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Aerodynamic Drag Reduction on Race Cars

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Abstract: **Among the various factors which influence the performance of a race car such as power, driver, weight, tires, aerodynamics, aerodynamics represents a major area. Aerodynamic drag in racecars will hinder top speed and more engine power is required to propel the car forward, and also decrease in downforce will results in low cornering powers at high speeds. The easiest and most effective solution to drag reduction problem came in the form of wings which is now designed to generate negative lift and are analyzed using computational fluid dynamics softwares..**

1. INTRODUCTION

Race car performance depends on elements such as engine, tires, suspension, road, driver and aerodynamics. Formula one has been at the forefront within the field of aerodynamics along and it was in the racing industry the exploitation of the underbody airflow was utilized at first. It was discovered that the airflow under the vehicle was noticeably affected by the close proximity to the ground and it was at this time a large amount of development time was dedicated to researching ground effect.

At first the objective was to increase the negative lift force (Downforce) by accelerating the underbody airflow by reducing the cross sectional area and creating a region of low pressure, but it was soon discovered that this under certain circumstances had a positive impact to the drag.

When investigating the aerodynamic behavior of a vehicle, Computational fluid dynamics in boundary layer suction (BLS), (MSES-suction method) and are compared with XFOIL-Suction method and is essentially used to predict the downforce and drag racecars should experience at high velocities.

2. AERODYNAMICS IN RACE CARS

First racing cars were primarily designed to achieve high top speeds and the main goal was to minimize the air drag. But at high speeds, cars developed lift forces, which affected their stability. In order to improve their stability and handling, engineers mounted inverted wings profiles generating negative lift.

In recent years, the rules relating to aerodynamics have changed, primarily for safety reasons. In the late sixties, wings first appeared on cars, and were progressively integrated into the design of the top motor sport category, Formula one.

In 1997, Lotus first applied profile underbodies, making use of close ground proximity aerodynamics, or ground effect. This lead to rapid development of underbodies shaped in the form of aerofoils, combined with movable side skirts to seal the underbody region from the outer flow. This development lead to the generation unprecedented amounts of downforce and a sharp increase in cornering speeds.

Aerodynamics development play a vital role in modern auto sport, either in reducing drag or creating downforce. This downforce or negative lift generated by the car increases the vertical load on the tires, thus increasing tire friction. This increased tire friction enables a racing car to take corners at speeds unobtainable without downforce.

The aerodynamic designer has two primary concerns: the creation of downforce, to help push the car's tires onto the track and improve cornering forces; and minimizing the drag that gets caused by turbulence and acts to slow the car down.

2.1 Aerodynamic Drag

One of the major factors that race car manufacturers focus on to decrease lap time, and gain a competitive edge is the aerodynamic performance of the vehicle. The lift and drag forces that act on a race vehicle impact the performance and the body shape of each car is formed in an attempt to control these forces to maximize vehicle performance.

As a car moves along, it pushes the air that surrounds it away. As a result the car is subjected to drag. Drag, also known as air resistance or fluid resistance refers to forces that oppose the motion of the vehicle.

Drag is the force that acts opposite to the path of the vehicles motion (Figure 1). Drag is detrimental to vehicle performance as it can limit the top speed of the vehicle and increase fuel consumption, both of which are negative consequences for race vehicles.

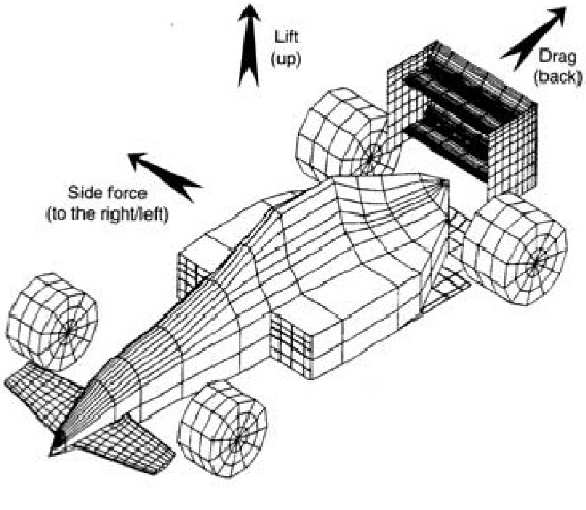

Figure 1. Aerodynamic forces acting on race cars.

