Review of Fluid Analysis and Modifications in F-1 Cars

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Abstract:- This work is about the comparison of the previous and the following aerodynamic design considerations for Formula 1 cars. FIA, the governing body of motorsport, introduced new vehicle design for the next era considering better racing and safety measures for the drivers. The new regulations have major changes in design approach of the front and rear wings and the body which dictate the aerodynamics of the car. Aerodynamics plays an important role in achieving the speed desired by the driver as well as it is also responsible to keep the cars glued to the road. In this paper, a review of the analysis of Aerodynamics of the previous cars will be carried out and compared to find the reasons and advantages and disadvantages of the new design.

Keywords:- *Aerodynamics, Formula, Cars, Motorsport, Fluid Analysis.*

I. INTRODUCTION

While the hybrid engine in a Formula One car produces more than a thousand horsepower which is responsible for the speeds, aerodynamics allows for the control of vehicles at those higher speeds. Factors like drag that affects objects moving through a fluid, which is directly proportional to the square of velocity, affected greatly as the speed increases. Environmental conditions such as moisture, density, temperature etc. also affect the overall speed of the car. For this, aerodynamic research has made it possible for the teams to adjust their cars according to present conditions to optimize their speed and grip. The design of the car dictates the air flow around it which alternatively also dictates whether clean or turbulent air is fed to the engine as well the cooling mechanism to keep them from overheating. Aerodynamic optimization in design also reduces fuel consumption and emission levels.

Formula cars are the most technologically advanced, single seater cars built for tracks. Unlike road-legal vehicles, formula cars require a much higher drag coefficient (0.7 to 1.1), as well as a higher down force requirement as they need to take high speed turns while keeping the tyres from slipping. These factors are controlled by how air interacts with the system. F1 teams and motorsports in general have dedicated Research and Development departments to improve their cars. Studies show that each year, the cars become about 2 seconds faster by the end of the season than at the start owing to the changes made in the front and rear wings of the vehicle.

The efficiency of Formula one cars also depends upon the design of the car. The front wing generates necessary downward force to keep the fast moving F1 cars in contact with the road surface. It works in the opposite way of an aircraft wing. This research intends to analyze the principal of designing of the wings, the body and fluid flow on the car. On the basis of an analysis, we will understand the significance of the modification done in the previous models of the Formula One cars.

II. HISTORY

Aerodynamics was a major factor in the invention of the first airborne vehicle but it came into the automobile industry as early as the 1920s when manufacturers desired to reduce the drag and make their design more streamlined. Soon, aerodynamics became the focus while designing the shape of a car. The sporting aspect of the industry further advanced the development in aerodynamics with the introduction of wings. Before that, aerodynamics was thought of as a tool to reduce drag and decrease the drag coefficient but a new innovation discovered that it can be used to increase downforce. This new discovery helped the driver to take faster turns while not losing contact with the ground.

When Formula Racing began in the 1950s, they had a streamlined design and the engine was placed at the front. Later that decade, a cigar shaped body was adopted by all teams with rear engine placement. As front and rear wings were introduced in the 1970s, aerodynamics began to gain much more momentum in research and development. Each component was designed to create as much downforce as possible. The area further advanced as turbo chargers were banned in F1 in the 1990s. This forced the teams to focus on aerodynamics for speed. Currently, numerous components such as barge boards, front and rear wings, diffusers, etc. are all advanced and are model specific to comply with the individual build of the car for an optimized effect.

III. LITERATURE REVIEW

Willem Toet [1] an engineer from Sauber F1 team addresses the engineering performance differentiators and highlights the difference aerodynamics can make to that performance. He listed the main performance factors such as drivers, grip, vehicle mass and center of gravity, engine and transmission, electronics, hydraulics and pneumatics and Aerodynamics. He broke down the downforce and drag acting on the car and tested the design with different conditions. He concluded that computer simulation is very valuable to the teams because of the strict restrictions over R&D imposed by the FIA.

Rajkamal Dhavamani [2] studied the effect of high speed on aerodynamic drag of formula one cars using CFD. They also studied the effect of dimples on the surface of the front wings. They first designed a CAD model and they analyzed it in CFD. In conclusion they found out that dimples on the front wing improve the downforce of the car. An average of 15 % improvement in Down force and L/D was shown from the results.

Unmukt Rajeev Bhatnagar [3] conducted experiments to determine the effect on performance by optimizing the front and rear wings of a formula one car. After reviewing research papers, he used the Covariance Matrix Adaptation – Evolution Strategy (CMA-ES), an adaptive genetic algorithm, to optimize the wing setups using the iteration process. He concluded that different front and rear wing setups are required at different circuits due to their requirements and that both wings should be in harmony to obtain best performance.

Triya Vadgama et.al [4] created a design of the formula 1 car using CATIA. They provided dimensions to their design and their process. They concluded that selection of air foils is crucial in F1.

