

A Study on the Influence of the Flow Field around the Front and Rear Wings on the Resistance of F1 Racing

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Abstract. In the racing field of F1 cars, the size of wind resistance and the flow field distribution of the environment around the car at high speed play a key role in the driving speed and turning speed of the car. The amount of wind resistance is controlled by a system called DRS, which controls both the nose and the rear wing of an F1 car. In this paper, the influence of the design of the front wing and rear wing on the air resistance of the car in driving is introduced in detail. The fluid characteristics around the F1 car are analyzed by analyzing the wind resistance and wind force in various places during driving. In addition, this paper will analyze the formation of the tail-vortex of the racing car, control the strength of the tail-vortex system and reduce its turbulence degree, and at the same time reduce the turbulent energy consumption of the air flow to achieve the purpose of drag reduction. The research shows that the formation of tail-vortices is the main reason for the drag of automobile driving. We want to reduce the drag of tail-wing and weaken the formation of these vortices.

Keywords: Front wing, Air resistance, Fluid characteristics, Wind force.

1. Introduction

In the racing field of F1 cars, the size of wind resistance and the flow field distribution of the environment around the car at high speed play a key role in the driving speed and turning speed of the car. The amount of wind resistance is controlled by a system called DRS, which controls both the nose and the rear wing of an F1 car. The biggest drag component in an F1 car is the tail, but it is impossible to remove the tail to reduce drag. If you remove the tail, F1 cars have poor stability and turn slowly [1]. The rear wing can provide downforce, which can improve the grip of the rear wheels, as well as speed of turning [2]. The front wing at the front of the car act as an effective diversion to support the front wing and speed up the replacement of the wing. This paper mainly analyzes the smooth distribution of front wing and rear wing around F1 cars in straights and turns, as well as their effect on car stability and wind resistance reduction [3, 4].

In this paper, the influence of the design of the front wing and rear wing on the air resistance of the car in driving is introduced in detail. The fluid characteristics around the F1 car are analyzed by analyzing the wind resistance and wind force in various places during driving. In addition, this paper will analyze the formation of the tail-vortex of the racing car, control the strength of the tail-vortex system and reduce its turbulence degree, and at the same time reduce the turbulent energy consumption of the air flow to achieve the purpose of drag reduction. The research shows that the formation of tail-vortices is the main reason for the drag of automobile driving. We want to reduce the drag of tail-wing and weaken the formation of these vortices.

2. Flow field distribution in front wing

2.1. Principles of front wing

The front wing assembly, which is made of carbon fiber, is the first component of the car to contact the air mass. As a result of the least amount of air disturbance and lowest level of friction, the flow

field here is better than at other locations on the vehicle. A sequence of smaller wings are positioned one behind the other to make up the front wing [5].

These wingspread carefully designed and aligned to optimize the downforce on a Formula One car. The engineers and designers have to also regulate the airflow in the wake of the front wing. when the car moves cross the air, the front wing manipulates this air in order to create a high pressure region on top of the. What's more, a low pressure region under the wing is created as well. The difference in air pressure is reflected by a force which pushes the wing downwards into the ground. What is more, another design purpose of the forward wing is to mitigate the amount of ride height sensitivity' to produce a car with consistent aero balance as the car is cruising through the track [6].

2.2. Flow field related elements

The article studies the relationship between flow field with the rear wing and the front wing in F1. The official definition of flow field we can search for is the distribution of the density and velocity of a fluid over space and time. FlowFields are not physical fields registered to the database. This is a description of a calculation and a location for viewing the result [7].

As the information in FlowFields only exists at runtime, the values in FlowFields are automatically reset to zero. You can update a FlowField with the CalcFields method.

2.3. The flow field distribution is aimed at the application of front wing in F1 race

While the whole F1 should weigh no less than 798 kg, the heaviest part of a Formula 1 car is the engine that must weigh a minimum of 150 kg, while the lightest part is the flywheel that weighs 1.3 kg.

The front wing is an essential part of an F1 car; it is the first part to hit the airflow, and therefore shapes the car's aerodynamics [8].

It is steeply tilted to turn the air up and over the body, while the end plates smooth and condition the airflow around the wheels and into the side nacelles. The image below is about a front wing in the Ferrari car. The curved-line shape can keep the air flowed above and below the flat surface at a balance level to make sure that the front part of the car can firmly grasp the ground and keep the car in a balance motion to accelerate more quickly. The Ferrari team has specifically test the type of front wing showed in the image [9]. Installing some sensors at some parts of the wing and the sensors can measure lots of datas such as velocity, force at different surfaces, the vibrate rate during motion and so on. If we compare the wing in the image to the old type, the new one has more tiers of carbon fiber material. Therefore, it can separate the air flow field into many layers in order to make the car more balance.



