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Comparative Analysis of Aerodynamic Performance: Computational Fluid Dynamics Simulation of Red Bull Formula 1 Cars from 2021 and 2022

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ABSTRACT
During 2021 and 2022, huge regulations changes happened in Formula One racing cars which FIA takes "Ground Effect" back to Formula One. With the help of the greatest aerodynamicistin the world, AndrianNeway, Red Bull's 2022 formula one racing car (RB18) became the fastest car in the field. In order to find out the difference between 2022 formula one racing car and previous formula one racing car, this passage will first introduce basic knowledge about aerodynamics. Through the comparison of the CAD models, basic differences can be found between two cars. 2022 Formula One car has simpler structure of front wing and wear wing. However, the floor of 2022's car is complicated and important which is responsible for the creation of down force. After analyzing CFD simulations, 2022's car created down force mainly based on it "ground effect" floor, and this new car can make the race more competitve than before.

KEYWORDS
Formula One; Aerodynamics; CFD; CAD

1 Introduction

Formula One, as one of the premier sporting events in the world, attracts billions of fans annually who are captivated by the thrill of extreme speed. Each year, teams invest over a hundred million dollars in the construction and development of their cars, utilizing the most advanced technology available. Since the first Formula One race in Britain in 1950, these cars have undergone significant transformations driven by technological advancements and regulatory changes from the Fédération Internationale de l' Automobile (FIA). Among these changes, the 2021 to 2022 regulations represent one of the most substantial shifts since 2014[1], with the reintroduction of the "Ground Effect" leading to major redesigns of the front wing, rear wing, and nose. As the reigning World Champion, Red Bull's RB18 was undoubtedly the most successful car in 2022. This paper aims to explore the differences between Red Bull's 2021 and 2022 cars to understand why the RB18 was the fastest car on the grid in 2022.

2 Background

2.1 Regulations that Formula 1

One of the most significant changes in the 2022 Formula 1 regulations was the return of the "Ground Effect." Initially introduced in the late 1970s by Lotus, the Ground Effect vastly increased grip and cornering speeds, leading to its rapid adoption across the field[2]. However, it was banned in 1983 due to safety concerns, as the extremely low clearance between the car's floor and the ground posed a risk to drivers on uneven tracks. With advancements in technology and more comprehensive regulations, the Ground Effect was reintroduced in 2022. The new regulations allow for the use of Ground Effect while limiting upper body aerodynamics, ideally leading to more consistent downforce from Venturi tunnels and providing greater opportunities for overtaking[3].

2.2 Red Bull Racing Team

The Red Bull Racing Team has firmly established itself as one of the most successful teams in modern Formula One history. Although Red Bull was initially involved in Formula One as a sponsor, the team officially entered the sport as a constructor in 2004. Their rise to prominence was rapid and remarkable. After securing their first podium in 2006, Red Bull became a dominant force in 2009, achieving six victories and finishing second in the constructors' standings. This success continued with four consecutive championship doubles from 2010 to 2013, driven by Sebastian Vettel, who became the sport's youngest four-time world champion. In recent years, Red Bull has regained its winning momentum with another extraordinary talent, Max Verstappen[4]. The 2022 Red Bull car, the RB18, is widely regarded as a technical masterpiece, largely credited to Adrian Newey, the team's Chief Technical Officer. Under his leadership, the RB18 benefited from significant advancements in key areas such as the floor and suspension design, giving Red Bull a competitive edge. This car ultimately led Max Verstappen to his second world title and secured Red Bull's fifth constructors' championship.

2.3 Aerodynamics

Aerodynamics has rapidly evolved since its introduction to motorsport engineering in 1968, becoming one of the most critical aspects of race car design. The evolution of aerodynamic designs in Formula One has significantly impacted the overall performance of the cars, particularly in terms of downforce generation and drag reduction[5].At high speeds, airflow around the car can destabilize its handling on the track, making aerodynamic design essential for maintaining stability and enhancing performance. Key aerodynamic components such as the front and rear wings, as well as the car's floor, are meticulously designed to generate downforce, a force that increases tire grip and improves cornering speeds.

In a Formula One car, the front wing plays a pivotal role in directing airflow over the car, while the rear wing is crucial for generating downforce[6]. Both wings are optimized to ensure smooth and effective airflow, maximizing downforce while minimizing drag. Advances in wind tunnel testing, Computer-Aided Design (CAD), and Computational Fluid Dynamics (CFD) have allowed engineers to fine-tune these designs with greater precision, ensuring that the aerodynamic features perform optimally under real-world conditions.

