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Aerodynamics of High Performance Vehicles

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Abstract - *The projects aim is to improve external fluid dynamics of the racing cars. The study of aerodynamics provides an interesting application for illustrating principles of fluid mechanics. Race cars are aerodynamically designed to reduce drag force or decrease vehicle's resistance and enhance downforce. Drag forces limit maximum speed and affect fuel consumption although downforce is used to provide stability when driving around corners. The CFD is very useful in automobile industry from system level to component level to analyze the fluid flows. In the present paper, effect of aerodynamics on various parameters of racing car and CFD has been reviewed briefly.*

Key Words: Aerodynamics, CFD Analysis, Racing car, Drag measurement, Formula SAE.

1. INTRODUCTION

The power consumption of vehicle can be reduce by various means such as improved engine efficiency and aerodynamic drag reduction. From the early days, the designers recognized the importance of drag reduction and tried to streamline the design as more as possible [1]. Hence it is very important to formulate basic principles of vehicle body optimization, and definition of drag lower limit. For a perfect car body configuration the lowest possible aerodynamic drag coefficient should be ~0.16.

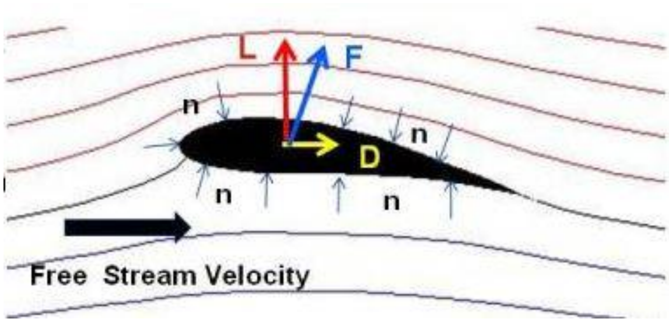
Great attention has being paid to the aerodynamics of racing cars as the race car is always at a high-speed condition compared with ordinary cars. The motive of the aerodynamic research and development of race car is to provide maximum downforce, minimum aerodynamic drag and good directional stability at high speeds.

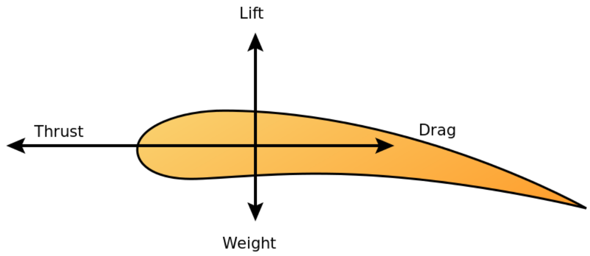
Also, considerable attention must be given to the unsteady aerodynamic effects on vehicles. In some of the typical cases in which the understanding of unsteady aerodynamics is essential are as follows: the effects of atmospheric turbulence on the aerodynamic drag, running stability under breezy crosswind conditions, and driving stability at a high-speed condition. In all cases, the problem that we face is strongly related to the correlation between the ideal steady measurement in a wind tunnel and the real unsteady condition on the road [2].

2. Characteristics of Aerodynamics:

Main forces which are to be consider in Aerodynamics are Lift, Thrust, Drag and Weight. Downforce and aerodynamic drag are two of the fundamental forces created by the air that flows around the car. Downforce acting downwards on a vehicle developed by a difference in air pressure and it can increase a car's performance by increasing the force that increases the stability of the vehicle.

Since the fluid is in motion, we can define a flow direction along the motion. The component of the net force perpendicular (or normal) to the flow direction is called the lift; the component of the net force along the flow direction is called the drag. These are definitions. Integrated force caused by the pressure variations along a body. This aerodynamic force acts through the average location of the pressure variation which is called the centre of pressure.





