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Structural Analysis of Formula One Racing Car

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Abstract

A modern Formula One (F1) Racing Car has almost as much in common with an aircraft as it does with an ordinary road car. Aerodynamics has become a key to success in the sport and teams spend millions of dollars on research and development in the field each year for improving performance. The aerodynamic designer has two primary concerns:

i. *The creation of downforce, to help push the car's tyres onto the track and improve cornering forces,*
ii. *To minimise the drag that occurs due to turbulence and acts to slow down the car.*

In this project, various features of the car will be enhanced to make the whole car more structurally efficient by analysing the corresponding structure and forces using Ansys Workbench (Static Structural) software. Structurally efficiency will be attained by considering the Downforce & Force Reaction, generated at a certain speed, weight, material, strength, and other performance parameters to achieve the above stated primary concerns.

Keywords – *Formula One race car, Airfoil, Angle of Attack (AOA), Force Reaction, Downforce.*

I. INTRODUCTION

On the surface, automobile racing appears simply as a popular sport. But in reality, racing serves as a proving ground for new technology and a battlefield for the giants of automobile industry. Although human factors are frequently publicized as the reason behind the success or failure of one racing team or another, engine power, tire adhesion, chassis design, and recently, aerodynamics probably play a very important role in winning this technology race. Aerodynamics is study of gases in motion. As the principal application of aerodynamics is the design of aircraft, air is the gas with which the science is most concerned. Although aerodynamics is primarily concerned with flight, its principles are also used in designing automobile. The wind tunnel is one of the aerodynamicist's basic experimental tools. However in recent years, it has been supplanted by the simulation of aerodynamic forces during the computer-aided design of aircraft and automobiles.

1.1. Work plan

Analysing the magnitude of Downforce over the following components of the car:

1. Front Wing Airfoil (NACA 4412) & Rear Wing Airfoil (NACA 2408) :
   a) Negative (-15^0) AOA at free stream velocity of 100 kmph
   b) Zero (-0^0) AOA at free stream velocity of 100 kmph
   c) Positive (+15^0) AOA at free stream velocity of 100 kmph
2. Front Wing Assembly & Rear Wing Assembly :
   a) Negative (-15^0) AOA at free stream velocity of 100 kmph
   b) Zero (-0^0) AOA at free stream velocity of 100 kmph

Refer [1] for the CAD Modelling phase of the project and [2] for the CFD analysis phase of the project.

1.2. Selection of Airfoil

NACA 4-series airfoils are the most widely used airfoils for Formula One race cars. The NACA four-digit wing sections define the profile by:

i. First digit - maximum camber as percentage of the chord.
ii. Second digit - the distance of maximum camber from the airfoil leading edge in tens of percentage of the chord.
iii. Last two digits - maximum thickness of the airfoil as a percentage of the chord.

1.2.1. Front Wing Airfoil – NACA 4412

The Front Wing of a Formula One car creates about 25% of the total car's downforce. This is one of the most widely used spoiler airfoil, but needs to be enhanced as per speed. Such a thicker airfoil is used to obtain the desired higher downforce from the front end of the car, at a given speed.

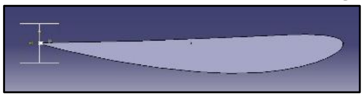


Figure 1. NACA 4412

1.2.2. Rear Wing Airfoil – NACA 2408

Due to location of engine at the rear end of the car, more downforce is generated. Hence, to compensate for minimization of downforce from rear end, a thinner airfoil is used. Thinner airfoil also helps to maintain the continuity of the flow without flow separation. Thus, NACA 2408 is employed at the rear end.