2.3.1 Bernoulli Principle / Venturi Effect

Bernoulli's Principle or Equation is the basic theory of aerodynamics. Bernoulli's principle states that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy[7].

Bernoulli's principle is widely used in our daily life. For example, it can explain how the wings of airplanes create lift force, and how front wings of Formula One racing cars create down force. Figure 1 and Equation 1 help to explain Bernoulli's principle.

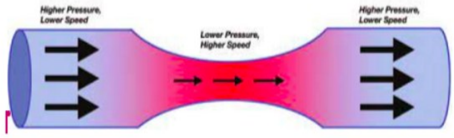

Figure 1

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (1)$$

Simply, Venturi's Effect is based on Bernoulli's principle. When a fluid (gas or liquid) in the subsonic regime is forced through a pipe that has a smaller cross-section, the static pressure decreases. The ideal, inviscid, incompressible form of the Bernoulli equation describes the relationship between velocity and pressure[8]:

$$p1 - p2 = \frac{\rho}{2}\left(v_2^2 - v_1^2\right) \quad (2)$$

We can figure out from the equation that there is a proportional ratio between the change in pressure and change in speed. Therefore, when a fluid travels from a high pressure area to a low pressure area, the speed of the fluid will increase, and that is the Venturi Effect.

2.3.2 Aerodynamic Forces

The aerodynamic forces, unlike other forces interacting between objects, are hard to measure and describe because when an object interacts with fluid, the fluid's shape is changeable. In order to simply understand aerodynamics forces, scientists classify the forces into 4 parts: lift, thrust, weight, and drag.

• Lift: This force counteracts gravity and is induced by airflow passing beneath the aircraft.

• Drag: As fluid flows along the body of the craft, its viscosity causes it to exert some drag that resists the forward motion of the aircraft.

• Thrust: This force is exerted by the engines and forces the craft to move along the forward direction.

• Gravity: This force determines the weight of the aircraft and always points in the down- ward direction.(8)

3 Methodology

To compare the aerodynamic performance of the 2021 and 2022 Formula One racing cars, Computational Fluid Dynamics (CFD) simulations were conducted using Computational-Aided Design (CAD) models of both cars. These simulations were designed to analyze airflow and pressure distribution around the car bodies under controlled conditions.

3.1 2021 and 2022 F1 Car Design

The CAD models for the 2021 and 2022 Formula One cars used in this study were sourced from public projects available on Simscale, a platform that allows designers and aerodynamics enthusiasts to share designs and perform CFD simulations. Although these models were not officially released by Formula One teams or the FIA, they are sufficiently accurate to serve the purpose of this comparative study.

Both the 2021 and 2022 car models were subjected to simulations at a constant speed of 50 meters per second, equivalent to 180 kilometers per hour. This speed approximates the average velocity typically used by automotive companies in wind tunnel testing, providing a consistent basis for comparison.

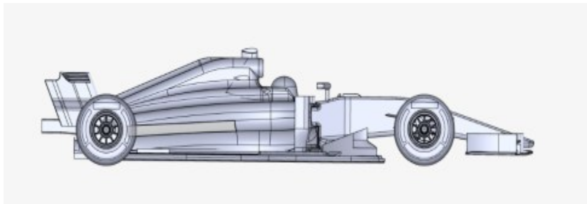

Figure 2 Formula One car before 2022

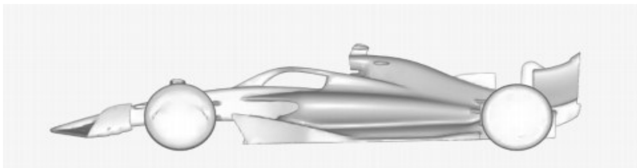

Figure 3 Formula One car in 2022

Only from the CAD models of the 2021 and 2022 car, there are a lot of differences between them. First of all, the front wing of the 2022 car is much simpler than the 2021 due to regulations. The previous generation of Formula 1's technical regulations allowed the front wing to be designed within areas bounded by boxes with minor limitations within those. Now, the rules specify surfaces that define the planform that the wing must take[9]. One important function of the new front wing is to diminish the vortex that will influence the racing cars behind it. Second, the rear wing is one of the most important aerodynamic components in a formula one racing car. In the 2022 car, the rear wing is just supported by two swan neck pylons instead of multiple of them.

