KAUNAS UNIVERSITY OF TECHNOLOGY
FACULTY OF MECHANICAL ENGINEERING AND DESIGN

Ajay Shashidhara

DESIGN AND ANALYSIS OF RACECAR WINGS

Master's Degree Final Project

Supervisor
Assoc. prof. Dr. Sigitas Kilikevicius

KAUNAS, 2017

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Mechanical Engineering (code 621H30001)

Supervisor
(signature)Assoc. prof. Dr. Sigitas Kilikevicius
(date)

Reviewer
(signature) Lect. Dr. Linas Paukštaitis
(date)

Project made by
(signature) Ajay Shashidhara
(date)

KAUNAS, 2017

KAUNAS UNIVERSITY OF TECHNOLOGY

Faculty of Mechanical Engineering and Design
(Faculty)

Ajay Shashidhara
(Student's name, surname)

Mechanical Engineering, 621H30001
(Title and code of study programme)

Design and Analysis of Racecar Wings

DECLARATION OF ACADEMIC HONESTY

14 June 2017
Kaunas

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Research field and area: Mechanical Engineering, Technological Sciences

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SUMMARY

This study is about creating a design and aerodynamic simulation of race car aerodynamic components and also the use of alternate materials in car body construction. The main objective of this work is to maximise the amount of performance by enhancing the aerodynamic characteristics of the race car. This is done by designing improved race car wings. The aerodynamic efficiency of the designed racecar wings is analysed using flow simulation in SolidWorks. The second stage of the study is about the use of alternative materials instead of the existing ones and this is done by analysing the designed racecar wings for strength and rigidity using different materials. The structural studies were carried out using SolidWorks Simulation.

Ajay Shashidhara. LENKTYNINIO AUTOMOBILIO APTAKŲ PROJEKTAVIMAS IR TYRIMAS: Magistro baigiamasis projektas / vadovas doc. Dr. Sigitas Kilikevičius; Kauno technologijos universitetas.

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SANTRAUKA

Šis darbas yra apie automobilio aerodinaminių komponentų projektavimą, aerodinamikos modeliavimą ir alternatyvių medžiagų panaudojimą automobilio kėbulo konstrukcijoje. Pagrindinis darbo tikslas padidinti lenktyninių automobilių efektyvumą pagerinant jų aerodinamines charakteristikas. Tai padaryta suprojektavus patobulintos konstrukcijos lenktyninio automobilio aptakus. Suprojektuotų lenktyninio automobilio aptakų aerodinaminis efektyvumas ištirtas atliekant aerodinaminių srautų modeliavimą SolidWorks sistemoje. Alternatyvių medžiagų panaudojimo galimybės analizuojamos atliekant suprojektuotų lenktyninio automobilio sparnų stiprumą ir standumą panaudojus skirtingas medžiagas. Struktūriniai tyrimai atlikti naudojant SolidWorks Simulation.

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Approved: Head of Mechanical Engineering Department	______________ *(Signature, date)*
	Vytautas Grigas *(Name, Surname)*
Head of Study Programmes in the Field of Mechanical Engineering	______________ *(Signature, date)*
	Kęstutis Pilkauskas *(Name, Surname)*

MASTER STUDIES FINAL PROJECT TASK ASSIGNMENT
Study programme MECHANICAL ENGINERING - 621H30001

Approved by the Dean's Order No.V25-11-7 of April 21th, 2017 y

Assigned to the student

______________ AJAY SHASHIDHARA______________
(Name, Surname)

1. Title of the Project

Design and analysis of racecar wings

2. Aim of the project

The aim of this thesis is to introduce a new design of a front and rear wing of a race car; and investigate its technical abilities to enhance the performance.

3. Tasks of the project

Summary, Introduction, Literature review, An illustration on the design of front and rear wing, CFD simulation (full car and rear wing), static analysis (front wing)

4. Specific Requirements

- conduct the flow simulation to estimate the aerodynamic parameters like: drag force, lift force, drag coefficient and lift coefficient in order to justify the proposed designed and to achieve the drag coefficient under 0.7.
- conduct a static FEA for the front wing using the flow forces, to determine the strength of the proposed material to withstand the real-world application

5. This task assignment is an integral part of the final project

6. Project submission deadline: 2017 May 17th .

Task Assignment received	Ajay Shashidhara (*Name, Surname of the Student*)	______________ (*Signature, date*)
Supervisor	Assoc. Prof. Dr. Sigitas Kilikevicus (*Position, Name, Surname*)	______________ (*Signature, date*)

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INTRODUCTION

Race car is used in motorsports and it has been the proving ground for all manufactures. New technologies are first introduced in race cars and then filtered down to the road cars [1]. In this thesis 2 key technologies in racing will be explored and analysed. They are Aerodynamics and Materials used for body construction [2]. As far as aerodynamics is concerned, it has played a very crucial part in the sport. The flow of air around the moving vehicle influences all the components of the vehicle in one way or the other. In Race cars aerodynamics development grew a lot of in the following years; because of the application of the negative lift (downforce) principle, yielding several performance enhancements. In all types of racing aerodynamics became a significant design parameter. The foundation for aerodynamics were formulated over the years, not all aerodynamic principles were utilized until recent years for race car design. Downforce is immensely exploited in the design of race cars. The performance that can be gained in the resulting increase of traction. In current era of motorsports were decrease in drag and increase in downforce gives a vastly sought-after performance edge. In order to achieve a race car that has low drag and sufficient downforce to give good handling, racing teams put a lot of effort by using prediction aerodynamic tools. In past wind tunnels were the only tool used to achieve required aerodynamic efficiency. But in recent years Computational Fluid Dynamics (CFD) has helped to predict lift and drag at an early stage of the design phase. Race car is an open-wheeled vehicle. The design of the race car is controlled by strict set of rules by the governing body. Race cars optimized for each circuit based on the requirement of the circuit. The design base changes every year based on the set of regulations imposed [3].

Another important area in the Race car is the body, which is very important in aerodynamics. Based on the design of the race car it’s used to reduce drag and hence provide clean air flow around the car. Apart from the car body enclosing the driver and all the important components so that it can protected against any foreign matter, it also houses all the important aerodynamic bits which provides the necessary aerodynamic efficiency to the race car. The choice of materials for the race car design is the most important factor. There are different types of materials that has be used on the race cars over the years, but the purpose of design is the main challenge here. The most vital aspects that a material should meet are lightweight, economic effectiveness, safety, recyclability and life cycle [4].

The aim of this thesis is to introduce a new design of a front and rear wing of a race car; and investigate its technical abilities to enhance the performance. The major tasks raised to reach the aims of project are:

1. Literature on the topic has to be reviewed for the design of the aerodynamic components and investigation method used to estimate the flow and static life of these aerodynamic parts.
2. design these aerodynamic parts, having all the dimensions based on the regulations set by the governing body.
3. conduct the flow simulation to estimate the aerodynamic parameters like: drag force, lift force, drag coefficient and lift coefficient in order to justify the proposed designed.
4. conduct a static FEA for the front wing using the flow forces, to determine the strength of the proposed material to withstand the real-world application.

Therefore, the overview is to design the aerodynamic components, estimate the flow acting over these aerodynamic components; and finding out the possibility of using alternate material in case of the carbon fibre.

1.LITERATURE SURVEY

1.1. AERODYNAMICS

In this review, we are going to be discussing in brief, the various studies that have been conducted over the years by scientists regarding to aerodynamics of race cars, and various ways to improve the bodywork and its components to bring down the lap times. This can be classified in the following order:

- aerodynamic of Race car;
- ground effects of aerodynamics.

1.2. AERODYNAMICS OF RACE CARS

Aerodynamics is the discipline that educates about the air flowing around the car. The study can be linked to fluid dynamics as air is the fluid. The aerodynamics play a vital role by enhancing the race car top speed. Aerodynamics has become the only study prospect of performance gain due to the changes to mechanical components are very marginal gain. The only way the car can be virtually planted on the road by increasing the weight or pressing the car down on to the road and this is done by creating aerodynamic downforce. The increase in downforce means the car is stable on road, therefore enabling the car to car to corner at higher speeds [5].

Aerodynamics of the car is computed using CFD (Computational Fluid Dynamics) and wind tunnel, only for validating and improving the design of the race car. While the rudimentary aerodynamic principals are, formulas can be determined and additional properties are verified using experimental formulas. Whereas, unique design such as Race car cannot be calculated precisely, rendered Computational Fluid Dynamic and wind tunnel are essential requirement to confirm the design [5].

Aerodynamics in race cars is nothing but adhesion of tire to the ground which enables the cars to negotiate the race track without any lift. Theoretically, tire adhesion is represented by the symbol μ. Assume, the direction of x is aligned with the car longitudinal axis, direction of y is aligned with the car lateral [1].

$$\mu = \frac{F_{x(orF_y)}}{F_z} \tag{1.1}$$

Where, F_x = Forces acting on braking.

F_y = Forces acting on cornering.

F_z = Normal force

The forces that are being considered in the numerator, based on that μ can either be called as braking coefficient or cornering coefficient. From the above Eq. (1.1), it can be seen that; the maximum value of the adhesion of the coefficient of tire is μ max. Therefore, if the friction coefficient is higher than the adhesion of tire, the tire will start to slip or slide. Hence, the normal force helps in dropping the adhesion of tire. [6].

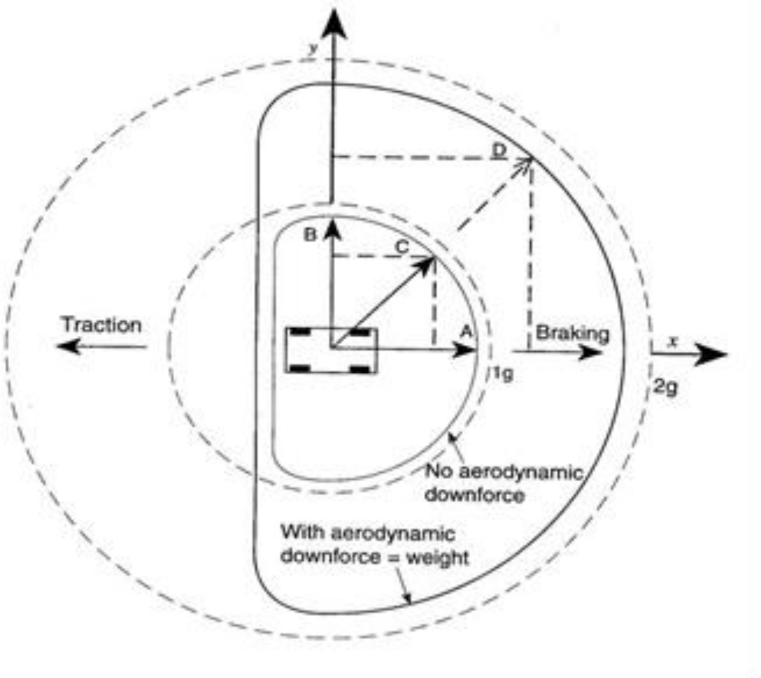


Fig-1 Tire performance based on downforce [6]

When we observe the above figure, the vehicle weight is equal to the downforce added, it increases the braking and cornering forces. By the increase of downforce; it aids in gripping the vehicle on the tarmac, but the enhancement of traction is not that significant in braking or cornering. To prevent the wheels from sliding we must increase the downforce of the car significantly. Theoretically, the downforce acting on the car must be higher, to make go faster in the corners without sliding.

There is also the penalty for increasing the downforce, excessive downforce comes from increased drag. Therefore, the designers strive on finding the optimal balance between downforce and drag, when designing the bodywork of the race car to obtain the fastest time around the track.

Here, are the lap simulation studies conducted and roughly calculated on how different parameters would affect the lap times in terms of percentage [7]. This is shown in the below table.

Table-1 Lap time affecting parameters [7]

Parameter	Parameter change in %	Lap time gain
Mechanical grip	10	3.2
Mass of vehicle	10	1.9
Height of cg	10	>0.4
Power from engine and transmission	10	1.5
KERS	6 secs of usage	0.5
Gain from aerodynamics	10	1.0

1.3. AERODYNAMICS ON GROUND EFFECT

Aerodynamics on ground effect is nothing but generation of downforce by lowering the ground clearances. The flow of air under the car accelerates as it flows under the nose of the race car towards the under floor of the car. At the same time, the air flowing over the car is slower as compared the bottom, it creates a pressure differential. This results in generation of downforce. Major contributor to the downforce are floor and diffuser in total they contribute to almost 55 percent of downforce. [8]

1.3.1. AERODYNAMIC BALANCE AND STABILITY

Aerodynamic balance plays an important role in creating stability and handling of the race car, it is of major importance for the cause of safety to discovery the right balance of the car. Aerodynamic stability also improves transient phases, such as braking, acceleration and cornering. As mentioned the relationship between aerodynamic performance and mechanical properties of the car was vital to understand the handling properties of the car. [8]

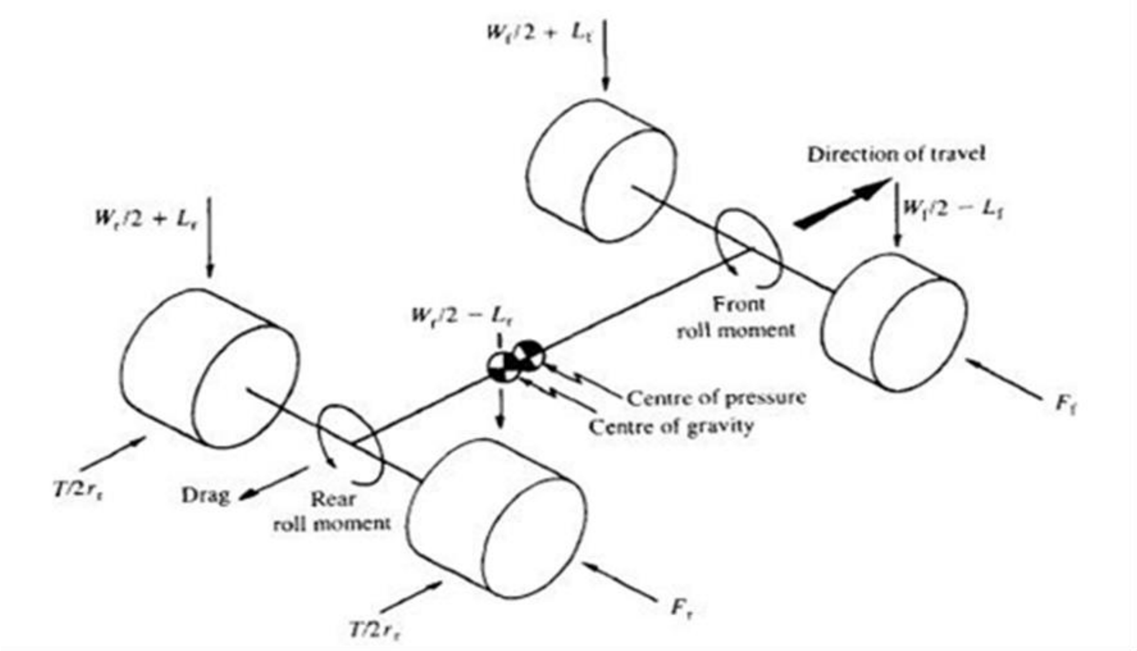


Fig-2 Forces and Moments acting on a car [8]

Here W_f and W_r are wheel loadings, and L_f and L_r are the weight transfers due to overturning moment, at the front and rear tires respectively.

1.4. AERODYNAMIC DEVICES

Aerodynamic parts are the main source of taking advantage of airflow around the car. Some parts increase the effectiveness of airflow within the body of the car, such as the ones feeding the radiator or the engine. Whereas the other parts create the downforce to increase traction. The aerodynamic parts are as follows [9]:

- Front wing;
- Rear wing;
- Nose cone
- Air box
- Barge boards
- Under tray
- Rear diffuser
- Winglets
- Chimney.

