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Analysis of a Split Dihedral and Anhedral Arrangement of the Rear Wing of a Formula One Car

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Abstract: *The downforce generated by the rear wing of a formula one car contributes to 30% of the total generated by other elements of the car. A thorough analysis has been conducted on the rear wing airfoil structure. A design change has been proposed wherein the rear wing of the car is split into two parts at its center axis. Each part is capable of changing its angle thus creating an Anhedral and Dihedral arrangement of the airfoil. ANSYS Fluent simulations have been conducted to analyze the variation in the angle of attack. The analysis shows how the anhedral and dihedral arrangement can give a substantial advantage during cornering by generating centripetal force. Further, it shows that by adopting an anhedral arrangement we can generate enough centripetal force without compromising the total downforce generated by the combined rear wing arrangement. A similar wing design when adopted for the front wing can help compensate for the understeer and oversteer faced by the driver.*

Keywords: formula one, ANSYS, analysis, rear wing, anhedral, centripetal, understeer, oversteer

1. Introduction

When formula one motor racing first began, there were no limitations on the power or the size of the cars. The races became unequal with cars with more power and bigger sizes easily outpacing the smaller cars. The races also created dangerous situations in which many participants got seriously hurt, some even fatally. When racing resumed after World War II, the governing body of the sport, the FIA, introduced a set of rules that set aerodynamic and mechanical restrictions on the cars. The FIA amends alters and introduces rules to Formula One so as to ensure the safety of the participants in the races, promote fair play, and ensure that the spectators get to watch good, clean racing. For decades, Formula 1 cars were designed with high aerodynamic performance in their mind. Even at the very dawn of F1, cars had slim streamlined bodywork – called cigar cars. These future classics had one thing in mind to generate the least possible amount of aerodynamic drag. This changed with the introduction of inverted wings on cars used to generate downforce. In 1968 inverted wings were introduced to Lotus 49 and this changed Formula 1 for good. In his typical fashion, Colin Chapman and his team bolted the wings directly to suspension parts, to have a direct load path for these new aerodynamic loads. This also placed the wings in a near-horizontal position all the time, making them more efficient. Even with a great design, thin wing struts broke several times, leaving the engineers with a single solution – bring those wings down, closer to the car. Let's look at the rear wing. The job of the rear wing is to provide huge amounts of downforce. It takes advantage of the huge masses of air that hit the car while it is traveling at such high speeds. When the air in an ideal laminar flow hits the wing, some of it tucks over the wing. These layers of air follow the curved surface of the top of the wing and exit out the back. The rest of the air that hits the wing will go underneath the wing. The natural tendency for this air is to keep going in the direction it is, but it instead follows the surface of the wing because the region between the expected path of the air and the bottom surface of the rear wing has little or no air, and is hence a region of low pressure. This causes all the high-pressure, high-energy air to bend into this pocket. This air also gets squeezed between the wing and the wall of fast-moving air below. This air accelerates and travels under the wing at a much higher velocity due to the Venturi effect, following the curve of the wing and exiting at the back tip. This means the air under the wing is at a lower pressure. So, with low pressure under the wing and high pressure over the wing, the net force will be downwards. Hence, downforce.

We have proposed a split rear wing arrangement for the F1 car. The traditional arrangement allows the angle of attack for the wings to be changed allowing the driver to control the downforce and the drag generated during various courses of the race track. In the proposed arrangement apart from being able to control the angle of attack the drivers will also be able to control the Anhedral/Dihedral angle of the wings. The dihedral arrangement has been used in airplane wings to increase the stability of the airplanes during flight by adding an additional sideways force component. We propose a similar but adjustable arrangement for the rear wing of an F1 car. The section on our proposed methodology contains relevant figures for this rear wing adjustment.

