Proceedings of CONF-MPCS 2026 Symposium: Theoretic Physics and Plasma Physics
DOI: 10.54254/2753-8818/2026.DL33849

Aerodynamic Synergy in Formula One: The Interplay Between Front Wing, Rear Wing, and Ground-Effect Underfloor

Weijia Liu

Shandong Experimental High School, Jinan, China
jessicaliuwj@outlook.com

Abstract. This paper looks at how the front wing, rear wing and underfloor work together to shape the aerodynamic behavior of Formula One cars. The front wing serves as the primary flow conditioner, the rear wing balances downforce and drag, and the underfloor uses ground effect to generate efficient downforce. The review first explains what each component does, then examines common design ideas like the downforce-drag trade-off, airflow management, and FIA regulatory limits. Recent technical solutions including multi-element wings, vortex generators and Venturi-channel floors are discussed, alongside a brief case study of a modern underfloor concept. The paper also lays out current problems designers face, most notably porpoising, tyre-wake interference and strict rule constraints, and suggests future directions such as active aerodynamics and machine-learning-based optimisation. The synthesis indicates that faster competitive lap times increasingly rely on designing the front wing, rear wing and underfloor as an integrated system rather than as separate parts.

Keywords: Formula One, aerodynamics, front wing, rear wing, underfloor

1. Introduction

Modern Formula One racing is connected closely with aerodynamics. Mechanical grip cannot deliver the cornering speeds alone at circuits like Silverstone or Suzuka; the cars rely on carefully managed airflow to push them onto the track. Three components are keys of this aero puzzle: the front wing, the rear wing, and the underfloor [1].

For years, designers treated these parts as separate chapters. The front wing generated frontend downforce and guided air around the front tyres, the rear wing was responsible for rear stability and drag tuning, and the floor was viewed as a bonus downforce generator. That situation changed dramatically after the 2022 technical regulations brought groundeffect floors back into the F1 paddock. How the front wing feeds the floor, and how the rear wing works with the diffuser exit, became just as important as the parts themselves [2].

There are already plenty of excellent texts exist on isolated wings, ground effect and vehicle aerodynamics [3, 4]. However, a synthesized discussion that connects the design philosophy of the front wing, rear wing and underfloor under the same roof is harder to find. This review aims to fill

DOI: 10.54254/2753-8818/2026.DL33849

that gap by telling the fundamental jobs these components perform, digging into the design principles that shape them, highlighting some advanced solutions and pointing out the obstacles and future opportunities the sport is staring at. The paper describes the aerodynamic roles and underlying principles of each component in Section 2. Section 3 traces their structural evolution under regulation changes and presents a contemporary integrated design example. Section 4 discusses current technical challenges and future trends, and Section 5 concludes the review.

2. Aerodynamic functions and design principles

2.1. Front wing

The front wing is the first part of the car to meet oncoming air, and its performance directly determines the quality of the downstream flow field [5]. In simple terms, it does two big jobs: create downforce at the front axle and shape the airflow for everything behind it. The outboard sections push messy turbulent air away from the sidepods and floor entrance by managing the fronttyre wake. The inboard section generates a strong vortex, often called the Y250 vortex after its regulatory reference point, helps seal the floor edges later on [2].

From a fluid mechanics perspective, the front wing generates downforce through the pressure difference between its upper and lower surfaces [6]. The core design aim to maximize this pressure difference while keeping drag under control and complying with the FIA size restrictions [7]. Designers must also reduce the wing's sensitivity to changes in vehicle attitude (pitch and yaw) and maintain uniform flow distribution toward the underfloor [8]. No matter how sophisticated the rear wing or floor might be, a poorly designed front wing would compromises the entire aero package,

2.2. Rear wing

The rear wing is the most visible downforce device. Its primary role is to load the rear axle, providing stability under braking and through highspeed corners [9]. Because the rear wing sits in upwash from the car body and diffuser, its efficiency is huge influenced by upstream flow conditions. Drag is always considered together, teams adjust rearwing angle and shape to suit different circuits, and the Drag Reduction System (DRS) is literally a movable rearwing flap that cuts drag on straights [10].

Rear wing design focuses on the balance between downforce and drag. The beam wing is a lower element below the main plane. It has evolved from a simple structural part into a downforceproducing device that also conditions flow into the diffuser [11]. DRS effectiveness is now a key system that is measured by how much drag is shed when the flap open. Teams design the mainplane and flap interaction to maximize this delta while maintaining cornering downforce. Modern rear wings must satisfy FIA dimensional limits and work in concert with the rear diffuser to improve overall aerodynamic efficiency [12].