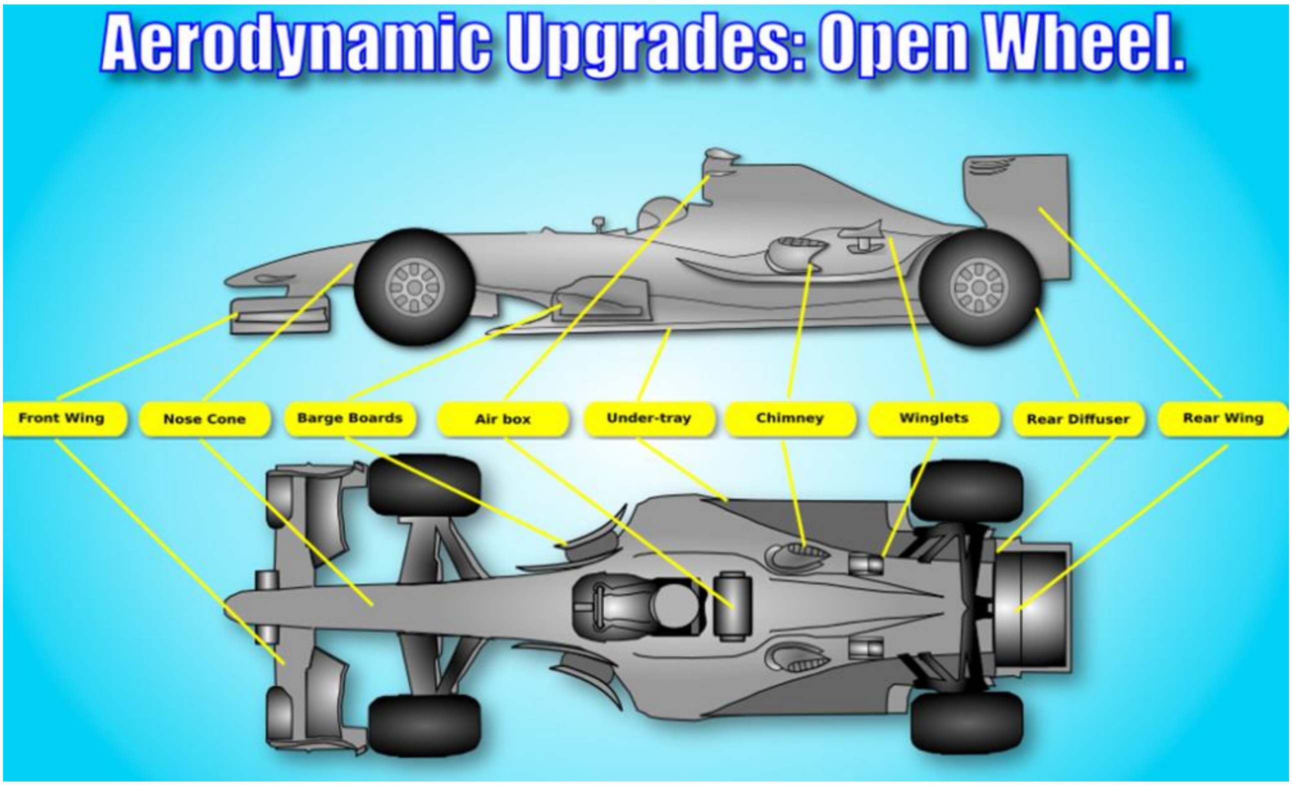


Fig-3 Aerodynamic upgrades of open wheel racing car [9]

1.4.1. FRONT WING

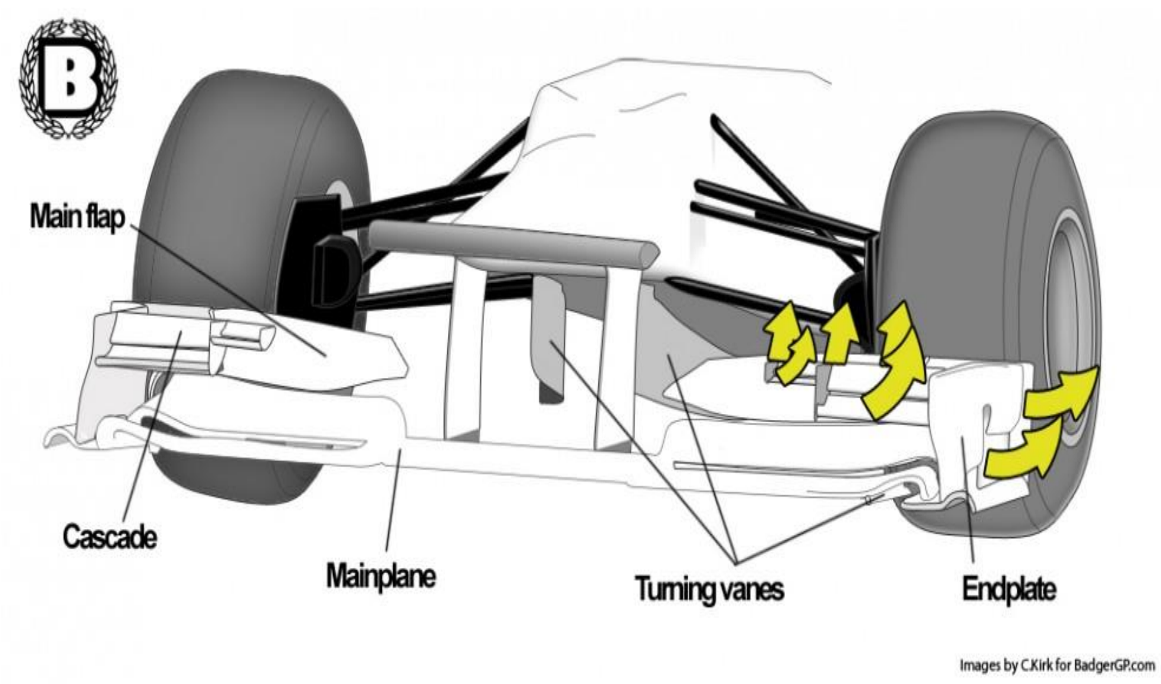


Fig-4 Front wing of race car [10]

The design of front wing is shaped opposite to that of an airfoil. This is done to prevent it from taking off! The front wing, unlike the rear, does not just provide downforce. As it is the aerodynamic device that precedes the entire car, it is also responsible for directing airflow back towards the rest of the car [10]. The optimal direction of this airflow is of critical importance to the overall downforce levels produced by the entire car. The front wing is connected to the nose and runs along the complete length of the car. To the front wing, adjustable flaps are connected and at the ends of the main plane, the end plates are connected. The different parts of the front-wing are shown in the above Fig. 4 [11].

The front wing of a Race car creates about 25 percent of the total cars downforce. Although this will only occur in a ideal circumstances. It is therefore a difficult task to create a performing front wing, even more because disturbing the airflow too much will affect the rest of the car's aerodynamic efficiency too [12].

1.4.2. REAR WING

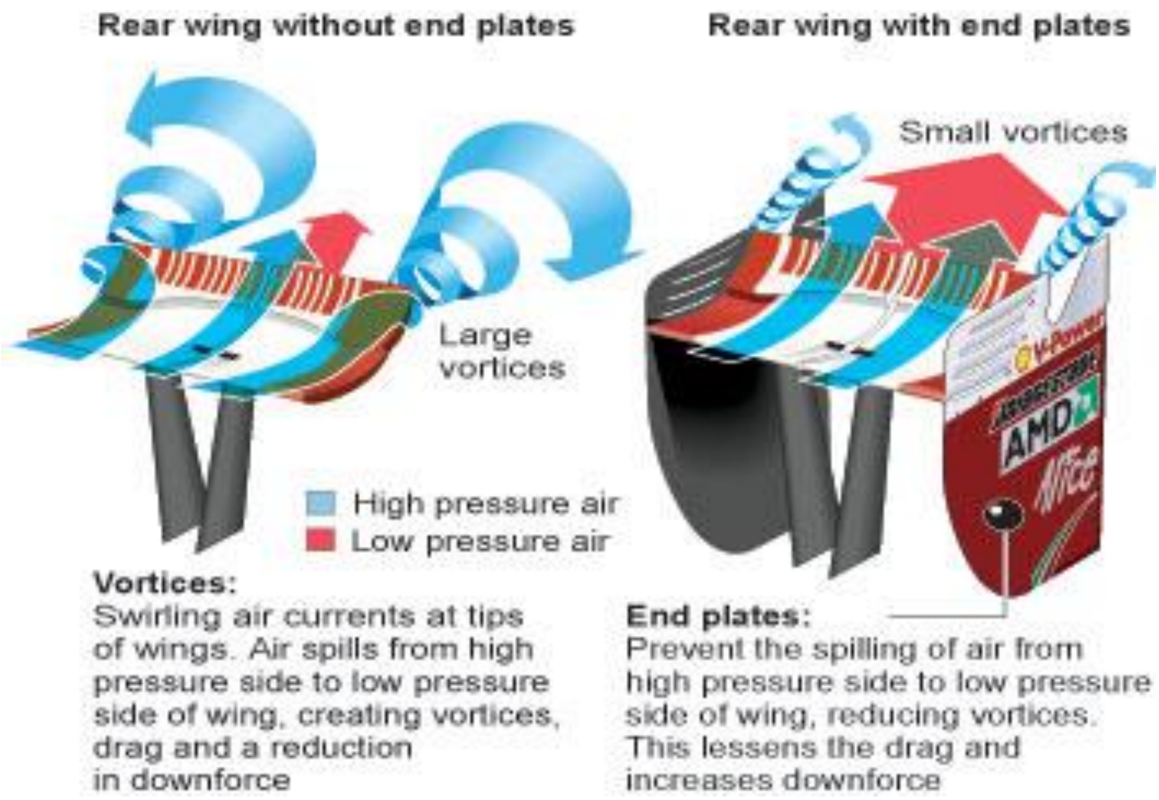


Fig-5 Rear wing [13]

The rear wing is a simpler aerodynamic part of the car because its job is to create downforce by changing the direction of airflow over the car. But, as the front wing is the most effective component of the race car, the rear wing, on the contrary, is extremely inefficient. The airflow that passes over the rear wing is complicated, because of the exposer to unsteady flow, the turbulent air that flows over the entire car and then to the rear. That is the reason the rear wing is not as efficient as the front wing [1].

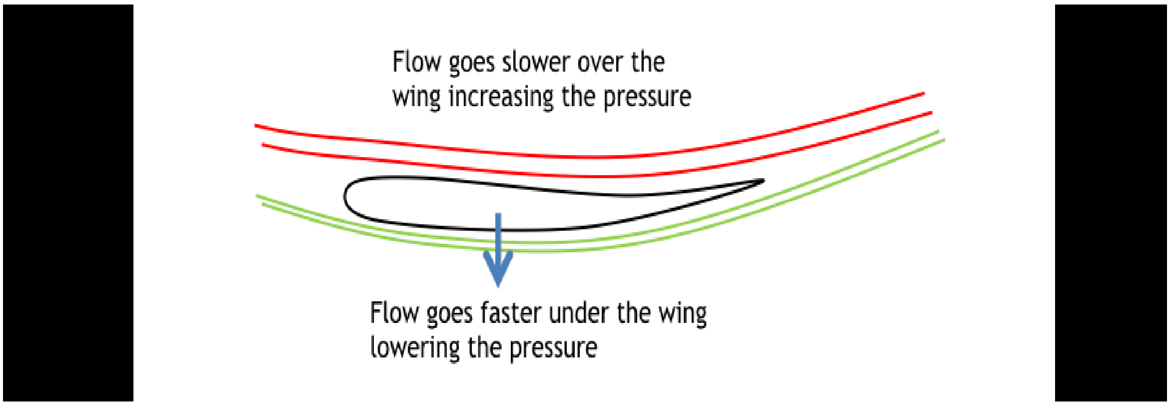


Fig-6 Flow of air over the wing [14]

1.4.3. AERODYNAMIC AIR BOX

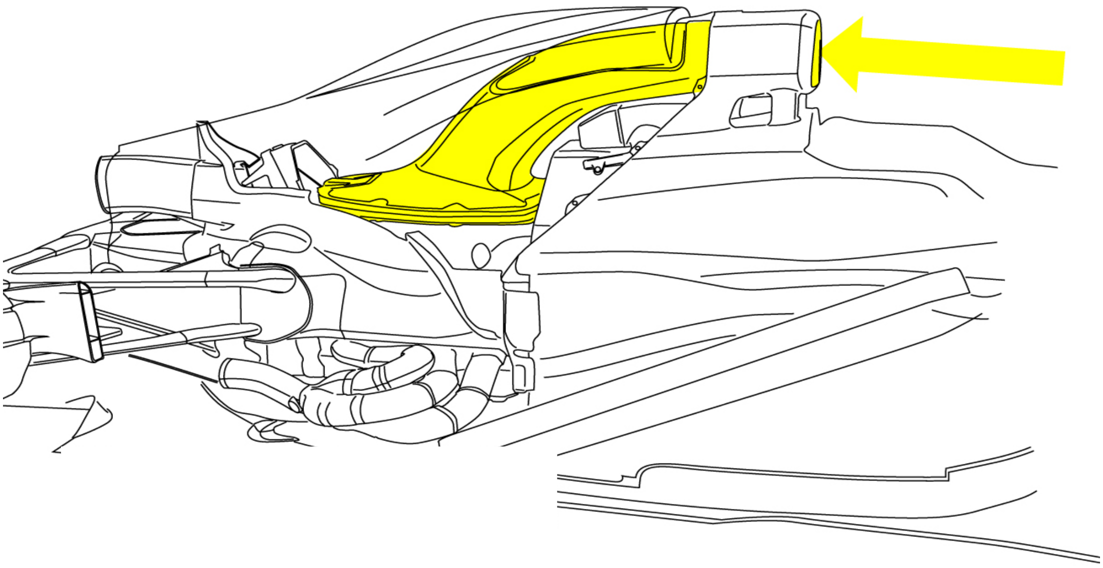


Fig-7 Aerodynamic air box [15]

In the design of the open wheel racecar designs, aerodynamic air boxes are used as supplier of air to the engine. The aerodynamic air box is very vital for the effectiveness of the aerodynamic and working of the engine. The air box supplies the required cold air in order to effectively run the engine at higher speeds. The design of the air box has some penalties of drag to certain extent on the design of the exterior.

Entire shape of the air box focuses on the effect of ram, as it sucks the required air through the air box, higher the acceleration, increases the air flow. The small opening which allows the air to enter the device, the forced air effectively speeds up the air flow at higher speed [9].

1.4.4. AERODYNAMIC SUSPENSION

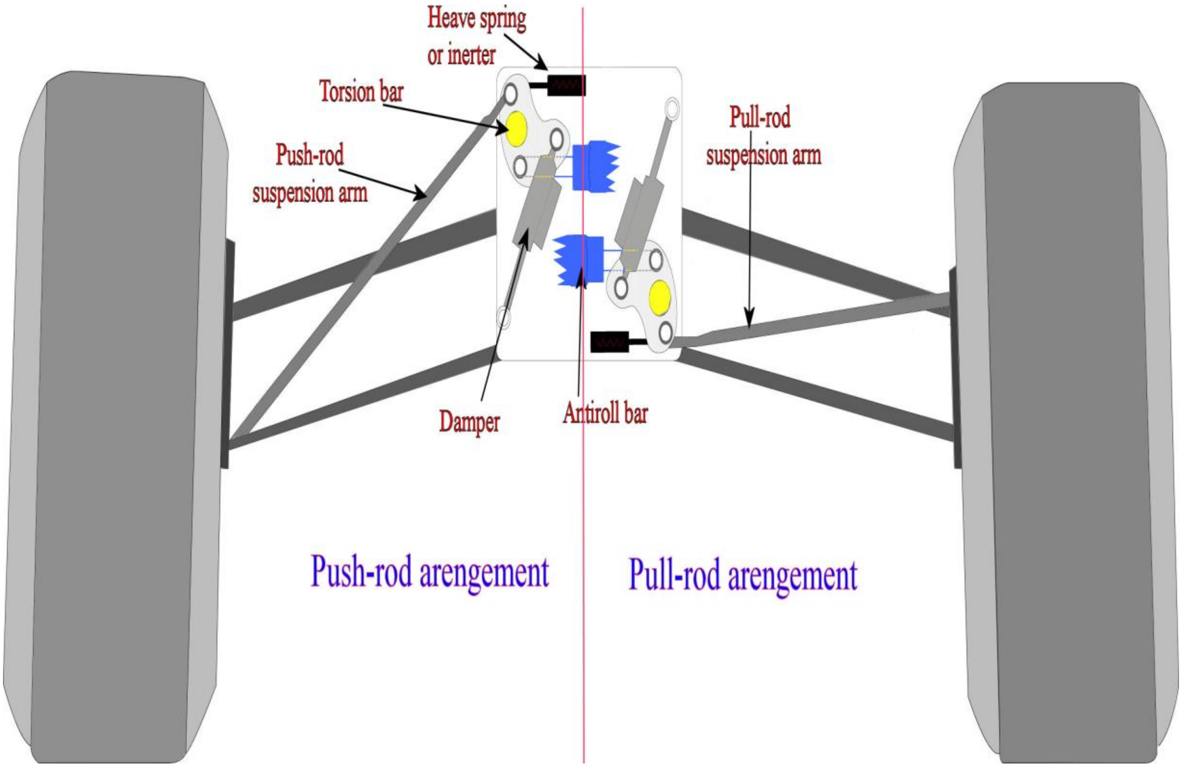


Fig-8 Aerodynamics on suspension [16]

Suspension is a very vital component in channelling the air flow from the front to the rear of the open wheel race car. In case of race car whose wheels are closed by the body work, suspension has a very less effect on the aerodynamics of the car. Aerodynamic suspension helps to increase overall downforce levels of the race car [9].

1.4.5. BARGE BOARD

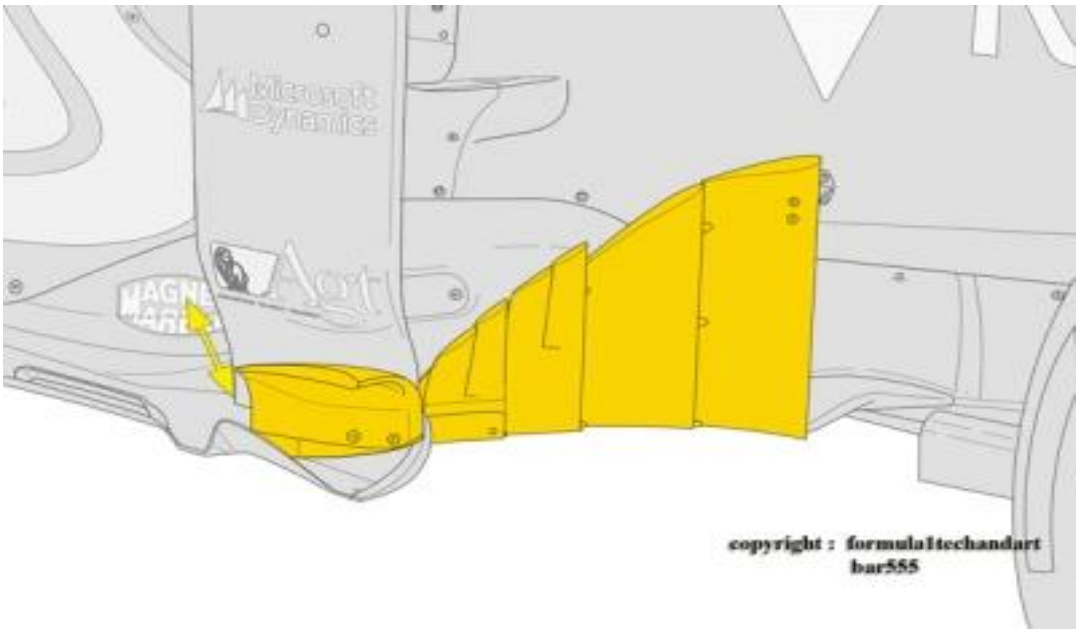


Fig-9 Barge board [17]

Barge boards are used widely in Race cars. Air which flows from the front of the car can be turbulent. Barge board are used to direct the air smoothly, to the rear of the car. The upright or flat plates of barge boards and guide vanes are design, they are usually integrated in the front suspension or behind the front suspension [9].