2. Literature Review

Formula One has always been an active field of research. The nuances in the cars are always researched by engineers and researchers across the world, pointing out the pros and cons of the changes that are made by teams. One of the significant elements of an F1 car is the airfoil structure in the front and the rear wing. These elements are of utmost importance at the high speeds at which these cars travel. Hence, the airfoil and the structures of the car that are in contact with the air have been researched widely. A. R. S. Azmi et al.[1] has carried out a CFD simulation to investigate the airflow along the rear wing. The study focuses on analyzing the effects of chord length and airfoil thickness on the airflow at the rear wing. Also, the effects of DRS opening and closing have been studied. Their analyses show mixed results and hence the paper concludes by stating that the airfoil type should be selected based on the circuit track. Jurij Iljaž et al.[2] has carried out a completed analysis of 2 different rear wing designs with five different heights. Also, various angles of attack were compared and tested in the analysis, which showed that newer advanced designs were able to withstand higher angles of attack thus generating greater lift and hence more downforce. The advanced designs increased the downforce by about 6%. B. Vidhya Darshiniet al.[3] To examine the airflow across the rear wing using CFD simulation, to examine the effects of flap wing chord length and thickness on airflow at the back of the wing. According to the findings, the downforce will decrease as the flap wing aerofoil's thickness increases. Arnav Pandit and Gwyn Harold[4] In this paper along with discussion on the aerodynamic concepts, the discussion has also been extended about how they relate to F1 cars. A survey of more than 200 STEM-related professionals and academics was also undertaken to gauge public opinion on F1 car aerodynamics. The information gathered through an Amazon Mechanical Turk survey has been examined to determine whether it is consistent with reality. Xabier Castro et al.[5] talks about how the aerodynamic loads that are generated by the rear wings are very high and how adequate structural design considerations need to be done.

3. Effect of Centripetal Force While Cornering

Centripetal Force comes into play and allows the car to follow a curved path during a turn, which can be banked or flat. We will not consider a banked turn in our computational analysis, as we unnecessarily have to account for the cosine and sine components of the mass of the car. We will consider a flat turn. When the car performs a circular motion around a turn, the necessary centripetal force is provided by the frictional force between the tires and the asphalt.

Let's consider the 2022 Redbull RB18 F1 car executing a turn at Parabolica (Turn 11) at the Monza Circuit, Italy.

1. The approximate weight m of the car with 3 liters of fuel is 798 kg, provided by the official website.
2. The radius r of the turn is approximately 125 meters, computed using the distance measuring tool on Google Earth.
3. The average velocity v of the car on this turn was found to be approximately 195 kph = 54.17 ms^{-1}, as evidenced from 10 simulations on the simulator 'Assetto Corsa'.

Using the given information We have centripetal force

$$F_c = \frac{mv^2}{r}$$

$$F_c = \frac{798 \cdot 54.17^2}{125} = 18.733\ kN$$

But, in reality, the centripetal force is less since it is provided by the force of friction between the tyres and cars, and hence, depends upon the coefficient of dynamic friction between the two - that was found to be approximately 1.5 using Assetto Corsa. It is given by

$$F_c = F_f = \mu \cdot m \cdot g$$

$$F_c = 1.5 \cdot 798 \cdot 9.8 = 11.731\ kN$$

We realized that this centripetal force was hugely advantageous to the driver while cornering, and it could be increased substantially by optimizing components of the car. A natural increase of centripetal force are banked roads. On a banked road, the resultant of the normal reaction and gravitational force act as centripetal force, along with friction, thus increasing the overall centripetal force. But, it is seemingly impossible to change the bank angle of existing roads, and the most logical method is to optimize/change component(s) of the car. Our proposal makes changes in the rear wing, and we have proposed a ‘split’ rear wing that is capable of maintaining an angle of attack and an anhedral/dihedral angle that provides substantial centripetal force. Our methodology and findings are given in the further part of this paper.