2.2 Downforce

Downforce is the downward thrust created by aerodynamic characteristics of a car. The purpose of downforce is to allow a car to travel faster through a corner by increasing the vertical force on tires, thus creating more grip.

By manipulating the race car geometry it is possible to create negative lift, or downforce. Aerodynamics, particularly Ground effect aerodynamics, as applied to open wheeled racecars is still mainly an experimental science.

Two primary components of a racing car can be used to create downforce when the car is travelling at racing speed:

- Shape of the body
- Use of aerofoils

3. AERODYNAMICS OF WINGS

In Fig. 2 below, a conventional airfoil (that is, as in an airplane wing) with air moving across it from left to right as identified by the streamlines. (The streamlines represent a pictorial description of the fluid motion of the air particles in a steady-state flow.)

The air that travels along the upper surf ace of the wing is forced upwards and becomes compressed against the air above it, which makes it flow at a higher velocity; in the region below the foil the air gets instead expanded causing it to travel at a lower velocity.

Following, Bernoulli's principle, the air traveling in the upper region has a lower pressure due to its higher velocity, whereas a higher pressure is seen in the lower region due to the air lower velocity. This pressure difference acting along the surface of the wing is what generates the net upward force known as lift. This pressure difference is clearly presented by the color of the air medium in Fig. 2 below; the blue and green regions represent areas of low pressure while the orange and red areas represent regions of high pressure.

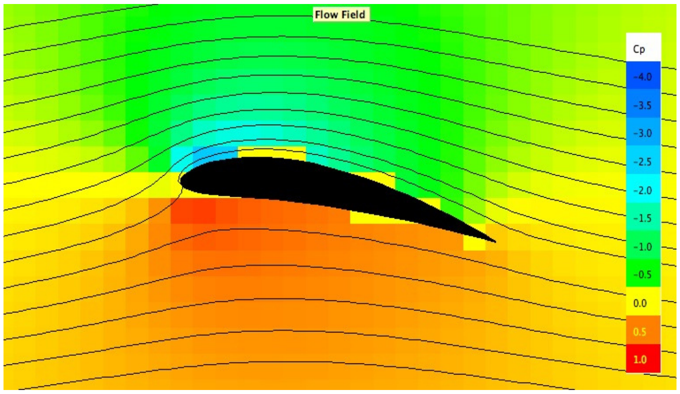

Figure 2. Profile of a conventional wing traveling through air.

In order to produce negative lift, or downforce, for race cars, the wing is simply inverted, so that the air traveling along the upper surface is slower than the air traveling along the lower surface, thus reversing the pressure difference and creating a net downward force.

The net lift or downforce, depending on orientation, of an airfoil is described non-dimensionally as,

$$L=\frac{1}{2}\rho v^2 A C_L$$

Where, ρ is the density, v is the flow velocity,
A is the span area of the wing also known as the planform area, C_L is the lift coefficient.

Airfoils also experience a drag force that acts in the opposing direction of the moving airfoil in the horizontal plane. The drag is a result of the tangential stress (frictional drag) and the pressure distributions that are normal to the surface of the wing (pressure drag). This force can also be expressed non-dimensionally as,

$$D=\frac{1}{2}\rho v^2 A C_D$$

As mentioned for the equations of lift and drag, much of their value is dependent upon the geometry and orientation of the object in question when moving through a flow. In the case of wings, the lift coefficient can be altered drastically based solely on its orientation with respect to the oncoming flow. This value that describes wing orientation is called the *angle of attack* (α) and more specifically, it describes the angle between the chord line of a wing and the direction of the oncoming flow. A pictorial representation can be found in fig. 3 below.

