International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-12 Issue-1, October 2022

Deflection of Formula One Race Car Rear Wing using Numerical Simulations

Vennelakanti Sai Hemanth Kumar

***Abstract:** Formula One is a track-based aerodynamic race between teams. In the design of motorsport cars, aerodynamics is crucial. When compared to the other race cars on the grid, the race car with the best aerodynamic performance performs well on the track and has a good lap time. The design of rear wing has significant influence on the performance of a race car as much of the downforce is provided by rear wing. Using structural and computational models, this paper tries to link the static and dynamic performance of a Formula 1 race car rear wing due to its deflection. Solidworks is used to design a rear wing model of an F-1 car, which is then transferred to Ansys. A speed of 300 kmph is considerd for the study as speed of F-1 cars range from 280 – 340 kmph on Straights. To determine the aerodynamic loadings on the model at 300 kmph, a fluid simulation is run in fluent. Turbulence model of Transition K- Kl- Omega was used. To determine deflection owing to the aerodynamic loads calculated, a structural analysis is performed in Ansys Static Structural. From structural analysis it is evident that deflection exists. Further computational simulations of deflected models about its center of gravity are performed to compare the effects of aeroelasticity of a race car's rear wing. It is evident from the simulations that a 2° deflection in the wing resulted in a 3 % decrease in drag and a 4 % decrease in downforce which gives a higher performance gain in case of high-speed race cars.*

***Index Terms:** Formula-1, Deflection, Angle of attack, Aerodynamic loads, Downforce, Drag.*

I. INTRODUCTION

Formula 1 cars experience aerodynamic loads as they are traveling at higher speeds. The load which opposes the race car and reduces the acceleration of the car is called drag. The load which gives grip to the car to avoid skidding is called downforce [1]. The rear wing of an F-1 car is the main part that contributes to aerodynamics. As cars move at higher speeds the downforce and drag produced result in deflection of the Wing which makes a significant influence on the aerodynamics of a race car. The material used to manufacture the wing is also a factor of deflection. International Automobile Federation (FIA) does not allow flexible aerodynamic devices [2]. Every wing has some deflection but it must be within a described limit. FIA's new regulations allow the rear wing to deflect 1° about its CG. A maximum allowed deflection is 3mm when static loads are applied. It differs when the race car is on the track [3].

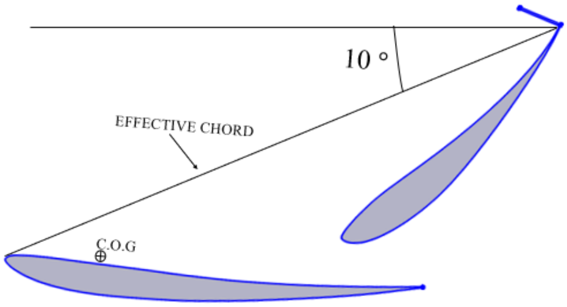


Fig. 1. (a) Airfoil at 10° angle of attack

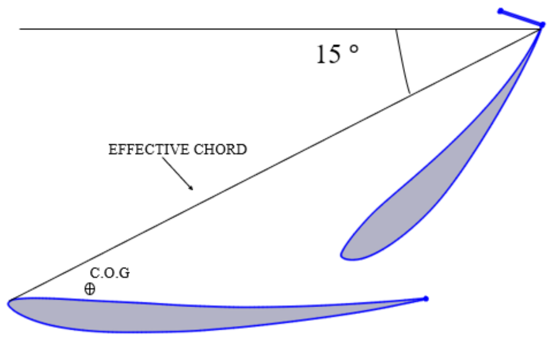


Fig. 1. (b) Airfoil at 15° angle of attack

Drag and downforce mainly depend on the coefficient of lift and drag (CL, CD). A change in the effective angle of attack of the wing changes drag and downforce. Airfoils at a different angle of attack are shown in the above Fig. 1. (a), (b) in Fig. 1. (a) the airfoil is at 10° angle of attack it has less drag and downforce when compared to the airfoil in Fig. 1. (b) which is at 15° angle of attack. Rear wings have excessive deflection at high speeds when compared to static deflection during testing. Rear wings are highly complex structures in an F- 1 car. The rear wings of race cars are manufactured using composite materials and carbon fiber. A car accelerates on straights and attains a speed of 300kmph. A straight is the part of the track where most of the DRS (Drag Reduction System) zones are located. If the defending car in front is within 1 sec of the following car at the DRS detection zones the following car can lift its rear wing DRS flap. DRS allows the following car to overtake by increasing 10 - 15 kmph of speed. Deflections play a major role in the straights. Due to deflection the effective angle of attack of the wing's aerofoil decreases. It reduces drag and downforce allowing the car to accelerate more quickly than defending car [4].

