Racing Technology Optimisation—Tail Wing Design and Aerodynamics

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Abstract. With the vigorous development of motorsport, the rear wing, as a key component to enhance the aerodynamic performance of racing cars, plays a decisive role in the competitive performance of vehicles. This paper systematically studies the core elements of the design and selection of the rear wing of racing cars, deeply analyses the working principle of the rear wing, and explores the influence of the downforce and drag generated in aerodynamics on the handling stability, cornering speed and straight-line driving performance of racing cars. Through theoretical analysis and numerical simulation, the mechanism of action of different geometric parameters of the rear wing (such as air foil, installation angle) on aerodynamic characteristics is studied. Combining with the characteristics of the track, the type of racing car and the competition rules, a comprehensive evaluation system for the design and selection of the rear wing is established. The research results show that a reasonable rear wing design can significantly optimise the aerodynamic performance of racing cars, and the parameters of the rear wing need to be dynamically adjusted according to specific competition scenarios. The achievements of this paper provide a theoretical basis and practical guidance for the design and selection of the rear wing of racing cars and are of great significance for improving the overall performance of racing cars and enhancing the competitiveness of competitions.

Keywords: Racing Aerodynamics, Rear Wing Design, Downforce Optimisation, Computational Fluid Dynamics (CFD), Adjustable Tail Systems.

1 Introduction

In the world of racing, every component is undergoing technological innovation and optimisation. From engines to lightweight bodies, every detail of the car has been sophisticatedly designed and tested. In the field of racing engineering, the racing rear wing, as the key aerodynamic component behind speed, plays a crucial role in optimising the vehicle's performance. Compared with the engine that directly affects speed through power, the tail wing passes through shape, using the pressure difference between the airflow on the upper and lower surfaces to increase the grip of the racing tires and reduce unstable situations. By changing the angle and size of the rear wing of the car, the aerodynamic efficiency is improved. The optimisation of the

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tail wing optimises handling and improves safety. The optimisation of the tail wing adjusts the aerodynamic balance. Therefore, the design optimisation of the tail wing has become an important topic in racing aerodynamic research and is of great significance to the development of racing.

The origin of the racing rear wing can be traced back to the early stages of racing development, when riders and engineers gradually realised the importance of aerodynamics to racing performance and began to explore the use of the tail wing to improve racing driving stability. With the continuous development of motorsports and the continuous pursuit of speed and control limits, the tail wing design has also undergone tremendous changes from simplicity to complexity, from basic functions to diverse and efficient ones. Today, advanced computational fluid mechanics (CFD) technology and wind tunnel experimental equipment have brought tail design into the era of precise optimisation.

2 The Basic Principles of Racing Aerodynamics

The theoretical basis of tail wing design relies on racing aerodynamics, which is the main component of racing's downforce. In Bernoulli's principle, when racing cars are driving at high speed, there is a relationship between the speed of the fluid and the pressure; that is, the faster the flow rate, the smaller the pressure, and the slower the flow rate, the greater the pressure. The body and tail of a racing car are designed in a special shape, so that when air flows through these parts, the flow rate of the upper and lower parts is different, thus forming a pressure difference and creating lift or pressure. In Newton's third law, the force acting on a racing car is equal to the force acting on the air and the direction of the car. The tail wing changes the direction of air flow, so that the air produces a downward force on the racing car. This force is downward pressure, which can increase the friction between the racing tires and the ground, thereby optimising the racing car's role [1-3].

3 Characteristics of the Tail

The tail wing design can rely on aerodynamic principles and needs to consider the connection between the three major characteristics of the tail wing and racing performance. The three main features are air foil, angle and size.

3.1 Effects of Air Foil and Angle of Attack on the Stability and Power of the Car

In appearance, the rear wing of the racing car is usually in an inverted wing shape. The upper surface is relatively flat, and the lower surface has a certain arc. This shape allows the airflow to flow through the tail wing, according to the Bernoulli principle, the upper surface airflow speed is fast and the pressure is small, and the lower surface airflow spe ed is slow and the pressure is high, thus creating downward pressure, pressing the car on the track, enhancing the tire grip, and improving the car's cornering performance. Moreover, the leading-edge part of its air foil is generally smooth, which can smoothly transition the airflow to the tail wing and reduce airflow separation. The trailing edge part is relatively thin, which is conducive to reducing the turbulence of the wake, reducing air resistance, and allowing the airflow to return to a stable state more quickly after leaving the tail, ensuring that the racing car has as little air interference as possible when driving at high speed. Only by combining the air foil and the angle of attack can the car have higher efficiency, and choosing the right air foil has a significant impact on the lift-drag ratio of the car [4,5].