4. Proposed Methodology

NACA4412 airfoil was selected as the profile for the airfoil as the rear wing for the analysis. The profile for the NACA4412 was imported into fusion 360 where the designing of the test setup was done. 16 separate 3D models were created by varying the various aspects of the airfoil. 4 separate angles of attack were selected - 0°, 5°, 10° and 15°. For each angle of attack, 4 variations of anhedral angles were selected. Once the design was ready, all the 3D models were exported in .step format so that the model could be imported into the ANSYS software. Since the student version of the ANSYS software was used there was a limitation on the number of nodes that can be used in the analysis so the rear wing model which has an FIA-allowed span of 101cm was scaled down by 20%. The proposed setup was a split rear wing which can be controlled individually during the turns. Since it would be impractical to work with a model of a two-part split rear wing, we decided to work with one half of the proposed rear wing setup, and doubled the values of our scaled findings to account for the second half. So, the model ~~that~~ was designed:

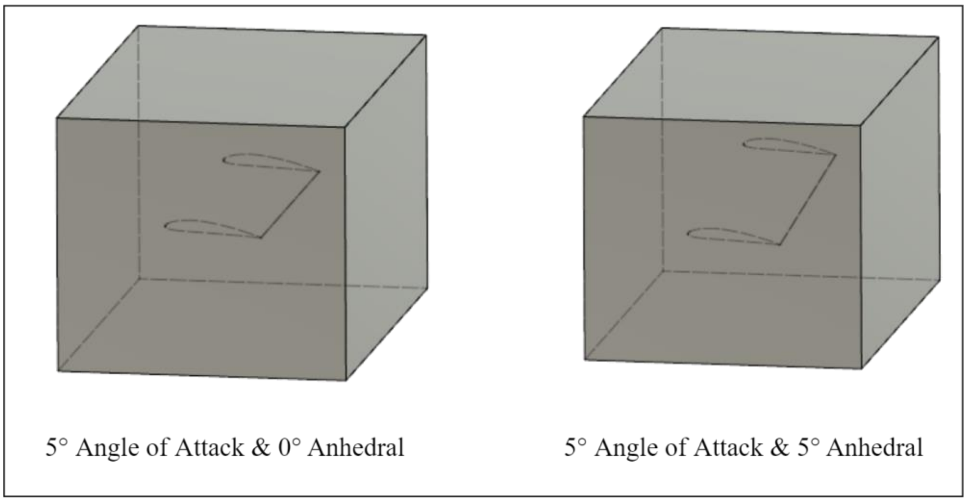

5° Angle of Attack & 0° Anhedral
5° Angle of Attack & 5° Anhedral

Fig 1. 3D models of the test setup created in Fusion 360

The scaled-down models of the test cases were imported to ANSYS for analysis. In general, when a 3D model has scaled the overall surface area changes by the cube of the scaling factor. In our case, the Airfoil model was scaled by 20% so the change in the surface area will be the square of the scale factor. And the change in volume displaced will be the cube of the scaling factor. This is important to note since once the analysis is complete and we have the force value, we will have to scale the force values with the scale factor. Since the lift or the drag generated by the airfoil is proportional to the volume of the air displaced we will use the volume scaling factor.

