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Research Paper

STUDY OF FRONT WING OF FORMULA ONE CAR USING COMPUTATIONAL FLUID DYNAMICS

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The 222 member organization worldwide and one of the richest sports Federation Internationale de Automobile (FIA) Formula 1 World Championship proposed new aerodynamic rules for 2009 season. The main intentions and goals were to reduce the downward force by 50% and improving the sensitivity of the car running at an average speed of 175 kmph. The CFD simulations point that the main factor contributing in the field of new aerodynamic rules and regulations is the design of front wing of F1 car. Till date steady state CFD simulations have been carried out with different add on devices like front wing, roof spoiler, nose wing, bargeboard at different speeds in order to improve aerodynamic performance. Front wing is vital component because it is where air first meets the car. Entire aerodynamic performance of an F1 car can be changed by subtlest of alterations in front wing design.

Keywords: Computational fluid dynamics, Down force, Drag, End plates, Front wing, Lift

INTRODUCTION

While designing a Formula One car the most important and significant aspects the designer has to deal with, is the field of aerodynamics. The aerodynamic designer has two primary concerns: the creation of down force, to help the car steer onto the track and improve cornering forces; and minimizing the drag force, caused by turbulence which in turn decreases the speed of the car (Mohd Syazrul Shafiq Saad, 2010). These factors enhance the performance of the car.

The front wing of the Formula One car is the single most crucial aerodynamic component. This is because the front wing of the car influences the flow of air over the rest of the body since it is the part, which first comes in contact with the air. It also influences the flow of air into the brake ducts, radiator and diffuser and also to the main engine intake. Down force is generated by the front wing due to the ground effect where more force is generated when aerofoil is moving close to the ground surface. This is one of the many factors

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that are influenced by the front wing. The wing also incorporates many small cascading winglets which refine the flow and ensures that the flow is laminar and attached to the body of the car in order to attain good aerodynamics result.

The Formula One is a very competitive event in which small improvements in the design of the car may largely affect the car's performance. Hence the use of robust and concrete technology is necessary to produce the best possible design for higher performance. CFD is one of those technologies. CFD, abbreviation of Computational Fluid Dynamics, is a branch of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The flow of any fluid comprises of three main principles which are:

- Conservation of mass.
- Newton's second law of motion.
- Energy conservation.

These fundamental principles can be expressed in terms of mathematical equations, which in their most general form are usually partial differential equations. Computational Fluid Dynamics (CFD) is the science of determining a numerical solution to the governing equations of fluid flow and helps to simulate the flow of fluid over the field of interest.

CFD allows engineers to examine the airflow over an automobile or a particular part such as a wing or hood and see the aerodynamic effect and, helps to solve complex problems without losing their integrity due to ease of the software. The main advantages of using CFD software is that the results are obtained without construction of the required prototype and this is very important because it can reduce the cost in constructing the F1 cars. The validity of results is the most important thing that we need to concern about while using the software simulation. Therefore specific parameters and conditions while analysing the data need to be valid. Among various components that contribute to the varying levels of down force it is the front wing that lends itself to theoretical aerodynamic analysis method and techniques for design using the CFD software.