1.4.6. DRS (DRAG REDUCTION SYSTEM)

Fig-10 DRS [18]

A drag reduction system (DRS) is a technique where the angle of rear wing can be changed for improving straight line speed. Basically, a lever is operated to change the angle of the flap, generally the angle of flap is changed in straights. Higher the flap angle, higher the downforce. decreasing the flap angle, the wing decreases downforce and drag, this increases the top speed of the race car [9].

1.4.7. NOSE CONE

In a Race cars, the nose cone is an effective way to mount the frontwing, with the installation of the frontwing it minimises the frontal area of the race car. The design of the front wing changes from race to race and for every season. The shape of the nose has a horizontal wing add on the flanks. This type of high mounted wing design encourages under tray and rear diffuser air flow optimisation, helping in decreasing drag and increasing downforce [9].

Fig-11 Nose cone [19]

1.4.8. REAR DIFFUSER

The main role of the diffuser on a modern race car is to accelerate the flow of air under the car, creating an area of low pressure, thus increasing downforce. As show the above figure-12 the downforce points are on both edges of the floor - the leading and the trailing, so the aero distribution is important, as the leading-edge point is ahead of the car's Centre of Gravity [20].

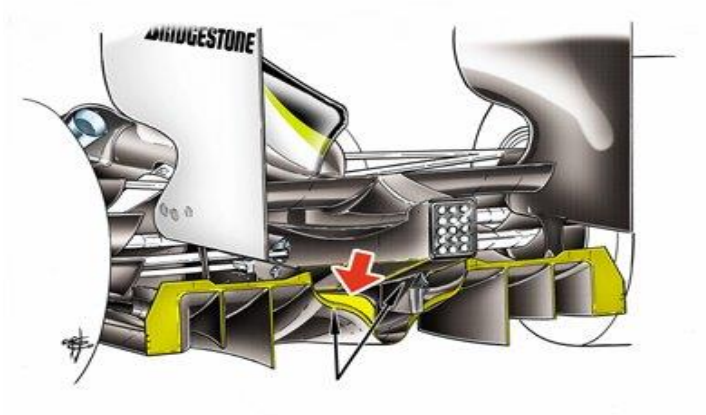


Fig-12 Rear diffuser [21]

1.5. MATERIALS USED FOR CONSTRUCTION

Design of body is a vital part for race car. Its importance can be easily seen through by the amount of money that has been invested by the teams. Race car body is particularly important in aerodynamic. It reduces drag and hence provides smooth air flow along the race car.

1.5.1. ALUMINIUM

Aluminium and its alloys are extensively used. So, every kilogram of aluminium used in a car reduces the overall weight of the vehicle by one kilogram. For this reason, more and more car parts are being made from aluminium. Two thirds of this weight of the car is aluminium. While the outer surface of the body is made from fibre plastic all the internal components and parts are made from aluminium alloys [22].

Fig-13 Some of the aluminium components used (engine) [23]

1.5.2. COMPOSITE MATERIALS

Composites are relatively new materials. Composites consists of two or more materials. Their basic constituents have own different characteristics and properties, while the composite presents a completely new material. This material has its own unique properties in relation to basic components. The basic advantages of composite materials with aluminium matrices in relation to materials without reinforce materials are:

- Strength is higher
- Stiffness is higher
- Reduction in weight
- At higher temperatures, improved properties
- Thermal expansion coefficient is controlled
- Heating of material is controlled
- Better electrical conductivity
- Resistance to wear
- Controlled weight [24]

1.5.3. CARBON FIBRE

Carbon fibre is a non-isotropic material and shows great strength throughout the fibres. This means that when producing a sheet of carbon fibre, it is vital to have all fibres arranged parallel to each other. Throughout, the length of the fibres, carbon is very strong material compared to its weight. carbon fibre is both stronger and lighter than steel [25].

Fig-14 Carbon fibre material [26]

1.5.4. GLASS FIBRE

Glass fibre is being used mostly for the sports car which includes Race cars. It is lighter than steel and aluminium, easy to be shaped and rust-proof. And more important factor is that it is cheap to be produced in small quantity [4].

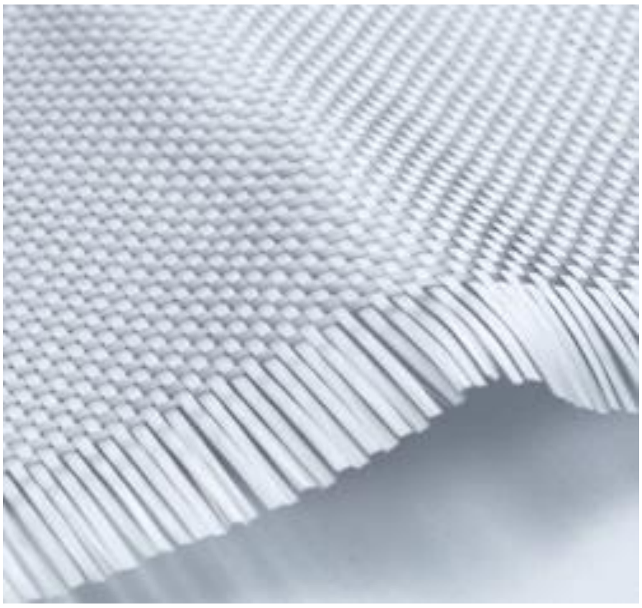


Fig-15 Glass fibre [27]

2. TOOL AND PROCESS USED

In this chapter, we discuss the tools used to enhance numerous parameters of the Race car to get the best possible lap time for a specific track. In this study, we focus on two main parameters mainly: aerodynamics and materials used in the car. In order to optimize these two parameters and to find the best possible lap time we have used the software called solidworks. This software has been used in this research for both creating 3-D model as well as for analysis (CFD, static study) [1].

2.1. OPTIMIZATION PROCESS

In order to optimize the above-mentioned parameters using software, we are going to be using two processes, those are:

- Computational fluid Dynamics for aerodynamic study
- Static linear study for materials

2.1.1. COMPUTATIONAL FLUID DYNAMICS

CFD study is done in order to increase the performance of the car by determine several aspects like:

- The flow of air around the car
- The flow of air through the body
- Flow process within the machinery

In this research, the primary focus is on the flow of air around the car, particularly rear and front wing of the race car. The external flow of air subjects the vehicle to forces and moments which significantly affect the vehicle’s performance and directional stability. Through this study, we can study the flow patterns. Some significant development can be determined, flow separation at the rearwing of the car, flow of air over the front wing and flow of air over the body and under the body. The case of cross winds also come into play, with crosswinds the air flow around the car is asymmetric to the longitudinal plane. The shape of the car should be such that the additional forces and moments remain so small that the directionally stability is not greatly affected. This study able the designer and engineer to design to create the optimal design so that the above-mentioned forces do not have a drastic effect on the performance of the car. By conducting this study, the designer can determine the amount of drag that the shape of the car is creating and determine the downforce created. If necessary additional wing can be added and negative lift can be achieved [28].

2.1.2. STATIC LINEAR STUDY

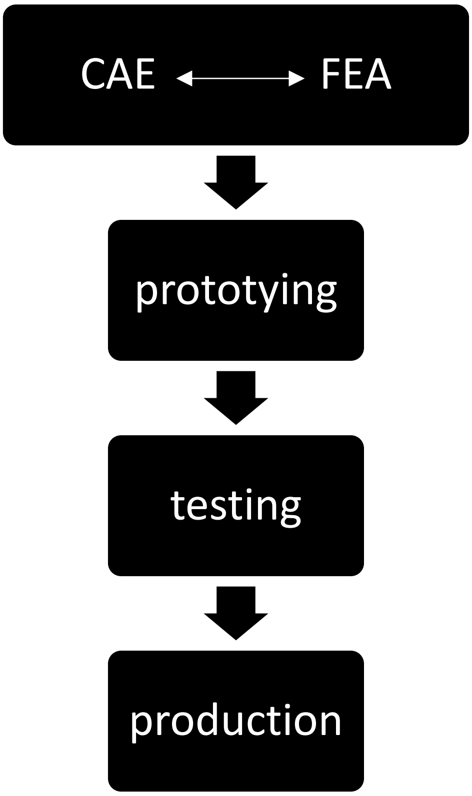


Fig-16 FEA-driven product development [29]

Simulation is a commercial implementation of FEA capable of solving problems commonly found in the design engineering. One of the simulations that has been used in this research for the finding the solution is static linear analysis. This analysis is done to find the displacements, stresses, strain and factor of safety. Just as shown in the above figure the FEA tool not only reduces the cost but also alerts the designers and engineer well in advance about the problems. From the perspective of the FEA software, each application requires three steps [29]:

- Pre-processing of the FEA model, which involves defining the model and the splitting it into finite elements.
- Solving the desired results
- Post processing for results analysis

3. WING DESIGN AND CONSTRUCTION

3.1. FRONT WING

Front wing is one of the main aerodynamic component of the race car. Since it is the first part of the car that come contact it play’s a very big role in producing enough drag and downforce. The below figure-17 shows the concept design of the front wing of the race car. This front wing is designed with optimal drag and generating enough negative lift required for the car. In order to be optimized to the requirement the wing is integrated with few clever aerodynamic bits like: 1) Having single main flap and integrated with additional two cascade wings as shown in the below figure-18 . This is done to reduce as much drag that is been generated by the front wheels and supplying with sufficient air to cool the front brakes. 2) Providing with multiple wings on the N-plate so that the air is channelled out cleanly and this way it not only provides enough downforce but also provide the required wing flexibility. The entire span of the wing is 1800mm and the chord length is 117mm.

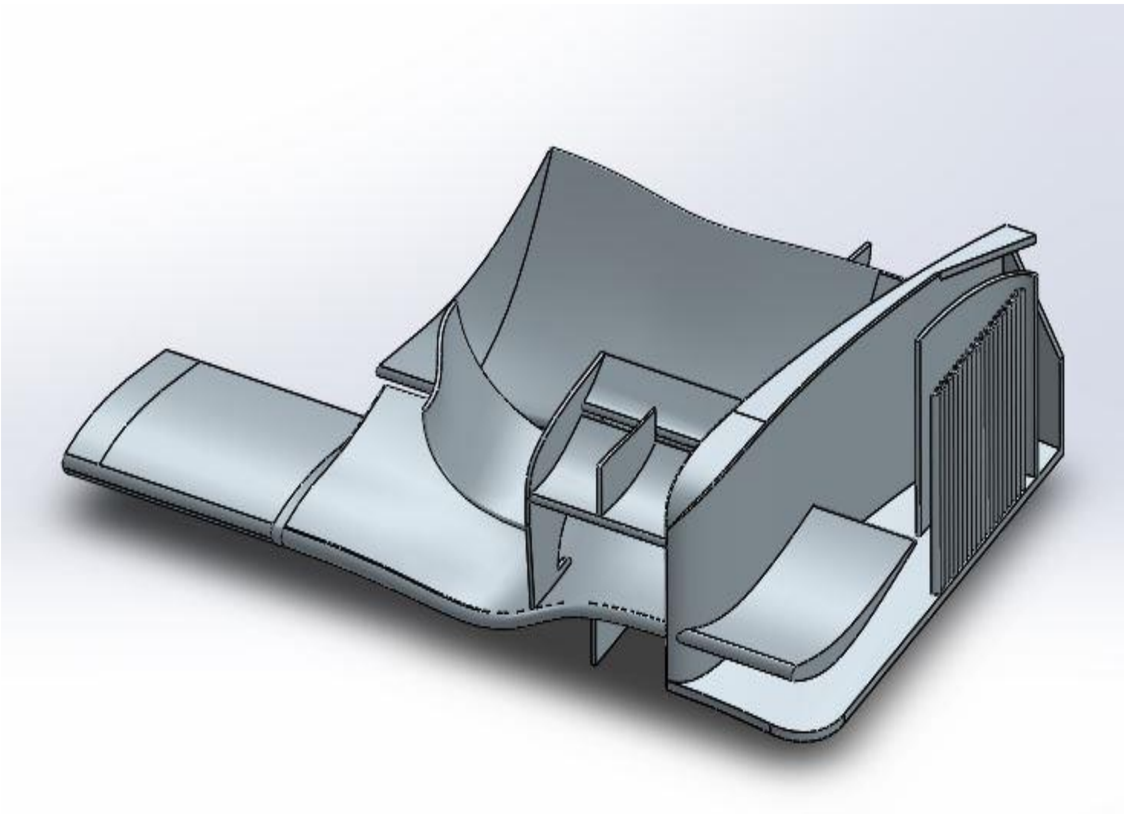


Fig-17 Front wing design

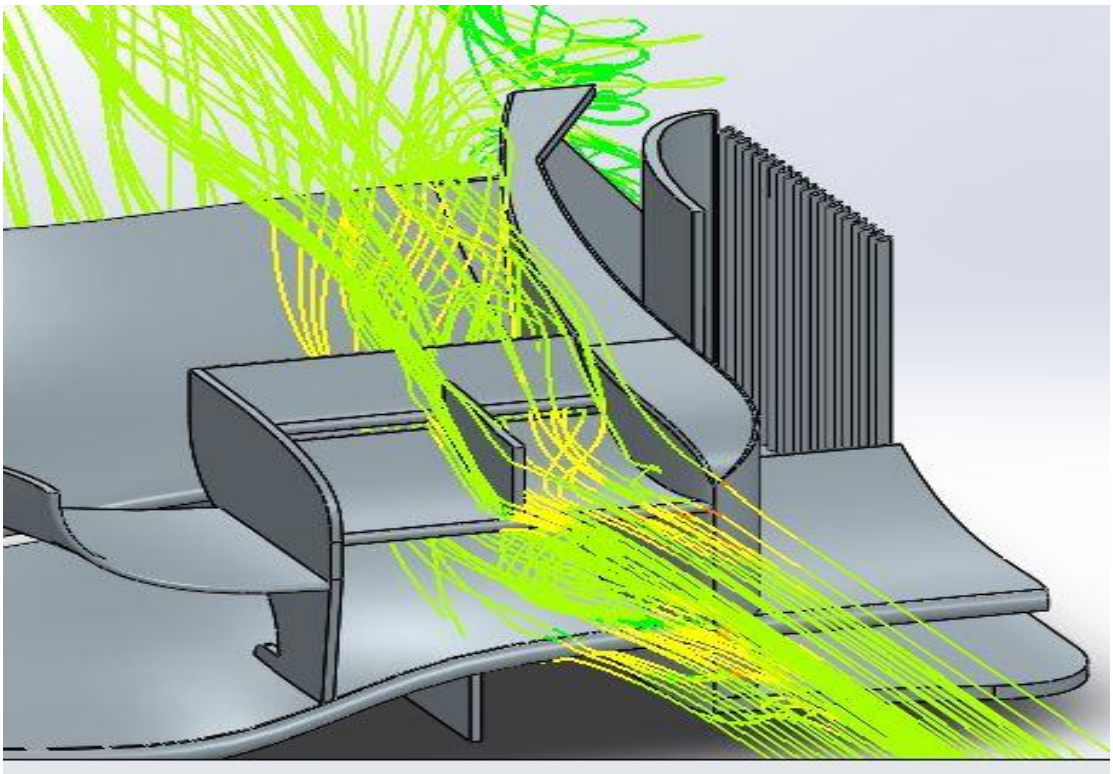


Fig-18 Unique cascade wings and single main flap (Arrows indicate the air flow)

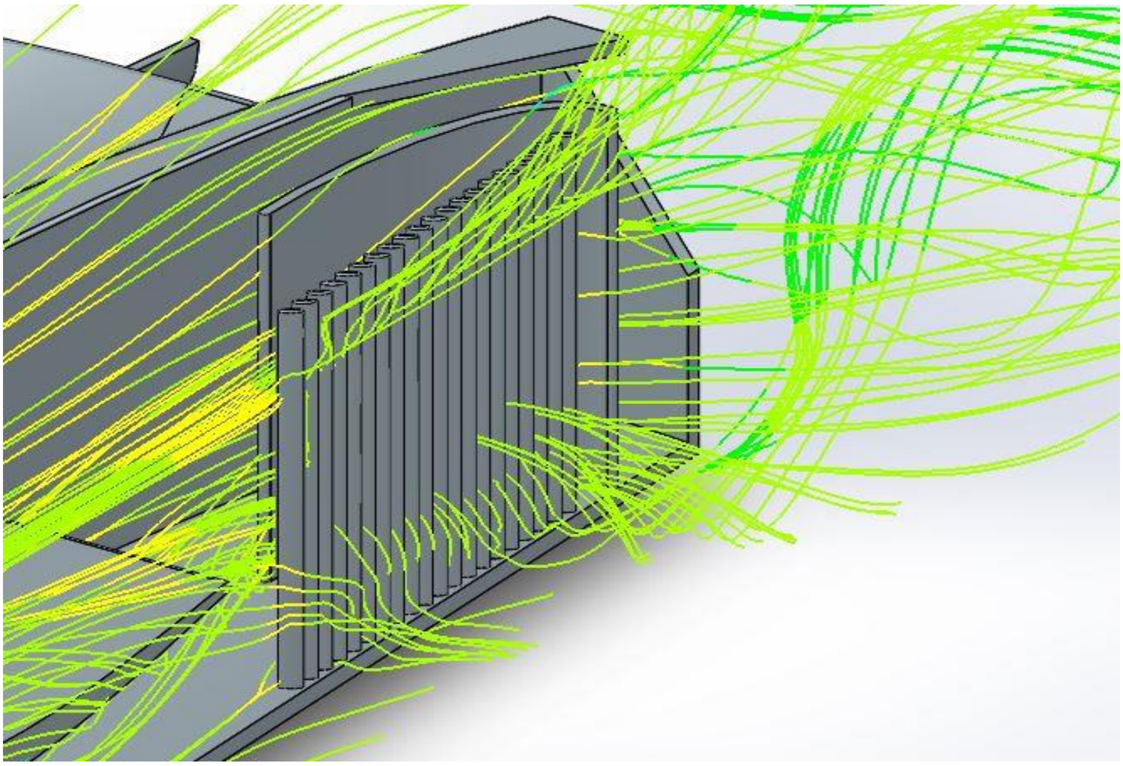


Fig-19 Unique vents to channel the air flow on the N-plate

3.2. REAR WING

Rear wing is the second major generator of drag and downforce after the body. Rear wing generates as much as 30% of the total drag and downforce produced by the car. In order to obtain the desired efficiency from the wing we have to make the wing work harder. The below figure- shows the concept design of the rear wing of the race car. Same as the front wing, the rear wing is also integrated with few clever aerodynamic bits like: 1) unique air vents at the bottom of the rear wing as shown in the below figure-21. This is done to encourage through flow and also fill the hole created by large rear tires, this later effect and cuts drag and boost top speed. 2) A single raked additional wing on the N-plate. This helps direct air upwards and as a result increases downforce. The entire span of the rear wing is about 800mm, the chord length 352mm and the height of the rear wing is 645mm. The rear wing varies from track to track as the angle of attack has to be varied based on high or low downforce track like: angle of attack reduces for lower downforce track and increases for higher down force track. As is the case in this research, flow simulation has been carried out by varying the angle of attack from higher to lower.