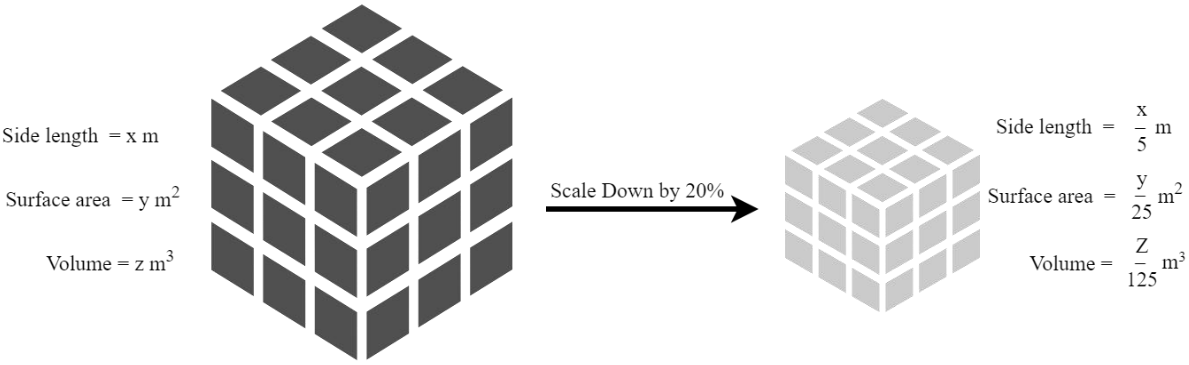
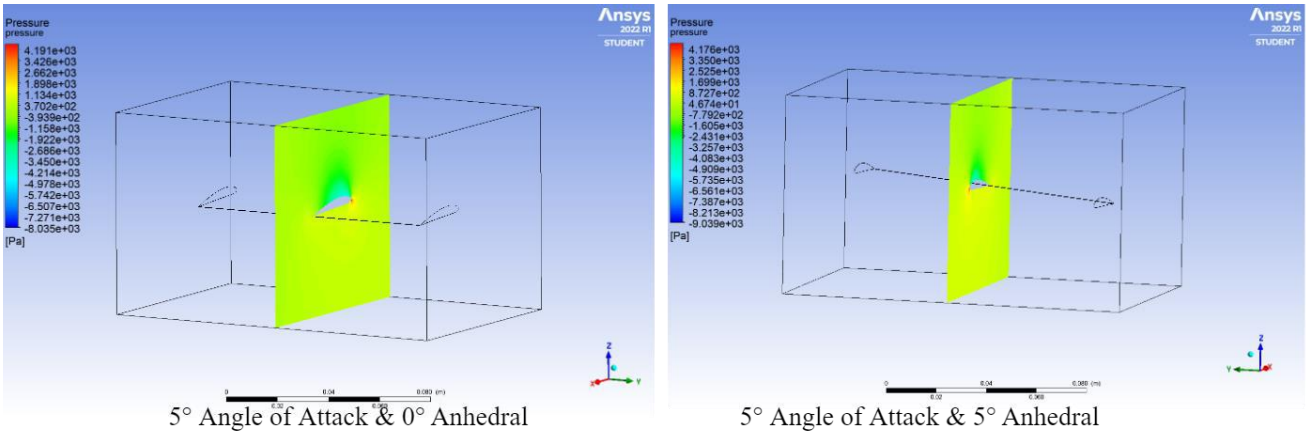


Fig 2. Scaling operation done on the Airfoil structure

Fluent was used for the airflow analysis of the airfoils. The Airfoil design in fusion 360 was created keeping into account the use case in Ansys. So instead of having 2 separate bodies, a single body with an airfoil-shaped hollow was created in fusion 360. This allowed for easy selection set creation in the software. The meshing was done using the automatic method. For solving the model, a pressure-based solver was used.