Manuscript received on 22 August 2022 | Revised Manuscript received on 27 August 2022 | Manuscript Accepted on 15 October 2022 | Manuscript published on 30 October 2022.

*Correspondence Author
Sai Hemanth Kumar V*, Department of Aerospace Engineering, Hindustan Institute of Technology and Science, Chennai (Tamil Nadu), India. E-mail: hemanthroyal2002@gmail.com

A C.F.D. (Computational Fluid Dynamics) is a program that allows us to solve a real-world engineering problem in a virtual environment. The problem is solved by creating a control volume utilizing tools and pre-determined algorithms [5,6]. In the software, initial conditions are set as boundary conditions. Algorithms address the continuity, momentum, and energy equations in differential forms using numerical methods. Drag, downforce, and other parameters are calculated. This article aims to compare the effects of deflection on the performance of high-speed cars. The workflow followed in this research is shown in Fig. 2. below. For fluid analysis, Ansys fluent is used. For static analysis, Ansys structural is used.

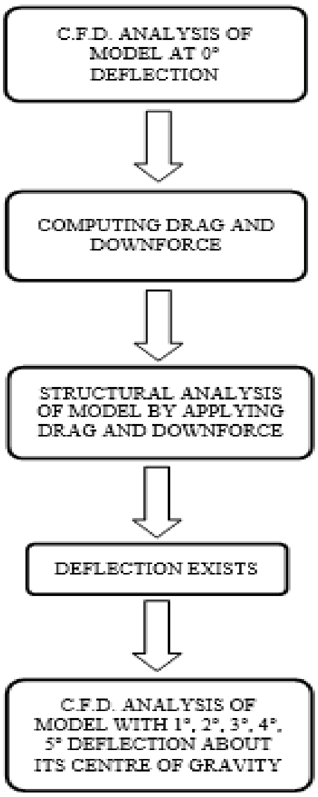


Fig. 2. Flow of work

II. METHODOLOGY

A. Rear Wing Design

The airfoiltools was used to import the Verbitsky BE50 [7] and Selig s1210 airfoils. The main flap of an F-1 car's rear wing is a BE50 aerofoil with a 20cm chord. The DRS flap is an s1210 aerofoil with a 15cm chord. A wing span of one meter is designed. The model is depicted in Fig. 3. (a), (b) below.

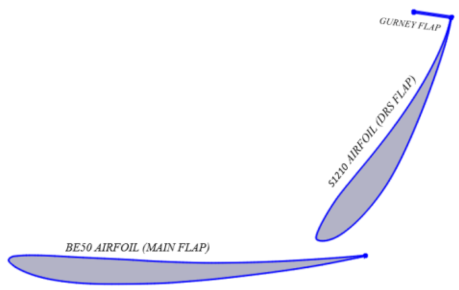


Fig. 3. (a) Airfoils

Fig. 3. (a) shows the BE50 and s1210 airfoils and their configuration in the rear wing. Fig. 3. (b) shows the fully extruded model of the rear wing with the D.R.S flap and main flap.

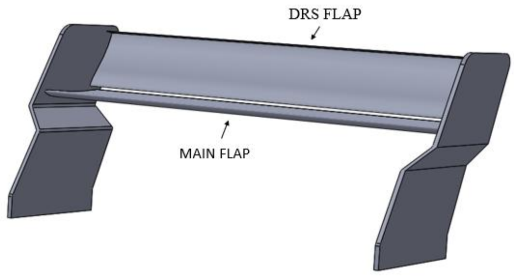


Fig. 3. (b) Rear Wing

B. Mesh Independency Test

The model is imported from solid works to Ansys. A box enclosure is created around the model, and the model is meshed. For the majority of the elements, the mesh had an orthogonal quality of 0.65- 0.94 and skewness of 0.04-0.38. The mesh is shown below in Fig. 4.

