

Optimized Design of Front and Rear Wings of Racing Car

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Abstract: Aerodynamic characteristics are the most important standard in the field of racing cars. It can not only reflect the combination properties of vehicles but also the highest dynamics. In history, many scientists published some optimized design schemes for racing cars. For example, Bernoulli and Newton created their Bernoulli aerofoil and Newton aerofoil. In the 1970s, Gordon Murray installed a cooling fan on the lower surface of the car to reduce the impact of the ground. However, these studies only focus on a part of vehicles and have a lack of integrity. Therefore, it is necessary to classify them. This article mainly talked about how to optimize the aerodynamic characteristics of the front and rear wings by collecting lots of experimental information. It included increasing the aerodynamic Angle of attack, decreasing the distance between the front wing and the ground, and installing additional wings and a DRS system. Then, a series of concrete experimental cases are presented to verify the reliability of the optimized scheme. Finally, concludes that within a certain range, increasing the aerodynamic Angle of attack of the car, reducing the distance between the aerofoil and the ground, and adding additional wings and the DRS system can increase the aerodynamic characteristics of the car.

Keywords: front wing, rear wing, aerodynamic negative lift

1. Introduction

F1 racing cars played an important role in the field of vehicle design and simulation. It is one of the world's highest-level cars, known for its high speed and cutting-edge technology. It not only represents the maximum speed of modern vehicles but an important benchmark for automotive aerodynamics [1].

All the time, aerodynamic performance (aerodynamic negative lift) decides the overall performance of the racing car. In research, a normal F1 racing car can accelerate from rest to more than 200km/h in 5 seconds, and the maximum speed is about 350 km/h. However, if the tyres cannot get enough grip in the corner, then even if the engine has enough power, there are no opportunities to fully play to it. Meanwhile, the racing car also faces some problems like rollover [2]. In this case, it is very essential to research how to optimize vehicles and increase their aerodynamic negative lift.

In history, a lot of scientists and designers published some optimized design schemes for racing cars. For instance, with the development of aerodynamics, Bernoulli and Newton created their aerofoils, which are called Bernoulli aerofoil and Newton aerofoil [3]. In the 1970s, designer

Gordon Murray installed a cooling fan on the lower surface of the car to reduce the impact of the ground. However, these studies only focus on a part of vehicles and have a lack of integrity. Therefore, it has special meanings to summarise and classify different optimized schemes of aerodynamics, which can help to improve the overall performance of F1 racing cars and boost the development of the F1 field.

This article mainly researched the optimal design scheme of the front and rear wings of racing cars by collecting various practical information. It included increasing the aerodynamic Angle of attack, decreasing the distance between the front wing and the ground, and installing additional wings and a DRS system. Then, a series of concrete experimental cases are presented to verify the reliability of the optimized scheme. Hopefully, you can build a clear and thorough understanding of aerodynamics after reading this article.

2. Optimal design scheme of the front wing of racing car

2.1. Increase the aerodynamic Angle of attack of the front wing

2.1.1. Theory

The aerodynamic angle is the angle between fins and incoming flow. It determines how much the fins block the airflow. When the aerodynamic angle of attack increases, fins improve the resistance to airflow, which can lead to an increase in the velocity difference between the upper and lower aerofoil. The enhancement of velocity difference increases the aerodynamic negative lift of racing cars[4].

2.1.2. Practical research

In the research of Aerodynamic optimization design of the new curved front wing tail of FSAE racing car, scientists studied Wortmann FX 74-CL5-140 Modified and S1210 12% aerofoil. Scientists used Profili to calculate the curves of lift coefficient C_L and drag coefficient C_D with the Angle of attack α respectively under the same Reynolds number. As shown in Figure 1.

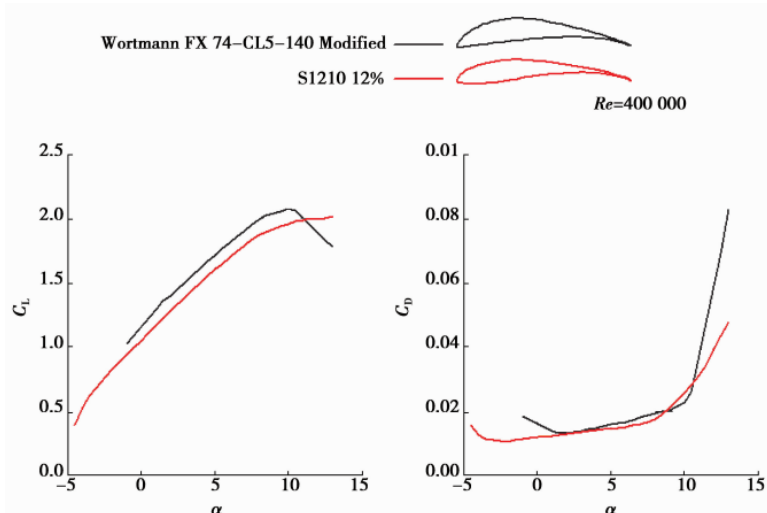


Figure 1: The relationship between the downforce coefficient and the angle of the wing section

