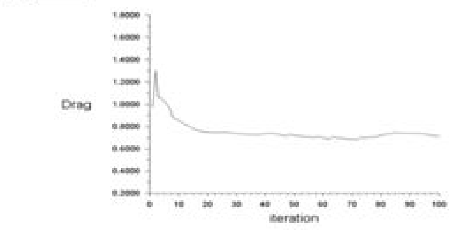


Figure 4.3: Drag coefficient Vs iterations for model 3

Co-efficient of drag always depends on shape of the vehicle body. In this study, shape of the race car is modified by cutting out firewall and provided wing at front end.

Modelname	Coefficient of drag
Model 1	0.93
Model 2	0.83
Model 3	0.76

Table 2: Coefficients of drag for the 3 models.

From the above graphs it can be observed that Cd for the modified car is lower, compared to the standard race car. Cd for the car with wing is found to 0.76and race car with cutting out of fire wall has drag of 0.83, whereas standard race car have Cd of 0.93.The drag for the model 1 with firewall is higher as it is like a flat plate, induces more frontal area and increases the drag force. Cutting out of fire wall for model 2 helps to provide space for air flow. It also provides the attached flow for the streamline reducing the drag resistance. Thus, the drag coefficient is reduced compared to model 1 with firewall.

Model 3 with the front wing decreases the stagnation pressure on the tires. Resulting in reduction of drag.

4.2. Lift coefficient

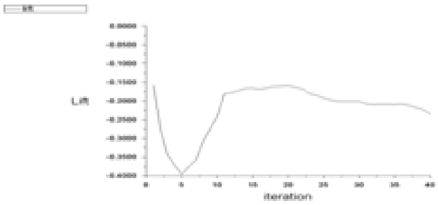


Figure 4.4: Coefficient of lift Vs iterations model 1

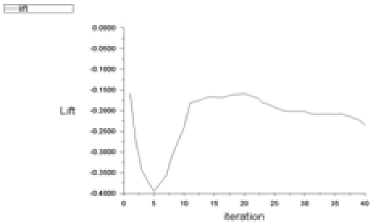


Figure 4.6: Coefficient of lift Vs iterations for model 3

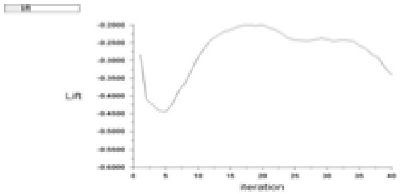


Figure 4.5: Coefficient of lift Vs iterations for model 2

Model name	Coefficient of lift
Model 1	-0.156
Model2	-0.216
Model 3	-0.254

Table 3: Coefficients of lift

Negative lift is the down force which pushes the vehicle closer to the ground. Underside of the race car is responsible for creating the down force. In order to reduce the lift, floor panel height of the car should be reduced. Front wing helps to provide the stability. From the above graph, it can be observed that co-efficient of lift is reduced from 0.156 for the standard race car to 0.256 for the modified race car with front wing. It is because the floor panel height of the model 3 is affecting on lift coefficient, which is comparatively lower than the other two models. Reducing the lift ultimately assists to achieve vehicle stability.

4.3. Static Pressure Contours

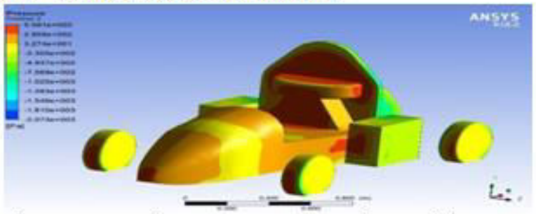


Figure 4.7:Static pressure counter for model 1

Figure 4.8: Static pressure counter for model 2

Figure 4.9: Static pressure counter for model 3

The static pressure counters are plotted for the 3 models. The standard race car model has flat firewall; hence more air flow impinges on frontal area which leads to rise in pressure. More pressure is developed at the stagnation region, on the front and at the firewall. As the pressure developed is high, the drag force developed is also high when compared to other2 models. In order to reduce the pressure at the firewall, upper portion of the fire wall is cut.For model 2, cutting out upper portion of firewall provide space for air flow. This raises the velocity of air and lowers the pressure at that point.