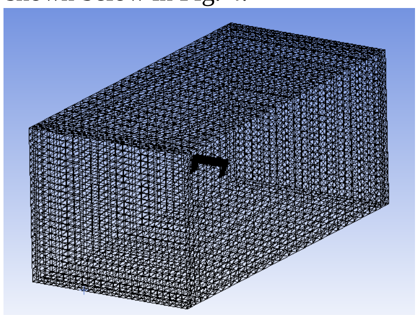


Fig. 4. Mesh

A grid independence test was performed to determine the correctness of the mesh and the results obtained. The test was carried out with three grids, first with coarse, then medium, and finally fine meshing. The medium mesh is a refinement of the coarse meshing, while the fine mesh is a refinement of the medium meshing. The elements, nodes, and drag force values of those three grids are shown in the Table I below.

Table I: Mesh independency test results

	Nodes	Elements	Drag Force	Error %
Coarse	323926	1790007	854.73	-
Medium	545408	3030234	816.61	4.459888
Fine	696433	3829359	792.14	2.996534

As the medium mesh is within acceptable range it is used in this entire study to save the computational time.

C. Computational Analysis

A simulation is performed on an undeflected model for determining aerodynamic forces. Turbulence modeling was performed using the transition k-kl-omega model [8]. The inlet velocity is set to 300 kmph. The aerodynamic forces are estimated using second-order methods.

Retrieval Number: 100.1/ijeat.A38001012122
DOI: 10.35940/ijeat.A3800.1012122
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

D. Structural Analysis

The drag and downforce estimated in the simulation are used as boundary conditions for structural analysis [9]. The model is imported and meshes in Ansys structural.

The global element size is set at 0.005m. The majority of the elements had orthogonal quality ranging from 0.54 to 0.94 and skewness ranging from 0.05 to 0.45.

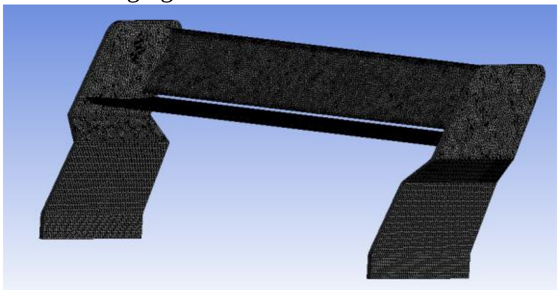


Fig. 5. Mesh

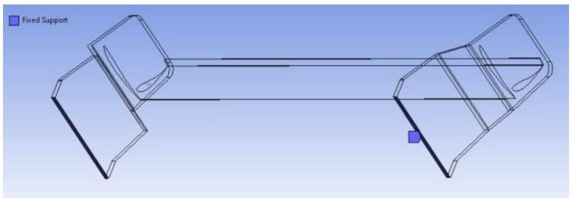


Fig. 6. (a) Fixed support

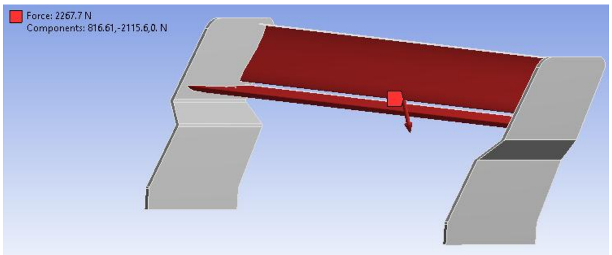


Fig. 6. (b) Force

The mesh model is depicted in Fig. 5. above. The bottom faces of the wing are fixed with fixed support. The drag and downforce from the simulation are applied to the flaps of the wing as boundary conditions as shown in Fig. 6. (a), (b). Initially, Aluminum is considered as material. Deflection, Von mises stress and strain of the rear wing are calculated.

E. Computational Analysis

Deflected models are analyzed using simulations because deflection is evident in static analysis. For analysis, models having deflections of 1°, 2°, 3°, 4°, and 5° around their CG are investigated. The turbulence model Transition k-kl-omega, inlet velocity of 300 kmph are chosen as default for all the models. The drag force and downforce are estimated.

