Increasing Downforce In High-Speed Vehicles Using Wheel Rotation

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Abstract - *Downforce, or downward lift force, is created by a vehicle's aerodynamic properties. The vertical force on the tires is increased by downforce, resulting in a higher grip. The purpose of the downforce on a fixed-wing aircraft's horizontal stabilizer is to maintain longitudinal stability and allow the pilot to direct the plane in pitch. Formula 1 vehicles are propelled off the ground by the same process that propels airplanes. This impact is referred to as "aerodynamic grip," as opposed to "mechanical grip," which is governed by the vehicle's mass, tires, and suspension. Passive devices can only increase downforce by increasing aerodynamic drag (or friction). Downforce increases in direct proportion to the square of the vehicle's speed and requires a specific minimum speed to have a noticeable effect. Some cars had relatively unstable aerodynamics, resulting in significant downforce fluctuations with minor changes in the angle of attack or vehicle height. In the worst-case scenarios, such as when passing over a bump or slipstreaming over a crest, this can result in lift rather than downforce. Sucking air beneath the car creates a low-pressure region beneath the vehicle, and the sucked air is sent to the back-end low-pressure region of the wake. As a result, a lot of work has already been done to improve this downforce, employing some traditional methods and their variations. However, because boosting downforce always increased the coefficient of drag, we made a change to the back wheels.*

***Key Words*: Aerodynamic grip; Downforce; Lift force; coefficient of drag; Negative lift.**

1. INTRODUCTION

Car stays on the ground because of downforce. The negative lift is known as downforce. In other words, the same physical law that allows planes to soar upward also forbids cars from flying. This is the shape of an aircraft's airfoil, which generates lift by creating a low-pressure area on the upper side and a high-pressure area on the lower side. Lift is developed by the pressure difference. What if the shape is flipped around? Due to this, there will be more pressure upward and less pressure downward, which in turn give a negative lift. Downforce is the term for this negative lift. As a result, the car's wing is bent in the opposite direction, causing the air deflected beneath it to flow at higher speeds and generate a lower pressure area than on top. The force that pushes the car down is referred to as "Downforce," and it improves grip

In 1977 Lotus team owners Colin Chapman and Peter Wright introduced their first 'Wing Car'. They had discovered that by shaping the whole car like a wing they could speed up the airflow underneath it relatively to the airflow over the top of the car. Thus, creating a vacuum under the car, it would be pulled down to the track creating a huge amount of downforce. An extra benefit to this way of creating downforce is that there would be less drag from the front- and the rear wing so the car's speed on the straights would be less compromised. The Lotus 78 was having reliability issues in the beginning but those were solved during the 1977 season, by fine-tuning the 'Venturi Tunnels' responsible for creating the increased downforce, and in 1978 Lotus won 4 out of the first 7 races. Cox had the wonderful idea of using a fan not just to create a ground effect, but also to keep the engine cool. Because most other builders were completely unaware of the reasons for the Lotus' success, Gordon Murray of Brabham was the one who finally figured out what brilliant solution Chapman had devised to generate such massive downforce. However, because of the bigger Alfa-Romeo Flat-12 engine in their Brabham BT46, the 'Venturi Tunnels' required to achieve the desired ground effect were not achievable due to a shortage of space under the back of the car. Murray was brainstorming with David Cox another way to create a vacuum beneath the car. They were inspired by a Can-Am sports car known as the 'Sucker Car,' the Chaparral 2J. In 1970, Chaparral competed with two fans in the back of the car, each using a small two-wheeled engine, pumping air behind the car, resulting in decreased pressure and increased downforce. Murray intended to try a similar concept with BT46 after seeing how fast Chaparral 2J was. The work made was using an active device to increase the downforce for the models were banned and use of an active device to increase the downforce was banned in F1 racing. But still, passive devices can be used to create this effect. And giving propeller blade structure to the wheel will fulfill this need.

1.1 LITERATURE SURVEY

This section discusses in brief, various studies conducted by researchers with regards to the aerodynamics of Formula One race cars, and the various techniques used to optimize the bodywork and its components to reduce lap times. The aerodynamics of race cars talks about the forces on the vehicle at high speed. The aerodynamics of racing cars is similar to the aerodynamics of an airplane. While the main purpose of the components of an aircraft is to generate lift, most of the components on a racing car are designed to create downforce, i.e., lift in a negative direction. Aerodynamics allow tons of downforce to be created on the front and rear axles, without increasing the weight of the body; thus, increasing tire adhesion, which, in turn, allows the race car to negotiate a turn at a higher speed.