Due to the track's speed limitation, the main wing's angle of attack is generally between 0 and 5 degrees, and the flap's angle of attack is generally between 30 and 60 degrees. Huang et al. selected four air foils in the Propili air foil library and studied them. The greater the lift-resistance ratio of the CH10 air foil changes from 0 to 8 degrees to change the angle of attack, and it is suitable as the main wing. It is found that the S1223 air foil changes the smallest as the angle increases, so it is suitable for flaps. In the final combination study, Huang et al. finally chose the CH10 air foil with an angle of attack as the main wing, and the S1223 air foil with an angle of attack and 62 degrees as the flap, which greatly improved the lift-drag ratio. Selecting the appropriate air foil will affect the magnitude of downforce for the tail wing. At the same time, the angle and air foil are in the research scope, thereby achieving a larger lift-to-deflation ratio [6].

3.2 Effect of Tail Position on Dynamics

Since there is a clear tendency to tighten from top to bottom and from front to back in the rear of the race car, a significant downward scrubbing airflow will occur [7]. The downwash airflow directly affects the position of the stagnant point (the stagnant point of the rear wing of the car refers to the point where the velocity decreases to zero when the airflow flows only on the surface). The position of the stagnant point has an important influence on the performance of the flap, and the position of the stagnant point determines the pressure difference between the upper and lower surfaces of the flap. When the airflow flows through the tail wing, the airflow above the stagnation point is fast and the pressure is small, and the airflow below is slow and the pressure is high, thus generating downward pressure. The appropriate stagnation point position can make the tail wing produce enough downforce at different speeds, allowing the racing tires to fit the track better, improving handling and cornering speed. The position of the stagnation point will also affect the airflow separation behind the tail wing. If the stagnation point is too far forward and the airflow separates too early, a large low-pressure zone will be formed, increasing air resistance and affecting the linear speed of the racing car; if the stagnation point is too far behind, it can reduce resistance, but it may lead to insufficient downforce. Therefore, it is necessary to reasonably adjust the stagnation point position to balance the air resistance and downforce to optimise the performance of the car in different track scenarios.

Zhang and others discovered that when the rear wing is installed relatively back away from the body, although the downforce of the rear wing is much reduced compared to the position close to the body, and the lift resistance is also poor, the lift at the rear of the body has been significantly improved, and the bottom plate downforce has also been greatly improved, which ultimately makes the downforce and lift-to-resistance ratio of the vehicle relatively optimal [8].

4 The Role of the Tail Wing on Curves and Straights

4.1 Straight

The tail wing mainly plays two roles in the straight. One is to reduce drag: On the straight, riders can adjust the tail wing angle to keep the tail wing in a low drag state, reduce the air resistance to the car, so that the car can accelerate faster and achieve higher speeds. The second is to maintain stability: even on the straight, the rear wing can provide a certain amount of downforce, so that the rear wheel of the car can better fit the ground, prevent the car from swinging or unstable at the rear when driving at high speed, and ensure the stability of the car's straight driving.

4.2 Bend

The tail also has two main functions on the curve. The first is to increase downforce: The car needs sufficient centripetal force to maintain a stable trajectory when driving on a corner. The tail wing increases the pressure on the car to the ground by generating downforce, thereby increasing the friction between the tires and the ground, so that the car can safely turn at a higher speed. Second balanced body: In corners, the car will produce roll and centre of gravity transfer. The downforce generated by the tail can help balance the body, reduce rolling, improve the handling and stability of the car, and allow drivers to more accurately control the driving direction of the car.

5 The Impact of the new tail Wing on Aerodynamics

5.1 Adjustable Tail Design

The adjustable rear wing system (DRS) is a technical means used in the racing field. Its main goal is to improve driving speed on straight sections while ensuring that the vehicle maintains the necessary grip and operating stability. The main purpose of the DRS is to reduce air resistance in the straight section of the car so that the car can achieve higher speeds. On corners, the DRS is closed to maintain the downforce of the car and improve cornering stability. DRS can reduce air resistance, and the DRS system levels the end plate at the bottom of the tail wing to reduce the inclination angle of the tail wing. This allows airflow to pass through the rear of the car more smoothly, reducing airflow separation and vortex generation, thereby reducing air resistance and helping the car achieve higher speeds on the straight.

The variable tail also increases the chance of overtaking. The DRS system is usually enabled in a designated area of the track. When the time difference between the rear car and the front car is within 1 second, the rear car can turn on the DRS. Currently, the rear wing of the car is adjusted, the air resistance and downforce are changed, and the speed is increased, making the rear car more accessible to the front car, increasing the chance of overtaking, and improving the viewing and competitive nature of the race.