Joshua Fields, [5] has provided a brief history of the sport since its beginning after World War II. He explains how the design of the car changed through the decade and how knowledge of aerodynamics became a focus in development of fast track cars. He concluded the paper by stating that aerodynamics on a car is regulated by the FIA to make the cars as green as possible.

James Bradford, Francesco Montomoli and Antonio D'Ammaro, [6] have addressed the various factors or random variables that cause uncertainty in the production of downforce using stochastic methods. A CFD analysis was done on the car to quantify the pressure variations around the car. They also simulated a scenario-based test to determine the optimization of the diffuser. It is mentioned that this was the first stochastic analysis method used on race car aerodynamics. In conclusion, they designed a new diffuser to increase performance and the time difference obtained from stochastic and deterministic values was about 1%.

X. Zhang, A. Senior, A. Ruhrmann, [7] studied the upswept aft vortices behind bluff bodies. The bluff body model is tested using CFD for different configurations and boundary conditions. They concluded that downforce and drag increases with a reduction in model height in the force enhancement region. Other regions give other results.

Marco De Luca [8] presents a patent on adjustable rear spoilers on high performance road cars. The design is a two-winged read spoiler with adjustable upper wing and a mechanical transmission to operate it.

Alberto Gómez Blázquez, [9] provides a project report of the aerodynamic analysis of the undertray of Formula 1. He showed the CFD analysis of the undertray when it is parallel as well as when it is at an inclination mimicking the actual configuration of the set up in F1 cars. He concluded that the undertray is one of the most influential components in the aerodynamics of the Formula 1 car.

Shreyas Vaidya, Chinmay Kulkarni [10] have analyzed the initial stages of aerodynamic design in FSAE cars. They have described the designing process and further demonstrated the CFD analysis on the aerodynamic components. The design and analysis of both front and rear wings are explained. They concluded that the wing profiles need to be studied to optimize drag and downforce co-relations.

Angel Huminic, Gabriela Huminic, [11] have shown how non-flat underbody diffusers affect the aerodynamics of a bluff body. Using CFD, they have analyzed two basic shapes for the underbody surface, circular and elliptical. During the computational analysis, the parameters are varied in a manner relevant to a hatchback car. It was found that curved diffusers produce less lift compared to plane diffusers.

Sang Wook Lee, and Hak Lim Kim [12] have performed a numerical investigation using flow discharge of an active aerodynamic control system. Computational Fluid Dynamics techniques were used for analysis. The flow discharge method uses the ram air flow to reduce aerodynamic drag and negative lift of a road vehicle. A two-dimensional simplified vehicle with a spoiler configuration was used as test model. Drag and downforce at different positions of the wing were observed and calculated.

Satyan Chandra, Allison Lee, Steven Gorrell and C. Greg Jensen [13] analyzed the PACE formula 1 car for air flow using CFD. They performed a simulation to maximize downforce and minimize drag for high speed cornering. Optimization of wing configurations and modifications in geometry on surfaces were performed to increase down force and decrease drag for maximum stability and control while driving. In conclusion, valuable insight was gained on how air flow affects the vehicle at high speeds and how they react to it owing to their designs.

Pikula Boran, Filipovic Ivan, Kepnik Goran [14] have provided a comparison between numerical simulations and experimental results of the air flow around the car. They concluded that using computational Fluid Dynamics software can improve development of external aerodynamics of the vehicle but some aspects of calculation require professional skills and experience.

Zhaowen Deng, Sijia Yu, Wei Gao, Qiang Yi, Wei Yu, [15] present a review paper on aerodynamic analysis and control of rear wing spoilers for improving aerodynamic performance. Both passive and active control have been reviewed. The review concludes that adding a rear spoiler increases stability in the car due to increased control over aerodynamic effects. Lower drag reduces fuel consumption while increased downforce increases cornering speed, i.e., grip.

Mattia Basso, Carlo Cravero and Davide Marsano, [16] have studied the aerodynamic effect of Gruney Flap on the front wing of the formula 1 car as well as how components interact with air flow.

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Xabier Castro, Zeeshan A. Rana [17] present the aerodynamic and structural design of the front wing assembly of 2022 Formula cars. After a thorough investigation of baseline configurations, a detailed analysis using various structural configurations as well as materials. They concluded that the bad aerodynamic effect at the wing tip is removed and the ground effect is increased. The deformation of flaps is considerably reduced than the 2020 design.

S. Pal, S. M. H. Kabir and M. M. M. Talukder [18] have analyzed a concept car using Computational Fluid Dynamics. They used both computational and experimental approach to identify the areas where modifications can be introduced in the design to reduce drag acting on a car while in motion. A subsonic open circuit suction type wind tunnel testing is also executed to verify the results from flow simulation. They concluded that the concept car they designed promised better fuel efficiency and performance through experimental and computational analysis.