III. RESULTS AND DISCUSSIONS

At 300 kmph, a simulation shows a drag of 816.61 N and downforce of 2115.59 N on the wing. The deflection of the wing under the impact of aerodynamic loads is shown in structural analysis. The maximum stress of $6.36 * 10^{6}$ pa, the maximum strain of $3.28 * 10^{-5}$, and the maximum deformation of $1.70 * 10^{-5}$ m are observed. The contours are shown below in Fig. 7. (a) –(d). Fig. 7. (a) shows the comparison of the deflected and undeflected models.

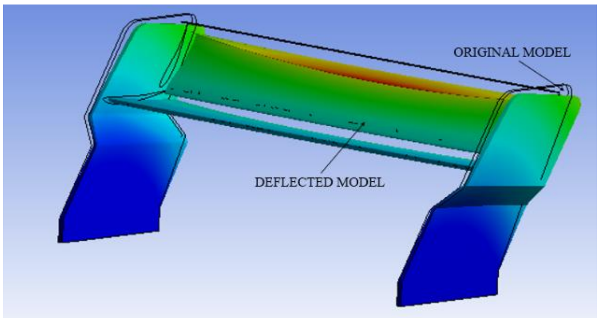


Fig. 7. (a) Comparing model deflection

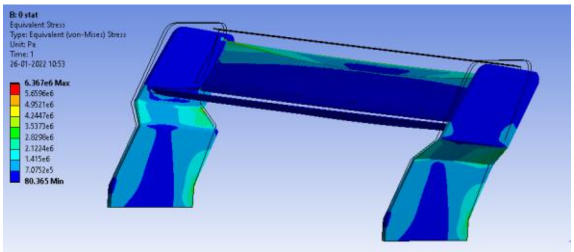


Fig. 7. (b) Von Mises Stress

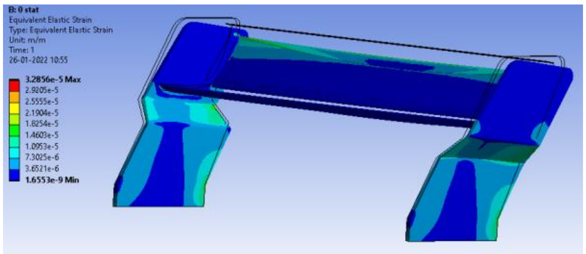


Fig. 7. (c) Von Mises Strain

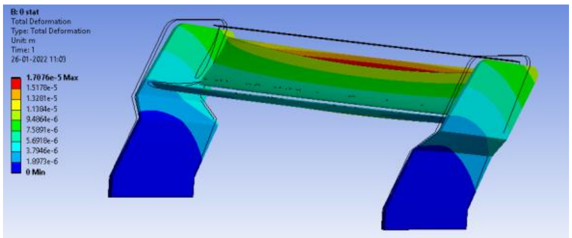


Fig. 7. (d) Deflection

The drag force and downforce values obtained from the simulation are tabulated in Table II below

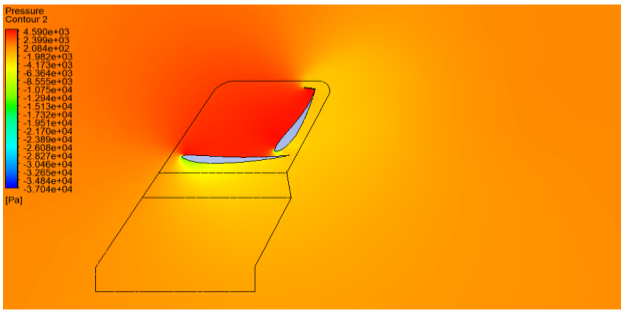
Table II: Dragforce and downforce at different deflection angles

θ (in Degrees)	DRAG FORCE (N)	*DOWN FORCE (N)*
0 °	816.61	*2115.59*
1 °	811.41	*2080.15*
2 °	792.15	*2031.20*
3 °	783.08	*1984.92*
4 °	780.24	*1949.45*
5 °	*767.22*	*1896.29*