Therefore, the rear wings in 2022 become lighter than the previous version. Last and the most significant change is the floor of the car. Due to the ground effect regulation, the floor is not flat anymore, and it is full of Venturi channels. These channels help the car to generate downforces. Different from the ground effect in the 20th centuries, the out-wash of the floor is not that huge, and FIA permitted teams using skirts on the floor to block the air flow. Thus, it is just a short interview on the different appearance of the car, and CFD simulations can help us figure out more

questions.

Figure 4 Upper image ofF1 car before 2022

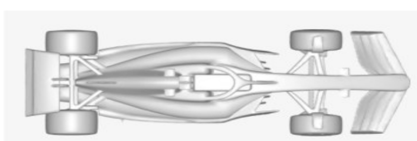

Figure 5 Formula One car in 2022

3.2 Simulation

After ensuring that the CAD models of the two cars are accurate, I also use Simscale to finish the

CFD simulation. After the CAD models are imported to Simscale, it can be edited, and we can add the air flow region to the CAD models. The air flow region is corresponding to the size of the formula one car. Usually, it will be 5 times the length of the car, 3 times the width of the car, and 3 times the height of the car.

After editing the CAD models, we will need to select the incompressible condition and set the basic data of the car, such as materials, initial conditions, and boundary conditions. Air of 50 meters per second has been selected for the material, and in the initial condition, basic values such as velocity, static pressure will be put into. Next, boundary conditions need to be set by selecting the velocity inlet, where air flows in, and pressure outlet, where air flows out, on the air flow region. For the ground, it needs to be set as the moving wall because then it can simulate the car for running at 50 meters per second. Moreover, for the four wheels of the formula racing car, they need to be set as rotational boundaries, and their centers of the wheels will be the rotation axis.

There is the angular velocity equation:

$$\omega rad = \frac{v}{r} \tag{3}$$

In this formula, w is the angular velocity in radians per second, v is the velocity in meters per second, andris the radians in meters.

Finishing other optional data such as advanced concepts, we can focus on the building of mesh. Mesh simply breaks down the object to be simulated into smaller cells that have the ability to accurately define the geometry of the object. The governing equation can be associated with each cell, which helps in the simulation of the flow in that discrete space. With a high-quality mesh, numerical analysis can be ensured with accuracy and precision[10]. In addition, the density of the mesh needs to be changed; closer to the car body, the density of the mesh should increase. Finally, we can start our simulation run, and after waiting for several hours, the simulation of the 2021 and 2022 formula one racing cars will be represented.

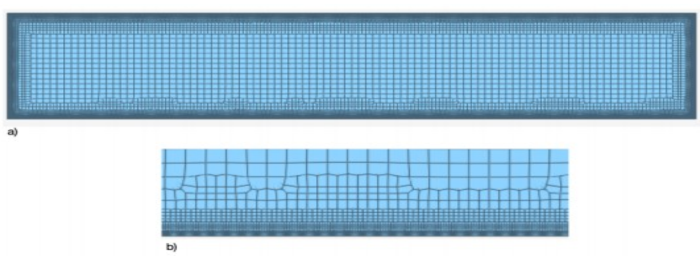

Figure 6 Meshing used on the simulation. a) Meshing of all the area. b) Zoom of the

detailed mesh on the boundary, close to the car.

4 Results and Analysis

Computational Fluid Dynamics (CFD) simulations were conducted on both the 2021 and 2022 Formula One cars at a velocity of 50 m/s. The velocity profiles for both models were calculated and visualized, revealing key aerodynamic characteristics. As depicted in the results, the stagnation point is located at the rear of both cars, where the airflow slows dramatically. The boundary layer, which forms near the car's surfaces, thickens as the flow progresses, leading to a gradual decrease in velocity around the car bodies. At the rear of both cars, a wake is formed, characterized by turbulent flow.

The most significant differences between the two models are found in the velocity distribution beneath the car and the wake formation behind it. The 2022 Formula One car exhibits a more pronounced airflow beneath the vehicle, contributing to a substantial increase in downforce. In contrast, the wake behind the 2021 car is wider, resulting in higher drag forces.