Figure 1. The front wing of a Ferrari F1 car with curved-line shape and flat surface [3]

3. F1 rear wing

3.1. Aerodynamic balance

The rear wing is at the end of the car and produces 30% of the car's negative lift. The tail can be divided into two parts: the upper tail, which towers over clean air, and the lower structure, known as the lower beam, which provides additional negative lift. The rear wing is the first part of an aerodynamic system. The rear wing has been a fixture on F1 cars since the 1960s. The structure has changed and grown more sophisticated since that time. The upper wing of the rear wing first appeared at the turn of the century with a composite structure made of several wings, which can have a very strong impact [10]. Since then, the FIA (Fédération Internationale de l'Automobile) has enacted new regulations to make the rear wing design simpler and less aerodynamically negative. The FIA divides the tail superstructure into two pieces, advances the upper tail's installation position, and narrows and heightens the top tail to an area that is only 22 cm high, 35 cm long, and 75 cm broad.

The rear wings is where the air will come together after passing over the upper and lower rear wings. Due to the disparity in velocity and pressure between the two airstreams, when they collide, they create a spiral vortex that expands at the trailing edge of the rear wing. In wet track conditions, this wake can be observed. The car's straight-line speed is decreased due to drag caused by this vortex. The edge and lower wing surface of the tail lift are typically low pressure, while the upper wing area is predominantly high pressure. In order to balance the pressure at the wing tip and lessen the vortex it created, the F1 designers fitted louvers to the end plate's upper tail. In order to improve the visibility of the race, the FIA introduced the DRS adjustable rear wing. Used to increase the number of overtakes during a race. The principle of this device is simple: through technical means (usually controlled by hydraulic devices), the upper tail auxiliary is flattened when needed, which eliminates the aerodynamic Angle of attack of the ailerons, reduces the area of ailerons relative to the airflow, and thus plays a good drag reduction effect.

When the car in a circuit allows the use of DRS area (is compared commonly long straight), through the driver by pressing a button, make the tail on the bottom of the wing plate flat, let air flowing through the upper half to reduce the car tail (Figure 1) on the wash effect, and thus reduce the tail under pressure (air resistance). Allowing the CAR to reduce the downforce of the air at high speed reduces the friction on the car's tires, allowing it to gain more speed and therefore have a chance to overtake the car in front of it. According to estimates from the International Automobile Federation (FIA), turning on DRS adds 10-20KM/H to a car's original speed.

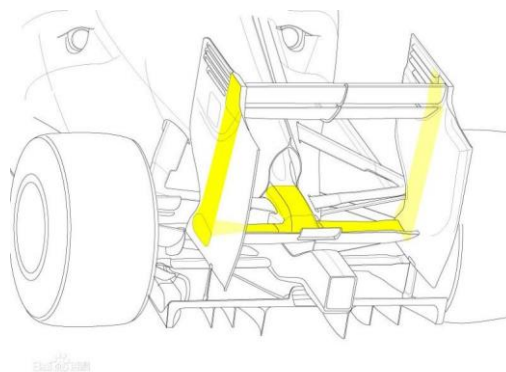


Figure 2. Racing tailstock structure [2]

3.2. Wind tunnel test

As an important part of fluid mechanics, vehicle aerodynamics is a subject which studies the relationship between the interaction force and the motion rule of the vehicle and the surrounding air when they are moving relative to each other. When the car is moving at a fast speed, the complicated interaction between the air and the vehicle has a significant impact on how the vehicle is operating. Because of the shape of the car, its aerodynamic drag can be reduced, improving both the vehicle's

dynamic performance and fuel efficiency. Aerodynamic stability is a need for the safe running of a racing automobile at high speeds. When a car is moving straight, it encounters air resistance, which is a portion of air force. There are two different types of air resistance: pressure resistance and friction resistance. The portion of the pressure resistance force that acts in the driving direction on the shape's surface is the resultant force of normal pressure. As a result of the tangential force caused by the viscosity of the air on the body surface, friction resistance is the component force in the driving direction.

