Proceedings of CONF-MPCS 2026 Symposium: Theoretic Physics and Plasma Physics
DOI: 10.54254/2753-8818/2026.DL33795

Literature Review of Formula 1 Aerodynamics: Wake Effects, Component Performance, and New 2026 Rules

Xi Ling

Beijing NO.2 Middle School, Beijing, China
lingxi0703@hotmail.com

Abstract. Formula 1 cars need good aerodynamics to go fast around corners. This paper reviews eleven studies on F1 aerodynamics, covering CFD methods, front wing, diffuser, wheels, wake effects, Gurney flaps, flexible wings, rear spoilers, and the 2026 regulations. CFD simulations using OpenFOAM or ANSYS Fluent can achieve errors below 7% for downforce and drag, making them reliable for designing. While the front wing generates about 23% of total downforce, the underbody contributes 61% with only 15% of drag. Wheels are less efficient, causing about 30% of total drag. The main problem is the wake effect: when a car follows another, its downforce drops by 23% to 62%, depending on the gap. The diffuser is the most sensitive component, losing up to 70% of its downforce in close proximity. Advanced devices such as Gurney flaps and active spoilers can improve performance, but tradeoffs still remain. To address the wake problem, the 2026 rules introduce active wings, simpler shapes, and greater reliance on ground effect. This review provides a simple overview of current knowledge and future directions in F1 aerodynamics.

Keywords: Formula 1, aerodynamics, wake, CFD, Gurney flap

1. Introduction

Motorsport is one of the most popular sports in the world, with cars with top speed and advanced technology. Cars go over 300 km/h and need a lot of grip while passing through corners. This grip comes from downforce generated by air, which pushes the car down onto the track. Most downforce comes from the wings and the floor.

However, when a car moves, it creates a messy wake behind it. If another car follows closely, it enters this wake and loses downforce, which makes overtaking very hard [1]. For example, studies show that a following car can lose more than half of its downforce when it is less than one car length behind. Because of this, the FIA (Fédération Internationale de l'Automobile) changed the regulations several times. Major changes came in 2022, and more changes are planned for 2026. The goal is to reduce the damage caused by the wake and make racing more exciting.

This review uses eleven studies to give a simple overview of F1 aerodynamics. It covers important topics such as how computers simulate air flow (CFD), how key parts like the front wing, diffuser, and wheels work, what happens when one car follows another, and what devices like Gurney flaps and flexible wings can do. It also discusses the upcoming 2026 rules and how they aim to fix the wake problem.

© 2026 The Authors. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).

DOI: 10.54254/2753-8818/2026.DL33795

2. The use of Computational Fluid Dynamics (CFD)

Computational Fluid Dynamics (CFD), which is cheaper than wind tunnels, is used by engineers to simulate air flow. Martins, Correia, and Silva [2] studied how the front wing pressure distribution affects the wake of the front wheel. They used a Detached-Eddy Simulation (DES) model in ANSYS Fluent. DES is better than normal RANS because it captures unsteady flow features. They changed the angle of the second flap on a three-element front wing, testing three angles: 30°, 32°, and 34°. They found that a more aggressive flap angle (34°) moved the separation point on the tire rearward, increasing downwash behind the wheel and making the wake shorter. The authors also detected higher drag force fluctuations than lift force fluctuations. The dominant frequency changed from 8 Hz at 30° to 24 Hz at 32° and 13/36 Hz at 34°. This shows that small changes in the front wing can change the unsteady flow behind the wheel.

Guerrero and Castilla [1] used OpenFOAM with the k-ω SST model. Their simulation errors were 4.45% for downforce and 6.50% for drag. This confirms that CFD is accurate enough for F1 design.

Granados-Ortiz and colleagues [3] used ANSYS Fluent to optimize a five-element front wing. They combined a Kriging surrogate model with the NSGA-II genetic algorithm to explore a 17-dimensional design space. After finding the best parametric design, they refined it using an adjoint method, which changes the shape automatically to improve the lift-to-drag ratio. Thus, depending on the design goal, like capturing unsteady wake features or refining local pressure distribution, different CFD approaches such as DES, RANS, or adjoint-based optimization may be appropriate.

3. Important parts of an F1 car

3.1. Front wing

The front wing is the first part to hit the air. It makes about 22.84% of the total downforce [1]. It also sends air to the floor and sidepods.