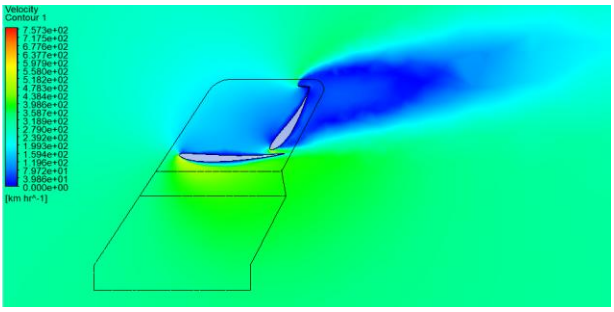
The pressure and velocity contours at different deflection angles are depicted below in Fig. 8.

Retrieval Number: 100.1/ijeat.A38001012122
DOI: 10.35940/ijeat.A3800.1012122
Journal Website: www.ijeat.org

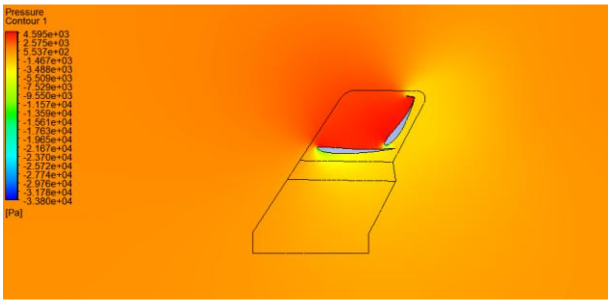
Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)



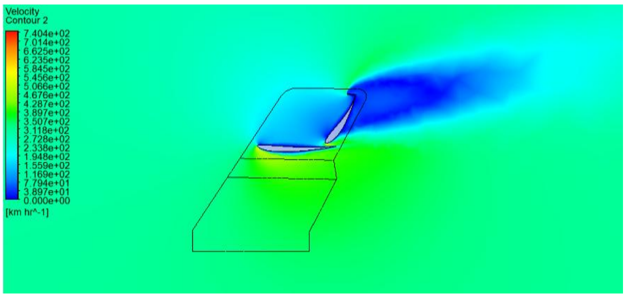
(a) Pressure contour ($\theta = 0^{\circ}$)



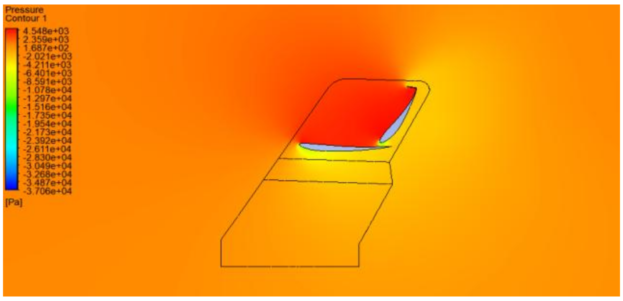
(b) Velocity contour ($\theta = 0^{\circ}$)



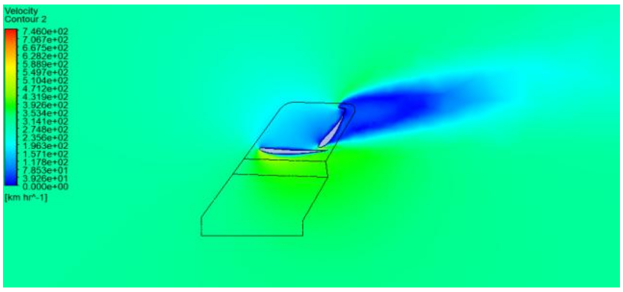
(c) Pressure contour ($\theta = 1^{\circ}$)



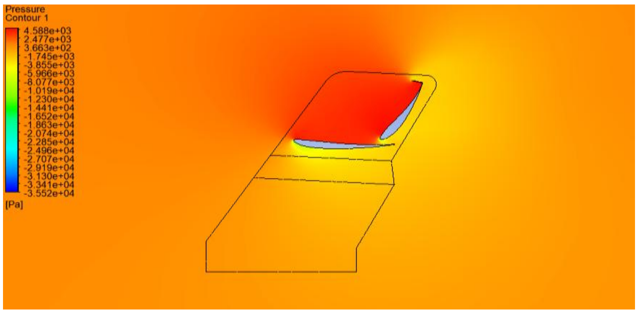
(d) Velocity contour ($\theta = 1^{\circ}$)