2.3. Floor and ground effect

The underfloor dominates modern F1 aerodynamics through ground effect [13]. When airflow accelerates through the narrow gap between the floor and the track surface, static pressure drops in according to Bernoulli's principle. It generates substantial downforce with a relatively small drag lose [3]. The integrated Venturi channels in post2022 floors amplify this effect by controlling the expansion of the flow carefully [11].

DOI: 10.54254/2753-8818/2026.DL33849

An efficient floor design enhances ground effect through optimized channel contour, rideheight sensitivity, and edge sealing [11]. The vortices generated by front wing and the flooredge wings and strakes help seal the underfloor cavity together to prevent highpressure air from leaking in and destroying suction. At the rear, the diffuser accelerates flow exit and promotes pressure recovery, further augmenting downforce and rearend stability [12]. Because the floor's performance is extremely sensitive to ride height and pitch, it also acts as the main trigger for porpoising when flow stalls and reattaches rhythmically [11].

3. Evolution of designs under regulation changes

3.1. Front wing evolution

Driven by FIA rule changes, the front wing has undergone multiple major revisions. Before 2009, multielement flaps were used aggressively to get high downforce, but they generated strong outwash and turbulent wakes that hindered close following [7]. In 2009 the FIA simplified the front wing to reduce wake intensity. Wider and lower front wings were introduced between 2019 and 2021 with the goal of improving flow quality. Since 2022, the core mission of the front wing has shifted toward guiding highenergy and clean airflow into the floor's Venturi channels [13].

Typical contemporary front wings consist of a main plane, multiple flaps and complex endplates. The endplates prevent spillage from highpressure to lowpressure regions and are often sculpted to steer the tyre wake outward [5]. Many teams further optimize curvature to reduce turbulence interference while strengthening the Y250 vortex that feeds the underfloor sealing system.

3.2. Rear wing and DRS

The rear wing has evolved from a simple singleelement wing to an efficient multielement assembly. The introduction of DRS in 2011 dramatically increased overtaking opportunities by allowing drivers to open the flap on designated straights [10]. After the 2022 regulations, the rear wing became smaller and the endplates were redesigned to reduce the intensity of the trailing wake.

Teams now treat the rear wing and diffuser as a coupled system. The beam wing conditions the flow entering the diffuser, while the main plane and flap are tailored to circuitspecific downforcedrag requirements [7]. DRS performance remains crucial that larger the drag reduction when the flap opens, the higher the straightline speed benefit.

3.3. Floor and ground effect revival

Ground effect was first exploited in F1 during the late 1970s with sculpted underbodies and side skirts, but it was banned on safety issues after a series of accidents [4]. In 2022 the FIA deliberately reintroduced groundeffect floors as the core aerodynamic concept, primarily to reduce the wake sensitivity that had made overtaking so difficult [13].

The newgeneration floor features precisely shaped Venturi channels, a raised central section, edge fences and a large diffuser [11]. These features generate stable, efficient downforce while throwing less turbulent air upward, which makes following cars less disturbed. The revival of ground effect has shifted the centre of aerodynamic development from upperbody flow conditioners to underbody geometry, forcing teams to rethink the entire aerodynamic chain.

DOI: 10.54254/2753-8818/2026.DL33849

3.4. A contemporary integrated example

Before the 2022 groundeffect era, some teams, most notably Red Bull Racing, ran a highrake philosophy where the rear ride height was significantly higher than the front. The floor itself acted as a large diffuser, and the Y250 vortex from the front wing, together with bargeboardconditioned flow, sealed the edges to maintain suction [11]. When the 2022 regulations forced a more level floor geometry, the same principles carried over. Red Bull's 2023 floor used intricate edgewing strakes and a subtly twisted central section to replicate the earlier sealing mechanism, achieving enormous cornering speeds with visibly less porpoising than rivals [13]. This case clearly illustrates that the biggest performance leaps occur when frontwing vortices, floor shape and the rearwingdiffuser combination are treated as a single unified system.

4. Current challenges and future trends

4.1. Major technical challenges

Even the most advanced modern aerodynamic designs still run into hard boundaries. We could find porpoising is still the clearest issue. When the car's floor stops working, then starts working again over and over at high speeds, the up-and-down movement that comes from this makes the car unstable. It also makes designers raise the car's ride height, which means the car loses some of its speed and performance [11]. Right now, it's still a hard, unsolved problem to find a floor shape that creates lots of downforce suction, but doesn't get stuck when the car goes over bumps or turns.

Tyre wake management is another persistent obstacle. The front tyres are the single biggest source of aerodynamic disturbance on the car; with many auxiliary wakecontrol devices banned, the burden now falls more heavily on the front wing and sidepod undercut geometry [2]. Even small improvements in this area translate into measurable gains in floor performance [14].