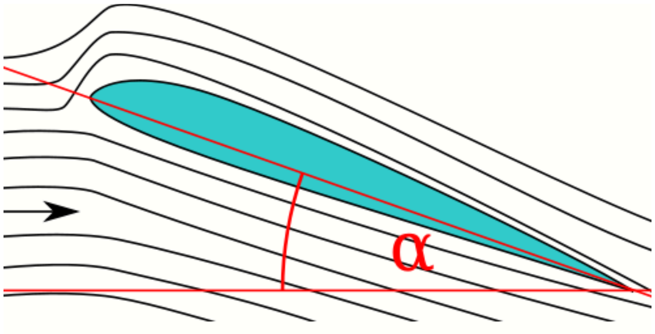

Figure 3. Diagram describing angle of attack.

This parameter is important because the lift coefficient can increase with increasing angle of attack until a maximum lift coefficient is reached. This value is important for race car engineers as they can fine tune how much downforce a race car needs for a particular track.

3.1. Race Car Wings

In the early days of race car design, the principal aerodynamic goal was to have a design that minimized drag in order to maximize top speed. Over the years, however, as racecars started to become faster and more powerful, the need for traction, or adhesive friction between the tires and road surface, during high-speed corners began to become a pressing issue.

The easiest and most effective solution to this problem came in the form of wings or airfoils similar to those found on airplanes, which, however, would be now designed to generate, instead of lift, “downforce," i.e. effectively negative lift. The difference between the lift produced by an aerofoil used in aircrafts and race cars is shown in figure4.

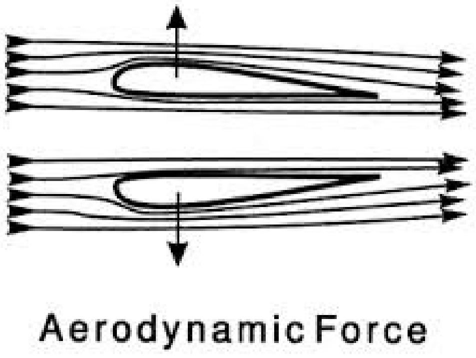

Figure 4. Difference between Airfoil and Inverted Airfoil.

These wings would be mounted to the chassis of a racecar to transfer the force generated to the chassis itself and through this to the car axles and wheels. This increases the downward pressure in the contact area between the tire and the road surface, thus also increasing the adhesive friction between these two surfaces.

4. WING DESIGN

4.1 Multi-Element Wing

The race car wing differs from the design of a traditional wing as presented in fig. 2, in that it uses a multi element design. Multi-element wings produces far more lift or downforce than a conventional single wing design.

By seperating the two elements, the effective range of angle of attack is increased leading to maximum lift or downforce.

The disadvantage of such a design, however, is an increase in drag. In race cars the increase in drag force can be counterded with increased engine power output. However, the ability to generate downforce for same ability with respect to single element wings make multi element design to be preferred by many race car designers.

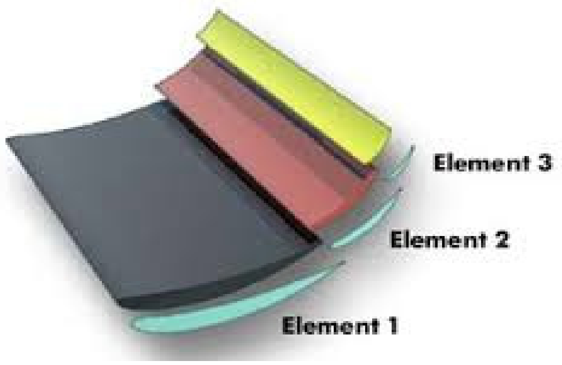

Figure.5 Multi-Element Wing used in race car rear wing.

5. COMPUTATIONAL STUDIES

5.1 Boundary layer Suction (BLS)

To overcome the problem, the aerodynamics of a wing profile should be influenced actively. One of those active techniques is called boundary layer suction (BLS). With this technique, the small layer of air just above the wing can be removed, which has a stabilizing effect in postponing transition (keeping the boundary layer laminar) and postponing separation (keeping the boundary layer attached). As a consequence, lower drag and higher lift forces can be achieved.