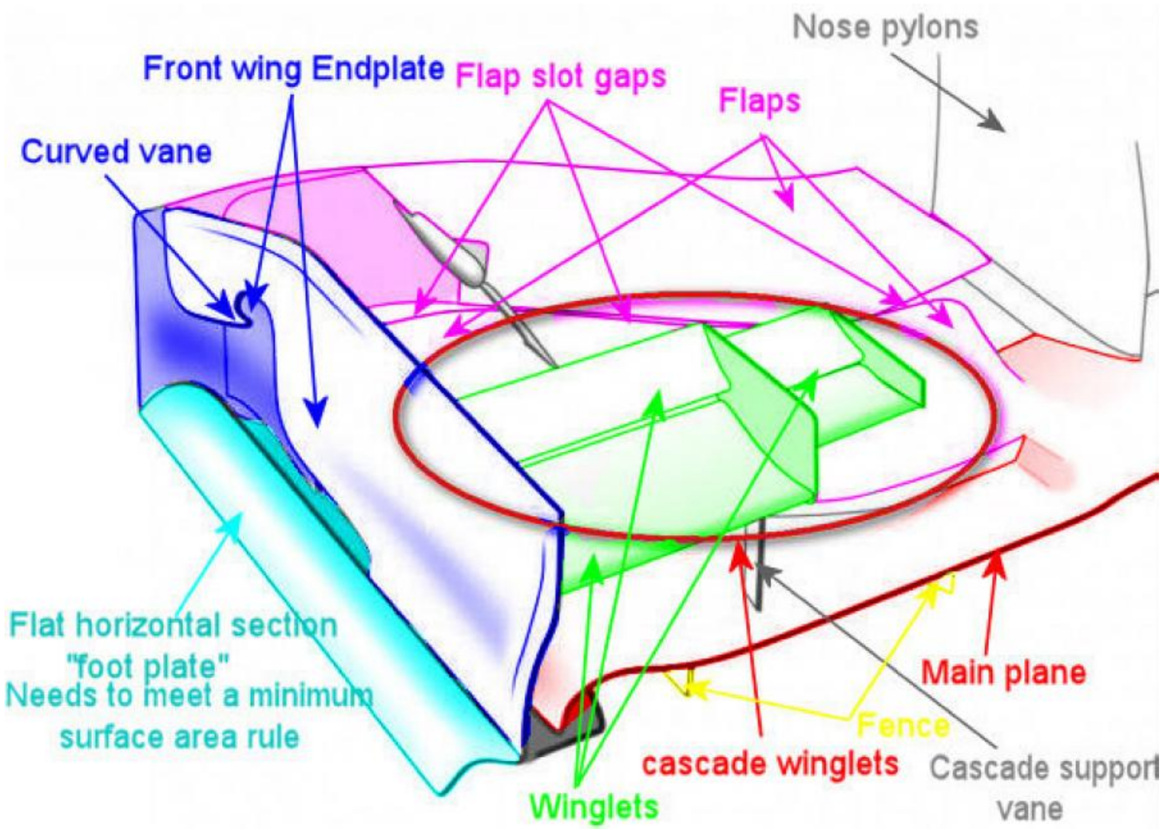
The role of CFD in engineering predictions has become so strong that today it may be viewed as a new third dimension of fluid dynamics, the other two being pure experimentations and pure theory.

OVERVIEW OF FRONT WING OF FORMULA ONE CAR

Front wing of Formula One car is the single most crucial aerodynamic component. The contributing factor for the above statement is the manner in which it influences the flow of air into brake ducts, radiators, diffusers and also main engine intake. The front wing is actually made into readily modifiable components where flaps and small winglets provide different levels of down force distribution as per the handling requirement of the driver during the race. The dynamic balance of the Formula One car is determined by load on the front wing which is required to be easily modified.

The basic front wing of the Formula One car consists of main plane, a pair of aero-flaps and a pair of end plates. The first element of the wing is rectangular in shape which provides

Figure 1: Details of Front Wing



air flow to the second element lower surface so that the latter's incidence may be increased at a very high angle.

Now a day's front wing is of two or three element aerofoil which is not actually straight along its span. On the other hand the main flap is a rectangular platform having different shapes due to downstream flow constraints. Aerodynamic down force on the Formula One car is not only generated by the difference in the air pressures on two sides of the main plane but also use to aerodynamic theory of venture. The venture theory shows that by reducing height of the main plate to ground, the velocity of air flowing through is increased and low air pressure is created which results in further down force.

Many researchers have studied the means to enhance the aerodynamic performance and also the effect these changes have on the overall performance of the car employing analytical and experimental methods. Different aerofoil shapes were considered for the design and were analysed during cornering, straight line braking and straight line acceleration conditions. These shapes were tried for single and dual wing configurations. The results showed the importance of maintaining a proper lift to drag ratio and that the front wing down force had to balance the rear wing down force for optimal results.