For the all model 3, more pressure is developed at the stagnation region, on front tires. This is minimized by placing a front wing. The upper surfaces are subject to the positive pressure which also acts to push the wing down. The positive pressure contributes a proportion of the overall downforce generated by the front wing.

4.4. Velocity counters along symmetry

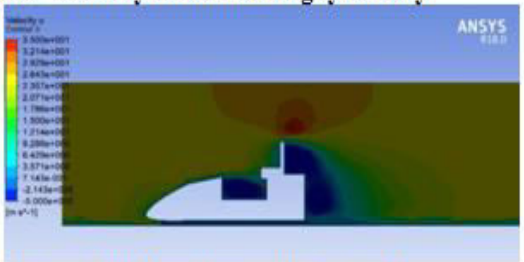


Figure 4.10: Velocity counter for model 1

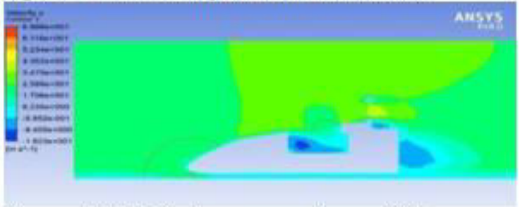


Figure 4.11: Velocity counter for model 2

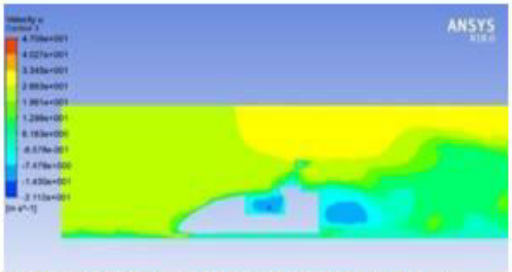


Figure 4.12: Velocity counters for model 3

The above 3 figures 4.10, 4.11, 4.12 states that the velocity of air at cut firewall for model 2 and 3 is higher than at the firewall of model 1. It also provides the free flow of air through the cut firewall.We can also observe the velocity below the stagnation point of vehicle is more for model 3 than model 1, and air gets accelerated near the point. Velocity of air is found to be increase below the stagnation point of car from 17m/sec to 26m/sec for model 3.From the velocity counters, we can select the location to assemble the air intake system and cooling systems.

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4.5. Total pressure counters along symmetry

Figure 4.13: Total pressure counter for model 1

Figure 4.14: Total pressure counter for model 2

Figure 4.15: Total pressure for model 3

From the figures 4.13, it can be stated that due to the firewall the total pressure at the driver position is found to be 400 Pa. Rounded edges at the front surface accelerates the air flow, but that air flow is gets obstructed by firewall In figure 4.14, 4.15, the total pressure at the driver position is found to be below 200 Pa. Inside the car or at driver space total pressure found to be less for model 2 and found least for model 3.

CONCLUSION & FUTURE SCOPE

To increase the aerodynamic performance of race car, an attempt is made to modify the design of a Formula SAE car. Comparative study is done on three car models by carrying out CFD simulations.

- Drag co-efficient is found to get reduced from 0.93 for the standard race car to 0.76 for the modified car with front wing.
- Negative lift is increased from 0.15 for standard race car to - 0.25 for the model 3.
- The pressure at firewall found to be reduced for the modified cars due to providing space to flow the air through cut out section, where flow remains attached and helps to decrease the drag.
- The overall pressure near the driver head region is reduced from 340Pa to 120 Pa. for the modified car with front wing.
- Velocity of air is found to be increase below the stagnation point of car from 17m/sec to 26m/sec for model 3. Whereas at the rear end more wake region is found for standard race car.
- Finally, model 3 having wing at the front end and having cut section at firewall shows less drag and lift, shows better aerodynamics characteristics than other two models.

Future scope

The present study gives the basic aerodynamic factors for the designed vehicle with a drag coefficient of 0.76 and a lift coefficient of 0.25.The team target to build a complete aerodynamic vehicle by 2019 which also includes several other departments like design, production, cost management, safety and comforts for customers. The main goal of aerodynamics in future is to provide the means of control and change in velocity of vehicle in the greatest possible time.Future scope on this project is to optimize the results from this project and to increase the stability of the vehicle by introducing the rear wing and to produce the vehicle in an economical way.

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