The FIA's increasingly tight deflection tests on wing flexibility and flooredge clearance continuously force engineers to find clever workarounds. Combined with restrictions on windtunnel hours and computational fluid dynamics resources [7], the tradeoffs among downforce, drag, stability and cost have become one of the most complex problems in contemporary aerodynamics [15].

4.2. Future development trends

Looking ahead, active aerodynamics is set to reshape the design landscape. The 2026 powerunit regulations will introduce movable front and rear wings that reduce drag on straights and increase downforce in corners [16]. This will rewrite the relationship between the wings and the floor again, pushing teams toward a controlsystem perspective where aerodynamic surfaces adjust in real time.

Machinelearningdriven aerodynamic optimization is gaining ground at the same time, allowing engineers to explore design spaces too complex for intuition alone [8]. The integration theme will only strengthen: active wings and adaptive floors will blur the line between mechanical setup and aero performance. In parallel, lightweight composite materials and sustainable design principles are expected to play larger roles, helping motorsport move toward lower carbon footprints without sacrificing speed.

DOI: 10.54254/2753-8818/2026.DL33849

5. Conclusion

This review set out to connect the dots between the front wing, rear wing and underfloor of a Formula One car. The evidence drawn from design practice and case examples makes it clear that these three components are joints in a single aerodynamic chain. The front wing's job is as much about feeding the floor as it is about frontend grip. The rear wing relies on a healthy diffuser exit, and the floor's efficiency depends on how well it is supplied and sealed.

Modern solutions, such as multielement wings, vortexsealing techniques and Venturi floors, work precisely because they are designed with this chain in mind. The case study of the post2022 floor underlines that the largest performance leaps happen when the system is treated as one. At the same time, challenges like porpoising remind us that interdependence is a doubleedged sword: a floor malfunction can undo the gains of a perfect front wing.

For future work, active aerodynamics and AIbased multicomponent optimization are promising directions. Whether one is a student building a CFD model or an engineer shaping the next championship contender, the real magic lies in making the front wing, rear wing and underfloor talk to each other.

References

[1] Katz, J. (2006). Aerodynamics of race cars. Annual Review of Fluid Mechanics 38, 27–63.

[2] Zhang, X., Toet, W., & Zerihan, J. (2006). Ground effect aerodynamics of race cars. Applied Mechanics Reviews, 59(1), 33–49.

[3] Zerihan, J., & Zhang, X. (2000). Aerodynamics of a single element wing in ground effect. AIAA Journal, 38(12), 2258–2266. https: //doi.org/10.2514/2.903

[4] Dominy, R. G. (1992). Aerodynamics of Grand Prix cars. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 206(4), 267–274.

[5] Granados-Ortiz, F.-J., Morales-Higueras, P., Ortega-Casanova, J., & López-Martínez, A. (2023). Two-dimensional-based hybrid shape optimisation of a 5-element Formula 1 race car front wing under FIA regulations. Machines, 11(2), 231.

[6] Hucho, W. H. (1998). Aerodynamics of road vehicles (4th ed.). SAE International.

[7] Agathangelou, P., & Gascoyne, M. (1998). Aerodynamic design considerations of a Formula 1 racing car (SAE Technical Paper 980399). SAE International.

[8] Irving, P., & Jones, S. (2022). Computational fluid dynamics for racing cars. Annual Review of Fluid Mechanics, 54, 611–636.

[9] Katz, J. (1995). Race car aerodynamics: Designing for speed. Bentley Publishers.

[10] FIA. (2010). 2011 Formula 1 World Championship: Technical regulations. Fédération Internationale de l'Automobile.

[11] Jain, A. N., & McBeath, S. (2024). Formula 1 race car aerodynamics: Understanding floor flow structures and why it is a key component in modern racing (SAE Technical Paper 2024-01-2078). SAE International.

[12] Ahmed, S. R., Ramm, G., & Faltin, G. (1984). Some salient features of the time-averaged ground vehicle wake (SAE Technical Paper 840300). SAE International.

[13] FIA. (2021). 2022 Formula 1 technical regulations. Fédération Internationale de l'Automobile. https: //www.fia.com/sites/default/files/fia_2022_formula_1_technical_regulations_-_iss_1_-_2021-12-08.pdf

[14] Ehirim, O. H., Knowles, K., & Saddington, A. J. (2019). A review of ground-effect diffuser aerodynamics. Journal of Fluids Engineering, 141(2), 020801.

[15] Wilson, A. C. W., Newbon, J., Dominy, R. G., & Sims-Williams, D. B. (2014). Aerodynamic structure and development of Formula 1 racing car wakes. SAE International Journal of Passenger Cars - Mechanical Systems, 7(3), 1096–1105.

[16] FIA. (2024).2026 Formula 1 World Championship: Technical regulations. Fédération Internationale de l'Automobile. https: //www.fia.com/regulation/category/110