Granados-Ortiz et al. [3] compared two optimized front wings. One came from parametric optimization, the other from adjoint optimization. The adjoint wing had a little more downforce but also a little more drag. The downforce increased from 157.63 kg to 162.67 kg, while drag increased by only 2.66 kg. More importantly, the adjoint method moved the Y250 vortex closer to the front wheel. This reduced pressure on the tire, which is good because tires cause a lot of drag. The adjoint design also had better ground suction under the floor.

Cravero and Marsano [4] showed that front wing endplates use the Coanda effect to push air around the outside of the wheel. This reduces the high-pressure zone on the tire. Without the endplates, more air would hit the tire directly, creating more drag.

3.2. Floor and diffuser

The floor and diffuser are very efficient. Guerrero and Castilla [1] found that the underbody gave 61% of total downforce but only 15% of total drag. In comparison, the front wing gave 23% downforce, and the rear wing gave 35%. Wheels and suspension actually created lift, which is bad. The underbody is the most important part for downforce.

Pérez Nebot and others [5] tested changes to the diffuser. They added small vertical walls (strakes), added flaps under the diffuser, and sealed the sides. They tested six different configurations. The best change was sealing the floor completely, which almost tripled downforce

DOI: 10.54254/2753-8818/2026.DL33795

while keeping drag almost the same. The downforce went from -2334 N to -7001 N, an increase of 200%. Drag went from 43.9 N to 60.2 N, an increase of 37%. Another good change was a vertical wall plus two flaps. This increased downforce by 200% but also increased drag by 60%. For tracks with many slow corners, the extra downforce may be worth the drag penalty.

3.3. Wheels

Wheels are a big problem. They cause about 30% of total drag. They also create messy air that hits the diffuser.

Cravero and Marsano [4] compared a stationary wheel and a rotating wheel. The rotating wheel had 7% less drag but 52% less downforce. Rotation also created a third vortex that did not exist with a stationary wheel. This vortex changed the shape of the wake behind the wheel.

Martins et al. [2] also studied wheels. They found that the front wing flap angle changes the wheel wake structure. When the flap angle was 34°, the separation point on the tire moved rearward. This created more downwash behind the wheel and made the wake shorter. However, this also increased wheel drag. The authors found that the 34° configuration produced a wider but shorter wake that was closer to the chassis. Therefore, front wing adjustments directly affect wheel aerodynamics.

Navarro Gorgojo [6] also noted that wheels are a major source of drag and lift. In his curved track study, he found that the front wing and wheels interact strongly, especially in corners.

4. The wake effect

4.1. The loss of much downforce

Guerrero and Castilla [1] did a key study on wake effects. They put a second car behind a leading car at four distances, where L is the car length (about 5.3 meters). The results were:

At 2L (10.6 meters): downforce loss 23.5%

At 1L (5.3 meters): downforce loss 42.3%

At 0.5L (2.65 meters): downforce loss 54.1%

At 0.25L (1.3 meters): downforce loss 62%

The result indicates a trend that the closer you get, the more downforce you lose. Simultaneously, drag also dropped, but less. At 0.25L, drag was 40% lower. This means the following car loses much more downforce than drag. That is bad for cornering because downforce is what gives grip in corners.

Navarro Gorgojo [6] studied wake effects on a curved track. He used a 90-degree corner with a radius of 46 meters. He found that downforce loss in corners was also very large. At a separation of 0.5L (about 2.65 meters), the following car lost about 42% of its downforce. At 0.25L, the loss was even bigger. This is important because downforce matters most in corners. With lower downforce, drivers have to slow down in corners. This makes overtaking even harder.

4.2. Changes in balance

Another problem is that the front balance changes. Front balance is the ratio of front downforce to total downforce. In clean air (free stream), it was about 45%. By comparison, in the wake, it goes up to between 58% and 63% [1]. Moreover, at 0.25L separation, the diffuser lost 70% of its downforce. The rear wing lost 58%, and the front wing lost only 38% [1]. This means the front of the car

DOI: 10.54254/2753-8818/2026.DL33795

generates more downforce than the rear. This causes oversteer. Oversteer means the car turns more than the driver wants. This could lead to a spin. So wake also changes how the car handles.