Comparatively the front wing of an F1 car has a lot of constraints unlike the rear wing and other parts. It is required to have a neutral central section and for a fruitful purpose it must be at least 50 cm in length and cannot induce any amount of down force, hence it is called as neutral central section. There is freedom though in the number of cascades and the flexibility of the wings it is not availing to specify or limit the number of cascades and its flexibility before actual design is done and tests are carried on it. It is found that the stability of a car, while slipstreaming, improves when the wings are flexible. Also the point to be considered is that the closer the wings are to the ground, the more is the down force that it produces, since it makes use of the ground effect of the car. But according to the regulations specifications the minimum ground clearance of the car at standstill position which cannot be compromised on. Hence in order to make utmost use of this regulation flexible wings are added which move down during cornering which induces a higher down force on the car and improves its handling and stability. The combined effect of the above factors proves to be the heart of design of front wing of the Formula One car considering the aerodynamics point of view using CFD.

Lift Force and Drag Force

When a fluid moves over a stationary object the lift, down force is generated perpendicular to the direction of travel for any object. On the other hand drag force is unavoidable consequence of an object which is generated parallel and in opposition to direction of travel for any object (Mohd Syazrul Shafiq Saad, 2010).

Drag force can be divided into two components—the pressure drag which is dependent on shape of any object moving through a fluid and skin friction drag which is dependent on viscous friction but a moving surface and fluid derived from wall shear stress. The lift and drag force depend on the density ° of the fluid, the upstream velocity V, the size, shape and orientation of the body. Lift and drag coefficient can be defined as:

Lift co-efficient: $CL = \dfrac{FL}{1/2 ° V2A}$

Drag Co-efficient: $CD = \dfrac{FD}{1/2 ° V2A}$

Two wings will produce less than twice the down force produced by a single wing. Lift coefficient and the ratio of Lift to Drag (L/D) decreases with increasing number of air foils. Earlier CFD was first developed to achieve the target lift and drag coefficient for 2D front wing design. But now maintaining high lift coefficient plays a crucial role in designing and testing of Formula One car's front wing using CFD package. Due to the very low aspect ratios of race car wings, the primary source of drag comes from the induced component of overall drag (Sriram Saranathy Pakkam, 2011). Two primary components which affect the lift and drag force are the shape of body and use of air foils. As it is evident that the front wing is sensitive to both angle and orientation as well as down force of drag it would not be wrong to conclude that with a view to achieve the goal of highest lift to drag ratio, the design of front wings anticipated by each and every F1 car franchise proves to be fruitful in doing so.

Role of the End Plates

Among different components of front wing like main plane, cascade winglets, curved vanes, flaps and nose pylons, one very important part is the end plate which is used to redirect the airflow around front tires. By directing the oncoming airflow around the front tires, minimizes the amount of drag resistance produced and allows the air low to continue back to side pods and cars floor.

End plates can be found at the limit of the wing, be it front or the rear wing, The size of these elements are dictated by the air regulations as they can be influential to the wings profile they are connected to. End plate increases the wing aspect ratio without the need to increase its wing span leveraging more down force. The end plates function is similar to the winglets on aircraft, that is to separate the negative pressure on the bottom of the wing flowing and the positive pressure on the top of the wing which eliminates induced drag. The other functions of end plates is to increase the aerodynamic efficiency while designing we cannot neglect the fact that when the endplate area is increased overall lift coefficient increases while there is significant reduction in drag coefficient. Over the time wheels were moved closer to the chassis which created unnecessary turbulence in front of the wings, further reducing aerodynamic efficiency and contributing to unwanted drag. In order to overcome this problem the teams made inside edges of front wing end plates curved to direct the air from of chassis.

Figure 2: Endplate

With the advent of new technical designs available due to CFD analysis there has been further front wing end plate design updates. Amongst the latest work into detailing of end plates, one of the features is attachment of shorter and less vertical fin and other is use of squared end to the upper element of end plate.

