

Chassis and Rear Wing Design for Formula 1 Racing Cars - Based on Aerodynamics

Xingyuan Wu

*School of Vehicle Engineering, Zhuhai College of Science and Technology, Zhuhai, China
Wuxingyuan @mail.zcst.edu.cn*

Abstract. The study is grounded in existing research on car aerodynamics. Understanding aerodynamic principles in cars, especially in high - performance vehicles like Formula 1 (F1), is crucial for enhancing performance. This paper focuses on two key aspects of F1 cars: the aerodynamic design of the chassis and the rear wing. The chassis design aims to generate downforce and optimize stability, while the rear wing balances downforce and drag. The research employs theoretical analysis, delving into fluid mechanics principles such as the Venturi effect, Bernoulli's principle, and boundary - layer theory. Case studies are also used, analyzing specific components like the Venturi piping system, diffuser, and rear - wing elements. The aerodynamic design of the F1 chassis, including components like the Venturi and diffuser, effectively generates downforce. The rear wing, with its various components and the DRS, can be adjusted to suit different track conditions, balancing downforce and drag. This research provides theoretical support for F1 car design and performance improvement. Additionally, future F1 cars may incorporate intelligent aerodynamic systems for real - time adjustments.

Keywords: Ground effect, F1 rear wing, Bernoulli, air pressure

1. Introduction.

In automotive aerodynamics research, precise analysis of rear - wing impact on vehicle aerodynamic performance is crucial. For example, a classic three - door sedan model was chosen. Three different rear wings were designed for it, and 3D aerodynamic numerical calculations were done using advanced computational methods. Results show that thickening the rear - wing's lower trailing - edge surface boosts lift coefficient, enhancing driving stability; thickening the upper trailing - edge surface prominently impacts the lift coefficient; and the sharp trailing - edge airfoil balances stability and fuel economy due to its high lift - to - drag ratio [1]. Moreover, based on automotive aerodynamic principles, with STAR - CCM +, a rear - wing physical model for a specific vehicle was created. Simulation indicates that proper rear - wing modification optimizes aerodynamics, reducing fuel consumption and improving handling stability [2]. This paper focuses on F1 racing car chassis and rear - wing design. By combining theoretical analysis and case - study methods, it aims to support China's racing industry development and increase the public's understanding of Formula One racing.

2. Formula 1 chassis design ingenuity

The aerodynamic design of Formula One (F1) chassis is a product of the deep integration of fluid mechanics principles and racing engineering. Its core objective is to generate sufficient downforce at high speeds through precise control of airflow to enhance tyre adhesion, while effectively reducing drag and optimising vehicle dynamic stability. The aerodynamic design of the F1 chassis guarantees stability, essentially by controlling the precise dynamic balance between airflow and downforce, transforming the air into a "stabiliser".

2.1. Structural design of chassis

The chassis of an F1 car is not only the skeleton that carries the mechanical system, but also the core carrier of aerodynamics. Designers aim to "generate efficient downforce" by transforming the airflow into a track-hugging adhesion force through the Venturi effect, boundary layer control and flow field synergy. The following is an analysis from two dimensions: core structure and technology iteration.

2.1.1. Venturi piping system: the "heart" of downforce generation

Structural principles and fluid logic.

The Venturi Tunnels underneath the chassis are designed to accelerate airflow through a "contraction-expansion" channel design. The ducts consist of a main tunnel in the centre and auxiliary channels on both sides.

Throat: The width of the centre tunnel narrows to approx. 200 mm and the height is lowered to 50-80 mm, where, according to Bernoulli's principle, the air velocity increases to 200-250 km/h and the pressure drops to less than 90% of the atmospheric pressure, creating a low-pressure zone underneath the chassis.

Expansion section and diffuser : The end of the pipe expands upwards to form an "airflow accelerator" with the tail diffuser, where an enlarged exit cross-sectional area reduces the flow velocity and raises the pressure, further widening the pressure difference between the top and bottom of the sump.