Navarro Gorgojo [6] also saw this balance shift in his curved track study. He reported that the front balance increased by about 26% to 40% in the wake, making the car unstable in corners.

5. Advanced devices

5.1. Gurney flap

A Gurney flap is a small strip attached to the trailing edge of a wing, usually only 1–5% of the wing chord. Basso, Cravero, and Marsano [7] added one to a front wing. The results showed that downforce increased by 24%, drag by 28%. The efficiency (downforce divided by drag) dropped only 5%, making it a good trade-off for F1 cars.

The flap created a larger low-pressure area under the main wing. This enhanced ground effect. Without the flap, there were large recirculation bubbles behind the wing. With the flap, the flow was cleaner and more attached. The flap also changed the flow to the wheels and suspension. The lower suspension gained 62% more downforce, and the upper suspension gained 22% more. The wheels had 26% less drag. Thus, the Gurney flap influences not only the wing itself but also downstream components such as wheels, as shown by the changes in downforce and drag distribution.

5.2. Flexible wings (FSI)

F1 wings are made of carbon fiber. They are not perfectly rigid, and flexibility plays an important role. They bend a little at high speed. Bang and colleagues [8] used a two-way fluid-structure interaction (FSI) model in ANSYS. They studied a double-element composite front wing near the ground. They found that the wing bends downward when it is close to the ground. This changed the pressure distribution on the wing. The maximum downforce occurred at a higher ride height than for a rigid wing.

The authors also found that the wing tip twisted slightly. This changed the spanwise pressure distribution. The aeroelastic effect was small but not zero. For precise design, FSI should be considered.

5.3. Rear spoilers and active systems

Nath and others [9] tested different add-on devices on a GT car. They tested a rear wing, a spoiler, a diffuser, and fins. They also tested combinations. The best for reducing drag was a spoiler plus diffuser. This cut drag by 16.5% (from 0.344 to 0.287). The rear wing alone increased drag by 38% but created negative lift (downforce). So there is always a trade-off. The authors also tested fins. Fins alone reduced drag only 1.6%, which is very small.

Deng et al. [10] reviewed many studies on rear spoilers. They found that active spoilers, which change its angle while driving, work best. On a straight road, the spoiler lies flat to reduce drag. In a corner, it tilts up to add downforce. Some studies showed that active spoilers can improve stability by 30%. The authors also discussed split rear wings. A split wing can control the left and right sides separately. This can help the car turn better.

DOI: 10.54254/2753-8818/2026.DL33795

5.4. Summary of advanced devices

The Gurney flap increases downforce by about 24% and drag by 28%, which is useful when extra downforce is needed. Flexible wings produce relatively small changes in downforce and drag but can shift the optimal ride height. For drag reduction, combining a spoiler and a diffuser works best in the reviewed studies, lowering drag by 16.5%. A rear wing alone does increase downforce but adds 38% more drag, so it is used only on highdownforce tracks. Active spoilers differ because they adjust their angle while driving, offering low drag on straights and high downforce in corners. Each device has tradeoffs, and the choice depends on track characteristics.

6. The 2026 rules

As discussed in previous sections, the wake effect causes severe downforce losses of 23% to 62% [1]. The diffuser is the most sensitive component [1, 5]. To solve this problem, the FIA will introduce new technical regulations in 2026. Li [11] summarized the key changes in these regulations. There are several main changes: active front and rear wings (X-mode),which are wings that can open on straights to reduce drag and help overtaking, similar to the old DRS but more powerful; simpler wing shapes, with fewer small winglets and complex endplates, which reduces the turbulence in the wake; inwash concept, where air is directed inwards (toward the car centerline) instead of outwards, making the wake narrower and less damaging for the following car; and more reliance on ground effect, which means the underbody, like floor and diffuser, will produce most of the downforce, under a limited reference volumes (RV).

Li [11] also pointed out that the 2026 rules require a reduction of about 30% in total downforce and 55% in drag (in X-mode) compared to current cars. This is consistent with the findings of Pérez Nebot et al. [5], who showed that a well-designed floor can be very efficient. Navarro Gorgojo [6] also argued that such changes are justified because under the 2017 rules a following car lost 42% of its downforce at 0.5L on a curved track.