Front Wing Before and After 2009

The year 2009 proved to be beginning of the new era in the history of Formula One racing since the introduction of new technical rules which closed off several areas for aerodynamic development. As a result the front wing became one of the most important areas of car development as the designers had the freedom to make changes and limit the scope for improvement.

Recalling the time period before 2009, the front wing design was simple, boxy, with very square end plates which had the single function of pushing air around the front tires. Though each and every team followed a different and more refined concept than other teams, the basic front wing itself was a simple three element device without any cascades or appendages. The most important physical factor contributing in the field of designing is the weight of the F1 car which was 640 kg. But as a result of use of servo and associated electronic equipment's along with storage of ballast contributed to further increase in weight which led to imbalance of the car design as a result making them bulky.Many Formula One constructors began to do the same thing and many wings flourished on the Formula 1 circus. The wings were fixed on the wheel hubs of the car to transfer the load directly to the wheels allows avoiding stiffening the springs of the suspension system that might create instability on undulating tracks (Mortel, 2003).

Changes made in the regulations from 2009 improved the entire body work of the car as a result reducing overall down force levels to allow closer racing. Drastic changes were made in the basic front wing design changing its width from 1400 mm to 1800 mm and lowering from 150 m to 75 mm from the reference planes which is the lowest point of the car. Earlier driver was allowed to perform adjustments to the main flap of the front wing twice a lap by 6 degrees, but now the front wing can only be adjusted manually only once in the pit lane. Upper cascade winglets have been added which are connected via end plates and the main plane, aid in guiding the air flow reducing the drag. The major front wing changes during the season are very rarely seen in one go because the rest of the car relies on the front wing design considering the aerodynamic point of view.

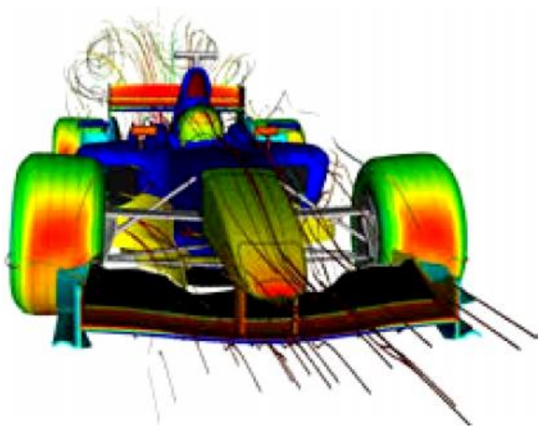
The main plane of the front wing and the various flaps are now being merged into one, with various slot gaps appearing in the wing. The flaps no longer connect directly to the main plate instead the main plane and the flaps now form their own end plate in the form of turning vane. This allows improved air flow redirection and improves the overall end plate design. In 2010, Red Bull brought a new design concept in to use "Flexi-wings" which allowed the wings to flex to a large degree and closer to the track surface thus giving the ability to the car to turn into corners much better than other cars at high speed. As the time passed, the importance of adjusting Front Flap Angle (FFA) increased thus resultinga drastic change in the car balance as the race develops.

CONCEPT AND USAGE OF CFD

CFD is a computational technology that enables researcher to study the dynamics of things that flow. Using CFD, a computational model that represents a system or device can be build. Then the fluid flow physics and chemistry can be applied to this virtual prototype and the software will output a prediction of the fluid dynamics and related physical phenomena. Therefore, CFD is a sophisticated computationally-based design and analysis technique. Besides that, CFD software can give the power to simulate flows of gases and liquids, heat and mass transfer, moving bodies, multiphase physics, chemical reaction, fluid-structure interaction and acoustics through computer modelling. Using CFD, the product will get to the market faster as result it can save time that used for building prototype. CFD is commonly used for aerodynamics of air craft and vehicles (lift and drag), hydrodynamics of ships, power plant combustion (I.C engines and gas turbines), marine engineering (loads on off shore structures) and meteorology (weather prediction) (Mohd Syazrul Shafiq Saad, 2010). Considering the design requirements we can conclude that the aim of CFD is to resolve the equation that drives theoretically every kind of flow using continuity and momentum equation.