Downforce aids traction as well; however, the improvement is not as large when compared to braking or cornering. The acceleration is limited by the engine power available. When the car turns and brakes simultaneously, a significant point to be noted is that even though the resultant force available to the tires is equal to pure cornering or braking force, the individual capacities of the components of the resultant force (cornering and braking force) are lesser. It can be concluded that braking while negotiating a turn will reduce the cornering force, leading to an unprecedented slide. Thus, levels of downforce have to be increased sufficiently to prevent the slide from occurring. Theoretically, the higher the downforce acting on the car, the faster it can make the turn without sliding.

Nothing comes free of charge though. The penalty for excessive downforce comes in the form of increased drag [3]. Hence, the main task for aerodynamicists in designing the bodywork is to optimize the balance between downforce and drag forces created to obtain the fastest possible time around a race track. Aerodynamics of race cars not only involves the creation of downforce but also includes areas such as airflow to engine box and radiators, cooling of brakes, limiting fuel sloshing, the release of exhaust gases, etc. However, this work primarily focuses on the issue of obtaining optimized downforce and drag values for F1 cars.

In [6] Motorsports are all about maximum performance, to be the fastest is absolute. There is nothing else. To be faster you need power, but there is a limit to how much power you can put on the ground. To increase this limit, force to the ground must be applied to the wheels. Weight gain can do this, but weight gain makes it worse and requires more energy. So we need a realistic weight, we call it downforce and get in the airflow near the car. The wings have been shown solely to give a sense of proportion.

Usually, the word "lift" is used to describe any kind of aerodynamically generated energy that works in space. This is given an indication, either "positive lift" (top) or "negative lift" (bottom) in terms of its path. In ground aerodynamics (cars, bicycles, etc.) the word "lift" is often avoided as its meaning is almost always defined as good, that is, lifting a car off the lane. The Downforce should always give a sense of negative force, i.e., to get more traction force.

The desire to continue to increase the adhesion of the wheels led to a major shift in the construction of race cars, the use of an improper lift or 'downforce'. As for the tires, the adhesion of the sides is almost equal to the load on it, or the friction between the wheel and the road, adding low aerodynamic strength to the weight component improves adhesion. The downforce also allows tires to transmit more power without wheel rotation, which increases the potential for acceleration. Apart from the aerodynamic downforce to increase grip, modern racing cars are so powerful that they can spin wheels or travel at speeds in excess of 160 km/h.

A spoiler is a simple plate placed somewhere on the body of the car so that it can obstruct or "spoil" the flow around the vehicle, allowing a controlled separation of the flow at the desired location. This is done because fast, smooth airflow leads to positive lift, so impeding this flow either reduces or perhaps cancels lift altogether.

A rear spoiler is a plate mounted at the rear of the vehicle and in order for it to be considered a spoiler, the plate must be integrally attached to the body. If there is space between the plate and the body, it is considered a wing. The spoiler causes a split in the back of the car, causing a disturbance just before flow, this distortion causes the flow to slow down, thus reducing the minimum pressure in the area in front of the spoiler. Therefore, the elevator in the back of the car is removed. When properly designed, the rear spoiler will create downforce on the back of the car.

The diffusers, behind the wings, are the tools that are basically used to create inflation on the back of a race car. In them, the Bernoulli equation is used as we do with the venturi tube. It can be seen that in a venturi, the square of pressure and velocity is inversely proportional. Thus, a diffuser can help reduce the low pressure under the car to increase speed.

At the front of a vehicle, the main sources of downforce are the underbody with the front spoiler (also known as a spoiler, dam, or splitter), cleats (also known as diving plates), vortex generators, and front diffusers.

Spoilers, dams, or splitters are better explained by following the link. They reduce the gap between the ground and the vehicle (facing it towards the side of the vehicle) by blocking as much air as it can get under the vehicle, using a spoiler on a vehicle with very turbulent airflow on a non-smooth-floored vehicle can result in less air passing through all elements of the vehicle's floor, significantly reducing drag and also reducing lift. (and maybe a little downforce) in this case.

Duck and the vortex generator in detail. A small fin in the front corner of a car. Although the inclination of this plate is minimal, it creates downforce in the front of the vehicle. The same device can be used in other parts of the car. However, care must be taken to ensure that the vortex on the leading edge does not interfere with the operation of the rear wing or other aerodynamic devices. This dive plate is sleeker than any other and is too small to generate as much downforce. Instead, it is used to adjust car handling before the race.

