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Numerical Study of Formula One Halo Frame Aerodynamic Analysis

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Abstract: ***This paper presents an in - depth study on the aerodynamics of the Halo frame used in Formula One cars, known for being the fastest road course racing vehicles globally. The primary objective of this research is to enhance safety and reduce accidents without compromising driver visibility by redesigning the Halo, initially developed by Mercedes in collaboration with the FIA. This redesigned Halo aims to deflect flying debris, such as loose wheels, while maintaining easy access through a hinged locking mechanism. A key focus is on modifying the Halo's design to lessen its weight without negatively impacting the car's aerodynamic performance. Utilizing Computational Fluid Dynamics (CFD) simulations, this study examines the flow dynamics around the Halo. The research involves observing velocity profiles and pressure contours to assess the aerodynamic impact. The Halo is designed using SOLIDWORKS, a modeling software, and its airflow is simulated with FLUENT 3D. This process facilitates geometry modifications to enhance the design by reducing air resistance and improving overall aerodynamics. Preliminary assumptions indicate that the new 3D Halo model exhibits superior aerodynamic properties compared to its original design.***

Keywords: Formula One, Halo aerodynamics, Computational Fluid Dynamics, safety design, airflow simulation

1. Introduction

The halo protection device shown in Figure 1 was introduced to Formula One racing in 2018. The device is a T - shape multi - joint CNC and welded titanium hoop beam assembly that protects the driver's head in case of flying debris or colliding with stationary objects [1]. The device is mandated by FIA, the governing body of Formula Racing Series, and is manufactured by CP Autosport in Germany [2]. The halo protection device is delivered to each race team and integrated into their car. Cosmetic changes are allowed in terms of paint color, and just this past year, a small aero deflector does not alter the structural performance of this safety device. The requirement to carry this bulky safety device has been both lauded and criticized in the racing community. Supporters and pundits each have valid arguments for allowing or excluding the use of this device [3] [4]. One example is that it takes away the true spirit of open - wheel racing that is inherently risky. Another argument is that the halo device is strong enough to hold up a London bus. This paper aims to provide a scientific study of the halo effects, both positive and negative, in the specific area of aerodynamics.

Figure 1: Halo Protection device

1.1 Reasons for the halo to come up:

A focused push for increased cockpit protection started in 2009 when Henry Surtees, son of former world champion John, was killed by a loose wheel in a Formula 2 race. Just over a week later, Felipe Massa suffered life - threatening injuries when hit in the head by a loose spring during practice for the Hungarian Grand Prix. The issue of head protection returned to prominence again after Jules Bianchi's fatal collision with a recovery vehicle at the 2014 Japanese Grand Prix, although a subsequent investigation found cockpit protection would have made no difference to his injuries. In 2015, former F1 driver Justin Wilson was killed by a flying piece of debris from another car during an IndyCar race, further underlining the dangers of open - cockpit racing and prompting the Grand Prix Drivers'

Association (GPDA) to call for extra cockpit protection in F1.

1.2 Problem Description

This paper delves into the aerodynamic impact of the halo protection system on a modern Formula One racecar, focusing on how different airflow angles affect the vehicle's performance. Illustrated in Figure 2, the study employs Computational Fluid Dynamics (CFD) to evaluate the aerodynamic characteristics of the halo frame under varied airflow conditions. The goal is to ascertain if changes in airflow angles enhance or diminish the racecar's performance, with an emphasis on crucial racing metrics.

Key assumptions in this study include:

a) For yaw simulations, the car's rotation around the vertical axis assumes a linear airflow, not a curved one. Yaw angles of zero, five, and a maximum of ten degrees are examined.
b) The temperature is considered constant throughout the analysis, although in actual race conditions, temperature varies as air flows over the car.
c) The simulations do not account for the car's roll during yaw movements; real - world scenarios would see the car rolling oppositely to the turn, altering the car's floor orientation relative to the ground.
d) The study models only the F1 halo frame structure depicted in Figure 2, as this constitutes a preliminary investigation. A more comprehensive simulation would incorporate a dynamic boundary influenced by vehicle velocity, reflecting a more accurate depiction of racing conditions.