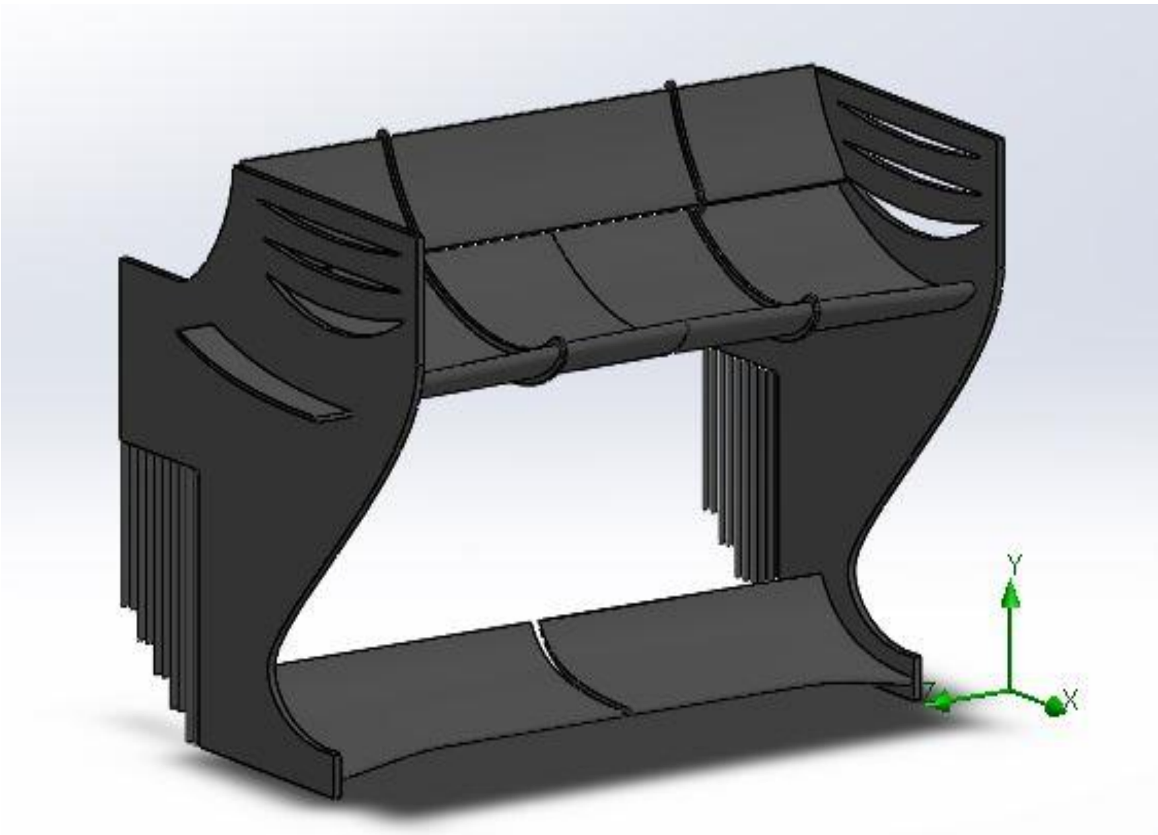


Fig-20 Rear wing design

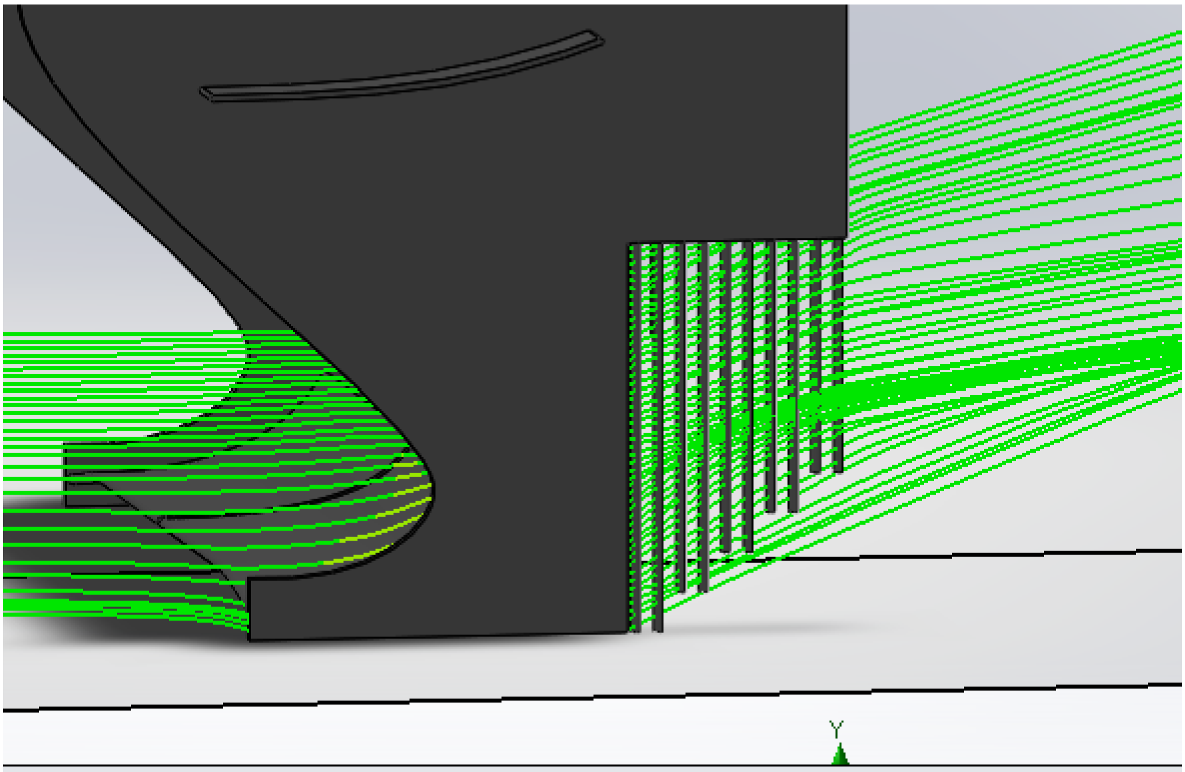


Fig-21 Unique vents to channel the air flow on the N-plate

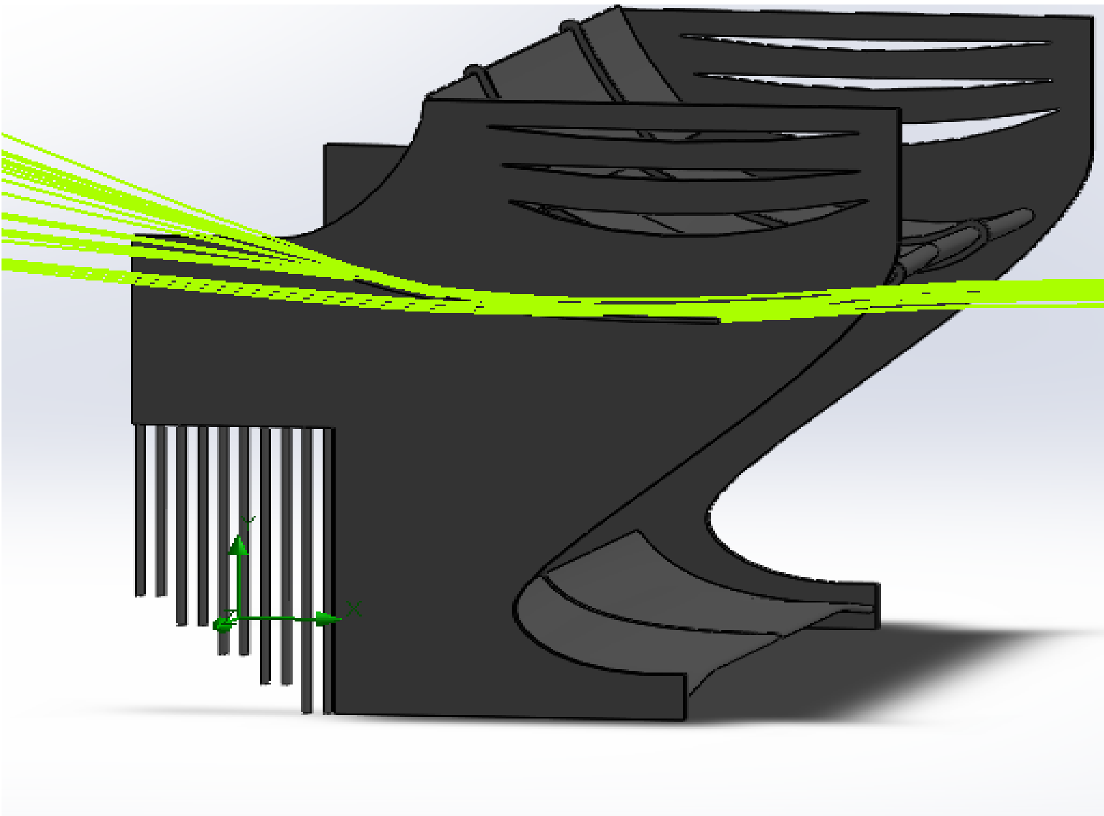


Fig-22 Single raked wing on the N-plate

4. PRELIMINARY CALCULATIONS

In the design of the Race car, one must recognise that front wings do not produce considerable drag. This has been proven over the years, from the tests on the full scale in wind-tunnel. Even when the angle of attack was altered largely it did not change the overall drag.

It is not the same when it comes to the configuration of the rear wing. A very small change to the attack of angle of the rear wing meant substantial changes to the car drag and downforce. Based on this situation an approximation of the wings set up is done [30]:

- Theoretical calculation of the top end speed of the car without front wings.
- Decide how much of top speed can be sacrificed by adding of wings
- Calculate the power difference for the top speed without wings and the top speed obtained with wings
- The change obtained among two power values is the sum of downforce which is going to be assigned to the rear wing.
- Calculate the wing maximum $C_D$value.
- Calculate the downforce that the rear wings in terms of kg.

Applying the above-mentioned rules. The first step is to calculate the frontal area of the race car without wings:

A=Frontal area without wings

=1.65m × 0.75m

=1.2375m^3

The estimated drag coefficient is C_D = 0.7 for low downforce track and C_D = 1.1 for high downforce track. The engine capacity of the Race car is 1.6 litres with single turbocharger at an output of 1000 bhp = 745.7kw. Let us assume the estimated transmission efficiency and rolling resistance is at 90%. Based on the above data, the engine power required to overcome the air resistance after taking into consideration the transmission efficiency is P = 671.13kw = 671130w. Using these above-mentioned data, the maximum top speed of the race car is calculated. The air density is ρ = 1.225kg/m^3 .

The velocity of the race car for low downforce track without wings is calculated using the formula:

$$V = \sqrt[3]{\frac{2.P}{C_D.\rho.A}} \tag{4.1}$$

P = Power, C_D = Drag Coefficient, ρ = Density of Air, A = Frontal Area, V = Velocity

$$V = \sqrt[3]{\frac{2 \times 671130}{0.7 \times 1.225 \times 1.2375}}$$

V = 108.148m/s

V = 389.33km/hr

The velocity of the Race car for high downforce track without wings is calculated using the formula:

$$V = \sqrt[3]{\frac{2.P}{C_D.\rho.A}} \tag{4.2}$$

$$V = \sqrt[3]{\frac{2 \times 671130}{1.1 \times 1.225 \times 1.2375}}$$

V = 93.022m/s

V = 334.87km/hr

According to the above theoretical value, this will be the maximum speed, that might be achieved based on the track configuration. Therefore, for example, let us assume the maximum speed of, 360km/hr, even though the fastest speed clocked by the race car is 353.72km/hr. The assumed maximum speed was going to be more than sufficient for top end acceleration at lower downforce and faster course [30].

Hence, the power required for the above-mentioned case is much lower as compared to actual power:

$$Pw = \frac{1}{2}.C_D.\rho.\ A.V^3 \tag{4.3}$$

ρ = Density of Air, A = Frontal Area, V = Velocity, C_D = Drag Coefficient, P_W = Power required.

$$P_W = \frac{1}{2}.0.7 \times 1.225 \times 1.2375 \times (\frac{360}{3.6})^3$$

$$P_W = 530578.125 \text{ w}$$

$$P_W = 530.578 \text{ kw}$$

Now, the differences in the power is calculated using the power required at the assumed top speed and the calculated power.

$$\Delta P = P - P_W \tag{4.4}$$

$$\Delta P = 671.13 – 530.578$$

$$\Delta P = 140.552\text{kw}$$

The Above obtained value, is the amount of power that is provide for the rear wing to obtain the required downforce.

Using the above obtained power difference, an appropriate drag coefficient, C_D, should be determined. I order to obtain the required, C_D, the following is required: the chord line of the wing, which is about 352mm and the span of the rear wing is about 750mm both of these dimensions are based on the design requirement lay down by the governing body. With the above-mentioned data, the frontal area (rear wing) is calculated which is the biggest contributor of the drag and down force on the race car [30].

Frontal area (rear wing) = A_{ZK} = 0.352 × 0.750 = 0.264m^3

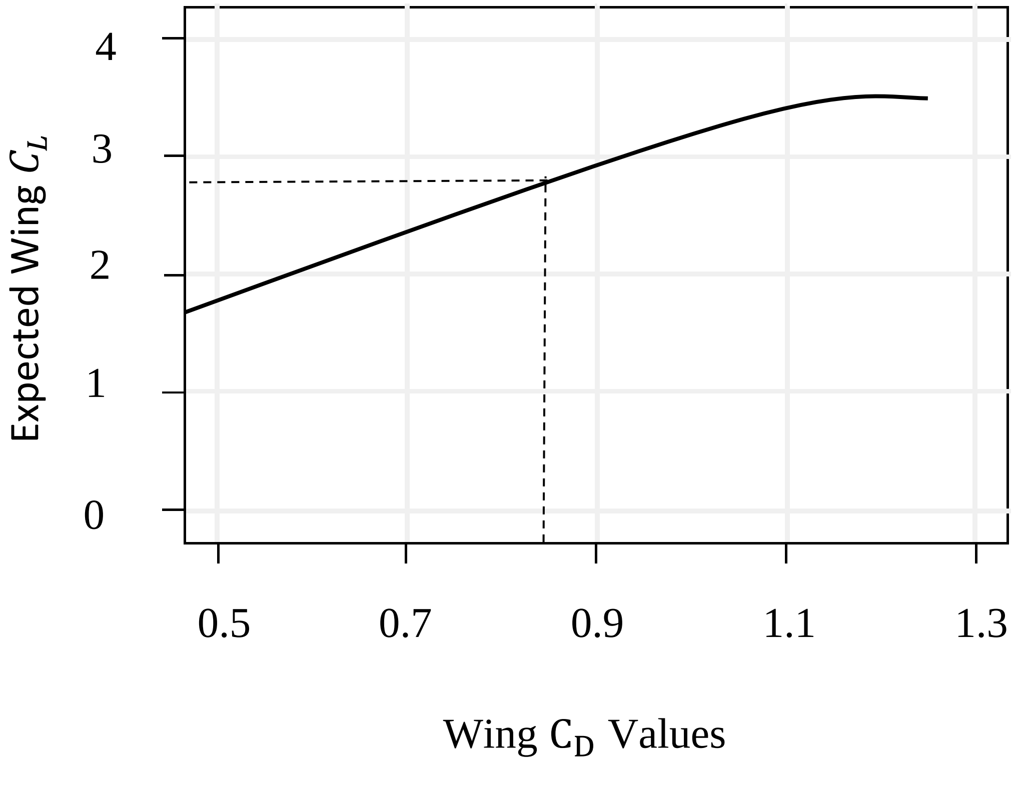
Using the above obtained power absorption equation, the peak possible drag coefficient of the rear wing is obtained:

$$C_{Dmax} = \frac{2.\Delta P}{\rho.A_{ZK}.V^2} \tag{4.5}$$

$$C_{Dmax} = \frac{2 \times 140552}{1.225 \times 0.264 \times (\frac{360}{3.6})^2}$$

$$C_{Dmax} = 0.869$$

Based on above obtained aerodynamic drag of C_D = 0.869. The below graph shows the uncertain correlation based on the information points. In our case, aerodynamic drag of C_D = 0.869 should correspond to a C_L of about 2.789 (this would be the actual downforce).