In [1] we can see To achieve the optimized drag for the vehicle, the research is being carried out on certain add-on aerodynamic devices to reduce the resistance offered by wind and improve the efficiency of the vehicle. In this research, the effects of various aerodynamic devices like the rear wing, spoiler, diffuser, and fins are examined and the change in the coefficient of drag is investigated.

Spoilers are one of the most widely used and important aerodynamic devices in the automotive industry. Its main purpose is to help reduce drag by "disturbing" unwanted airflow and sequencing the airflow. However, the actual use of the spoiler is noticeable at high speeds above about 120 km/h. Commercial vehicles typically use it to enhance the appeal of vehicle designs that offer little or no aerodynamic advantage. So basically, high-performance cars apply it to achieve higher speeds. The low-pressure area behind the vehicle is reduced, which creates less turbulence and consequently reduces drag.

The ultimate aim of every race car designer is to improve the lap time, without compromising safety and other aspects. To achieve this objective, the most predominant factor is cornering ability at high speed. During cornering, the cars have to reduce their longitudinal acceleration to compensate for the lateral acceleration i.e., it has to slow down while cornering to avoid sliding or deviating from the desired path, as the traction provided by the tire is limited for a given load. One such way to improve the cornering ability, ultimately improving lap time, is by improving the traction of the tires by increasing the load acting on them. Resistance forces acting on the body are generally of two types: viscous and forced. Induced drag results from the creation of lift and viscous drag results from the boundary layer interaction between the body and the fluid (air in this case). Thus, the overall drag coefficient for the final wing is calculated.

The best way to increase the load on the tires when cornering is to increase the car's aerodynamic downforce coefficient to some extent (up to the critical downforce coefficient). An important factor in reducing the amount of resistance is the positive effect of the time delay due to the decrease in muscle strength on the hip. [2] introduces a method to determine the most important deceleration factor of a vehicle on a specific track. Significant reduction factors are determined by a series of analytical statistics and simulations performed using OptimumLap software. The critical coefficient of downforce for the FSAE- no aero car on the Buddh International circuit is found to be 2.2 and the corresponding lap time is 128.950 which is about 10 seconds clear from the lap time by the initial setup without any aerodynamic downforce. Going further the critical coefficient, the lap time increases which is undesirable. So the aerodynamic add-ons should be designed to reach the downforce coefficient of 2.2.

2. METHODOLOGY

The challenge is to decrease the lift that is created due to air moving under the car and creating an undesirable lift force. So, to eliminate this effect wheels have been used to ignore unnecessary power consumption. The rotation of the wheel itself creates a suction effect that makes the air under the car model to move out and create a low-pressure area which in turn increases downforce without affecting the fuel efficiency of the car as we used a passive device for the job. The air exhausted from the wheel will increase drag substantially due to its rotation. So, to ignore this increase in drag further a covering is given for the rear wheel and two holes have been made to guide the flow to the low-pressure wake zone which is made behind the car. So that it can increase the pressure at the rear end of the which further decrease the drag coefficient.

2.1 MODEL

For designing the base model car, CATIA V5 was used and the basic model was created. Then the file was exported for analysis in .igs format for Ansys.

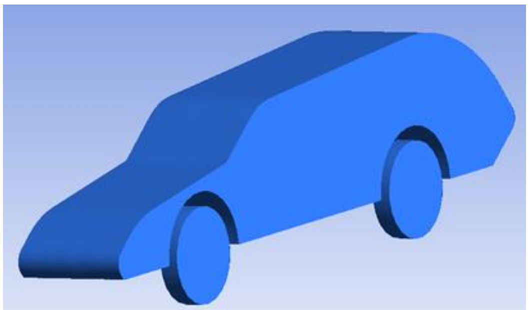

Fig -1: Base model car

The three-dimensional car model was imported to the ANSYS™ workbench. Computational Fluid Dynamics (CFD) was carried out in the FLUENT module. In Design Modeler, an enclosure is developed of dimensions 1500 × 300 × 600 mm to form a virtual wind tunnel.

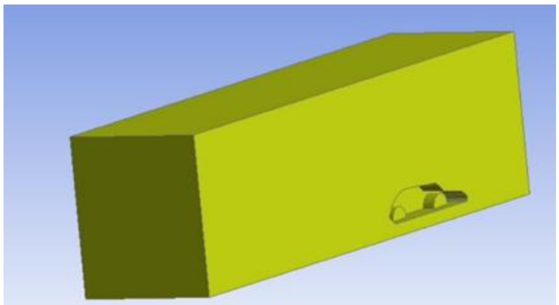

Fig -2: Enclosure

2.2 MESHING

An appropriate mesh was developed using ANSYS™ Mesh Tool. The mesh was observed to be coarser at the inner domain and finer at the contact region with the vehicle as shown in Figure 4.3. A total of 591,978 nodes and 424,773 elements were formed after the meshing was done.