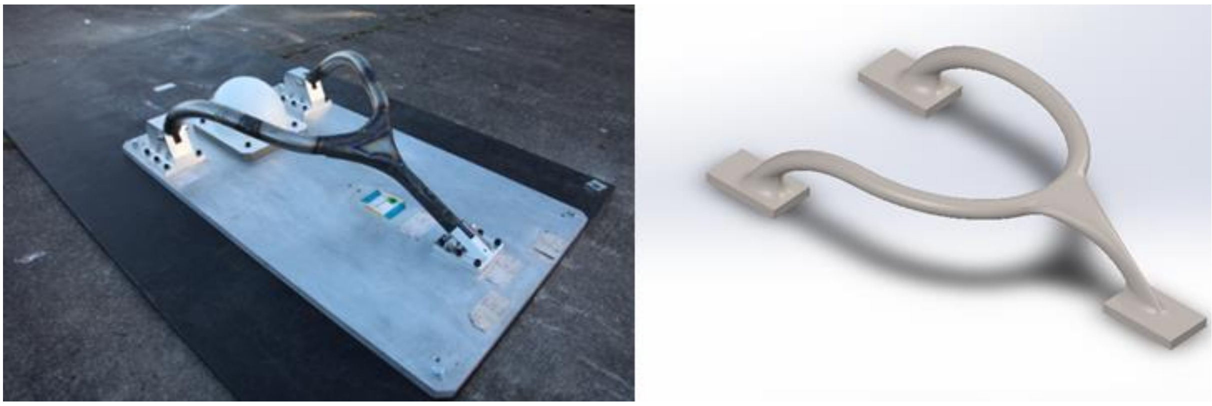


Figure 2: HALO Frame design and CAD model

2. Methodology

This paper conducts an analysis of the HALO frame in Formula One racecars under two distinct scenarios: 1. Evaluating the aerodynamic performance of the HALO frame, and 2. Assessing the frame's resilience to debris impact. The primary focus of this research is on the aerodynamic aspect of the HALO frame. For insights into the debris impact analysis, readers are referred to the discussion in reference [12].

3D CAD geometry is then manipulated to isolate (or segregate) the wheels, the engine cover, and the rear wing so different parameters can be extracted during analysis. The wheels are segregated so that a rotational velocity can be applied to create a rotating wheel boundary condition, and that the front wheels can be turned 7 degrees for the yaw simulation. The engine cover is segregated (using split - by - patch) so that a separate zone can be created to measure air intake mass flow rate. The rear wing is segregated so that the downstream effect of the halo device can be measured in terms of affected downforce. For the yaw simulation that is performed later, the entire car model is rotated 7 degrees in the horizontal plane with respect to the incoming freestream.

The halo protection device on the DRS (Drag Reduction System) is comprised of the upper flap of the rear wing. The DRS system was introduced 7 years earlier in 2011 and allows the rear wing's upper flap to be “opened” during specific segments of the race to assist in overtaking. When the DRS flap is opened, less drag and as a result less downforce is produced by the rear wing. In the model, the DRS flap is segregated into a separate zone and rotated about its axis to give it a zero - degree of angle - of - attack (AoA α). The predicted downforce reduction can be compared for both the case with and without the halo protection device being present.