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Referring to few examples from the wing data charts the obtained drag coefficient C_D and Expected lift coefficient C_L would correspond to two elements of the wing. According to the rules specified only these two wing elements can used to achieve, high enough lift coefficients. Due to the restrictions on the aerodynamics used on the car it is not possible to achieve the aerodynamic downforce to the full extent. This also means that car can achieve the speed higher than that of 360km/hr.

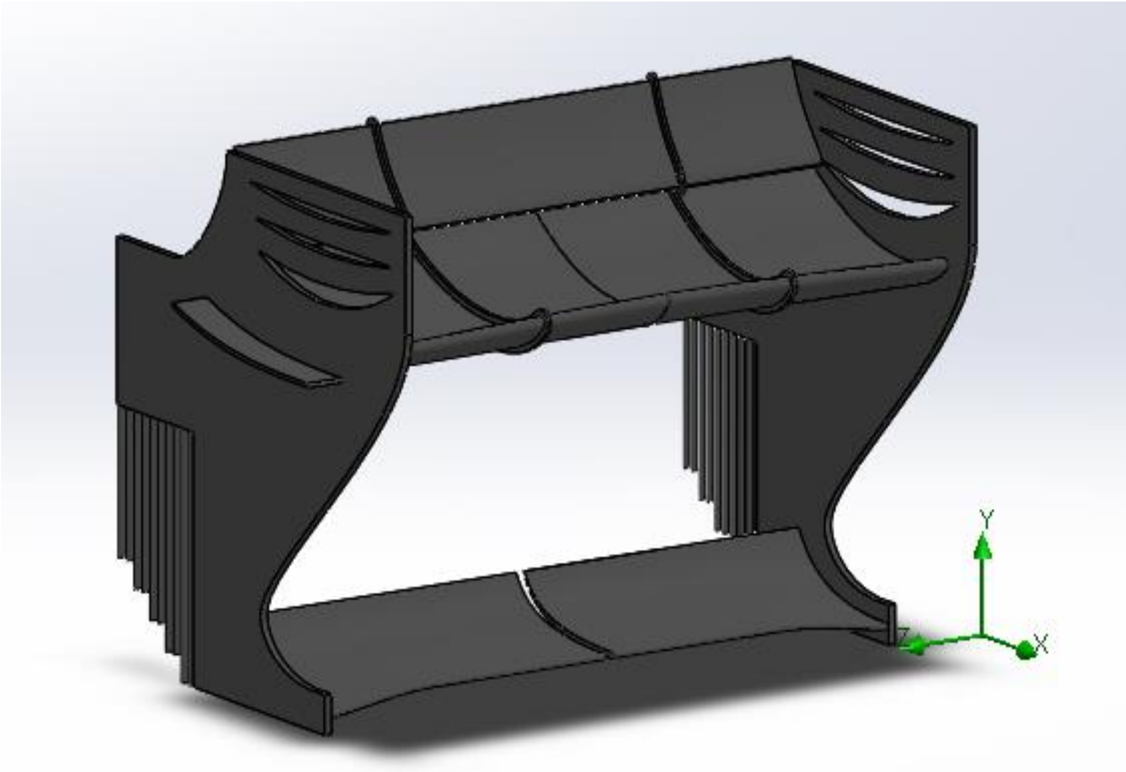

Fig-23 Rear wing design

As the Race teams, have the luxury of the obtaining the data from 3 different forms Computational fluid dynamics (CFD), wind tunnel and the real-time data, it is difficult to find the correlation between these data obtained. So, teams find the way to optimize the aerodynamic components using these data. In the above figure shows the concept shape of the rear wing.

Based on the above values obtained we will determine the theoretical downforce produce by the race car. That means balancing the rear wing which is the major contributor of the downforce in the race car. The balance of the aerodynamic forces on the race car should be relational to the weight distribution, which, when weighed with the driver in cockpit, is about fifty: fifty front: rear. But, balance of car is varied by the driver according to the track and to optimal lap time. Then, the L/D ratio is also changing of the race car, they are not the most aerodynamic cars, the wheel’s alone account for 35% of the drag because of the open wheel. Some of the race cars which has closed wheels will have higher top speed than the race car like LeMans.

Downforce on the rear wing in kg [31] [32] [33]:

$$D_F = \frac{1}{2}.\rho.V^2.A_{ZK}.C_L \tag{4.6}$$

$$D_F = \frac{1}{2} \times 1.225 \times (\frac{360}{3.6})^2 \times 0.264 \times 2.381$$

$$D_F = 329.77\text{kg}$$

5. CFD SIMULATION

5.1. GOVERNING EQUATIONS OF CFD

Navier-Stokes equations is solved in flow simulation, which are the formulations of energy conservation, mass and momentum rules for fluid flows. The formulas are augmented by fluid state formulas defining the nature of the fluid. The consideration of Inelastic non-Newtonian fluids is done by presenting the dependence of the dynamic viscosity. A specific problem is stated by the description of its initial conditions, geometry and boundary.

The laws for mass, angular momentum and energy in the Cartesian coordinate system rotating with angular velocity Ω about an axis are as follows [34]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{5.1}$$

$$\frac{\partial \rho u_i}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}(\tau_{ij} + \tau_{ij}{}^{R}) + S_i \quad i = 1,2,3 \tag{5.2}$$

$$\frac{\partial \rho H}{\partial t} + \frac{\partial \rho u_i H}{\partial x_i} = \frac{\partial}{\partial x_i}(u_j(\tau_{ij} + \tau_{ij}{}^{R}) + q_i) + \frac{\partial p}{\partial t} - \tau_{ij}{}^{R}\frac{\partial u_i}{\partial x_j} + \rho\varepsilon + S_i u_i + Q_H, \tag{5.3}$$

$$H = h + \frac{u^2}{2} \tag{5.4}$$

Additional two transport equations are used to describe the turbulent kinetic energy and dissipation:

$$\frac{\partial \rho k}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i k) = \frac{\partial}{\partial x_i}((\mu + \frac{\mu_i}{\sigma_k})\frac{\partial k}{\partial x_i}) + S_k \tag{5.5}$$

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i \varepsilon) = \frac{\partial}{\partial x_i}((\mu + \frac{\mu_i}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_i}) + S_\varepsilon \tag{5.6}$$

5.2. GENERAL EQUATIONS

Lift or downforce

$$L = \frac{1}{2}\rho v^2 A C_L \qquad (5.7)$$

where ρ is the air density, v is the flow velocity, A is the span area of the wing also known as the planform area, and C_L is the lift coefficient [35].

Drag force

$$D = \frac{1}{2}\rho v^2 A C_D \qquad (5.8)$$

Where C_D is drag coefficient

Mach number and Reynolds number

$$M = \frac{v_s}{u} \qquad (5.9)$$

v_s represents the flow velocity and u represents the speed of sound within a given medium.

$$Re = \frac{\rho V L}{\mu} \qquad (5.10)$$

where ρ is the fluid density, V is the flow velocity, and L is the length of the object moving through the flow [35].

5.3. FULL CAR SIMULATION

Model- Creating the model required for the simulation using the dimensions specified by the governing body.

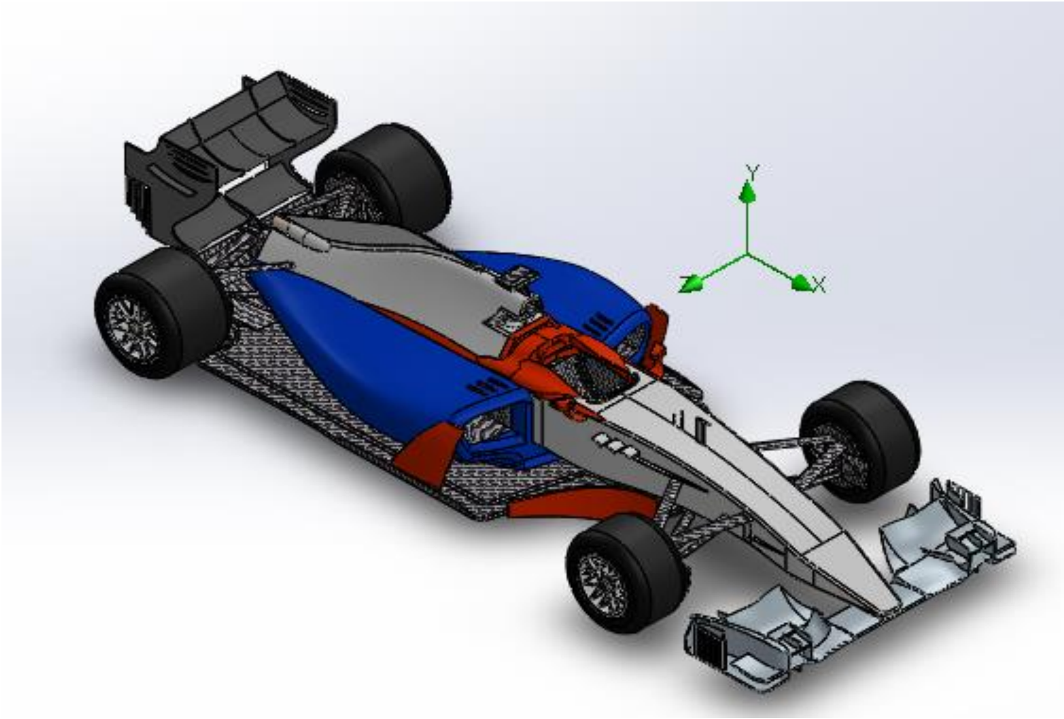

Fig-24 Full car design

Computational domain- About one fourth of the car length in the front and 3/4 of the car length in the back.

Mesh- The level of initial mesh was set to level 8 and in calculation control option, the refinement of global domain was set to level 7. In order to obtain fine mesh.

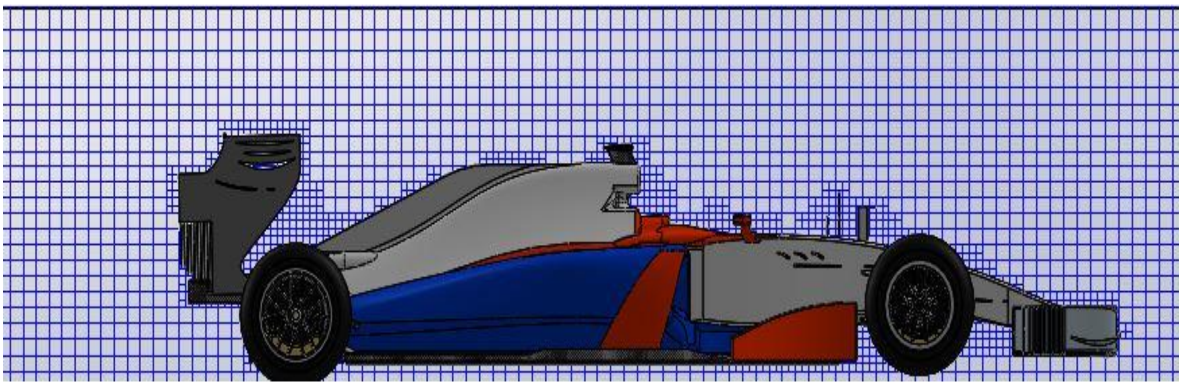

Fig-25 Mesh condition

Results-

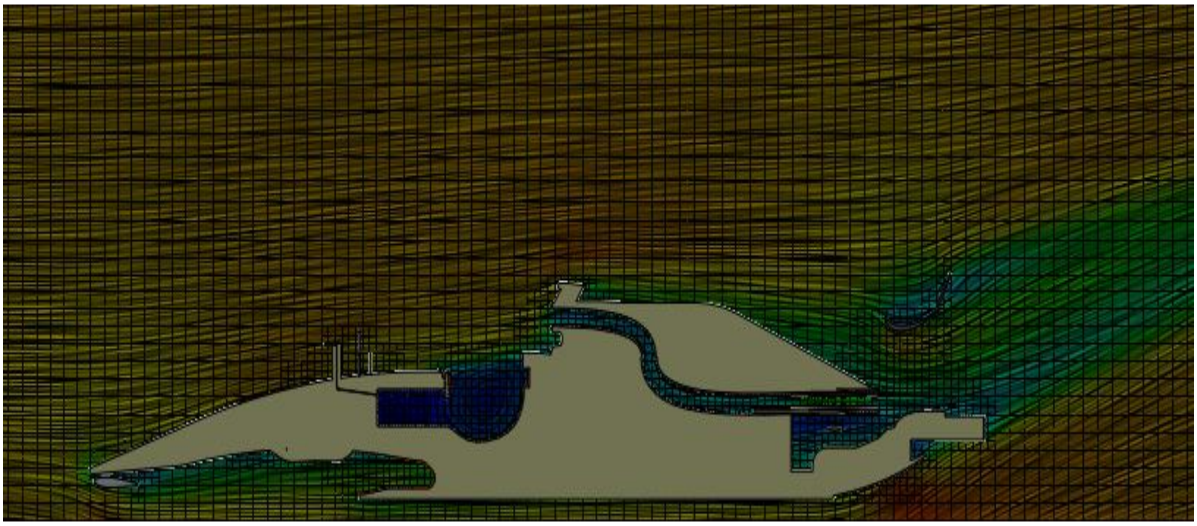

Fig-26 Streamline plot of full car

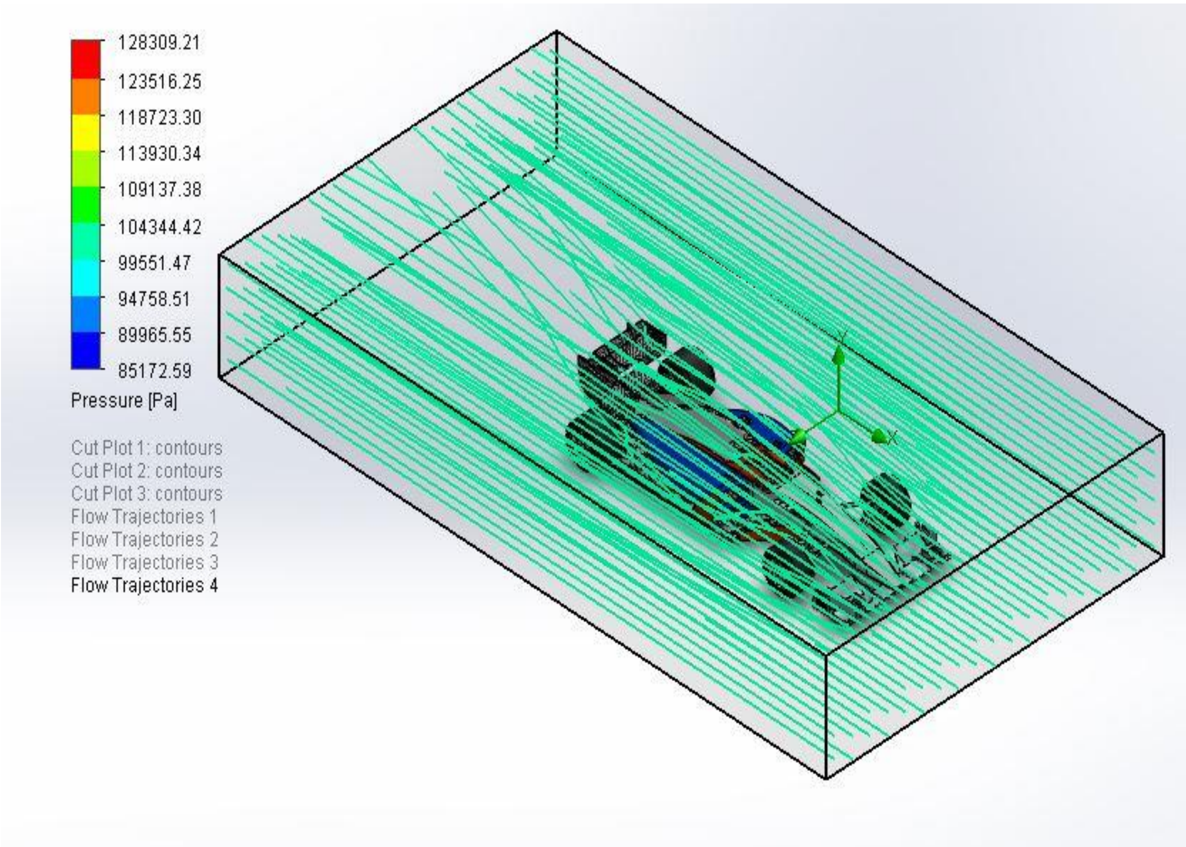

Fig-27 Flow Trajectories of full car

Using the results obtained from the flow simulation following parameters were calculated and the tabulated:

Table-2 Wing configuration

No of angle of attack	UPPER FLAP	LOWER FLAP
1	63.22	13.76
2	59.23	10.74
3	55.18	6.88