The angle of inclination of the duct (usually 12° - 15° to the ground) needs to be balanced between airflow acceleration and chassis ground clearance (minimum 100 mm according to the FIA) [3]. If the angle is too large, it is likely to lead to airflow separation. If it is too small, the downforce will be insufficient. The "Step" structure of the two side channels guides the airflow to form a vortex through the raised vertical airfoils, enhances the boundary layer energy, and prevents the airflow from overflowing from the edges of the pipe at high speeds.

2.1.2. Diffuser: "end amplifier" for downforce

Fluid effect of three-dimensional expansion structure.

The diffuser is located at the rear of the chassis, and its upward expanding channel cross-section is directly connected to the outlet of the venturi pipe. The outlet flow velocity is reduced and the

pressure is restored to close to the atmospheric pressure, forming a strong pressure difference of "low pressure zone - normal pressure zone". Winglet vortexes on either side of the diffuser generate a rotating airflow through the deflector plates, wrapping around the diffuser outlet, preventing backflow of high pressure from the outside and maintaining a low pressure environment inside.

The venturi contributes about 50% of the chassis downforce, while the diffuser boosts another 30%-40% by increasing the pressure at the end, which together form a "duct acceleration - diffuser boost" downforce generation chain.[4] When driven by a diffuser, the device both generates downforce and accelerates the duct flow.[4] When the car is travelling at 300 km/h, the chassis underneath can generate about 3 tonnes of downforce, which is equivalent to four times the weight of the car.

2.1.3. Edge sealing and airflow management: a "moat" against energy loss

Sealing system at the edge of the chassis.

Flexible Skirt: Carbon - fibre or rubber skirts are installed on both sides of the chassis. There is a 5 - 10 mm gap between their bottom and the ground, which prevents airflow from overflowing from the chassis sides through mechanical contact. Some cars have built-in sensors in the skirts to monitor the ground clearance in real time and fine-tune the height through the active suspension to ensure the sealing effect.

Barge Board: A cluster of 6 - 8 vertical wings at the front of the chassis directs front - wheel turbulence to the sides and channels clean airflow into the venturi, enhancing the airflow quality in the channel.

Airflow coupling between front wing and chassis

The front - wing splitter divides the airflow into two paths: the upper one flows over the body top, and the lower one is precisely directed into the chassis channel. The angle of the front wing's downwash airflow must be matched to the inlet of the venturi (with an error of less than 2°). If the airflow hits the edge of the inlet of the venturi, it will lead to a downforce loss of 5%-10%.

3. Principle of ground effect

The realisation of the ground effect mainly relies on several principles of fluid mechanics: the Venturi effect, Bernoulli effect and boundary layer theory.

3.1. Venturi effect and bernoulli effect

The Venturi effect is a significant phenomenon in fluid mechanics, and its core principle concerns the relationship between fluid flow rate and pressure.

Core definition: When a fluid (gas or liquid) flowing through a pipe cross - section suddenly narrows at the throat, its flow rate increases significantly while the static pressure at the throat decreases, as is shown in figure 1. When the fluid flows from the throat into the expansion section, the flow rate gradually decreases, and the pressure then recovers. This phenomenon, in which changes in the pipeline's cross - section cause the fluid flow rate and pressure to change in opposite

directions, is known as the Venturi effect. At its essence, the fluid adheres to the law of energy conservation and the continuity equation during its flow.

Bernoulli's equation is the key theory to explain the Venturi effect and its expression is:

$$p + \frac{1}{2} \rho v^2 + \rho gh = \text{constant} \quad (1)$$

Where p is the pressure, ρ is the fluid density, v is the flow velocity, g is the gravitational acceleration and h is the height.

In a horizontal pipe (ignoring the height difference h), the equation simplifies to:

$$p + \frac{1}{2} \rho v^2 = \text{constant} \quad (2)$$

When the fluid passes through the throat with a reduced cross - section, according to the continuity equation $A_1 v_1 = A_2 v_2$ (where A represents the cross - sectional area and v represents the flow velocity), as the cross - sectional area A decreases, the flow velocity v increases. To maintain energy conservation, the pressure p must decrease, thus creating a low - pressure region in the throat.