The small layer of air just above the surface of the body which is subjected to friction is called the boundary layer. In this layer instabilities can arise. When only the shaping technique is applied, these instabilities are able to grow and cause transition from laminar to turbulent flow.

This turbulent flow causes an increase of the thickness of the boundary layer and an increase of the friction drag. Secondly the boundary layer is also subjected to pressure gradients due to the shape of the body. When an adverse pressure gradient is encountered, the boundary layer (laminar or turbulent) becomes thicker and eventually adverse flow can arise, i.e. the boundary layer separates from the surface of the body. Separation of the flow causes an increase of pressure drag and finally a big separated region cause's stall, a serious decrease of lift and increase of drag.

5.2 BLS Applied to Race car wings

Race car wings always consist of several elements to maximize the downforce of the car. Approximately half of the total downforce of the car is generated by the front and rear wing.

By applying BLS to race car wings, the downforce of the car can be increased by using a small amount of engine power. This way the aerodynamic limits to the downforce of the car are exceeded by the use of BLS. Also the pressure drag of the wing will decrease, but this is of less importance, because the increasing induced drag will undo this advantage. Increasing the downforce is especially interesting for the front wing of the cars.

In race conditions, the front wing is subjected to variable conditions which sometimes cause a loss of downforce. For example during overtaking, the front wing will lose downforce due to the slip stream behind another car. With BLS, this problem of low energy airflow can be solved, which makes it easier to overtake. A second advantage is the ability to decrease the downforce on high speed parts of the racetrack, and consequently also the induced drag, by blowing a small amount of air into the boundary layer. This way, the location of separation can be moved as the designer wishes. As a consequence BLS contributes to better racing results.

When applying BLS to race car front wings, it is also important to keep in mind the so called wake bursting effect. Wake bursting is a phenomenon which only occurs on highly loaded multi-element airfoils. Without any separation on the wing surface, the airfoil can stall because of flow reversal in the center of the wake of the main element. This happens when the wake of the main element flows from the low pressure at the trailing edge of the main element into a region of high adverse pressure gradient. This pressure recovery results in an amplification of the displacement thickness of the wake, which in turn suppresses the upper surface pressure distribution on the following elements. With increasing angle of attack, the off- the surface pressure recovery exceeds a certain limit and flow reversal occurs near the centerline of the wake. The rapid growth of the wake is called wake bursting and reduces the circulation of the airfoil system which causes stall.

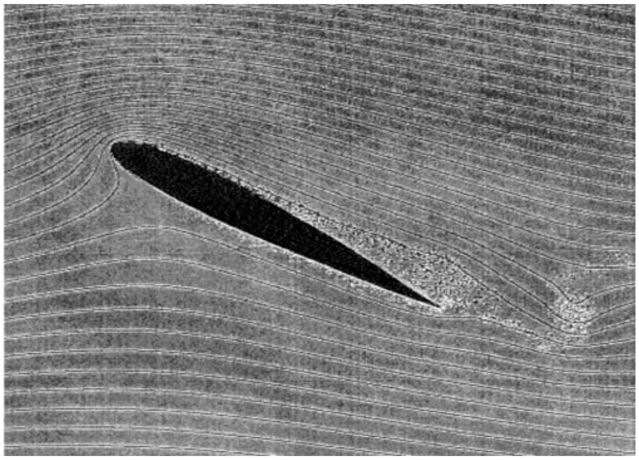

Figure 6. Boundary Layer Suction applied to Airfoil in Race Cars.

6. CFD RESULTS FOR NACA747A315

For the NACA747A315 wing profile, BLS is applied between 40% and 95% chord. When the transition point is located behind or in the suction area, the suction distributions are obtained by specifying a target shape factor of $Hk = 2{:}6+0{:}05$ for the laminar part of the boundary layer and a target shape factor of $Hk = 1{:}4 + 0{:}05$ for the turbulent part. At angles of attack beyond 6 degrees, transition will occur in front of the suction area. At these angles a prescribed suction distribution for the turbulent boundary layer is used.

The calculations are performed in a range of angles of attack between -1.5^0 and 14^0. As a result, the next graphs are shown: Cl versus α (figure 7), Cd versus α (figure 8), Cl versus Cd (figure 9), Cdf versus α (figure 10) and are compared with XFOIL-Suction method.