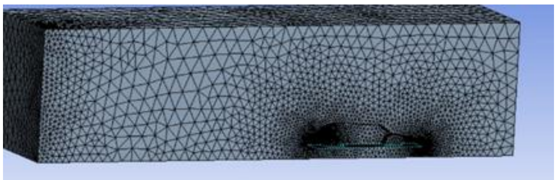

Fig -3: Mesh

2.3 BOUNDARY CONDITIONS

The fluent was set to work on double precision and solver processes were made to 4. Due to its stability and ease of convergence, the Standard k-epsilon model was selected as a turbulence model.

Table -1: Boundary Conditions

Boundary conditions	
Region	**Boundary Condition**
Inlet	Velocity Inlet, v=50 m/s
Outlet	Pressure outlet, reference pressure = 0 Pa

2.4 SIMULATION

The streamline diagram of different cases is listed below:-

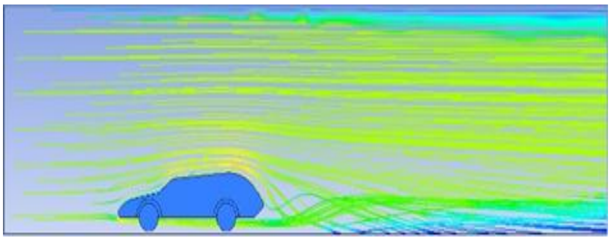

Fig -4: Streamline diagram of the base model

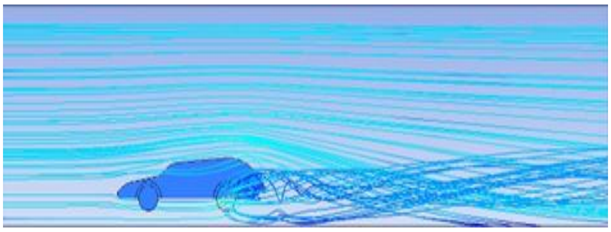

Fig -5: Streamline diagram of case 1

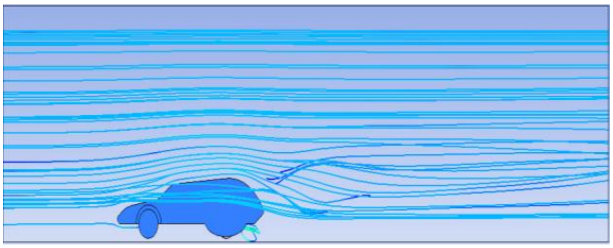

Fig -6: Streamline diagram of case 2

All the designed car models with wheel conditions are simulated in ANSYS™ 21.0 Fluent. The results of the drag coefficients obtained are discussed below:-

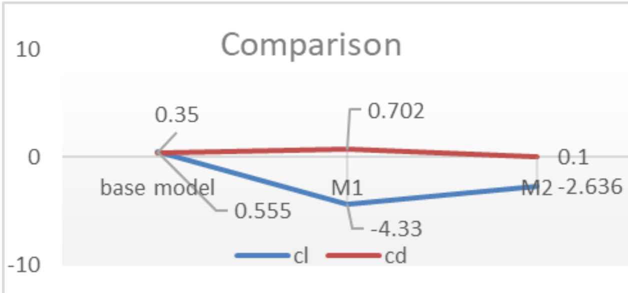

Chart -1: Graphical comparison of cd and cl of different model

The objective of this study was to develop a methodology to create downforce by creating low-pressure region below the model. After providing a historical background of Downforce and developments in the field of race aerodynamics to increase downforce, a literature review was conducted to develop a focus area for this research study.

An introduction was provided for the basic boundary condition (Ansys) used for simulating the models to get cl and cd value. A model was created in CATIA to start the simulation. Enclosure and other geometrical specifications were given.

An Analysis using Ansys was performed to determine the cl and cd values of different model conditions. The resulting best cl was -0.26 and the cd value for same was found to be 0.1.

3. CONCLUSION

After getting more drag value in case 2 the wheel was given a covering over it and two holes to guide the flow to the low-pressure wake region. The cl value for case 3 got closer to the optimized value that is 0.22 and also the drag value reduced from 0.35 to 0.1.

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