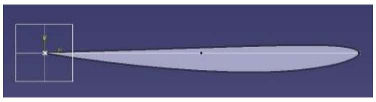


Figure 2. NACA 2408

1.3 Aerodynamics Background

Aerodynamics is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a moving object. Understanding the motion of air (often called a flow field) around an object enables the calculation of forces and moments acting on the object. Typical properties calculated for a flow field include velocity, pressure, density and temperature as a function of position and time. By defining a control volume around the flow field, equations for the conservation of mass, momentum, and energy can be defined and used to solve for the properties. The drag over a body can be minimized by streamlining it (smooth exterior surface). As a result, there will be potential improvements in fuel economy. An inverted airfoil to generate a negative lift force – Downforce. This leads to major improvements in race car performance, especially on tracks with numerous high-speed, unbanked turns. Aerodynamic downforce increases the tires' cornering ability by increasing loads on the tires without increasing the vehicle's weight. The result is increased cornering ability, with no weight penalty, which gives a reduction in lap times.

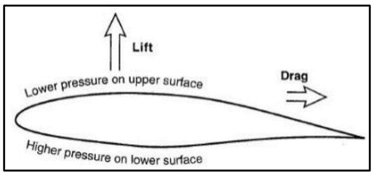


Figure 3. Flow over a Streamlined Body

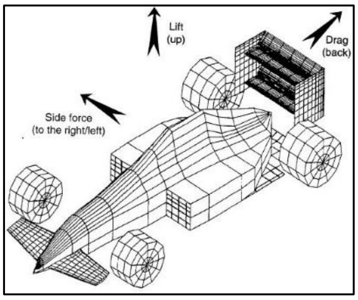


Figure 4. Aerodynamic Forces

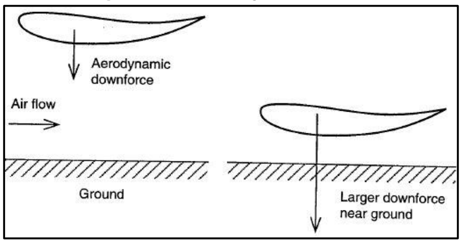


Figure 5. Schematic description of the "Ground Effect" that increases the aerodynamic lift of the wings when placed near the ground.

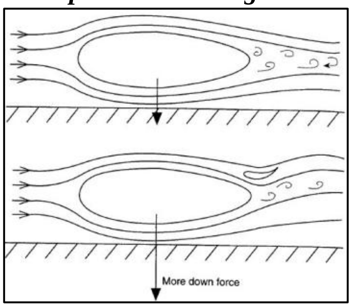


Figure 6. Schematic description of the effect of rear wing on the streamlines nearby a generic body.

(All photographs are the courtesy of Race Care Aerodynamics – By Joseph Katz)

II. DOWNFORCE CALCULATION AT FREESTREAM VELOCITY OF 100 KMPH USING ANSYS WORKBENCH 14.0 – STATIC STRUCTURAL

2.1. Front Wing Airfoil (NACA 4412)

2.1.1. Model

The Geometry and Solution is imported from CFX to Static Structural. Thereafter, the airfoil is meshed as follows:

Patch Conformal Method = Tetrahedrons
Body Sizing = 5 mm
Material Assigned = Structural Steel

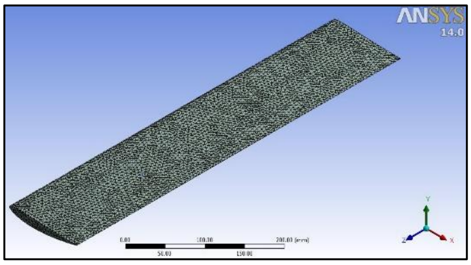


Figure 7. Airfoil Mesh for Static Structural

2.1.2. Static Structural Setup

Under the setup, the Pressure Load is imported as Imported Load for the Fixed Support. 100% of Mechanical nodes are mapped to the CFD Surface.