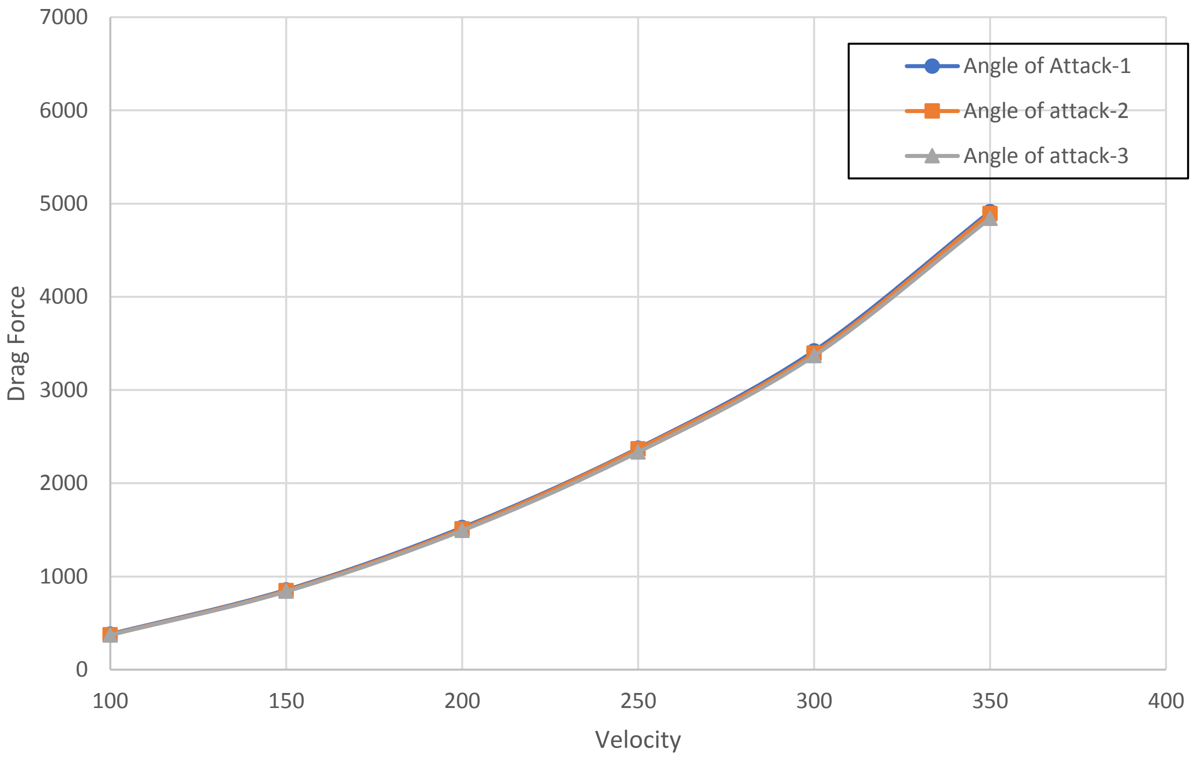

Fig-28 Drag forces for full car

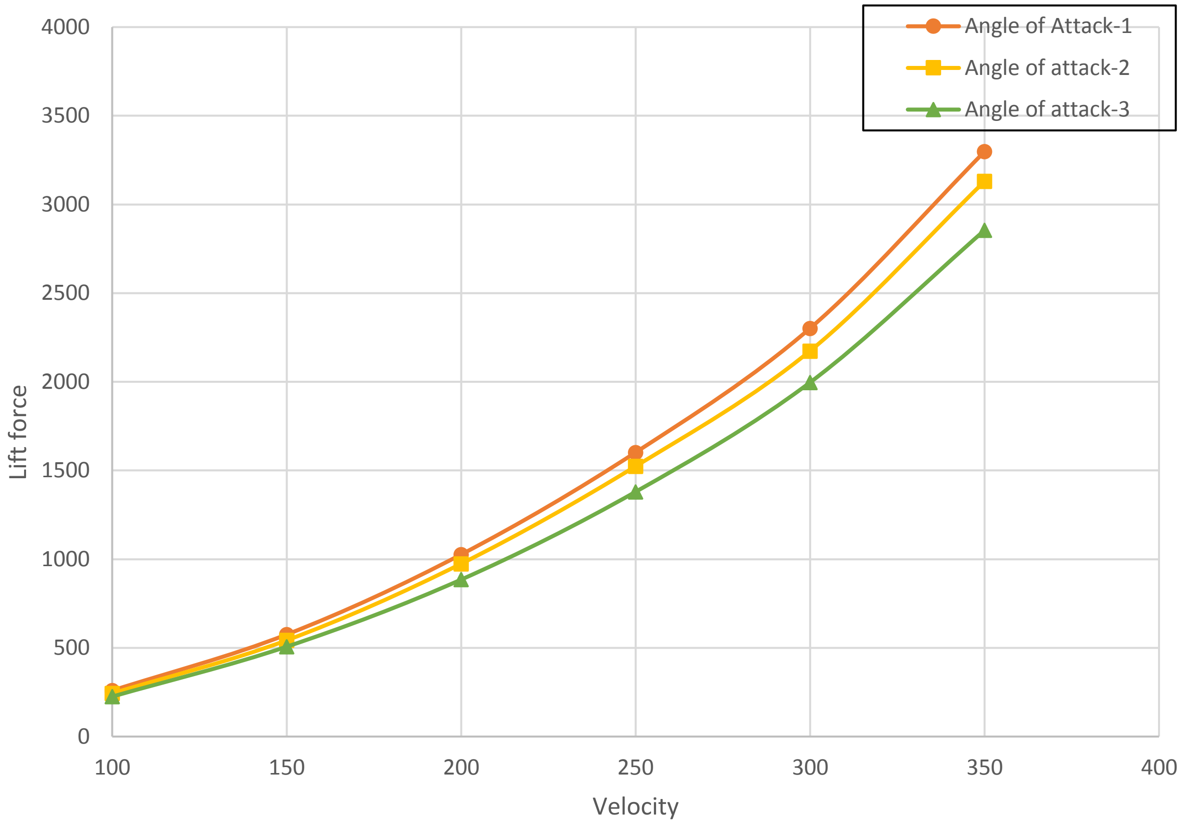

Fig-29 Lift forces for full car

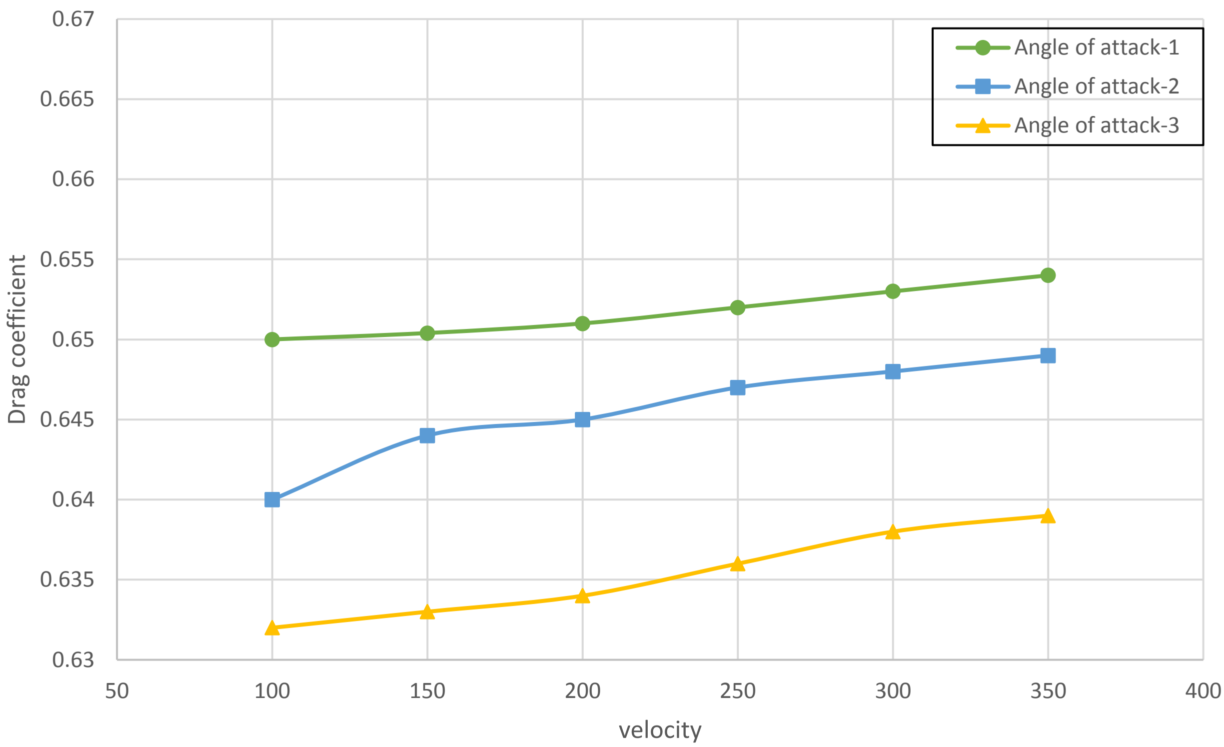

Fig-30 Drag coefficient for full car

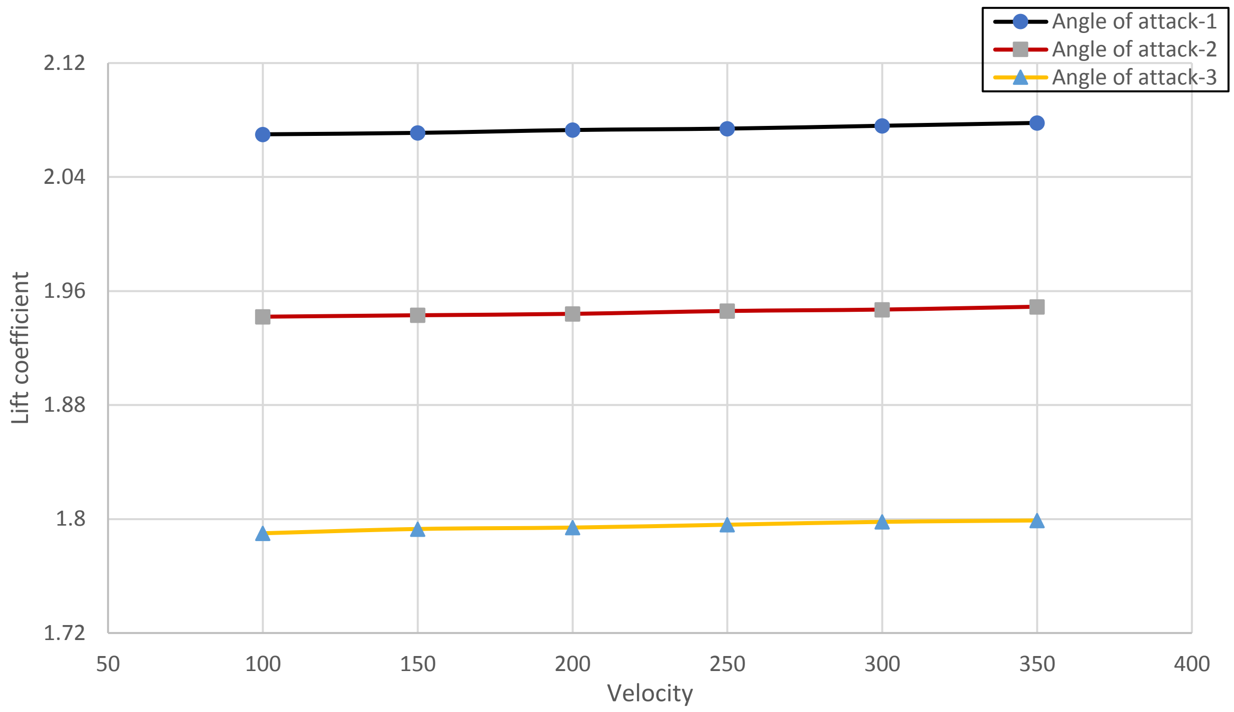

Fig-31 Lift coefficient for full car

5.4. REAR WING SIMULATION

Model- Creating the model required for the simulation using the dimensions specified by the governing body.

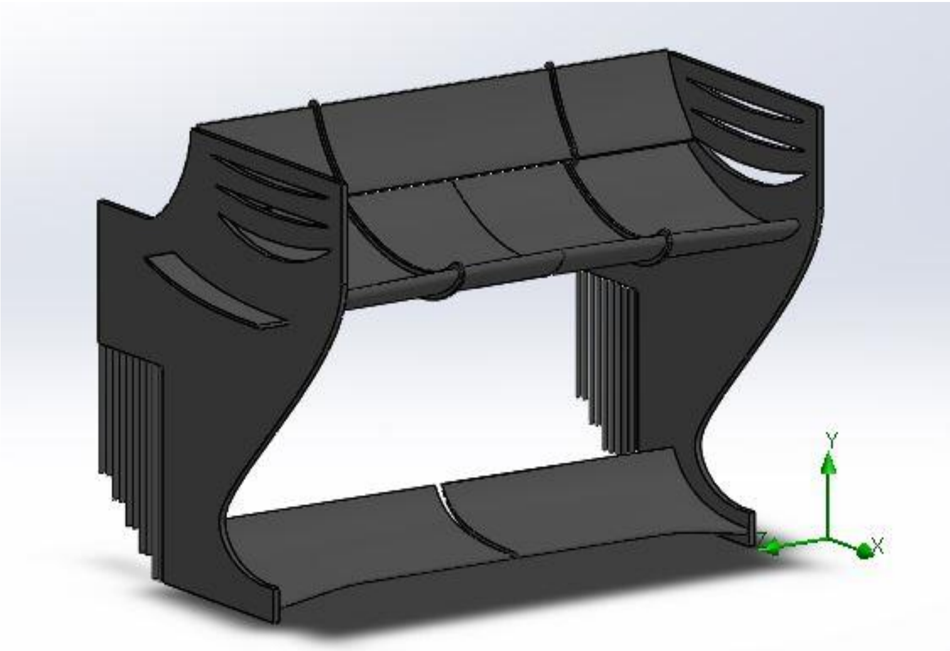

Fig-32 Rear wing

Computational domain- About one the length of the wing in the front and twice the length of the wing in the back.

Mesh- The level of initial mesh was set to level 8 and in calculation control option, the refinement of global domain was set to level 7. In order to obtain fine mesh.