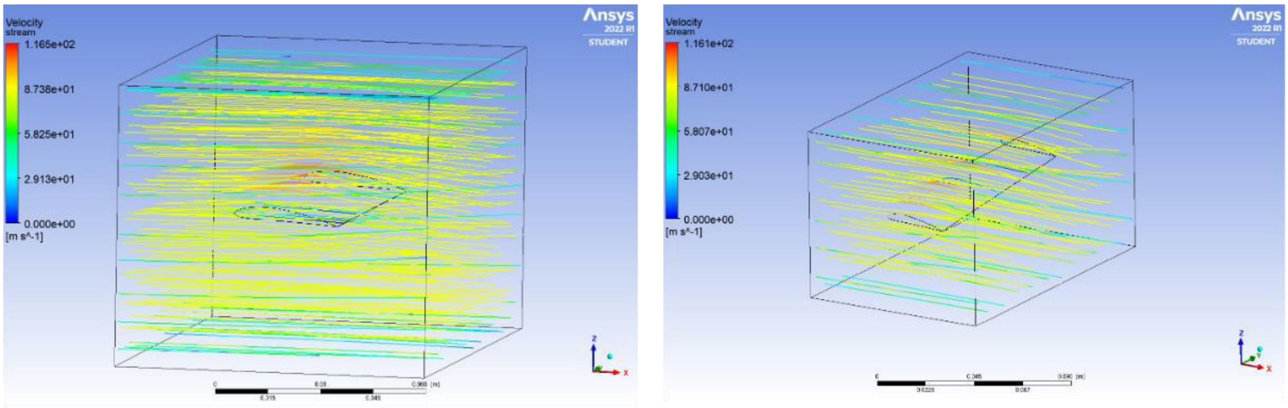
Once the analysis was completed, the pressure profile on the contours and the velocity streamline plots were done to verify the analysis. Also, the average force on the walls of the airfoil in different directions was calculated for all the 3D models.



5° Angle of Attack & 0° Anhedral

5° Angle of Attack & 5° Anhedral

Fig 3. Pressure variation on the air domain due to Airfoil



5° Angle of Attack & 0° Anhedral 5° Angle of Attack & 5° Anhedral

Fig 4. Velocity variations across the air domain

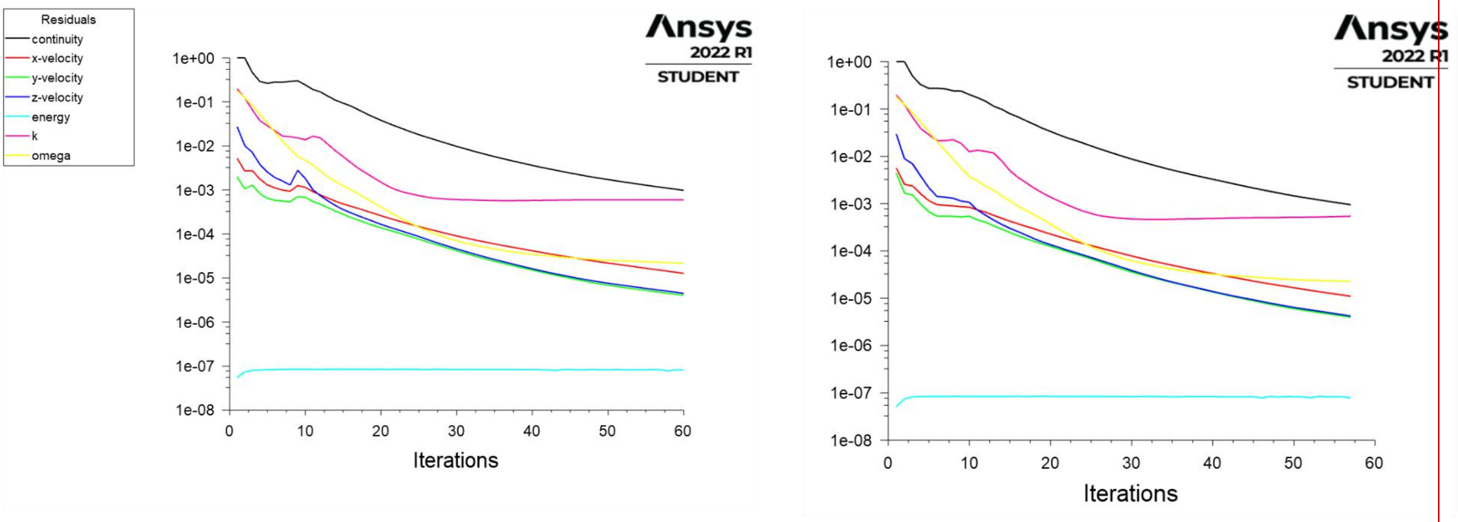
A 3-dimensional sketch was designed using Fusion 360, the renders of which are shown below: *(Note: The mechanism that controls the anhedral angle of the wing is not shown, they are representations to give an idea of how the rear wing would look with the proposed changes)*

10° Angle of Attack & 0° Anhedral Angle

10° Angle of Attack & 5° Anhedral Angle

5. Test Results

The Ansys simulation was run for 100 iterations to allow the model to reach convergence. The residual monitors for important parameters were captured during the iterations. The residuals reached the set convergence limit of 10^{-5} and hence the results generated from the model can be considered reliable.