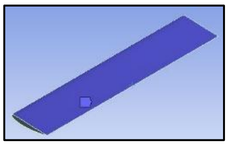


Figure 8. Fixed Support (1-face)

2.2. Rear Airfoil (NACA 2408)

2.2.1. Model

The Geometry and Solution is imported from CFX to Static Structural. Thereafter, the airfoil is meshed as follows:

Patch Conformal Method = Tetrahedrons
Body Sizing = 5 mm
Material Assigned = Structural Steel

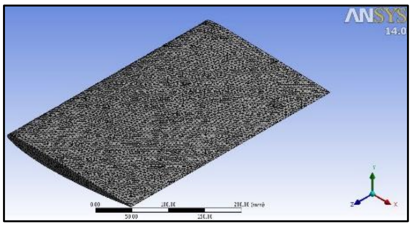


Figure 9. Airfoil Mesh for Static Structural

2.2.2. Static Structural Setup

Under the setup, the Pressure Load is imported as Imported Load for the Fixed Support. 100% of Mechanical nodes are mapped to the CFD Surface.

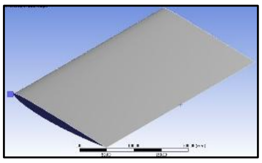


Figure 10. Fixed Support (2-faces)

2.3. Front Wing Assembly (6 Plates of NACA 4412)

2.3.1. Model

The Geometry and Solution is imported from CFX to Static Structural. Thereafter, the airfoil is meshed as follows:

Patch Conformal Method = Tetrahedrons
Body Sizing = 10 mm
Material Assigned = Structural Steel

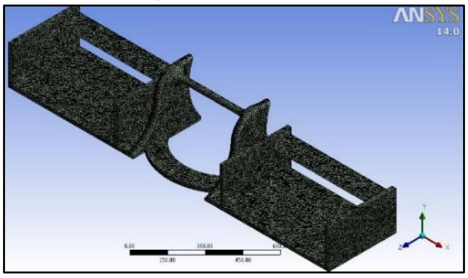


Figure 11. Mesh for Static Structural

2.3.2. Static Structural Setup

Under the setup, the Pressure Load is imported as Imported Load for the Fixed Support. 100% of Mechanical nodes are mapped to the CFD Surface.

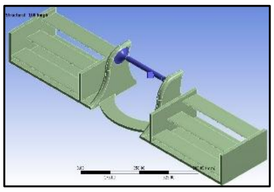


Figure 12. Fixed Support (1-face)

2.4. Rear Wing Assembly (2 Plates of NACA 2408)

2.4.1. Model

The Geometry and Solution is imported from CFX to Static Structural. Thereafter, the airfoil is meshed as follows:

Patch Conformal Method = Tetrahedrons
Body Sizing = 10 mm
Material Assigned = Structural Steel

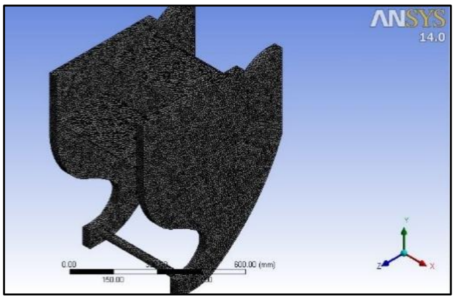


Figure 13. Mesh for Static Structural

2.4.2. Static Structural Setup

Under the setup, the Pressure Load is imported as Imported Load for the Fixed Support. 100% of Mechanical nodes are mapped to the CFD Surface.

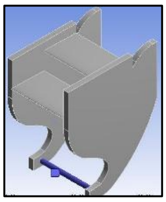


Figure 14. Fixed Support (1-face)