2.1 Aerodynamic drag (Cd):

When the fluid flows over the surface of the body, it tries to resist the motion of body this is called drag. Aerodynamic drag is the combination of pressure drag and viscous drag. The pressure drag is the most dominant one of the both. The pressure drag is causes due the shear forces acting between the two layers of fluid.

$$\text{Aerodynamic drag } Cd = \text{Drag force}/0.5\rho v^2 A$$

Where,

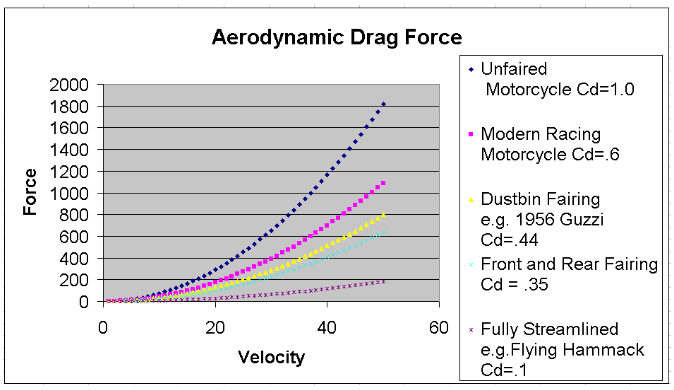
ρ is the air density in kg/m3
A is the effective frontal area in m2
v is the velocity in m/s

In order to decrease the aerodynamic drag on a vehicle, the sources of drag must be analyzed. As discussed earlier, aerodynamic drag is the force that opposes the direction of thrust of a car hence this is not a desirable force. With the given conditions of the vehicle, the drag force can be calculated.

Drag is a function of the frontal area, air density, the coefficient of drag of the vehicle, and the vehicle speed squared [5]. The fact that the vehicle speed has a cubic relation to the force of drag reveals that a small change in the speed of the car can require a huge amount of engine power to overcome the forces of drag. The density of air and the speed of vehicle cannot be altered by the design of the vehicle, the frontal area and coefficient of drag can. Reducing dimensions of the car can reduce the frontal area, but there is a limit to how small this area can be since people must be able to sit comfortably inside the vehicle. Therefore, the easiest method of reducing drag is to lower the coefficient of drag of the car [3].

The coefficient of drag of a vehicle depends predominantly on the shape. Therefore, vehicle designers change particular aspects of the shape of the body of the vehicle in order to reduce the total aerodynamic drag and thus increase fuel economy.

The main difference between the aerodynamics of a racing vehicle and the aerodynamics of a passenger vehicle is that racing vehicles aim to increase downforce, while passenger vehicle aim to decrease drag [6].



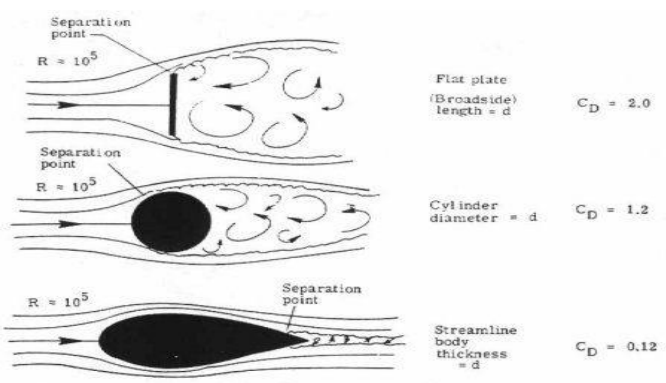


Fig. Drag coefficients of different objects

Very less aerodynamic modernization has taken place with wheels compared to the top surface and underbody. Vehicle aerodynamics can be complicated, specifically around the wheels and wheel wells as shown in Fig 1. Only recently has development focused on the wheel region of the vehicle. [4]