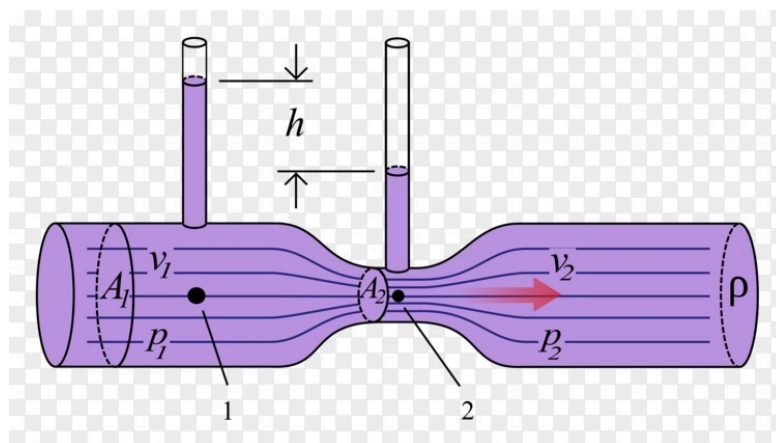


Figure 1. Venturi effect principle diagram

The bottom of the F1 car's body is designed to resemble a Venturi tube. The curved bottom plate, low in the middle and high at both ends, is like an inverted wing. This design guides the airflow from the front to the rear of the car, thus forming a low - pressure zone. This principle is used to enhance the ground effect. As is shown in Figure 2, the Venturi channel at the bottom of the body accelerates the airflow in the middle region, creating a low-pressure area and generating a strong downforce.

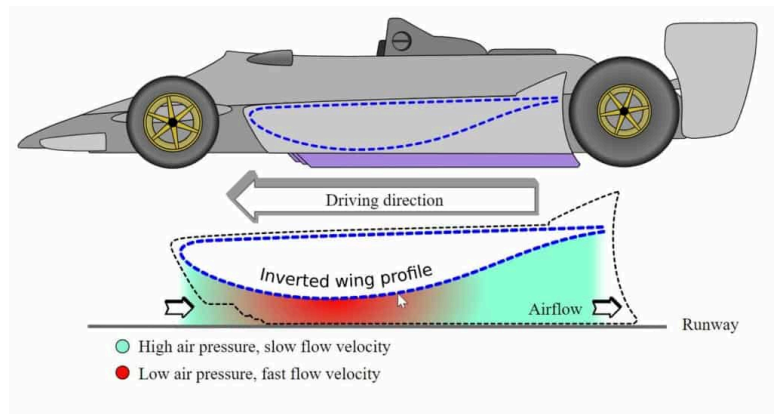


Figure 2. Venturi and Bernoulli effects in an F1 chassis.

3.2. Boundary layer theory

The Boundary Layer refers to the thin layer that forms when fluid flows over a solid surface. Due to the viscous effect near the surface, a significant flow - velocity gradient is created within this layer. The velocity of the fluid is zero at the point of contact with the solid surface, as we can see in the Figure 3. For example, when air flows over a racing - car body, the air near the surface “sticks” to it. The velocity then gradually transitions from zero at the surface to the prevailing velocity outward, forming a gradient layer that is typically only a few millimetres to a few centimetres thick. [5]

As the airflow passes over the underside of the body, the airflow near the ground is affected by friction from the ground, forming a slower - moving boundary layer. The presence of the boundary layer influences the airflow’s flow and pressure distribution. Moreover, its thickness and velocity distribution impact the strength of the ground effect; specifically, an excessively thick boundary layer reduces the downforce.