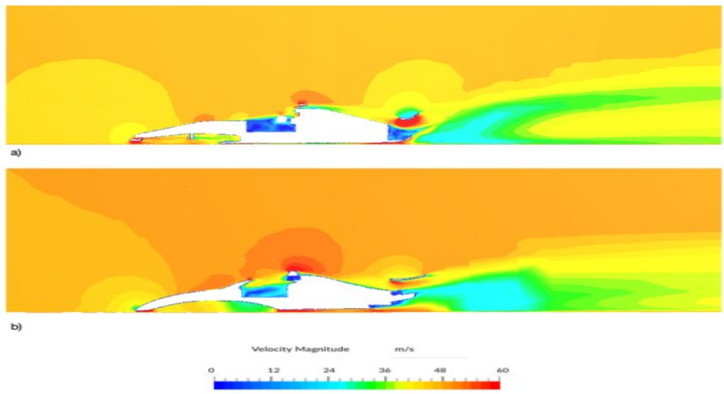

Figure 7 Velocity distribution of air around a Formula one car at 50 m/s. a) Formula one before 2022 b) Formula one 2022

Moreover, the drag coefficient and lift coefficient were calculated, and the results are shown in following table:

	Model 2021	Model 2022
Drag coefficient Lift coefficient	0.9 -1.52	0.58 -0.01

The drag coefficient from the formula one car 2022 is 0.58 while the drag coefficient from the formula one car 2021 is 0.9. The drag coefficient is affected by the shape of the body of the car. To obtain a low drag coefficient the boundary layer must remain attach to the surface of the body as long as possible, causing the wake to narrow.

This can be observed on figure 7. As the wake of the model 2022 is slightly narrow of the model 2021. We also calculated the lift coefficient, that were of value negative for both models, meaning that there is a downforce keeping the car to the ground, due to the Venturi Effect explained in seccion 2.3.1.

5 Conclusions

The primary objective of this study was to identify and analyze the differences between the 2021 and 2022 Formula One cars, particularly in light of the substantial regulatory changes introduced in 2022. The 2022 regulations imposed several limitations on aerodynamic components, notably on the front and rear wings. The front wing design was restricted to just four elements, a significant reduction compared to previous designs where aerodynamicists employed multiple elements to optimize downforce. The rear wing design also saw changes, with the removal of vertical plates and a reduction in the number of supporting pylons to two.

The most notable alteration in the 2022 car, however, is the redesign of the floor. With the reintroduction of the “Ground Effect” in Formula One, the car’s floor is no longer flat but features a series of tunnels designed to accelerate airflow beneath the car. This design is complemented by an out-wash structure based on the Venturi Effect, which further enhances downforce. In conclusion, the floor of the 2022 car plays a critical role in generating substantial downforce, particularly during high-speed cornering, making it a key factor in the car’s superior aerodynamic performance.

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References

[1] Stuart, G. "10 things you need to know about the all-new 2022 F1 car."(2021) (accessed 15 July 2021) https://www.formula1.com/en/latest/article. 10-things-you-need-to-know-about-the-all-new-2022-f1-car.

[2] Stuart, G. "Five classic Formula 1 ground effect cars." (6 February 2020) (accessed 15 March 2024) https://www.motorsportmagazine.com/articles/single-seaters/f1/ five-classic-formula-1-ground-effect-cars/.

[3] Fernandes, M. "What Is Ground Effect and Why Are the 2022 F1 Teams Talking About It?" (6 February 2020) (accessed 05 March 2024) https://www. essentiallysports. com/ f1-news-what-is-ground-effect-and-why-are-the-2022-f1-teams-talking-about-it/.

[4] Bull, R. "Formula One official Website." (accessed 05 March 2024) https://www.formula1. com/en/ teams/Red-Bull-Racing.html.

[5] Katz, J. (2010). Race Car Aerodynamics: Designing for Speed. Bentley Publishers.

[6] "Aerodynamics F1." (accessed 05 March 2024) https://racingnews365.com/aerodynamics-f1.

[7] "Bernoulli's Principle." (accessed 05 March 2024) https://skybrary.aero/articles/ bernoullis-principle..

[8] FelfÖld, A. "What is the Venturi Effect?" (December 12th, 2023) (accessed 05 March 2024) https: //www.simscale.com/blog/what-is-venturi-effect/.

[9] "Tech Explained: 2022 F1 Technical Regulations." (15 February 2022) (accessed 20 March 2024) https://www.racecar-engineering.com/articles/tech-explained-2022-f1-technical-regulations. 10. "The Importance of Meshing in CFD and Structural FEA." .