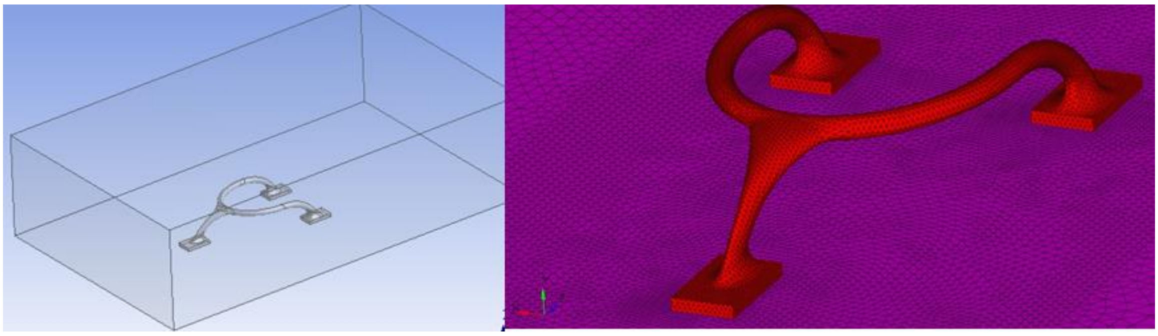


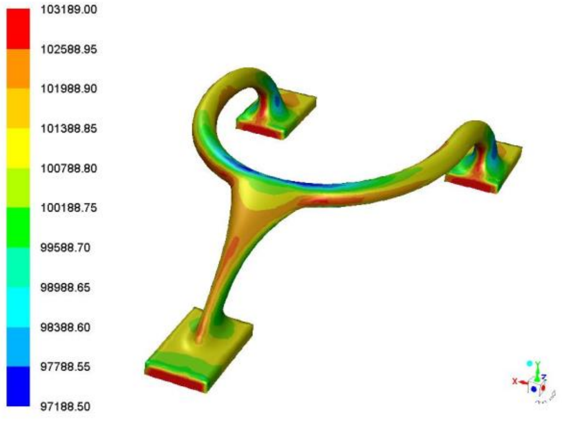
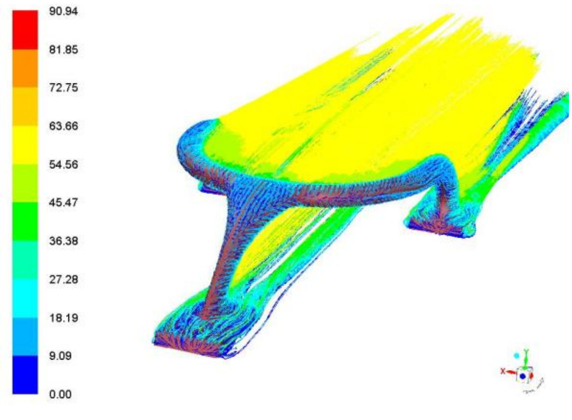
Figure 3: CFD Boundary Conditions

All models are meshed and ran using a commercial CFD software Fluent made available by Siemens AG. Because this is a complicated geometry with surface geometries present in the CAD model, a water - tight meshing scheme would not be possible; instead a fault - tolerant meshing scheme was used to successfully generate a cut - cell mesh [9]. As a way to improve the mesh quality, contact prevention was specified at places where there are small gaps that need to be simulated (e. g. gap between wing flaps). Prism layer is added along the car body to create inflation to capture boundary layer growth. For solving the mesh, SST κ–ω model is used to model turbulence. Since Reynold’s number here ranges from 7, 000, 000 - 35, 000, 000; the flow is fully turbulent even at the lowest speed that’s simulated (40 mph). Segregated flow (a. k. a. pressure - based) model is used because the Mach number is less than 1 so the fluid is assumed to have constant density. Transient effects are not considered in this study, so the problem is run as steady state.

4. Results & Discussion

The CFD simulation results, summarized in in Figure 4, Figure 5, and Figure 6. Pressure and Forces are summarized in **Error! Reference source not found.** focusing on downforce and air intake mass flow rate, provide insights into the aerodynamic impact of the HALO protection device on a Formula One racecar. it's evident that the HALO device alters the airflow to the rear wing, leading to a reduction in downforce. This effect is consistent across various speeds, becoming most pronounced at the highest velocity of 200 mph. Essentially, the HALO diverts air away from the rear wing, diminishing its aerodynamic efficiency.

The HALO device's influence on air intake mass flow, which is crucial for engine performance. The HALO redirects airflow away from the engine's air intake, potentially decreasing engine efficiency and power output. This scenario is somewhat analogous to the Formula SAE series, where air intake restrictors are used to level the playing field. [10]. In the CFD model, the engine air intake was considered an open area to accurately measure air flux. The reduced flux observed in the presence of the HALO device can be attributed to the diversion of airflow, possibly due to turbulence and vortex formation. This suggests that despite the unchanged design of the air intake since the introduction of the HALO device in 2018, its effectiveness in guiding air into the engine has been compromised by the HALO's presence.