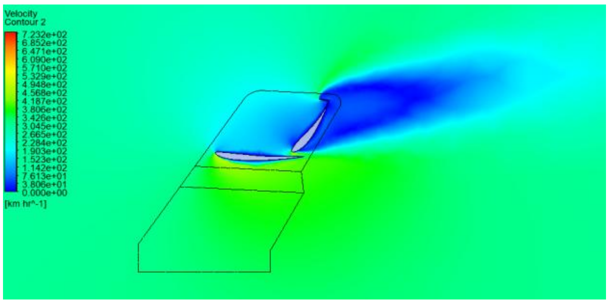
(e) Pressure contour ($\theta = 2^{\circ}$)



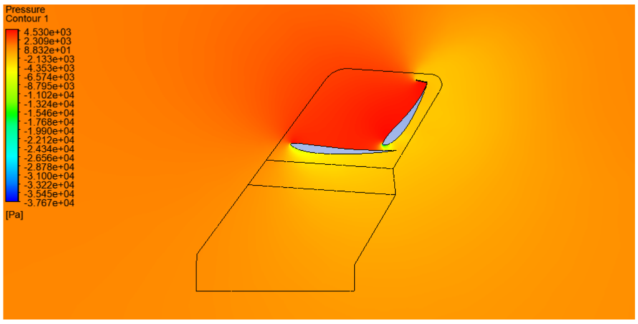
(f) Velocity contour ($\theta = 2^{\circ}$)



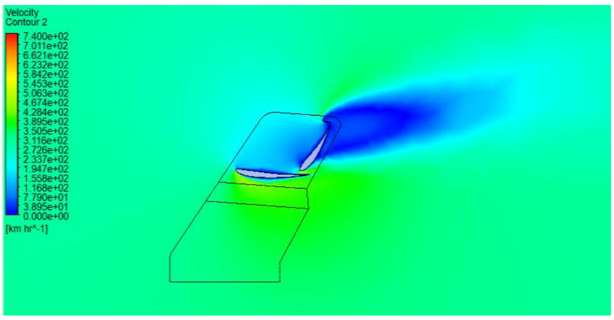
(g) Pressure contour ($\theta = 3^{\circ}$)



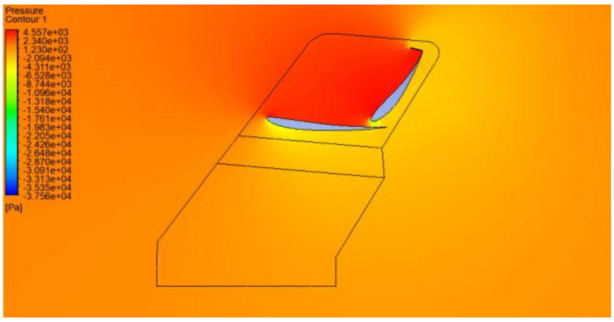
(h) Velocity contour ($\theta = 3^{\circ}$)



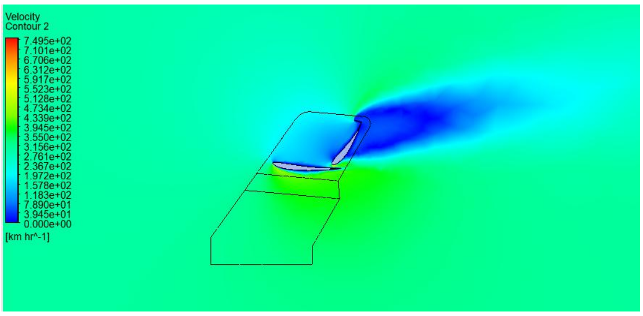
(i) Pressure contour ($\theta = 4^{\circ}$)



(j) Velocity contour ($\theta = 4^{\circ}$)



(k) Pressure contour (θ = 5°)



(l) Velocity contour (θ = 5°)

Fig 8. Pressure, Velocity Contours

The pressure contours show the pressure on the upper surface is higher than on the lower surface which results in downforce. The velocity contours show the velocity is higher on the lower surface of the wing.