III. RESULTS

3.1. Front Wing Airfoil (NACA 4412)

3.1.1. Negative (-15^0) AOA at free stream velocity of 100 kmph

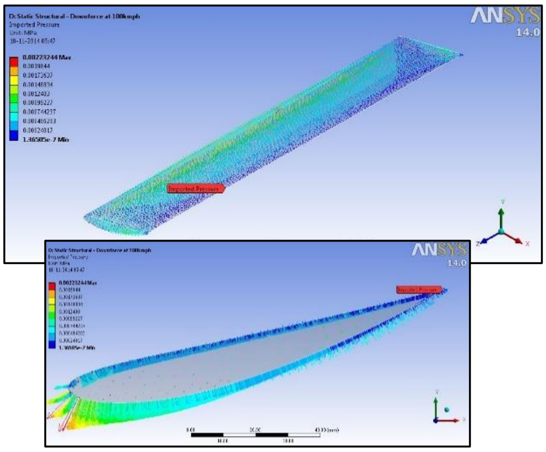


Figure 15. Imported Pressure

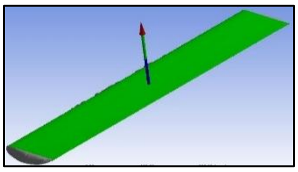


Figure 16. Force Reaction

X = -9.1747 N Y = 57.239 N Z = -0.0155 N

TOTAL = 57.97 N (+Y)

Hence, Total Downforce = 57.97 N (–Y Direction)

3.1.2. Zero (0^0) AOA at free stream velocity of 100 kmph

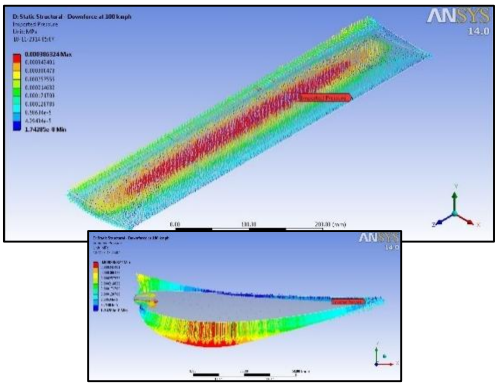


Figure 17. Imported Pressure

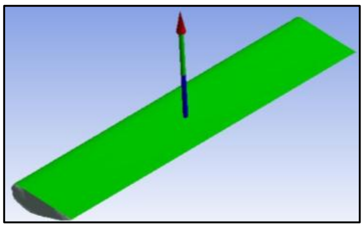


Figure 18. Force Reaction

X = -0.93611 N   Y = 14.411 N   Z = 0.00068 N
TOTAL = 14.442 N (+Y)
Hence, Total Downforce = 14.442 N (–Y Direction)

3.1.3. Positive (+15^0) AOA at free stream velocity of 100 kmph

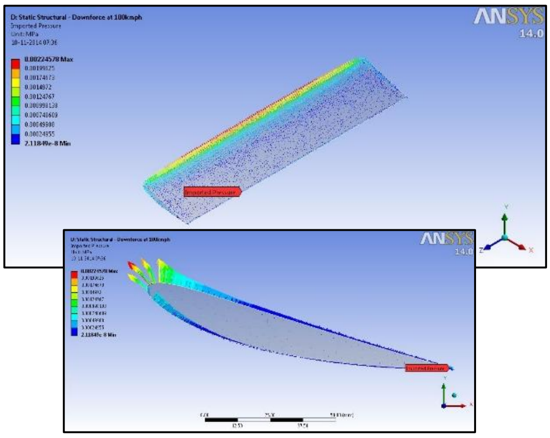


Figure 19. Imported Pressure

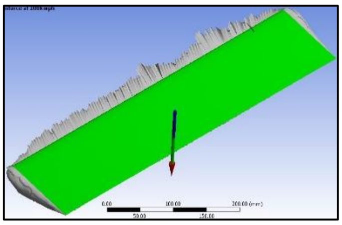


Figure 20. Force Reaction

X = -1.5673 N   Y = -25.114 N   Z = -0.00738 N
TOTAL = 25.163 N (-Y)
Hence, Total Downforce = 25.163 N (+Y Direction)