In CFD simulation, it is easier to optimize and change certain features in the design rather than changing the shape of prototype in the wing tunnel tests. This is a significant

Figure 3: CFD Analysis of F1 Car



advantage as it leads to a reduction in time. In Formula One not only case of aerodynamics can be used in CFD. CFD also can be used to monitor the heat transfer from the brakes. Formula One brake comprise of carbon fibre discs with carbon fibre brake pads. It is vital to ensure that the optimum air flow is achieved for engine induction in the engine intake opening. This can be done by using CFD. Hence, the air flow can be optimized to increase the power of the engine. Another advantage of CFD is that the level of detail of the data that is obtained from the solution is wide. This data can be viewed from different perspectives, which is a big advantage.

DESIGN PARAMETERS AND FEATURES

Designing of front wing of a car is mainly dependent on the Bernoulli's principle which comprises that air flowing over the different side of the wings creates a pressure difference when the air travels different distances over the contour of the wing. As this pressure tries to balance, the wing tries to move in the direction of the low pressure. Planes use their wings to create lift, whereas race cars use theirs to create down force. Efficient designing of the front wing helps the Formula One car to create cornering force of up to 3.5 g due to aerodynamic down force.

Role of CFD in field of design changes and depends on phase of study. The numerical model is set up and run using CAD software which produces boundary conditions for analysis. This analysis result plays a very important role in optimizing design components such that there should be minimum drag and maximum negative lift. Earlier CFD solutions were computed with the help of 2D simulations which was considered ideal. But as it was not feasible to build a 2D grid without one element thickness in Z direction, 3D simulation was thus undertaken. This simulation could solve for each angle of attack even though it would require immense amount of computational resources and proportional amount of time.

Effective design for the 19 Grand Prix held in one season the analysis of the front wing using CFD is possible mainly by using 2 types:

Grid Generation (Meshing)

Any design flow under considerations divided into shapes like triangles and quadrilaterals along with some assumptions of flow properties. Grid or mesh generation is used only while designing complex geometries and when lower cell count is desired because of smaller gradients. Grid generation is by far one of the most crucial processes of CFD analysis as the grid chosen can make or break the numerical solutions.

Based on association of cells there are two types of grids:

Figure 4: Grid Generation (Meshing) of F1 Car

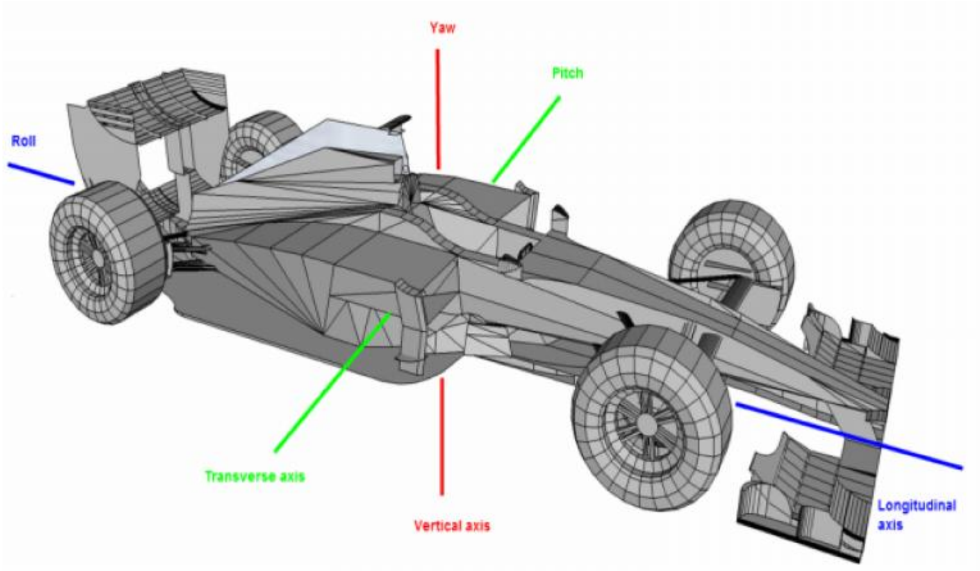
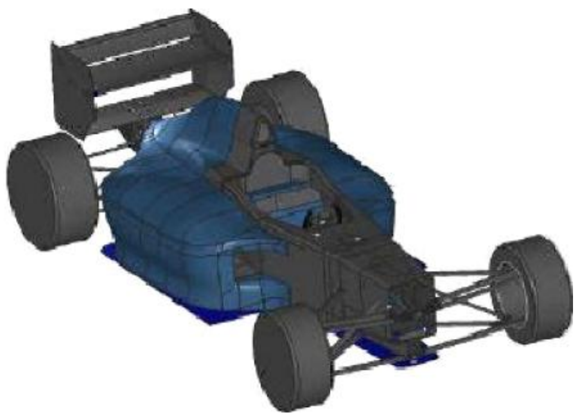