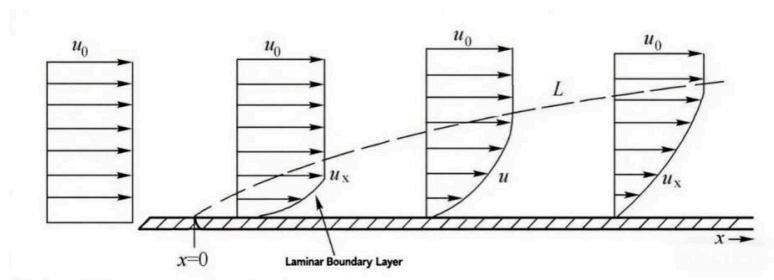


Figure 3. Schematic of velocity gradient of boundary layer

Table 1. Difference between laminar boundary layer and turbulent boundary layer

Type	Laminar Boundary Layer	Turbulent Boundary Layer
Flow Regime Characteristics	The fluid flows in layers without lateral mixing	The fluid fluctuates chaotically, with eddies and vortices
Thickness	Relatively thin (about 0.1-1mm)	Relatively thick (can reach 1-10mm)
Friction Resistance	Relatively low (caused only by viscous shear stress)	Relatively high (Eddies intensify energy loss)
Separation Risk	Higher (poor stability of laminar flow)	Lower (turbulent flow has high energy and strong anti-separation ability)
Typical Positions in F1	Front edge of the front wing of the racing car , smooth body surface	Chassis diffuser , around the tires

Airflow in the boundary layer flows slower due to viscosity and generates wall shear, i.e., frictional drag. The thicker the boundary layer, the greater the frictional resistance, which will consume the racing power and reduce the speed. Therefore, F1 cars are designed to minimize the thickness of the boundary layer. For example, smooth bodywork materials are used and surface roughness is reduced to decrease frictional resistance. The most significant challenge lies in the fact that the laminar boundary layer is prone to separation yet has low resistance, whereas the turbulent boundary layer is resistant to separation but has high resistance. It is necessary to balance the two through design. For example, in areas prone to separation (such as the trailing edge of the wing), laminar flow is converted to turbulent flow, and part of the frictional resistance is sacrificed for the stability of downforce.

4. How does the F1 rear wing keep the F1 car firmly on the ground?

The F1 rear wing is a crucial aerodynamic component of a racing car. Its primary function is to generate down - force, pressing the car onto the track, enhancing grip and speed while reducing air resistance. The modern F1 rear wing consists of a main wing, ailerons, end plates, Gurney flaps, etc. and is equipped with DRS (drag reduction system). The driver can adjust the rear wing according to the track conditions, turning on the DRS on straights to reduce drag and increase speed, while the rear wing on corners provides downforce to ensure cornering stability. The design and tuning of the rear wing should follow the FIA rules and reflect the technical strength of the team.

4.1. Composition and structure of F1 tail wing

The F1 tail fin consists of main wing, ailerons, end plates, Gurney flaps, DRS, etc. The specific structure is as follows:

Main wing: The largest rearward - tilting part of the rear wing, spanning the car's width, it is a major down - force - generating component. Its angle and shape significantly influence the rear wing's overall performance.

Aileron: the smaller horizontal part that slopes downwards from the main wing and works in conjunction with the main wing to increase downforce. Teams can adjust the angle of the aileron to optimise the performance of the car according to the track conditions.

End Plates: Vertical aerodynamic plates installed at the ends of the rear wing. They manage the airflow around the rear wing, reducing turbulence and drag, preventing airflow from escaping the wing's sides, and enhancing the rear wing's efficiency.

Gurney flaps: Gurney flaps: Short upright components mounted on the aileron's trailing edge, typically made of right - angled carbon fibre and secured with tape. They create vortices, reducing turbulence behind the rear wing and adding a small amount of down - force, albeit with some additional drag.

DRS (Drag Reduction System): A hydraulically actuated flap adjustment device that hydraulically pushes the upper rear wing to a higher and flatter position on straights, reducing downforce and drag and increasing the speed of the car to aid overtaking.

Beam: Positioned vertically below the upper part of the rear wing, typically with a single flap. The end plate transfers pressure from the upper part of the rear wing to the beam, which then transmits it to the chassis. The beam is designed to be robust enough to withstand pressure loads.

Louver structure: Parallel louver slits are present on both sides of the rear - wing end plate. These slits equalise the air pressure near the wingtip, prevent vortex formation, reduce the rear - wing drag, and increase straight - line speed.