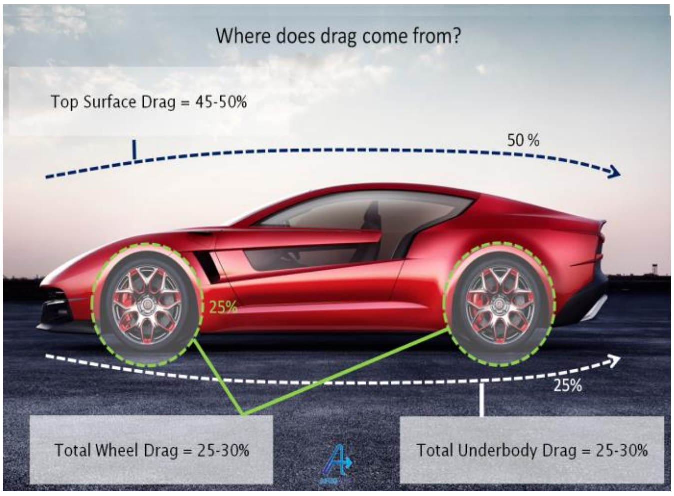


Fig. 1

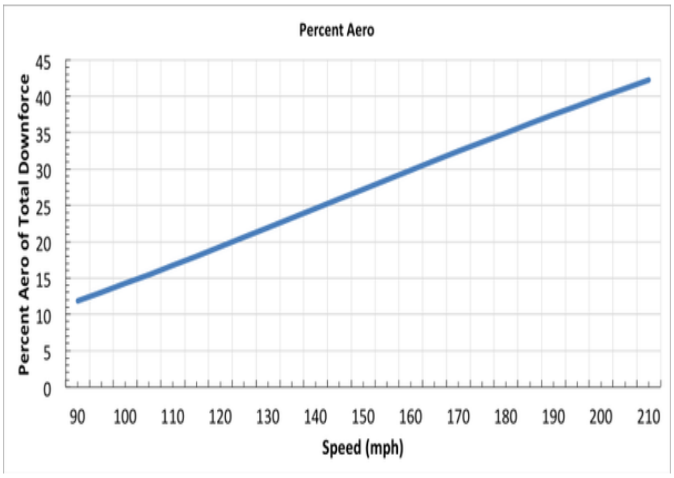
2.1.2 Aerodynamic Downforce

Downforce is the force of the air acting downward on the car and helping the wheels stick when you want to corner, and stick when you want to accelerate down the straight.

Downforce is generated by air flowing over the car generating negative lift. For an airplane wing, the shape of the wing is designed to lift the airplane off the ground. [7] For a racing car, that's seen as a bad thing. By shaping the car so air is pushed up and over the body shape, the pressure of that air forces the car down and helps the vehicle stable onto the track. The front shape of the car directs air over the top of the car. The front end fascia features a very low nose and flared, wide from fenders. This means that, as a much air as possible hits the air dam and it pushed up and over the car, instead of being allowed to go below it. The higher pressure at the top of the car and low pressure below work together to suck the car onto the ground.

The importance of downforce starts with motorsport. When the need is to go as fast as possible, one goal is to maximize straight line speed. The other solution is to increase speed on corners so that cars arrive on the straights going faster already and that increases speed overall, in every part of the track. The challenge with cornering a car harder is centrifugal force. Which essentially spends all its time trying to push anything going in a circular path, radially to the outside, pushing harder and harder as speeds rise. Engineers will add stickier tires, stiffer suspension and increase the width of the car to raise the speed at which centrifugal force overcomes grip but like the hunt for great straight line speeds, costs, technology and often rules will limit what is possible.

Enter wings, aero foils, splitters etc., are help the vehicle to increase the grip of the car by aerodynamic means by using downforce with respect to speed. And the faster you go, the more downforce gets created and hence, more grip you will have. It is stupendous amounts of downforce that allow F1 cars to corner as fast as they can. Ironically, it is also downforce that often prevents drivers from chasing each other closely into corners.