3.2. Rear Wing Airfoil (NACA 2408)

3.2.1. Negative (-15^0) AOA at free stream velocity of 100 kmph

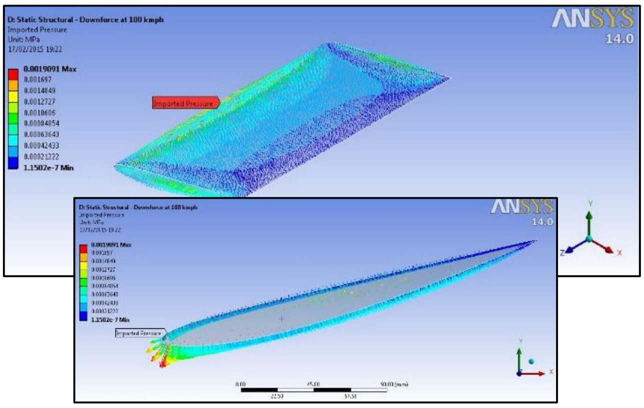


Figure 21. Imported Pressure

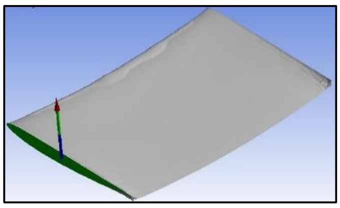


Figure 22. Force Reaction

X = -9.0429 N   Y = 54.755 N   Z= 0.0394 N
TOTAL = 55.496 N (+Y)
Hence, Total Downforce = 55.496 N (–Y Direction)

3.2.2. Zero (0^0) AOA at free stream velocity of 100 kmph

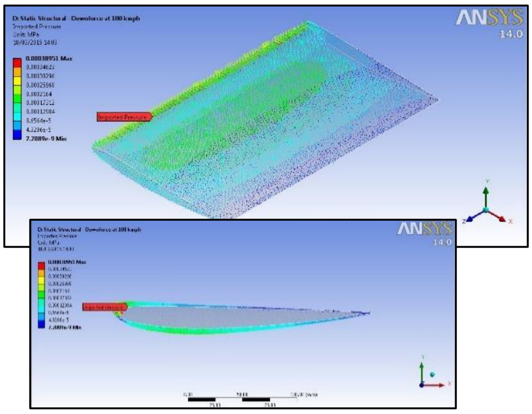


Figure 23. Imported Pressure

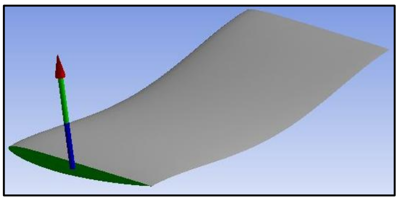


Figure 24. Force Reaction

X = -0.64124 N   Y = 5.766 N   Z= 0.00124 N
TOTAL = 5.8016 N (+Y)
Hence, Total Downforce = 5.8016 N (–Y Direction)

3.2.3. Positive (+15^0) AOA at free stream velocity of 100 kmph

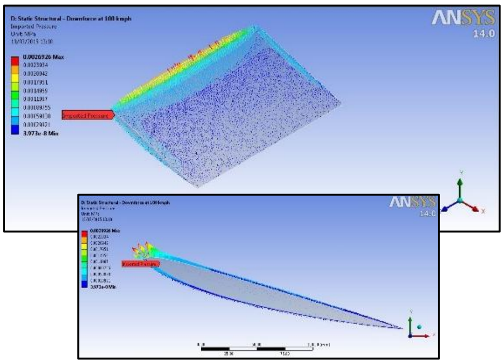


Figure 25. Imported Pressure

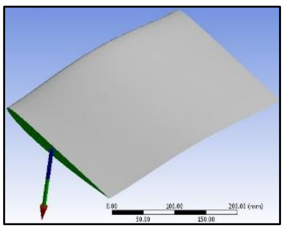
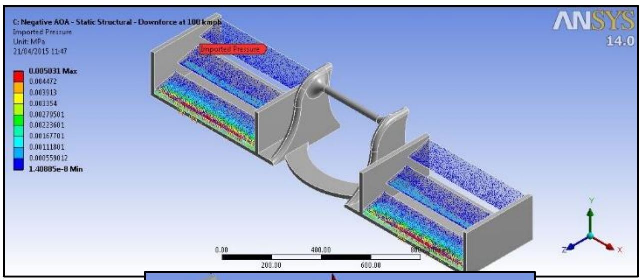