According to the table, when the degree of attack angle of Wortmann FX 74-CL5-140 Modified is 5 degrees, the value of the lift coefficient is about 1.5, and when the degree of attack angle of Wortmann FX 74-CL5-140 Modified increases to 8 degrees, the value of lift coefficient is 1.9905.

1.995 is more than 1.5, so the aerodynamic characteristics at 8 degrees pneumatic Angle of attack are better than those at 5 degrees pneumatic angle of attack. When the degree of attack angle of S1210 12% is 5 degrees, the value of the lift coefficient is about 1.5, and when the degree of attack angle of S1210 12% increases to 13 degrees, the value of the lift coefficient is 2.014. 2.014 is more than 1.5, so the aerodynamic characteristics at 13 degrees pneumatic Angle of attack are better than those at 5 degrees pneumatic angle of attack [5]. In this case, increasing the aerodynamic angle of attack can improve the aerodynamic lift of the car.

2.2. Decrease the distance between the front wing and the ground

2.2.1. Theory

According to Bernoulli's principle, the pressure is low where the airflow is fast, and the pressure is high where the flow is slow. When the front wing is close to the ground, the air will flow relatively slowly as it passes under the front wing due to the obstruction of the ground, thus creating an area of high pressure under the front wing [6]. At the same time, the air above the front wing travels faster, creating a low-pressure area. This pressure difference results in a downward pressure, known as downforce. This kind of phenomenon can continue until the ground height (h) is so small that the airflow can be difficult to flow at the bottom of the car [7].

2.2.2. Practical research

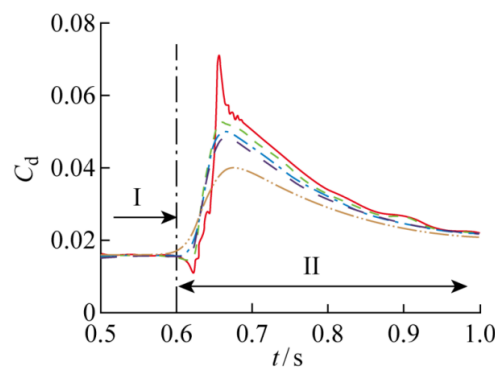


Figure 2: Lift resistance at 10 degrees of attack Angle, different height from the ground

In the research on the effect of height on aerodynamic characteristics, scientists took the 10 degrees of attack as an example and analysed the lift situation at different altitudes [8]. From Figure 2(a), in the critical range, at different altitudes, $h/c=0.2, 0.3, 0.4, 0.5, 1.0$, the aerofoil got less and less lift. For instance, when $h/c=0.3$, $C_l=1.4$, when $h/c=0.2$, $C_l=1.51$. In this case, decreasing the altitude of the car can help to improve the aerodynamic negative lift of a racing car.

2.3. Install additional wings for the front wing

2.3.1. Theory

Additional wings can also help to improve the aerodynamic negative lift for racing cars. That is because additional wings can create a shunt effect [9]. The additional wing can not only direct the air around the front wheels and make air to the sides and under the car but also allow airflow to form a more orderly and efficient flow pattern around the car, which can increase the aerodynamic negative lift. However, it also depends on the degree of aerodynamic angle of attack. This solution is effective within a specific range.

2.3.2. Practical research

In the research on the influence of an additional wing to the front wing, scientists compared the original aerofoil with the aerofoil which installed the additional wing. As shown in Figure 3. (The broken line with the inverted triangle symbol represents the lift coefficient of aerofoil adding the addition of the additional wing. The broken line with the round symbol represents the lift coefficient of the original aerofoil.)