Subhasis Sarkar, Kunj Thummar, Neel Shah, Vishal Vagrecha, [19] provide a review paper on Aerodynamic drag reduction and CFD analysis of vehicles. Having reviewed various papers, they concluded that aerodynamic drag is majorly responsible for fuel consumption, power loss and top speed in a vehicle. Addition of vortex generators, rear screen, rear fairing, fenders, etc. can be done to optimize vehicle performance.

IV. DISCUSSION AND RESULTS

Fig. 1: Formula 1 2022 concept design.

Since the vehicle designs for the 2022 seasons has changed, a new aerodynamic package has been launched to promote better racing among other technical benefits. The major changes can be seen on the nose, the body and the undertray. By using diffusers in the design of the undertray, the new model eliminates the concept of rake. In this review, the design of previous existing models and research was analyzed to get a better understanding. Two of the most important factors affecting aerodynamics are Drag and Downforce. Below is a brief summary of Drag in the previous models of design.

Drag force is a force that acts as resistance when an object is moving through a fluid. It is a result of how fluids interact with solid objects. Drag is generated when there is a difference in the velocities of the fluid and the object moving through it. When the object displaces the fluid around its shape, an area of low fluid density is generated behind the object. This created a low-pressure region. As fluids flow from high pressure to low pressure, a resistance is created as the body moving through the fluid is pulled in the direction opposite to the direction of motion. Drag is an important factor in determining the speed of vehicles. The lower the drag the more the speed of the vehicle.

To calculate drag force,

$F_{drag} = 0.5CdDAV^2$

where is:

F - Aerodynamic drag

C_d*- Coefficient of drag*

D- Air density

A- Frontal area

V- Object velocity

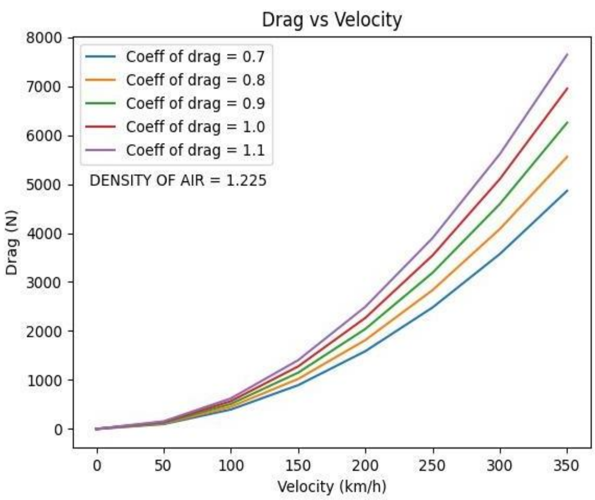

Fig. 2

The Drag vs Velocity graph shows that as the speed increases periodically, drag increases exponentially. This is because drag is directly proportional to the square of velocity.

The front wing is designed in such a way that it prevents the uplift motion of the car. So, the front wing is designed in the shape opposite to the airfoil. The endplates on the front wings play a crucial role. The optimization and position of them can significantly improve the performance of the F1 cars.

They control the fluid flow by diverting the flow around the tyres of the Formula One car. This results in the reduction of the drag force on the car. Moverover, they stop the high pressure air on the top of the wing from rolling over the wing to the low pressure air beneath which generates an induced drag. Hence, increasing the speed of the F1 cars. New model introduced underfloor tunnels which greatly control the airflow underneath the car.

To calculate down fore,
Fdown = 0.5ClAV²

where is:
Fdown - Aerodynamic downforce
Cl- Coefficient of lift
D- Air density
A- Frontal area
V- Object velocity

There were a plethora of modifications happened in F1 cars design compared to previous cars. The front wing is the part which comes in contact with air. The new design of the front wing is more simplified and the endplates made higher and less complex than that of the previous model. Rear wing also got revamped, it became curved instead of flat endplates meeting at the sharp angle. This change in shape reduces the amount of air spinning at the corner creating drag. Wheels of the F1 cars are placed near the chassis which helps to increase down force.

V. CONCLUSIONS

After reviewing all the technical papers, it can be concluded that Computational Fluid Dynamics is an effective tool to accurately analyze air flow above the surface of vehicles and can used to suggest modifications in the design to optimize aerodynamic factors like drag and downforce which are incredibly essential in high performance motorsport events like Formula 1. As drag increases exponentially with periodic increase in speed, drag reduction is necessary to optimize aerodynamic effect as well the fuel economy. It is also learned that front wings, rear spoilers and underbody design dictate the downforce generated by the car. Adjustable rear spoilers, as used in Formula 1, are useful to maximize straight line speed as well as cornering speed by reducing drag and increasing downforce respectively. Vortices play an important role in directing the air to desired parts of the car. It is also evident that the 2022 formula car has better aerodynamic design with respect to front wing and underbody curves.

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