5° Angle of Attack & 0° Anhedral

5° Angle of Attack & 5° Anhedral

Fig. 2 Plot of Residuals from the ANSYS simulation

Table 1. Comparison of airfoil arrangements and the forces generated

Angle of attack	Anhedral / Dihedral angle	Downforce generated(N)	Centripetal force generated(N)
0	0	4.2562	0.0017
0	5	4.2116	0.3661
0	10	4.1207	0.577
0	15	4.0072	0.8725
5	0	8.5125	0.0034
5	5	8.4233	0.7322
5	10	8.2415	1.154
5	15	8.0145	1.7451
10	0	12.7687	0.0051
10	5	12.6349	1.0983
10	10	12.3622	1.731
10	15	12.0217	2.8176
15	0	12.4811	0.0123
15	5	12.9846	1.1456
15	10	12.3151	1.2544
15	15	12.8411	2.1485

Table 2. Scaled-up values for the forces generated

Angle of attack	Anhedral / Dihedral angle	Scaled values of Downforce generated(N)	Scaled Centripetal force generated(N)
0	0	1064.05	0.425
0	5	1052.9	91.525
0	10	1030.175	144.25
0	15	1001.8	218.125
5	0	2128.125	0.85
5	5	2105.825	183.05
5	10	2060.375	288.5
5	15	2003.625	436.275
10	0	3192.175	1.275
10	5	3158.725	274.575
10	10	3090.55	432.75
10	15	3005.425	704.4
15	0	3120.275	3.075
15	5	3246.15	286.4
15	10	3078.775	313.6
15	15	3210.275	537.125

Above, Table 1 shows the analysis results for the downforce and the centripetal forces generated by the airfoil arrangement. These values are for the scaled-down model for the single side of the proposed split rear wing. So to compensate for the reduction in surface area due to the scaling, all the force values were multiplied by 125 in Table 2, as per the discussion in the methodology. Since the analysis was done on the split rear wing the force values were also multiplied by 2 to bring it up to scale. Hence, a total scaling of 250 is required. The scaled force values match up with the average downforce generated by a cornering F1 car, thus validating the results

6. Conclusion

The analysis of the model on ANSYS shows that the Anhedral arrangement of the F1 rear wing can generate a centripetal force of about 2.8176N which when scaled to the real-life model of a rear wing comes to 704.4N. Going back to our centripetal force calculation, it increases F_c from 11.731kN to 12.435kN, that is, an increase of 6% - which is quite substantial.

The sideward directing force generated by the wing reduces the total amount of downforce exerted by the wing, but the additional centripetal force generated is high enough to compensate for the loss in downforce. The additional force generated should be able to compensate for the understeering or oversteering issues that might occur. So by adjusting the amount of anhedral angle the drivers can accurately compensate for the understeering issues.

7. Future Scope

Although we will have to analyze the rear wing before commenting on the advantage provided, such a setup as the proposed one requires an additional control mechanism and hence extra weight. This could impact the overall weight of the car, but it would be a minor disadvantage compared to the advantage gained. A setup similar to the one proposed for the rear wing can also be implemented for the front wing allowing the driver to compensate for oversteer. We can also have a setup where the sideways force generated by the rear wings can be utilized to adjust the suspension stiffness of the car during turns directly. Although this might be against the F1 regulations as any automatic adjustments of the car control surfaces are not allowed.

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