Wu found that when the DRS system is not enabled, the flap is set at a larger inclination angle. When a large drag coefficient and air downforce coefficient are felt, the DRS function will automatically be turned on, and the flap will be adjusted to a position almost parallel to the ground. The drag coefficient and air downforce coefficient will drop rapidly [9]. Therefore, it can be concluded that when the racing car is turning, the DRS system should be turned off to increase the air downforce of the body. This can expand the contact area between the rear wheels and the ground and increase the pressure, thereby enhancing the grip performance, which can improve the stability of the racing car in corners. When the racing car is accelerating in a straight line, the DRS system should be turned on to keep the flap at level and the ground state, reducing the contact area between the rear wheels of the racing car and the road surface, thereby reducing friction and improving the driving speed of the racing car.

5.2 Disconnected Adjustable Tail Wing

The disconnect adjustable racing rear wing is an advanced racing rear wing design that is commonly found in top racing events such as F1. It mainly optimises the aerodynamics of a car by changing the shape or angle of the tail wing.

The disconnected tail wing is usually composed of parts such as the main wing and movable aileron. The aileron and the main wing are connected by a specific connecting mechanism. Under the action of the DRS system, the aileron can adjust the angle relative to the main wing, such as to a state parallel to or close to parallel to the main wing. When a car enters a straight road and other scenarios where resistance is needed, the driver operates the DRS system to open the ailerons of the tail wing and adjust them to a specific angle, generally trying to level it as much as possible. This action allows airflow to flow more smoothly through the upper half of the tail wing, reducing the "up wash effect", thereby reducing the downforce at the tail, reducing the friction resistance of the racing tires, and helping the racing car achieve greater acceleration and higher speed on the straight. When a car enters a scene where downforce is required, such as a curve, the ailerons will return to the initial large angle state to generate sufficient downforce to ensure that the car has good handling and stability in the curve.

Shen et al. optimised the disconnected tail wing to optimise it into a tail wing structure that can improve the car's rollover. They disconnected the first and second flaps in the tail wing structure in the middle position, and the main wing remains unchanged. And by using the electric motor, the attack angle size of the first flap and the second flap can be changed at any time, so that the attack angle sizes on both sides can be of different sizes [10].

Different angles of attack lead to different downforce on both sides. By controlling the difference in downforce between the two sides, the pressure difference is generated, that the roll trend of the car during corners, which can greatly improve the stability of the car's cornering at high speed.

5.3 Active Tail Wing

The active racing rear wing is an important technological innovation in the field of racing aerodynamics. The active tail wing adopts a multi-segment design, and the airflow can be adjusted more finely through multiple independently controlled flaps or flaps. For example, wings of different angles and sizes are set at different parts of the tail wing, and the angles of each wing are controlled separately according to the driving state of the race car to achieve more complex aerodynamic effects. The active tail wing also integrates complex sensors and control systems, which can automatically adjust the angle and shape of the tail wing according to a variety of real-time parameters such as the speed, acceleration, steering angle, etc.

The active tail wing will use smart materials such as shape memory alloys or piezoelectric materials. When these materials are subject to external stimulation such as electricity and heat, they can automatically change their shape, thereby achieving rapid and precise adjustment of the tail angle. Compared with traditional mechanical drive methods, smart material-driven tail wings are faster and have a more compact structure.

It can accurately optimise performance, adjust it in real time according to the driving status of the car, accurately meet the aerodynamic needs in different track scenarios, and maximise the performance of the car. At the same time, it can improve driver handling and provide drivers with a more stable driving experience. It can maintain good handling under various track conditions, helping drivers control the car more accurately and improve race performance.

6 Choice of Racing Tail Wing in Different Situations

The selection of racing rear wing types requires comprehensive consideration of various factors such as competition rules, track characteristics, racing performance and other factors.

6.1 According to the Event Level

Low-level events: limited budget and relatively low technical requirements, more fixed tail wings are selected. Its structure is simple and low cost, and can meet basic down force needs and help the racing car maintain a certain degree of stability on the track.

Middle and high-level events: An Adjustable tail wing is more common. Drivers can manually adjust the tail angle according to actual conditions during the competition, so that the car can better adapt to different track environments. While improving the racing performance, it also tests the driver's grasp of the racing rhythm and technical level.

Top events: For example, F1, etc., the team has strong technical strength and sufficient budget and mostly uses disconnected adjustable tail wings or active tail wings. These tail wings can more accurately optimise the aerodynamics of the car based on track conditions, providing the car with the best downforce and drag balance during high speeds and complex corners.