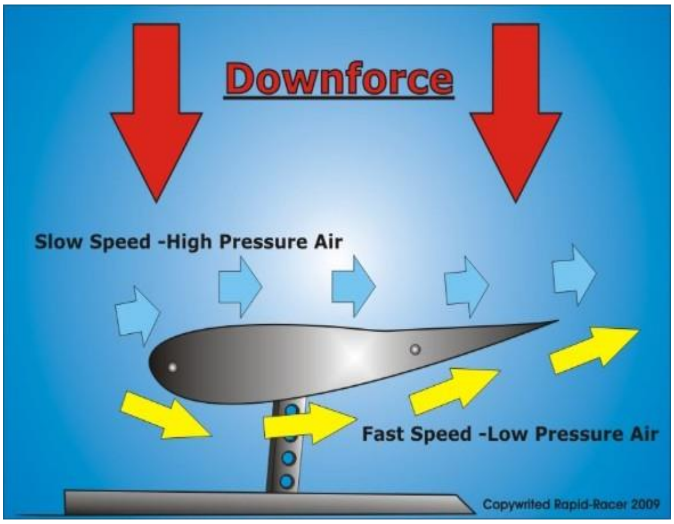


Fig. Downforce acting on wings

The motive of further increase in the tire grip led the major revolution in racing car design, by the use of negative lift or 'downforce'. Since the tires lateral adhesion is roughly proportional to the force acting downwards on it, or the friction between tire and road, adding aerodynamic downforce or negative lift to the weight component enhance the adhesion. The more downforce also allows the tires to transmit a greater thrust force without spin of wheels, and enhances the maximum possible acceleration. Without aerodynamic downforce to increase grip, modern racing cars have so much power that they would be able to spin the wheels even at speeds of more than 160 km/h.

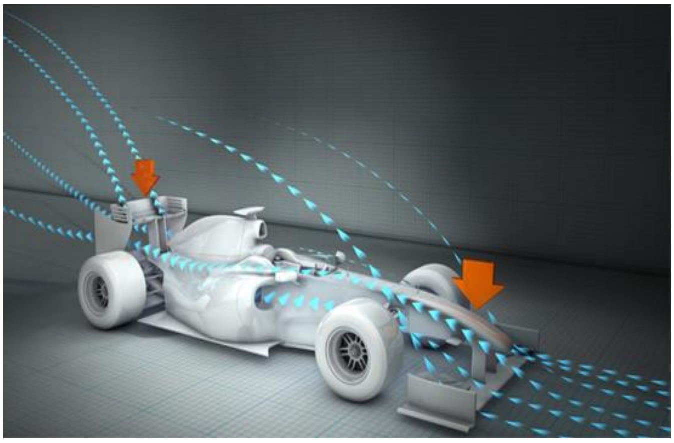


Fig. Downforce acting on F1 car

Downforce, or negative lift, which pushes the car onto the track and makes the vehicle stable at high speed. It is said that at maximum speed, an F1 car produces 5 *g's* of downforce that is 5 times its weight pressing it down onto the track.

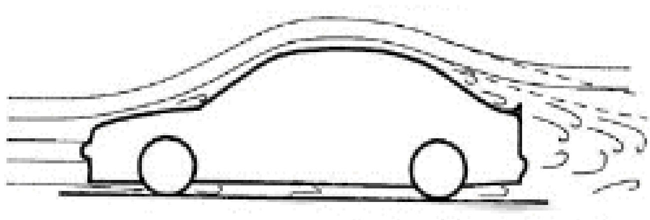
Downforce has to be balanced between front and rear, left and right. We can easily achieve the balance between left and right by simple symmetry. Flow in the front greatly affects flow in the back of the car, and flow in the back also affects flow on the front of the car. Downforce must be adjusted according to racing track and behavior of the car. Example, too much front downforce lead to oversteer. Too much back downforce lead to understeer.

3. All body surface can develop downforce, and we can divide the car in three parts: front and rear.

3.1 On rear

Main source of downforce are rear spoilers, wings and diffuser.

Spoiler



Effect of a rear spoiler

A spoiler is a simple kind of plate placed at the end of the car body so that it can interfere or spoil the flow around the vehicle, creating a controlled segregation of the flow in a desired place. This is done because fast, smooth airflow increases positive lift, so by interfering this flow the lift is either reduced or maybe completely wipe out.