One concern with greater reliance on ground effect could be the possibility of sudden floor stall, where the underbody loses suction without warning. This could cause an unexpected loss of grip. Although the FIA has introduced safety measures in the 2026 regulations, it remains to be seen how these changes perform in real racing conditions

7. Conclusion

In summary, this review leads to the following observations. Firstly, CFD simulations using DES or RANS models can capture important wake features, with errors below 7% for downforce and drag, making them reliable for design work. Secondly, the underbody is the most efficient downforce source, contributing about 60% of total downforce with only 15% of drag, while front wings and wheels are less efficient; sealing the floor can nearly triple downforce. Thirdly, wake effects remain severe: a following car loses 23% to 62% of its downforce depending on the gap, with the diffuser being the component most affected. The problem becomes even worse in corners. Fourthly, devices like Gurney flaps, flexible wings, and active spoilers each offer benefits with trade-offs; for example, a Gurney flap increases downforce by 24% at a drag penalty of 28%. Fifthly, the 2026 regulations – including active wings, simpler shapes, and greater reliance on ground effect – are designed to mitigate wake problems, which is consistent with the wake studies reviewed here. Overall, F1 aerodynamics remains a challenging field, and the eleven studies provide a solid foundation for understanding current knowledge and the expected changes under the 2026 rules.

DOI: 10.54254/2753-8818/2026.DL33795

References

[1] Guerrero, A., & Castilla, R. (2020). Aerodynamic Study of the Wake Effects on a Formula 1 Car. Energies, 13(19), 5183. https: //doi.org/10.3390/en13195183
[2] Martins, D., Correia, J., & Silva, A. (2021). The Influence of Front Wing Pressure Distribution on Wheel Wake Aerodynamics of a F1 Car. Energies, 14(15), 4421. https: //doi.org/10.3390/en14154421
[3] GranadosOrtiz, F.J., MoralesHigueras, P., & OrtegaCasanova, J. (2023). 3D CFD simulation of the interaction between front wheels & brake ducts and optimised fiveelement F1 race car front wings under regulations. Alexandria Engineering Journal, 69, 677–698. https: //doi.org/10.1016/j.aej.2023.02.011
[4] Cravero, C., & Marsano, D. (2022). Computational Investigation of the Aerodynamics of a Wheel Installed on a Race Car with a MultiElement Front Wing. Fluids, 7(6), 182. https: //doi.org/10.3390/fluids7060182
[5] Pérez Nebot, E., Gupta, A., & Mahak, M. (2025). Investigating the Impact of Structural Features on F1 Car Diffuser Performance Using Computational Fluid Dynamics (CFD). Mathematics, 13(9), 1455. https: //doi.org/10.3390/math13091455
[6] Navarro Gorgojo, P. (2021). Aerodynamic study of the wake effect on a Formula 1 car in curves. Universitat Politècnica de Catalunya. https: //hdl.handle.net/2117/360878
[7] Basso, M., Cravero, C., & Marsano, D. (2021). Aerodynamic Effect of the Gurney Flap on the Front Wing of a F1 Car and Flow Interactions with Car Components. Energies, 14(8), 2059. https: //doi.org/10.3390/en14082059
[8] Bang, C. S., Rana, Z. A., Könözsy, L., Marchante Rodriguez, V., & Temple, C. (2022). Numerical Investigation and FluidStructure Interaction (FSI) Analysis on a DoubleElement Simplified Formula One (F1) Composite Wing in the Presence of Ground Effect. Fluids, 7(2), 85. https: //doi.org/10.3390/fluids7020085
[9] Nath, D. S., Pujari, P. C., Jain, A., & Rastogi, V. (2021). Drag reduction by application of aerodynamic devices in a race car. Advances in Aerodynamics, 3(1), 4. https: //doi.org/10.1186/s42774-020-00054-7
[10] Deng, Z., Yu, S., Gao, W., Yi, Q., & Yu, W. (2020). Review of effects the rear spoiler aerodynamic analysis on ground vehicle performance. Journal of Physics: Conference Series, 1600(1), 012027. https: //doi.org/10.1088/1742-6596/1600/1/012027
[11] Li, H. (2025). Optimization of Formula 1 Core Aerodynamic Technologies under the 2026 FIA Regulations. Highlights in Science, Engineering and Technology, 160, 371-376. https: //doi.org/10.54097/96jps48