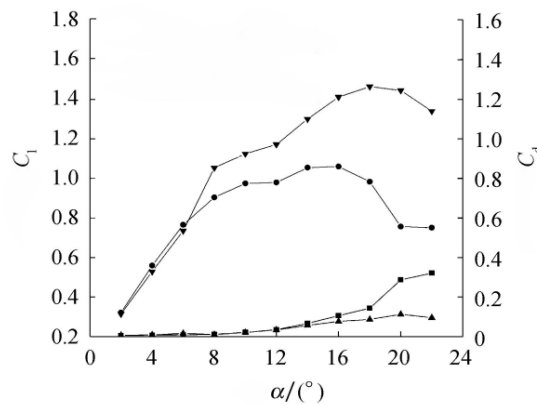


Figure 3: Comparison of aerodynamic characteristics

According to Figure 3, in the range of 2 to 6 degrees of attack, the lift obtained by an aerofoil with additional wings is less than that obtained by the original aerofoil. For instance, When the aerodynamic attack Angle of the aerofoil is 4 degrees, the lift of the aerofoil that installed the additional wing decreased by 5% compared with the original aerofoil, and the resistance increased by 7% compared with the original aerofoil [10]. When the degree of aerodynamic angle of attack is more than 8 degrees, the lift of the aerofoil which installed the additional wing began to bigger than the original aerofoil. For instance, when the degree of attack angle is 12 degrees, the lift coefficient of the aerofoil that installed the additional wing is about 1.2, and the lift coefficient of the original aerofoil is about 1.0. The formal is more than the latter one [11]. In this case, installing the additional wing can help to increase the aerodynamic negative lift within a specific range of attack angle.

3. Practical application of aerodynamics in tail wing of F1

The tail wing is located at the end of the car, creating the aerodynamic negative lift that accounts for 30% of the car. The tail wing can be divided into upper and lower parts. The optimized design of the tail wing can greatly increase the aerodynamic negative lift of the car and optimize the overall performance of the car.

3.1. Changing the angle of the tail wing

The tail wing has a significant impact on the downforce at the rear of the racing car, like the front wing, which has an inverted wing shape. On high-speed tracks, there are more straights on the track, and more teams will reduce the angle of attack of the car's tail wing, increasing the car's tail speed [12]. In low-speed tracks, the team will increase the angle of attack of the tail wing. The car will have enough downforce in corners.

For example, shown in Figure 4, in Monaco, the team usually spares no effort to obtain negative lift, so the angle of attack of the tail pillar is adjusted as much as possible, at the expense of the

speed of the car; if it is in Monza, the small angle of attack, low negative lift, and low resistance can be used to obtain the speed output at the end of the straight road[13].



Figure 4: The tail wings of Monaco and Monza

3.2. DRS (Drag Reduction System)

The tail wing of an F1 car is divided into two parts. In specific straights, drivers can open the DRS (Drag Reduction System) to make the upper part of the rear wing horizontal. The angle of attack of the tail wing becomes zero, the resistance of the racing car will decrease, and the speed will increase. The DRS (Drag Reduction System) makes the tail wing the only active aerodynamic package [14]. DRS can help to meet the demand for aerodynamic negative lift of racing cars by changing the angle of the tail wing.

In the 2023 Formula One Belgium Grand Prix, the maximum speed of the Red Bull Racing team's car without DRS activation is 320.5km/h, but the speed of the car with DRS activation is 340.8km/h (Figure 5) [15].



Figure 5: DRS OFF and DRS ON

4. Conclusion

This article mainly studies the optimal design of the front wing and tail wing of an F1 racing car. Based on the basic definition of aerodynamics and the causes of negative lift, this paper studies the optimal design scheme of the front and rear wings of a racing car which can meet the aerodynamic

requirements. This paper focuses on the optimization design of the front and rear wings of the racing car, such as changing the air attack Angle, reducing the distance between the aerofoil and the ground, installing additional wings, increasing the aerofoil area, installing end plates and so on. In general, through a series of optimization schemes, the aerodynamic downforce of the car is increased, and the aerodynamic performance of the car is improved so that the car has the best aerodynamic performance in the know and turn. In these two seasons, the teams have developed a high level of aerodynamic performance under the ground effect rules, and the teams need to innovate more efficient aerodynamic packages and improve the performance of the car to cope with the increasing competition. But at the same time, it is also necessary to prevent negative upgrades of the car and reduce the performance of the car. This year the FIA issued new regulations for the start of 2026, under which the focus is on reducing the impact of dirty air on the following car, trying to eliminate dirty air at the rear of the car. Including variable front and rear wings, narrow front wings, three-layer variable tail, simplified end plate, the beam wing, remove the front wheel cover, the overall downforce is reduced by 30%, and the resistance is reduced by 55%. Therefore, the team needs to find the right development direction as soon as possible and start the research and development work under the 2026 rules in advance.

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All the authors contributed equally, and their names were listed in alphabetical order.

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