4.2. Principles of F1 tail fins and how to adjust them to different circuits

The F1 tail fins work mainly on aerodynamic principles to increase the performance of the car by generating downforce and to reduce the drag on the straights with the help of the DRS system, as follows:

Generation of downforce: The F1 tail fins feature a scooped shape, curving downward at the front and upward at the rear, with the lower surface more curved than the upper one. According to Bernoulli's principle, air flows at different speeds over the upper and lower surfaces of the rear wing, creating a pressure difference and resulting in "negative aerodynamic lift," or downforce. In addition, the rear half of the tail fin at an angle of 70 - 80 degrees to the horizontal creates an "upwash effect", and according to Newton's third law, the tail fin of a racing car receives a downward reaction force from the air, which contributes to downforce.[6] Downforce is the result of the downward pressure of the tail fin, which causes the air to flow through the upper and lower surfaces at different speeds. Downforce keeps the car on the ground, increasing rear wheel grip, cornering speed and stability.

DRS (Drag Reduction System): DRS (Drag Reduction System) is an important technology in F1 tailgating. In the designated DRS area of the track, the driver presses a button to level the ailerons above the tail. At this point, the airflow flows freely over the upper part of the car's tail, reducing the "upwash effect" and thus lowering the downforce on the tail. The reduced downforce reduces the frictional resistance of the tyres, resulting in greater acceleration and higher top speeds, making it easier for drivers to overtake on the straights.

In the aerodynamic design of an F1 car, the ratio of Drag to Downforce (D/F) is a key measure of the aerodynamic efficiency of the rear wing and bodywork. The smaller the ratio, the less drag is produced for the same downforce, and the more efficient the aerodynamic design.

To strike the right balance between downforce and drag, teams adjust the rear - wing according to the specific demands of each track and race conditions. For low - speed tracks, a larger angle of attack and increased surface area are employed to maximise downforce, enhancing grip and stability in tight corners and slow - speed sections. For high - speed tracks, a smaller angle of attack and reduced surface area are used to minimise drag, enabling higher straight - line speeds.

For example, high-speed circuits such as Monza, where low drag is more important, require a lower angle of attack of the rear wing to reduce the D/F, while a twisty circuit such as Monaco, where downforce is increased, allows for a moderate increase in the D/F ratio, as we can see in the Figure 4. Through Computational Fluid Dynamics (CFD) simulations and wind tunnel tests, teams are constantly optimizing the aerodynamic layout of the rear wing and bodywork to find the optimum balance between 'grip' and 'speed', which is one of the core competencies of F1 aerodynamic technology. [7]