Figure 5: Grid Generation (Meshing) of F1 Car



Structured Grid

In this grid the computational cells can be associated with ordered triplet of indices that are independent and have a fixed range. The advantage of using structural grid is that the number of cells in the entire mesh can easily be associated with their index direction. Based on the general shape of the grid the structured grid can be O-type grid, C-type grid and H-type grid.

Unstructured Grid

Unlike the structured grid this grid consists of grid points placed in flow fields in a very irregular fashion. Thus unstructured grid requires more information to be stored and recovered than structured grids.

As the front wing of Formula One car consists of many parts of any arbitrary shape, Finite Volume Method (FVM) is preferred which demands a structured meshes. The FVM allows meshing to be performed using the triangulation method for all the surfaces followed by creation of tetrahedral mesh in the volume bounded by the wing.Despite recent gains made In aerodynamic design, there is still little known about the influence that race-car wings have on the production of a car's overall downforce (William Jasinski and Michael Selig, 1998).

Modelling with Help of Solver Models

Simulation of front wing of Formula One car which is a single element configuration comprising of two sections on either side of its nose, concentrates on the angle of attack and the effect of the ground on lift and drag. Preparation of physical model helps us to determine the amount of computer resources required for future work. With the help of physical model generated the two dimensional approach can be easily applied to any problem. The wings of Formula One car are inverted at a certain angle of attack which creates down force instead of lift. By preparing the actual physical model we can validate the concept of positive angle of attack which further contributed in determining braking, acceleration and cornering force of the race car. On the other hand the geometric model designed using computer modelling (CAD system) is necessary for making changes during the numerical simulation procedure.

The main advantage of following the above two design procedures in CFD is that the candidate design which is being produced can easily be compared against a backdrop of the required parameters.

CONCLUSION

From the above study, it can be said that the performance of the front wing of the Formula One car is greatly affected by the existence of ground nearby. The nearby ground helps to develop a large net down force, also known as the negative lift when the flow is simulated with the ground effect (Kieffera *et al.*, 2005). After studying the analysis of the model it can be inferred that the vertical plate deflects the flow of air, thus reducing the drag force and also further prevents the super pressure the wheel to extent to multi-element air foil surfaces thereby increasing the down force. It can be said that even the slightest changes in the design of the end-plates may affect the performance of the front wing of the Formula One race car. When the endplate area is increased, overall lift coefficient increases while there is a significant reduction in drag coefficient. Therefore, it is one of the important design aspects which are to be considered. From the above study we can conclude that drag reduction is the primary and the most basic parameter regarding the design and performance of the Formula One car (Shi Sun *et al.*, 2013). Hence, drag minimization is the key design criterion in Formula One.

Moreover, the above study was highly educational regarding the fields of aerodynamics, fluid dynamics, CFD simulations and automobile design (Satyan Chandra *et al.*, 2011). Further the performance of the car and its aerodynamics were evaluated and if the simulations were not up to the mark then necessary recommendations and suggestions were provided. With the aid of Computational Fluid Dynamics (CFD) simulations the development cycle and overall cost were greatly reduced while new and creative ideas were easily tested on the virtual platform with accuracy.

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