A graph of deflection vs drag force and downforce is plotted to compare the aerodynamic performance. The graph is depicted in Fig. 9. below

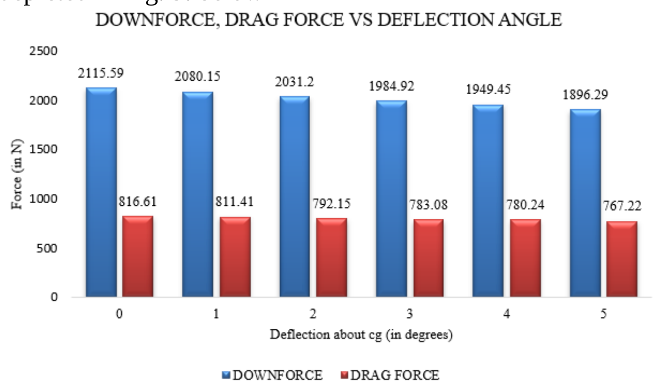


Fig. 9. Drag force, downforce vs θ

On a straight, a race car accelerates. The wing experiences a drag and downforce due to the airfoils of the wing. It has a drag of 816.61 N and downforce of 2115.59 N. If the acceleration of the car is a_1 at the start of the straight. If the rear wing bends back 2° due to its flexibility the effective angle of attack of the wing decreases. Therefore, drag and downforce on the wing decrease. We observe a 3 % decrease in drag and a 4 % decrease in downforce. If the acceleration of the car is a_2 after deflection, due to reduce in drag the acceleration $a_2 > a_1$. As drag opposes the motion of the race car, the acceleration of the car depends on drag. As a result, the race car accelerates quickly on straights. At the end of the straight velocity is reduced for the cornering maneuver the wing will return to its normal position and the effective angle of attack of the wing increases. As a result, downforce is increased at the end of straight for cornering maneuvers.

IV. CONCLUSION

Under aerodynamic loads, rear wings bend according to structural analysis. On straights, the wing's flexibility effects result in improved aerodynamic performance. The key area of the course where you can get an advantage is straight. At higher speeds, the wings bend back reducing drag force and downforce to maximize velocity on straight. At lower speeds, the wing recovers to its original position, creating the downforce required for cornering at the end of the straight. It enables the car to outperform its operational conditions. This is the reason why FIA does not allow flexible aerodynamic equipment in F-1.

REFERENCES

1. Karimirad, M. "Aerodynamic Loads". Comprehensive Renewable Energy. (2012).
2. Barretto, L. "Flexi- wings what are they and why is everyone talking about them?". F1. (2021, May 21).
3. Legge, B. J. "What are flexi-wings and why do F1 teams want them?" AUTOSPORT. (2021, May 12).
4. Somerfield, M. "*The flapping phenomenon behind F1's latest flexi-wing intrigue*". Motorsport.com. (2021, May 21).
5. Nguyen, M.T. "Aerodynamic Analysis of Aircraft Wing". *VNU Journal of Science: Mathematics – Physics, Vol-31.* (2015).
6. Jiapeng, T. "A Finite Element Parametric Modeling technique of aircraft wing structures". *Chinese Journal of Aeronautics, Vol-6, Issue-5.* (2013).
7. Kajiwara, S. "Passive variable rear-wing aerodynamics of an open-wheel racing car". *Automot. Engine Technol.* 2**,** 107–117 (2017). [CrossRef]
8. A.R.S Azmi. "Study on airflow characteristics of rear wing of F1 car". IOP Conference Series: Material Science and Engineering, (2017). [CrossRef]
9. Abbas, Y. "Structural Analysis of a Transport Aircraft Wing". *INCAS. Vol-13, Issue-1.* (2021). [CrossRef]

AUTHORS PROFILE

Sai Hemanth Kumar V, is a student studying B. Tech Aerospace Engineering in Hindustan Institute of Technology and Science, Chennai, India. His area of interest is Design and Simulations in the field of Aerodynamics. He has an achievement of making World's Smallest and Lightest Nano Satellite with Wireless Data Transmission recognized by International Book of Records, Universal Records Forum. Email: hemanthroyal2002@gmail.com.