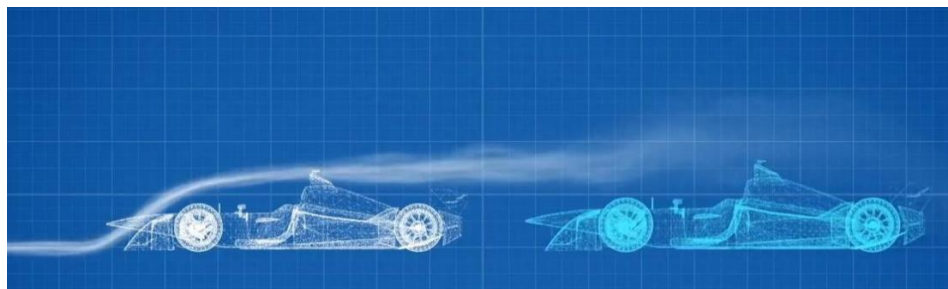


Figure 3. External flow field of racing car [2]

3.3. Velocity deficit

The main goal of aerodynamics research in Formula One is to reduce air resistance to the absolute minimum while ensuring that the car generates adequate downforce to increase its speed and stability at high speeds. All the components that serve the aerodynamics are called the aerodynamics kit. The aerodynamic components on every F1 car need to undergo wind tunnel testing to observe the flow field distribution of the F1 car at high speed (Figure 2). There is still considerable controversy over the wind tunnel. Wind tunnels cost tens of millions of dollars to build and millions to operate. Some teams can't afford their own wind tunnels and have to use another team's, while others can have two or more. Testing cars in wind tunnels is expensive, expensive, and the energy consumption is staggering. In addition, wind tunnel test can only test the air flow field in the case of relatively stable wind speed during driving, and the rest of the situation can only be simulated by computational fluid dynamics test (CFD). Wind-tunnel testing time can be reduced by more efficient use of CFD, a numerical method that programmatically calculates the expected performance of a car by entering all its dimensions into a computer (Figure 3)

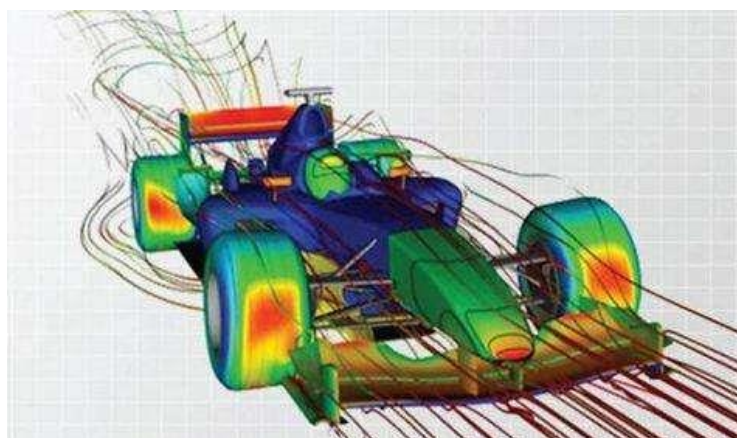


Figure 4. Racing external speed streamline

Aerodynamicists tell us that the F1 wind tunnel is a low-speed closed circuit wind tunnel. That means we're talking about wind speeds close to 10 to 100 meters per second, and that same air would be recirculated in the wind tunnel. The airflow is rotating, typically in four 90-degree corners, with the fins in each corner next to each other, to prevent turbulence.

In the process of automobile driving, the value of air resistance is usually proportional to the dynamic pressure ($\frac{1}{2} \rho u^2$) of the airflow velocity. The expression is:

$$F_w = \frac{1}{2} C_d A \rho u^2 \quad (1)$$

Where C_d is air resistance coefficient; ρ is air density; A is windward side base.

4. Effect of wake flow

4.1. External flow of racing car

Internal flow and exterior flow are the two categories under which the flow field around an F1 car falls. The internal flow refers to the air flow in the engine and exhaust system, while the external flow refers to all the air that flows over the surface of the car.