Diffusers

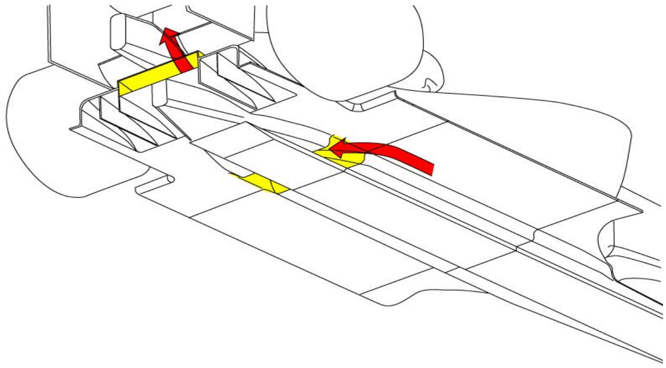


Fig. Rear Diffuser

Diffusers are the most frequently seen devices to develop downforce in the rear section of the racing vehicle. In the diffusers, we use the Bernoulli equation, much in the same way that we do with a venture tube. In a venture, we can see certainly that pressure and velocity of fluid squared are inversely proportional, so diffusers can help to decrease the pressure of the flow under the car by increasing its velocity.

3.2 On Front

Main source of downforce are front spoilers (called spoilers, dam or splitters), canards (called also dive plates), vortex generators, front diffuser.

Splitter

Fig. Splitter

Splitters reduces the gap between the ground and bottom of the vehicle blocking most of the air that would go under the vehicle. A leading edge on the front of the racing car, relatively parallel to the ground, which attempts to keep high pressure air on top of the car, rather than flowing underneath it. The high pressure pushes down on the splitter, also helping to create downforce or negative lift.

4. Aerodynamic Flow of Fluid Simulation Methods

1. Wind Tunnel Test
2. Computational Fluid Dynamics (CFD)
3. Track test

4.1 Wind Tunnel Test

Wind tunnel is the main experimental development facility. Measurement in the wind tunnel are based on the relative difference in the wind speed and vehicle speed. That is, vehicle is steady, air is moving.

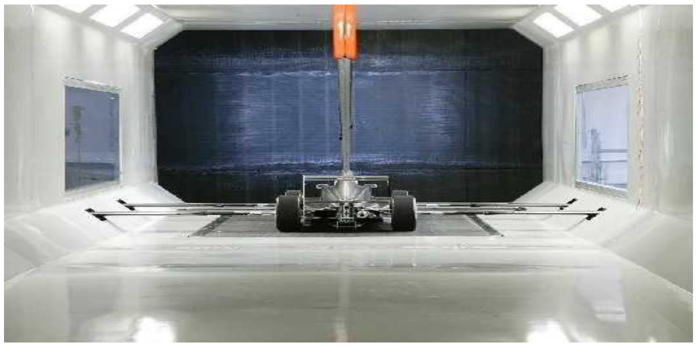


Fig. Wind Tunnel Test

4.2 Computational Fluid Dynamics

Computational Fluid Dynamic (CFD) is the branch of fluid dynamics providing a cost-effective mean of simulating real flows by the numerical solution of the governing equation. [8]. the governing equations for Newtonian fluid dynamics, namely the Navier-Stoke equation. The differential equation governing the system is converted to a set of algebraic equation at discrete points, and then solved using digital computer. For such a complex interaction, CFD analysis is probably the only efficient tool in order to assess specific design parameterization of a generic car shape.

Aerodynamic evaluation of air flow over an object can be performed using analytical method or CFD approach. On one hand the analytical method of solving air flow over an object can be done only for simple flows over simple geometries like laminar flow over a flat plate. If air flow gets complex as in flows over a bluff body, the flow becomes turbulent and it is impossible to solve Navier-Stokes and continuity equations analytically, in that case CFD is useful.

3. CONCLUSIONS

This paper gives idea about the concept of various characteristics of aerodynamics and their effects on the racing vehicle. Also, the methods to stabilize the vehicle at high speed and while taking corners during the racing. The different accessories are discussed which are very useful in handling of vehicle and reducing the fuel consumption as well. The different methods to calculate aerodynamic forces are reviewed. Computational Fluid Dynamics (CFD) is very useful to understand the behavior of fluid over the vehicle and calculation of different aerodynamic aspects at different speeds.

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