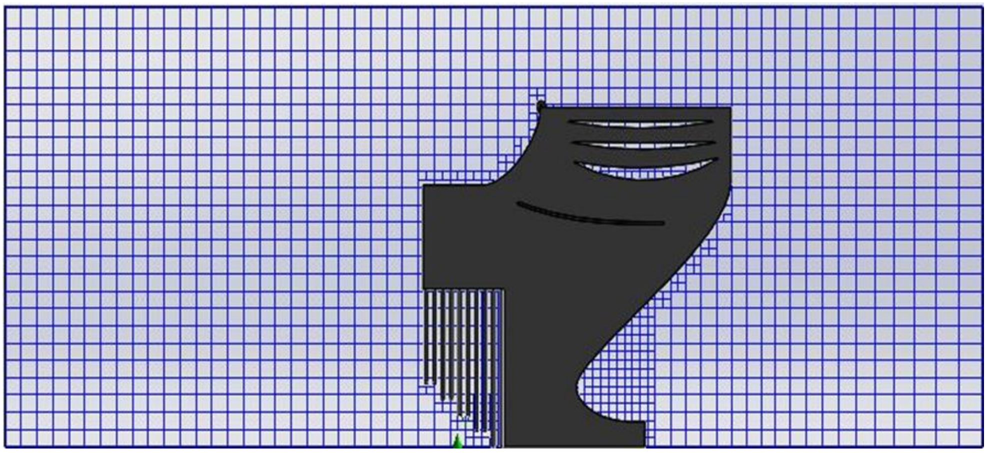

Fig-33 Mesh condition

Results-

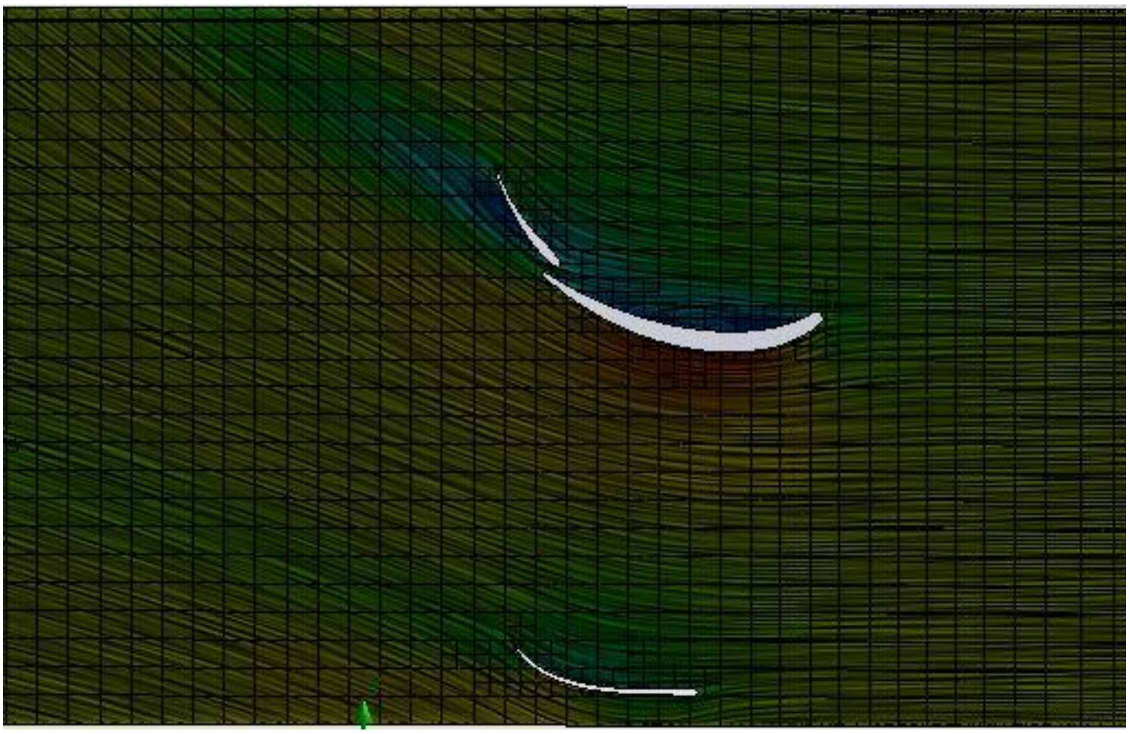

Fig-34 Streamline plot of rearwing

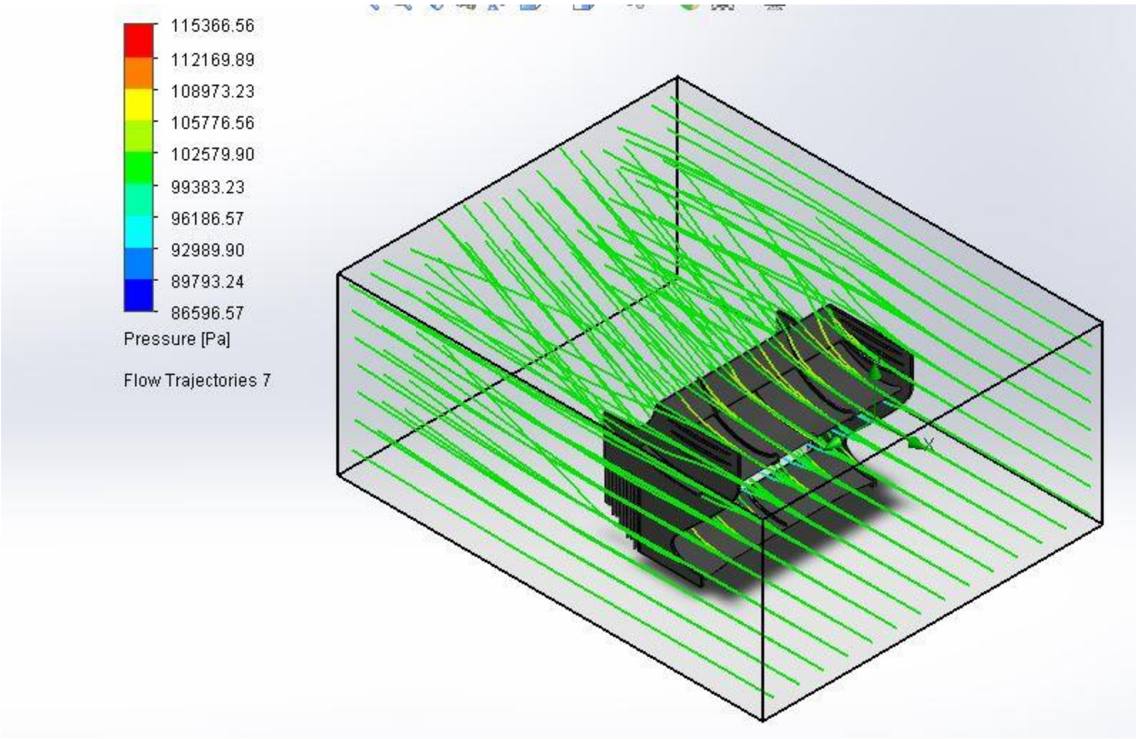

Fig-35 Flow trajectories of rear wing

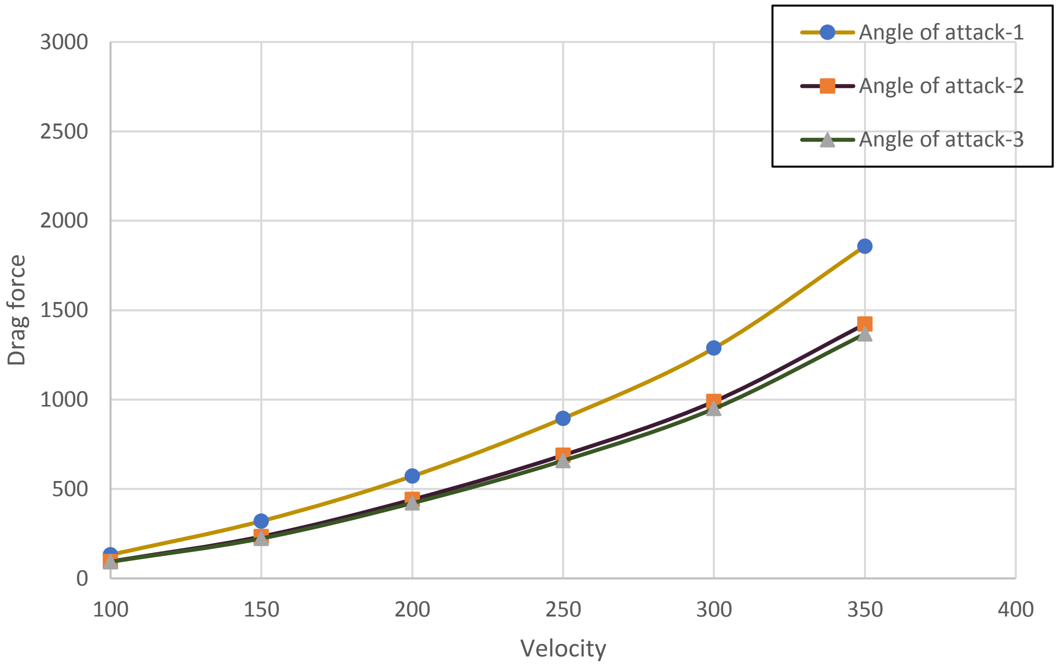

Fig-36 Drag force for rear wing

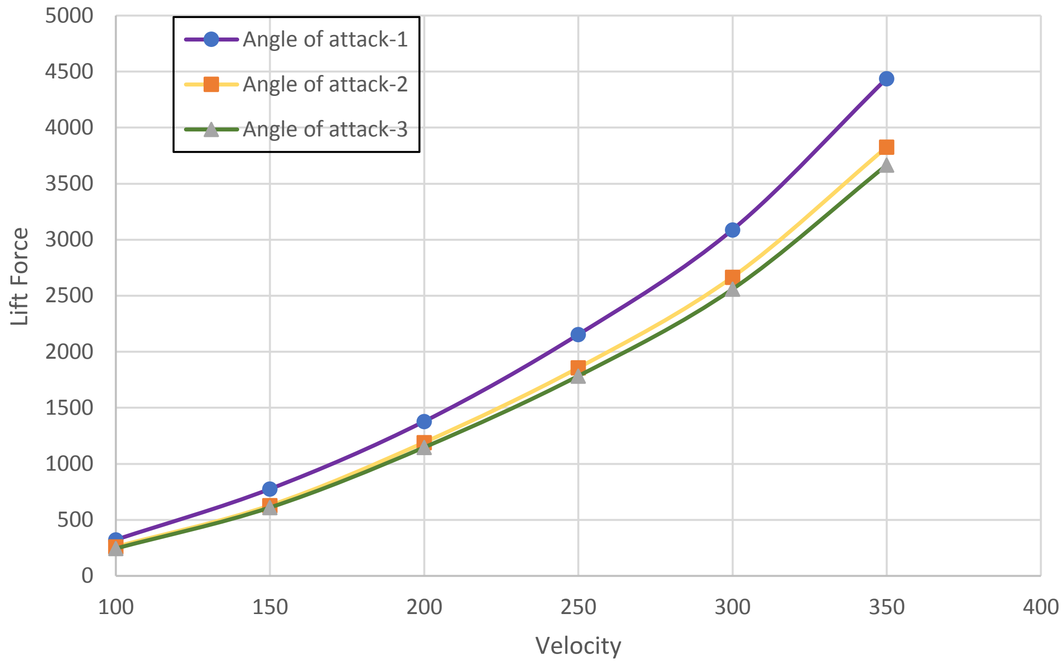

Fig-37 Lift force for rear wing

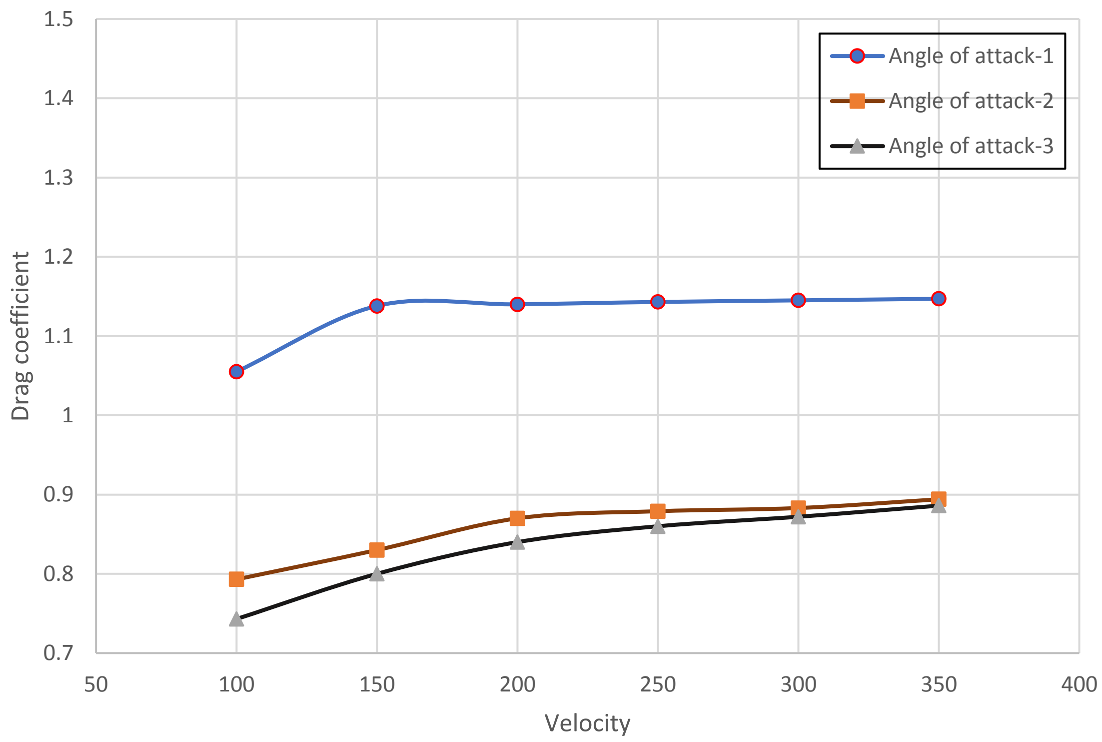

Fig-38 Drag coefficient for rear wing

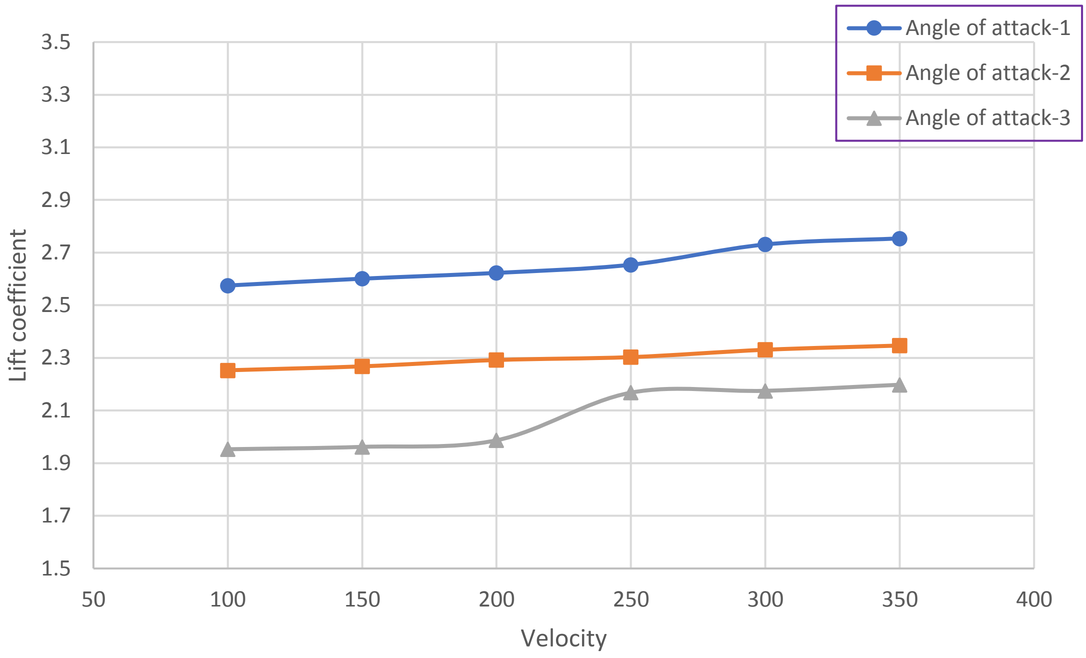

Fig-39 Lift coefficient for rear wing

5.5. COMPARISON OF RESULTS

The above result obtain for the full car simulation has a downforce of 3130.509N which is considerably higher than that of the downforce obtained from the standard car which is of 2558.062N. Hence, the proposed changes for the front and rear wing is effective in enhancing the performance of the race car.

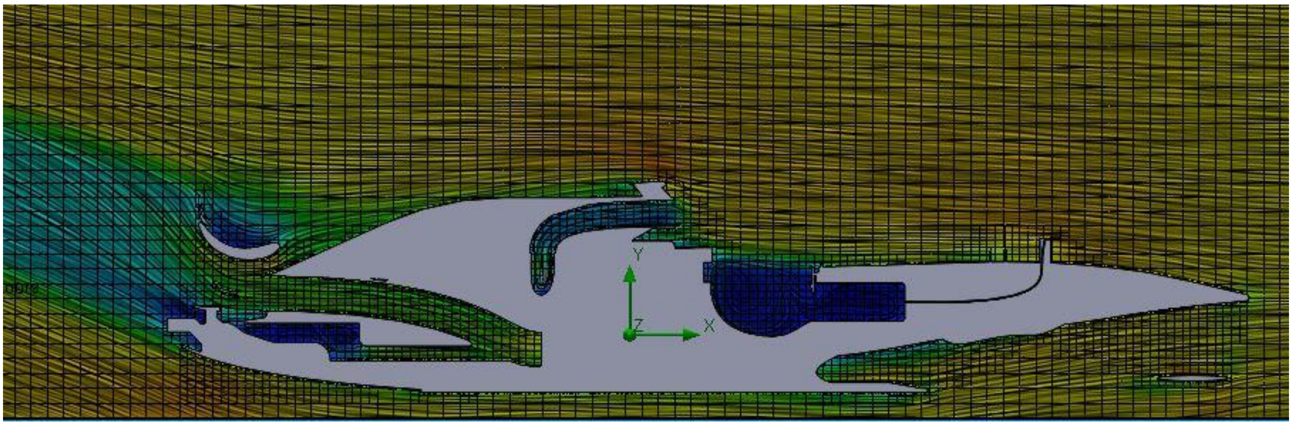

Fig-40 Streamline plot of benchmark car

6. STATIC ANALYSIS

The objective of the static analysis is to determine the stress, displacements and the factor of safety. The static analysis was done to find out if the material could withstand the applied load. In this research two materials were used one is carbon fibre and the second material is glass fibre (S type). The component which will be designed using these materials is the front wing of the Race car. The properties of the of the materials used are:

Table-3 Material Properties [36]

	Carbon fibre	**Glass fibre (S type)**
Modulus of elasticity	70000 N/mm2	93000 N/mm2
Poisson's ratio	0.45	0.23
Shear modulus	7000 N/mm2	39000 N/mm2
Mass density	1800 kg/m3	2480 kg/m3
Tensile strength	600 N/mm2	4800 N/mm2
Compression strength	570N/mm2	5000 N/mm2

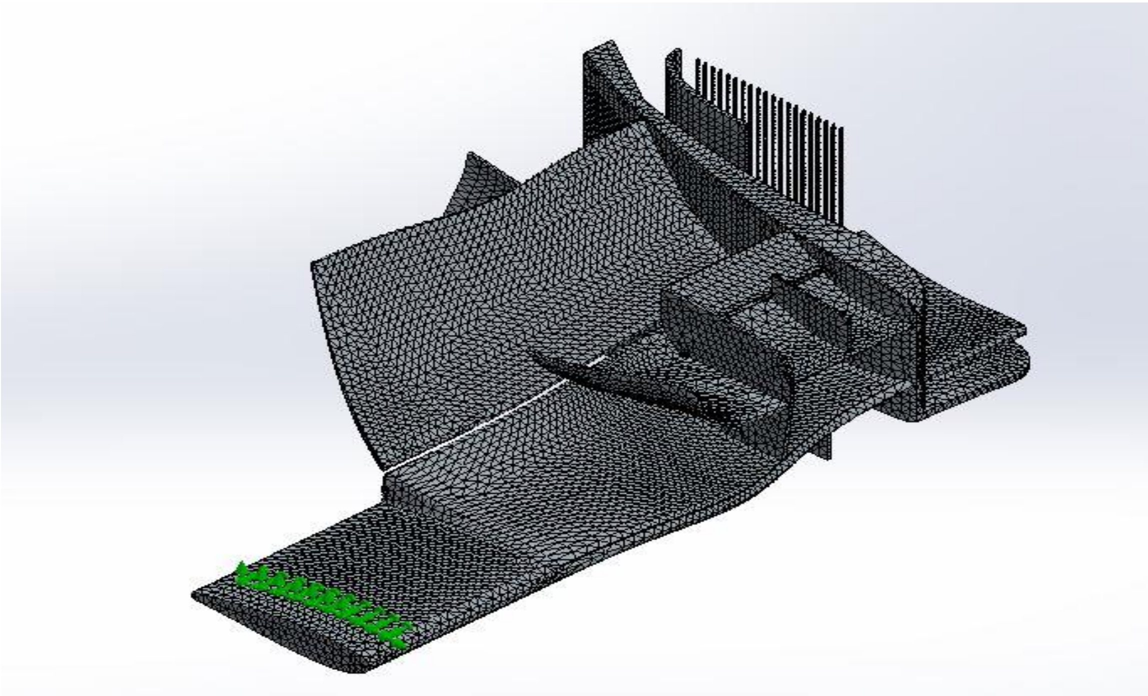

Fig-41 Front wing mesh and fixtures

The front wing was designed using the dimensions specified by the governing body. The test was done using model without symmetry. The mesh was done using the solid mesh of global size of 10mm and tolerance of 0.69mm. The fixtures are used as fixed geometry and it is fixed where the chord will be fixed to the front wing. The forces obtained from the flow simulation were imported and used as external forces for the study, the forces in x direction is 293.89 N and forces in y direction is 239.150 N at the velocity of 100m/s (360km/h). The large load displacement and large problem direct sparse option was used.