Figure 26. Force Reaction

X = -6.1027 N   Y = -40.679 N   Z= 0.00494 N
TOTAL = 41.134 N (-Y)
Hence, Total Downforce = 41.134 N (+Y Direction)

3.3. Front Wing Assembly (6 Plates of NACA 4412)

3.3.1. Negative (-15^0) AOA at free stream velocity of 100 kmph



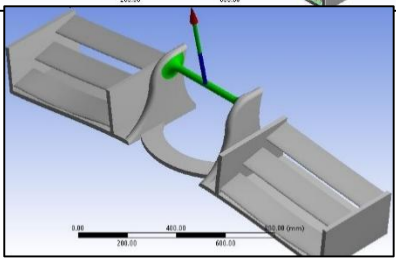


Figure 27. Imported Pressure

Figure 28. Force Reaction

X = -0.11321 N   Y = 405.08 N   Z= 77.866 N

TOTAL = 412.5 N (+Y)

Hence, Total Downforce = 412.5 N (–Y Direction)

3.3.2. Zero (0^0) AOA at free stream velocity of 100 kmph

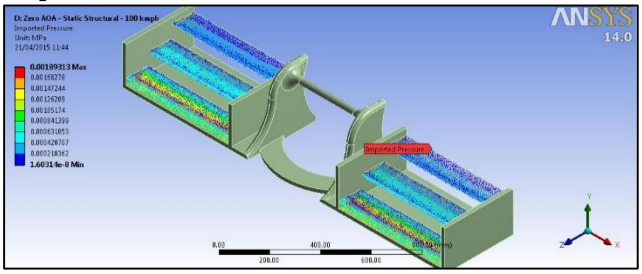


Figure 29. Imported Pressure

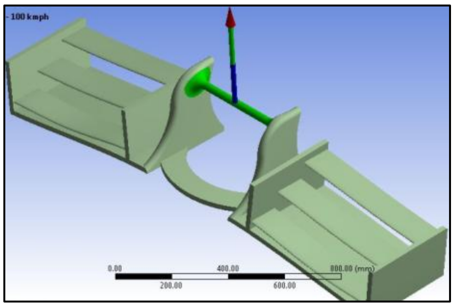


Figure 30. Force Reaction

X = 0.00282 N   Y = 220.67 N   Z= 14.122 N

TOTAL = 221.12 N (+Y)

Hence, Total Downforce = 221.12 N (–Y Direction)

3.4. Rear Wing Assembly (2 Plates of NACA 2408)

3.4.1. Negative (-15^0) AOA at free stream velocity of 100 kmph

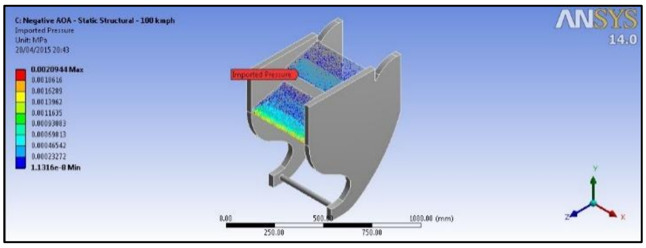


Figure 31. Imported Pressure

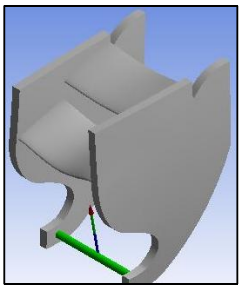


Figure 32. Force Reaction

X = -0.0184 N   Y = 79.802 N   Z= 13.924 N

TOTAL = 81.008 N (+Y)

Hence, Total Downforce = 81.008 N (–Y Direction)