6.2 According to Track Type

Tracks with many high-speed straights: For example, Monza Track, you can choose a fixed tail with a smaller angle or an adjustable tail with a large reduction in the angle during the straight stage, a disconnected adjustable tail and an active tail to reduce air resistance and allow the car to obtain higher speeds on the straight.

Tracks with many curves and complex corners: For example, the Monaco track requires a large downforce to ensure the stability and handling of the car in the corners. A fixed tail with a large angle or an adjustable tail with a high-pressure, and an active tail with a high-angle capacity when cornering should be selected.

6.3 According to the Performance Characteristics of the Car

Racing cars with strong power but average handling: they can be matched with an active tail wing or an adjustable tail wing. By adjusting the tail wing angle in real time, it reduces resistance when the car accelerates and increases downforce in corners to make up for the lack of handling.

Racing cars with good handling but relatively weak power: when choosing a fixed tail, focus on optimising its aerodynamic design to provide a certain downforce without adding too much resistance; a simple adjustable tail can also be used.

Appropriately reduce the tail angle in the straight, reduce drag and increase speed.

7 Outlook on the Rear Wing of the Racing Car

7.1 Technological Innovation and Performance Improvement

Further applications of smart materials: In addition to existing shape memory alloys and piezoelectric materials, more advanced smart materials may be developed to make the tail wing respond faster, have higher adjustment accuracy, and withstand more complex mechanical loads.

Deep integration with vehicle system: the active tail wing is deeply integrated with the racing power, suspension, electronic stability and other systems, and works in concert through the central control system. For example, when a racing car accelerates out of a corner, the tail wing cooperates with the power system to adjust downforce in real time according to the engine output power and tire grip, optimising acceleration performance and handling stability.

7.2 Design Concept and Style Change

Expansion of bionic design: draw more inspiration from nature and mimic the aerodynamic forms and principles of organisms in flight or movement. For example, imitating the deformation mechanism of bird wings in different flight states, a tail wing that can automatically change its shape according to airflow conditions is designed to improve aerodynamic efficiency.

Customised and personalised design: With the development of technology and the advancement of production processes, more customised and personalised tail designs may be carried out based on the driving styles of different drivers, the characteristics of different tracks, and the brand image of the team.

7.3 Adapt to the Competition Rules and Environmental Protection Requirements

Respond to changes in rules: The restrictions on the rear wing of the racing rules may be constantly adjusted, and teams need to carry out innovative designs within the scope of the rules. For example, better aerodynamic performance is achieved by optimising the air foil and adopting new materials and structures, while limiting the tail size and adjusting stability.

Environmental protection and sustainable development: Environmental protection factors will be considered more during the R&D process, using recyclable and degradable materials to reduce energy consumption and waste emissions during the production process, and to adapt to increasingly stringent environmental protection regulations.

8 Conclusion

This study explores the aerodynamic optimisation of racing car tail wing structures, emphasising their critical role in enhancing downforce, stability, and cornering performance. Through theoretical analysis and practical simulations, it evaluates the influence of tail wing angle, shape, and positioning on aerodynamic efficiency. The implementation of Computational Fluid Dynamics (CFD) tools enables detailed examination of airflow behaviour and drag-to-downforce ratios under various design configurations. Experimental data and design comparisons demonstrate that even slight adjustments in tail wing geometry can significantly impact aerodynamic balance and overall vehicle handling. The study also reviews the evolution of tail wing design in motorsports, from fixed elements to adjustable and active systems, illustrating how regulatory changes and performance demands have driven continuous innovation.

Despite notable progress in aerodynamic enhancement, several challenges persist. Balancing drag reduction with downforce generation remains a complex task, especially under real-time racing conditions involving variable speeds and angles of attack. The integration of adjustable or active tail wing systems introduces further complications, including mechanical complexity, regulatory compliance, and reliability concerns under high-stress racing environments. Additionally, achieving optimal aerodynamic performance without compromising safety, structural integrity, or weight remains a key engineering trade-off.

Future development in tail wing design and racing aerodynamics will likely focus on adaptive systems capable of responding dynamically to track conditions, vehicle speed, and driver input. Advances in materials science, such as the use of lightweight composites and shape-memory alloys, are expected to facilitate more responsive and efficient aerodynamic components. Machine learning algorithms integrated with real-time sensor data may also contribute to predictive aerodynamic adjustments, enhancing vehicle performance across varying race scenarios. As motorsports continue to evolve with greater emphasis on safety, efficiency, and sustainability, aerodynamic optimisation—particularly of rear wing structures—will remain a vital area of research and innovation, guiding the next generation of competitive racing vehicle design.

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