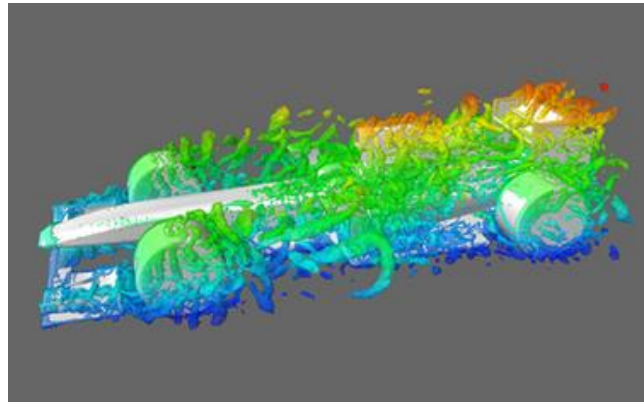


Figure 5. Racing external speed vortex

The external flow has the property that some air close to the ground must be driven through between the vehicle and the road. The streamline will continue through the car as the air flows through it, creating a vortex at the back of the vehicle and causing resistance. Boundary layer refers to the fact that viscosity only affects a narrow layer a few millimeters thick on the surface of the automobile in still air, when there is no air flow separation. The border layer is this thin layer. The Reynolds number, a dimensionless number that describes fluid flow, and the geometry of a racing car are intimately tied to the vehicle's viscous flow properties. The Reynolds number can be represented as:

$$Re_t = \frac{V_\infty l}{\nu} > 10^4 \quad (2)$$

In the equation, V_∞ is the speed of the F1 car, ν is kinematic viscosity of a fluid and l is the characteristic length of a racing car. If different objects have different air velocity, fluid characteristics and characteristic length, according to the above equation, the objects will be geometrically similar. When different objects have the same Reynolds number, the surrounding flow fields are said to be “kinetically similar”.

4.2. Influence of tail vortex

When two cars follow each other closely, there is an aerodynamic contact. The rear car frequently uses the front car's “pull” to accelerate in Formula One racing, as illustrated below:



Figure 6. Air flow generated outside the car [8]

The impact of the vehicle's front and rear lift forces on the automobile following is fairly convoluted. Due to the airflow not flowing behind the rear end plate and the difficulty in identifying front lift changes, the rear downforce of the front car will be reduced. Due to the stronger air separation in such position, when a car is following another car, the pressure on its front side will rise while the pressure on its back side would fall. At the same time, both vehicles' stability will be compromised, which primarily manifests as easier over-steering. The effect on the automobile in back is more noticeable. For F1 cars with high and low forces, the loss of downforce is a highly critical issue, especially for the car trailing them. The most evident occurrence is that the car's rear airflow will flow upward, which will have an impact on the downforce of the vehicle. The rear vehicle will experience an airflow velocity loss and a drop in airflow inflow due to the change in flow direction, which will also modify the airflow inflow Angle of the front wing.

The automobile behind will experience less lift and drag as a result. With a loss of approximately 50% of the front power at distances of less than a car length, this reduction is significant. In essence, air is removed from the front wing of the back car by the rear wing of the front car. Because airflow under the car's floor is reduced and the kinetic energy of the airflow reaching the rear wing is decreased, airflow has a comparably large effect on the downward force on the race car which is obvious. As a result of less downward force, the car's rear end experiences less drag.

5. Prospects and discussion

Although the information showed from the article is not very advanced, the article can describe the basic knowledge about the influence of the front wing to the motion of F1 cars and show the role of the flow field during the motion. The article shows the basic equation that shows the pressure gradient is proportional to the field strength and density as well. The equation and the annotation below is used for helping readers to understand quickly and have an initial understanding before reading the paragraph below. What's more, the purport of the article is help students to learn about what the flow field is. The article uses an interesting example, the F1 car, to help readers to comprehend the equations and effects from the flow field showed by the article and reduce the strange sense of the knowledge to simulate interest by using the cool pictures of F1 cars. The article is pretty suitable for a person who has no concept about what is flow field or how flow field influences motion, because the example and knowledge showed from the article is basic and readily comprehensible. Although there isn't enough information in this research to definitively establish our theory in the car wake section. However, this fundamental understanding will enable readers interested in the causes and impacts of vehicle wake flow to acquire additional in-depth knowledge. This article's goal is to inform readers who are interested in racing cars about some of the principles and structures that are used to reduce drag during competitions and outperform opponents.

6. Conclusion

The front wing manipulates this air in order to create a high pressure region on top of the wing and a low pressure region under the wing. The difference in air pressure results in a force that pushes the wing down into the ground to keep the motion stable. In the tail section, the different angles of the upper and lower tail sections also allow air to pass through to increase downforce, which makes the car more stable in driving, while the DRS allows airflow to flow more smoothly to achieve lower wind resistance and further increase the speed. This paper provides a basic explanation of the car wake's operation and its impact on the vehicle. This paper also describes the use of different methods to simulate the airflow through the racing car in the field, used to ensure the stability of the racing car. This essay's goal is to inform the audience about some of the preparations that F1 drivers undertake before passing and how they can use airflow to lower both their own vehicle's resistance and the solid line of resistance of the car in front of them.

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