3.4.2. Zero (0^0) AOA at free stream velocity of 100 kmph

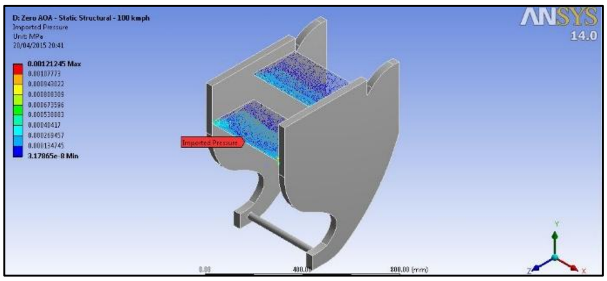


Figure 33. Imported Pressure

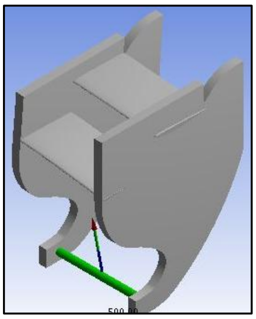


Figure 34. Force Reaction

X = -0.2293 N   Y = 14.399 N   Z= 2.5457 N

TOTAL = 14.624 N (+Y)

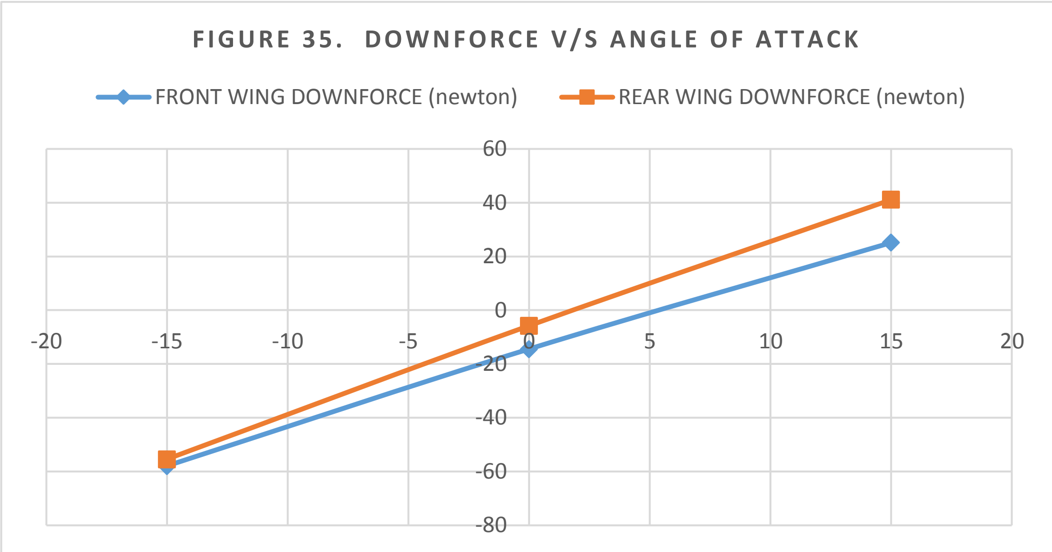
Hence, Total Downforce = 14.624 N (–Y Direction)