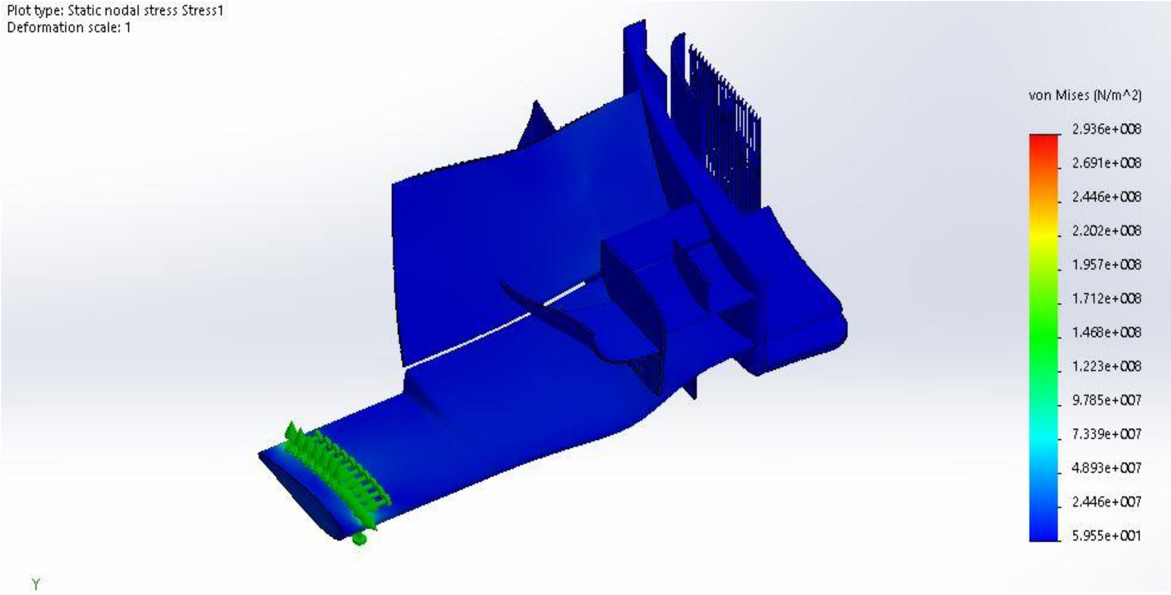

Fig-42 Von-Mises Stress for carbon fibre

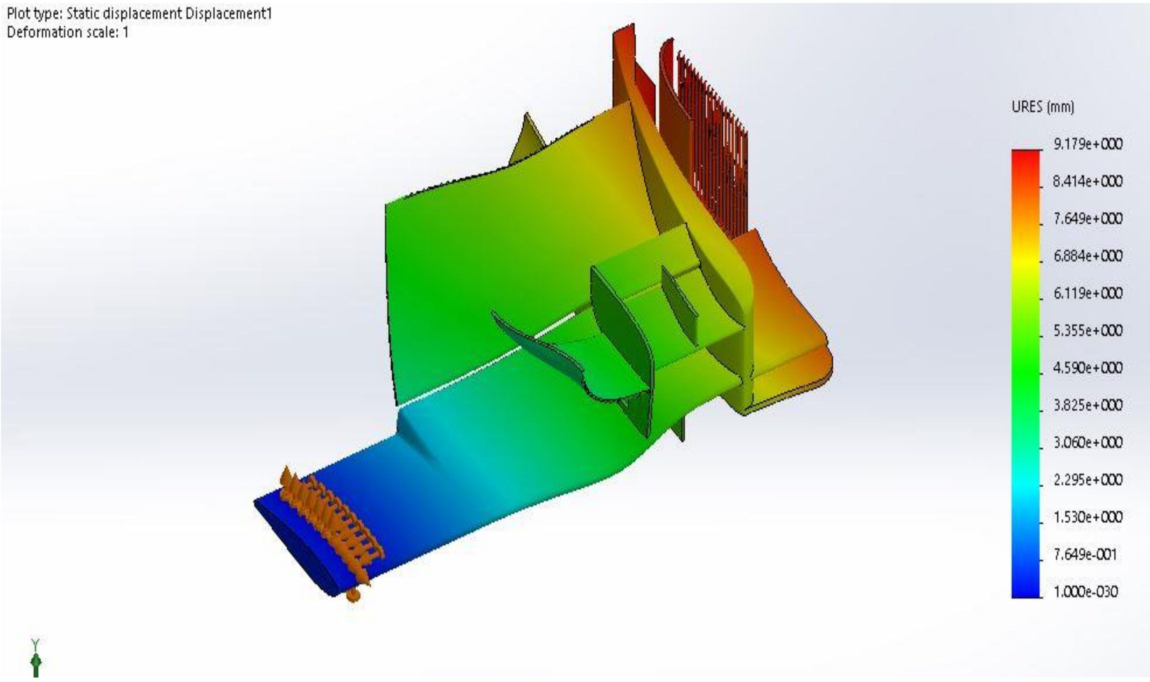

Fig-43 Displacements for carbon fibre

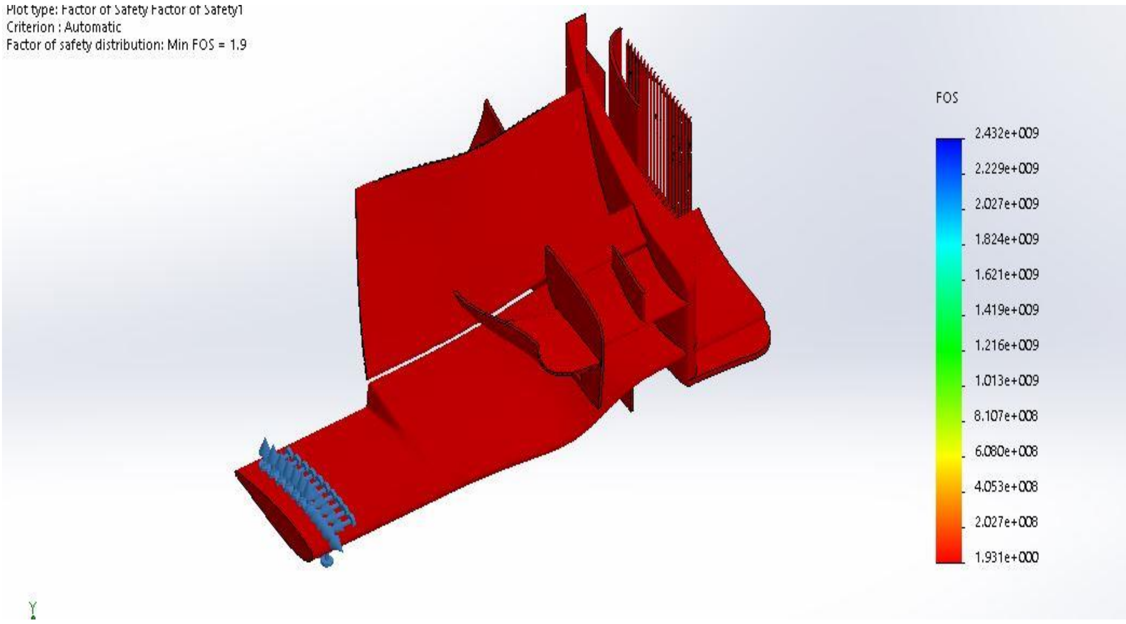

Fig-44 FOS for carbon fibre

From the above fig-43, we can notice that the maximum displacement of 9.179mm is safe within the specified speed and material will survive the load acting on it will the motion of the race car and the FOS lies in the elastic limit for carbon fibre at 1.9 as shown in above fig-44.

The static study was also conducted for the glass fibre (S type). The maximum stress concentration for the front wing of both material is at the area where the chord is connected to front wing, as shown in below fig-45

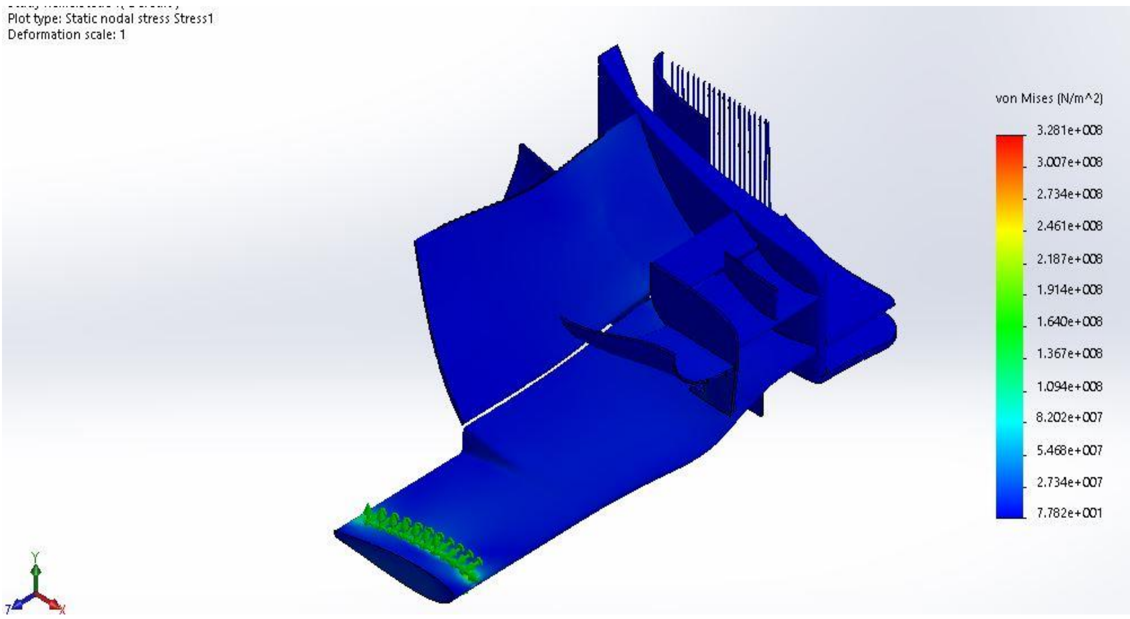

Fig-45 Von Mises stress for glass fibre (S type)

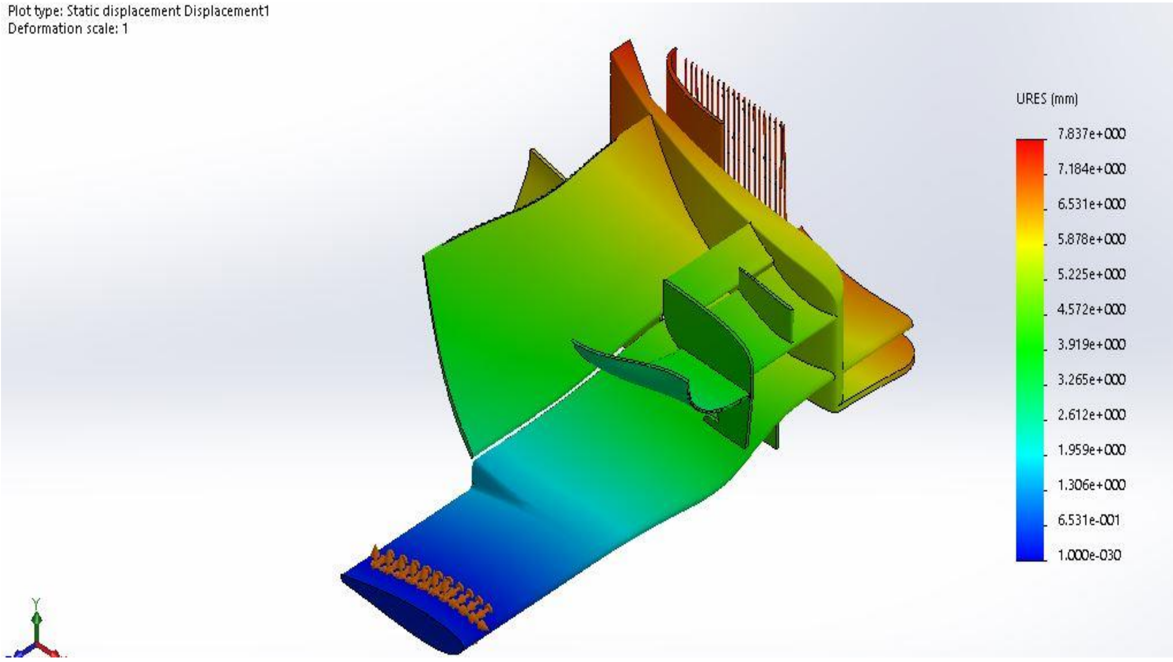

Fig-46 Displacements for glass fibre (S type)

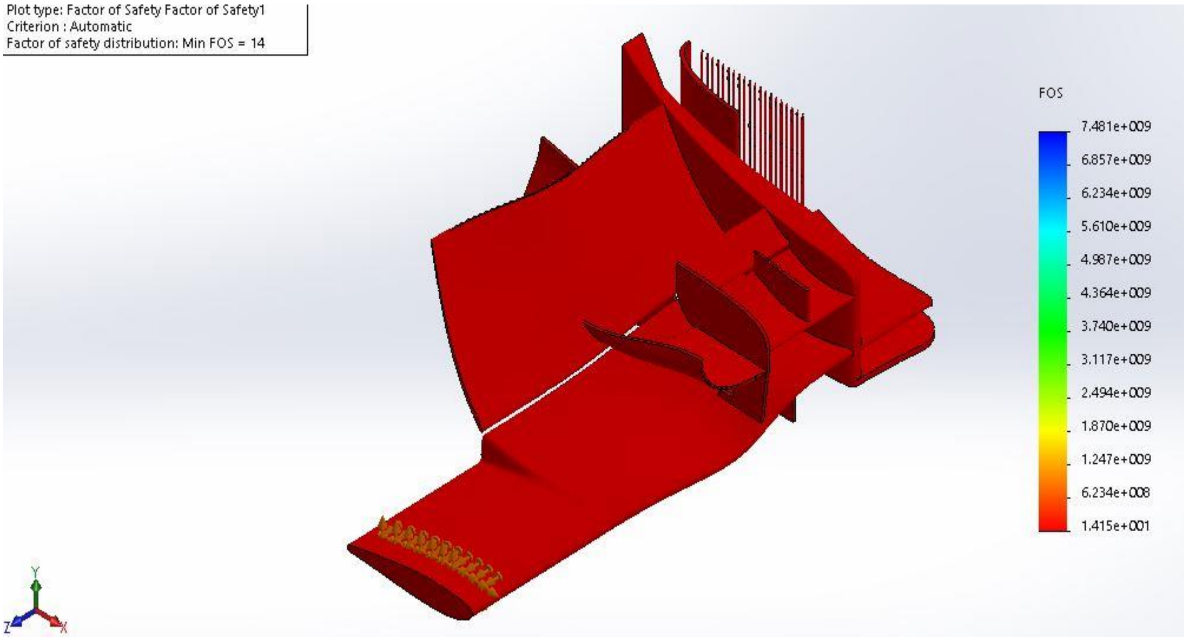

Fig-47 FOS for glass fibre (S type)

From the above fig-46, it shows the maximum displacement of 7.837mm, which is again in the safe working limits of the material as the FOS for the glass fibre is at 14.

CONCLUSION

- The conclusion that can be drawn from the literature survey, is that there is more performance gain to be had through aerodynamics by reducing the drag and increasing the downforce. The second part is the scope for the use of new materials in the body construction.
- The aerodynamic wings are designed in a way to increase downforce. The proposed design changes made to the wing aids in the increase in performance of the car.
- The flow simulation study is carried out on the aerodynamic components designed using the solidworks, the results obtained from the study yields to drag coefficient of maximum 0.65 for full car and maximum of 1.2 for the rear wing, lift coefficient/downforce of maximum 2.06 for full car and 2.75 for rear wing. So, the design of these aerodynamic components has meet the target of keeping the drag coefficient under 0.7 for the full car.
- The static study shows that maximum stress concentration is at the point where the chord is connected for both the materials. This study shows that for same loads acting on the material, the displacement of the glass fibre is about 15% less than that of the carbon fibre and the factor of safety for the front wing in case of glass fibre is 14, which is far greater than that of the carbon fibre 1.9. Hence, the material lies in the safe working limit. This shows the scope for the use of glass fibre in place of carbon fibre.

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