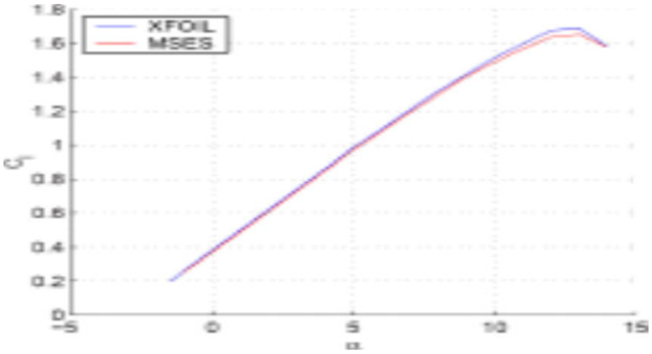

Figure 7. C_L versus α

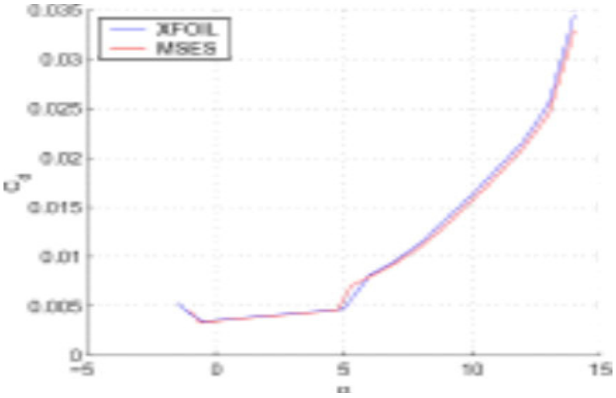

Figure 8. C_D Versus α

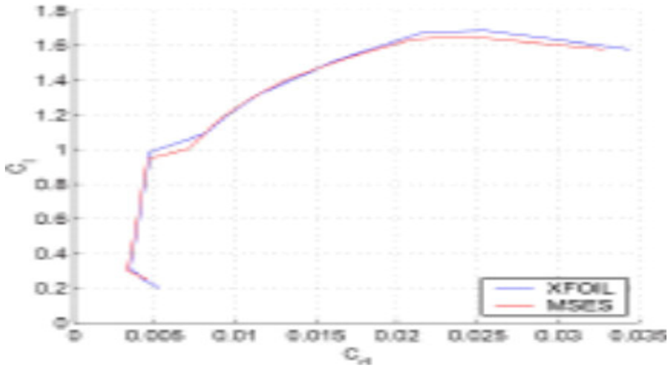

Figure 9. C_L Versus C_D

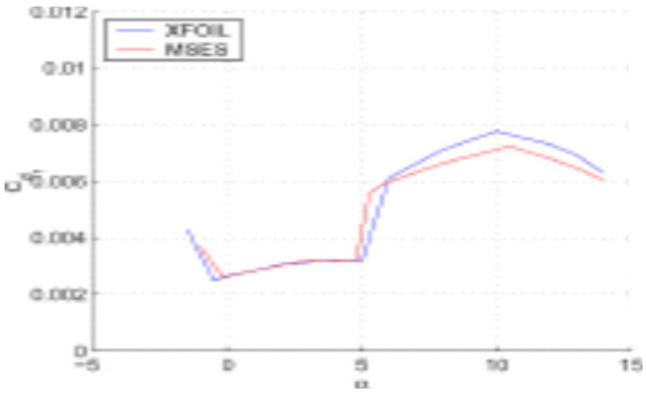

Figure 10. C_{Df} Versus α

7. CONCLUSIONS

A number of highly complex flow features are associated with ground effect aerodynamics of cars. For the wings in ground effect major physical features are identified and force regimes classified, including the phenomenon and regions of downforce enhancement, maximum downforce, and downforce reduction. Through this performance of the race car wing was analyzed, its aerodynamics evaluated. The results for NACA717A315 airfoil was obtained and were found satisfactory using MSES-suction method.

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