IV. CONCLUSIONS

4.1. Front Wing Airfoil V/S Rear Wing Airfoil

Table 1. Front Wing Airfoil V/S Rear Wing Airfoil

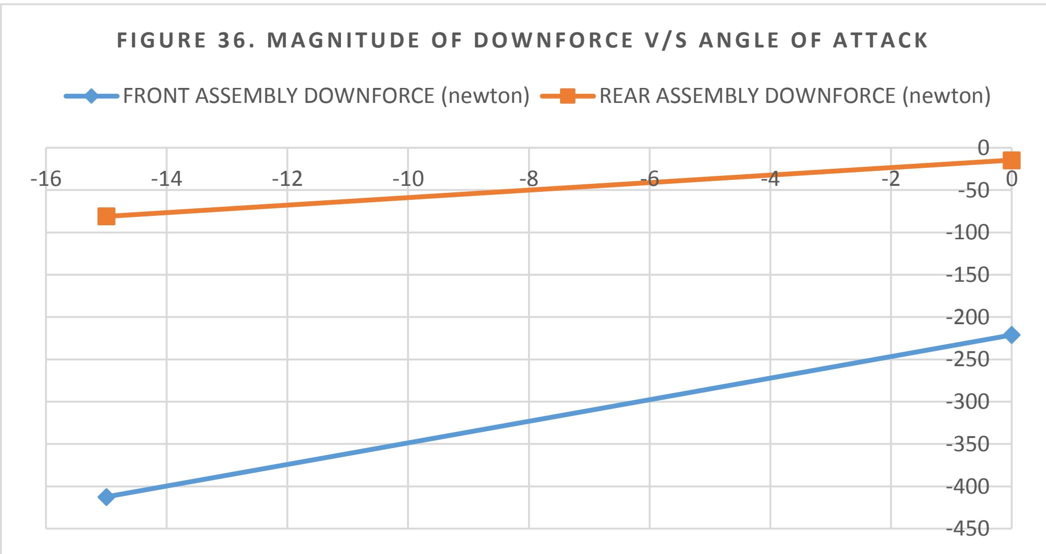
ANGLE OF ATTACK (degree)	FRONT WING DOWNFORCE (newton)	REAR WING DOWNFORCE (newton)
-15	-57.97	-55.496
0	-14.442	-5.8016
+15	25.163	41.134



4.2. Front Wing Assembly V/S Rear Wing Assembly

Table 2. Front Wing Assembly V/S Rear Wing Assembly

ANGLE OF ATTACK (degree)	FRONT ASSEMBLY DOWNFORCE (newton)	REAR ASSEMBLY DOWNFORCE (newton)
-15	-412.5	-81.008
0	-221.12	-14.624



Hence, it is concluded that a very high downforce is created by the Front Wing Assembly as compared to the Rear Wing Assembly. This is very beneficial to keep the car on the road and not let it get lifted up in the air during its travel. Thus, the airfoils very effectively accomplish the required following results :

i. Front Wing Assembly Downforce must be greater than that corresponding to the Rear Wing Assembly. Due to placement of engine at the rear end of the car, more downforce is already generated at the rear end & hence a thinner airfoil can be used.
ii. The approximate top speed as read from the analysis is 330 kmph – A definite race to the finish!
iii. Aerodynamics plays an integrated and essential role in the racing world.
iv. Such a CFD testing helps to achieve great results alongwith an appreciable saving in costs.
v. The streamlined body of the car helped to minimize the drag caused due to turbulence.
vi. The creation of such a significant downforce helps to push the car's tyres onto the track.

V. FUTURE SCOPE

i. Computational Fluid Flow and Structural Analysis of the Car Body Chassis.
ii. Computational Fluid Flow and Structural Analysis of the Wheels.
iii. Computational Fluid Flow and Structural Analysis of the entire car model using Supercomputers.
iv. Manufacturing a prototype of the model.
v. Wind Tunnel testing of the model.
vi. Optimization of the Design to achieve higher speeds and downforce.

ACKNOWLEDGEMENT

It is always a pleasure to remind the fine people who helped me throughout my project.

I am extremely thankful to Dr. Dipali Thakkar for giving me an opportunity to undertake this project. I would like to give a special thanks and express my deep sense of gratitude to Mr. Arpit Patel for his assistance, expert guidance, and suggestions throughout this project work. Without the help of their knowledge and expertise in every facet of the study, from helping to find the relevant data and in analyzing the results, this project would not have been completed. I sincerely thank all other faculty members of the Aeronautical Department for helping me in all possible ways for the betterment of my project.

Last, but certainly not the least, I am very thankful to my family and friends who have been giving me unconditional support throughout the entire period of my project, because without them, none of this would have been possible.

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