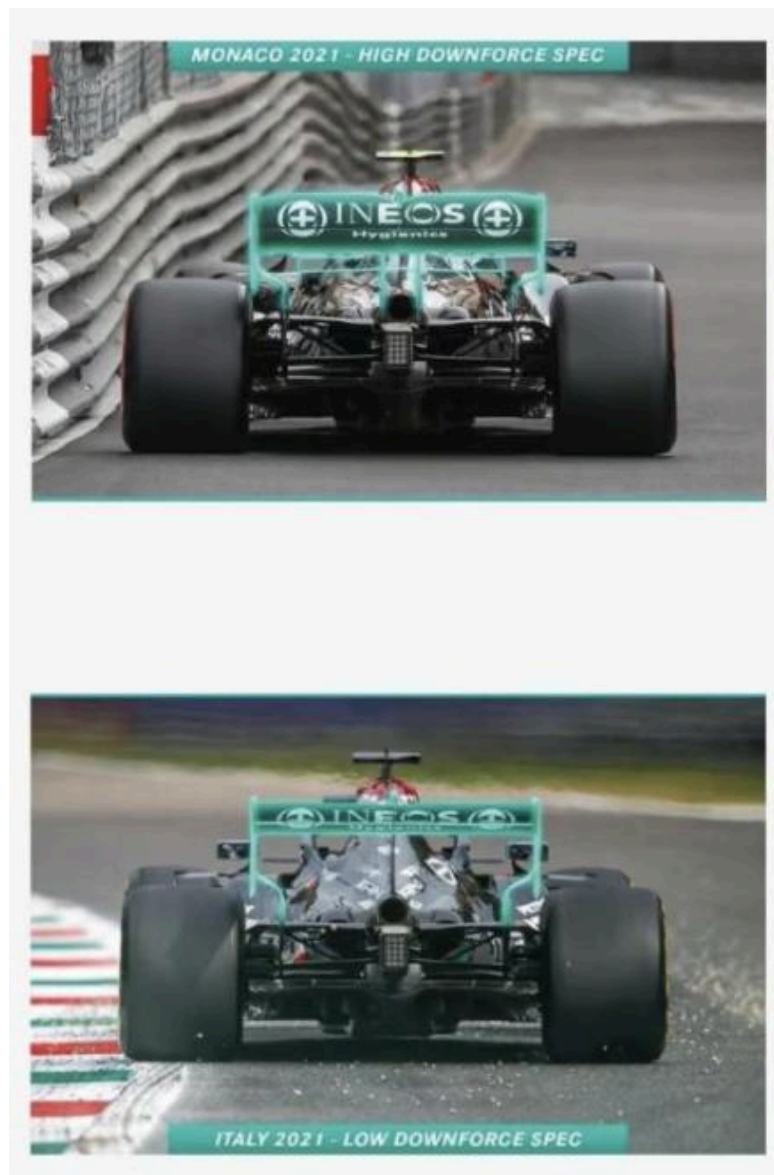


Figure 4. Adjustment of F1 Tail Wing

5. Conclusion

This paper focuses on the aerodynamic design of the chassis and rear wing of a Formula 1 car. Regarding the chassis, its aerodynamic design encompasses components such as the venturi and the flexible skirt. The venturi accelerates airflow via a “contraction - expansion” mechanism and collaborates with the diffuser to augment downforce. The flexible skirt is dynamically sealed to minimize airflow leakage. The rear wing, a crucial aerodynamic component, comprises the main wing, aileron, and end plate. Its angle and the Drag Reduction System (DRS) can be adjusted to balance downforce and drag on various tracks. For instance, on low - speed tracks, increasing the angle and area boosts downforce, while on high - speed tracks, drag is reduced. This adjustment enhances the car’s handling and speed, optimizes race performance, and offers aerodynamic theoretical support for the design and performance enhancement of F1 cars.

Future F1 cars will be equipped with intelligent aerodynamic systems that monitor airflow and downforce in real time and automatically adjust body components. For example, through sensors and control systems, the car can automatically adjust the height of the side skirts and the angle of the rear wing according to the speed and track conditions.

References

- [1] Wang Dejiao (2024). The influence of car tail fin on vehicle stability. *Journal of Lanzhou Institute of Technology*, 31(02), 53-56.
- [2] Liu Wang, Hou Lufei, Gu Junjie, Wang Jing & Wang Huanjun (2020). The influence of tail fin on aerodynamic performance of automobiles. *Automotive Engineers*, 06, 56-57.
- [3] Guo Junzhao (2007). Ideal body aerodynamic modelling and preliminary study on aerodynamic characteristics of F1 racing cars. master's thesis, Hunan University.
- [4] Long, P. (2003). Aerodynamics under the F1 race car chassis. *Automotive & Accessories*, 31: 36-37.
- [5] Song Tao and Hu Rui (2014). Application of aerodynamics in F1 racing. *Small Internal Combustion Engines and Vehicle Technology*, 43(04), 93-96.
- [6] Zhang Jiaolong (2016). Research on Racing Car Body Design and Aerodynamic Analysis. Master's Thesis, Hebei University of Technology
- [7] Wang Yuanan & Gao Feng. (2017). Development of variable tail system for formula racing. *Journal of Henan University of Science and Technology (Natural Science Edition)*, 38(04), 30-34 +117. doi: 10.15926/j.cnki.issn1672-6871.2017.04.007.