Absolute Pressure (Pa)	**Velocity Streamlines (m/s)**
	
Static Pressure (Pa)	**Dynamic Pressure (Pa)**

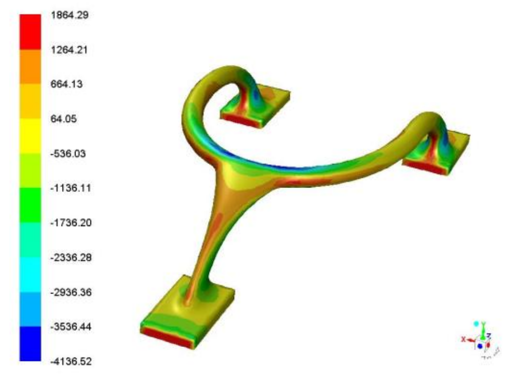
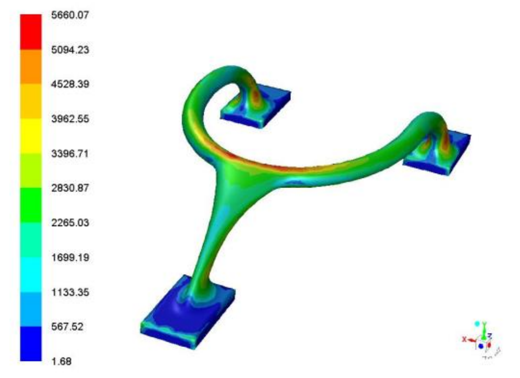
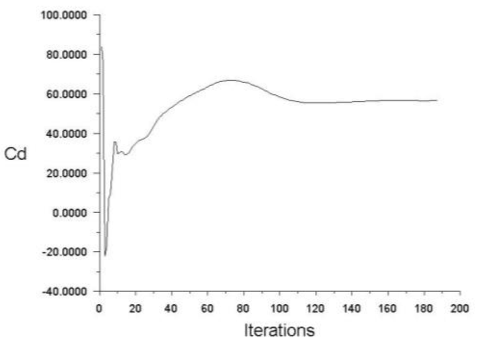
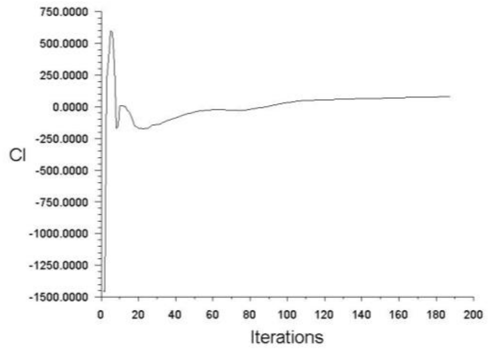
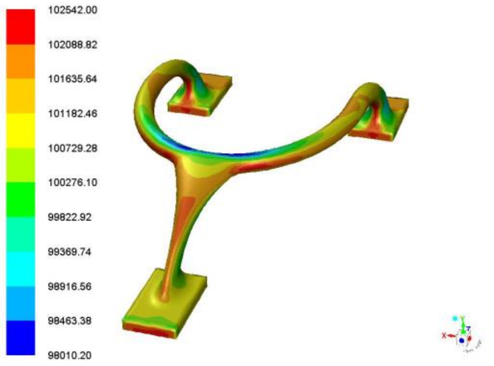
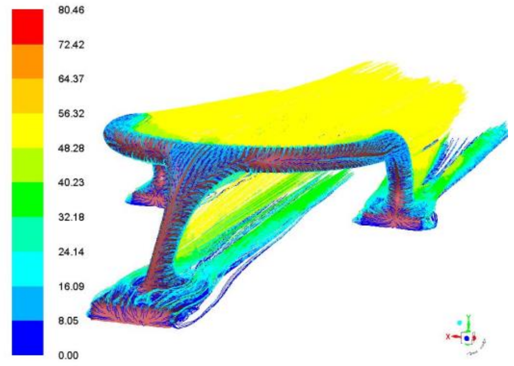
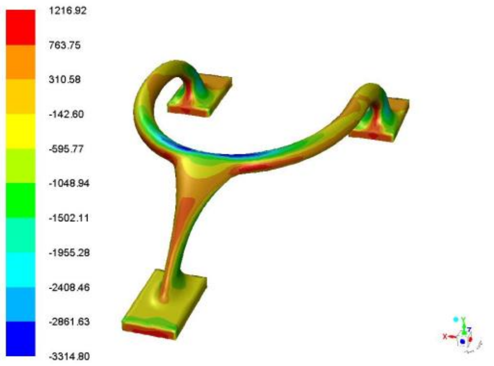
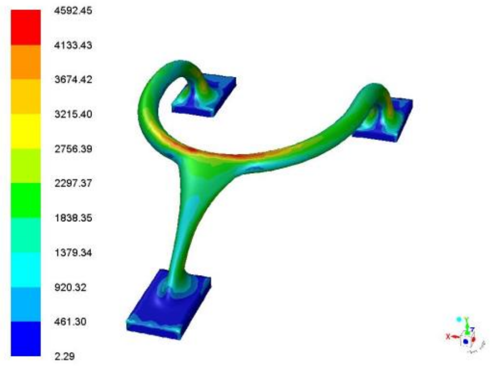
 	
Drag Force (N)  	**Lift Force (N)** 

Figure 4: Pressure and Force Summary on Halo frame for "0^0" Incident angle

Absolute Pressure (Pa)  	**Velocity Streamlines (m/s)** 
Static Pressure (Pa)  	**Dynamic Pressure (Pa)** 
Drag Force (N)	Lift Force (N)

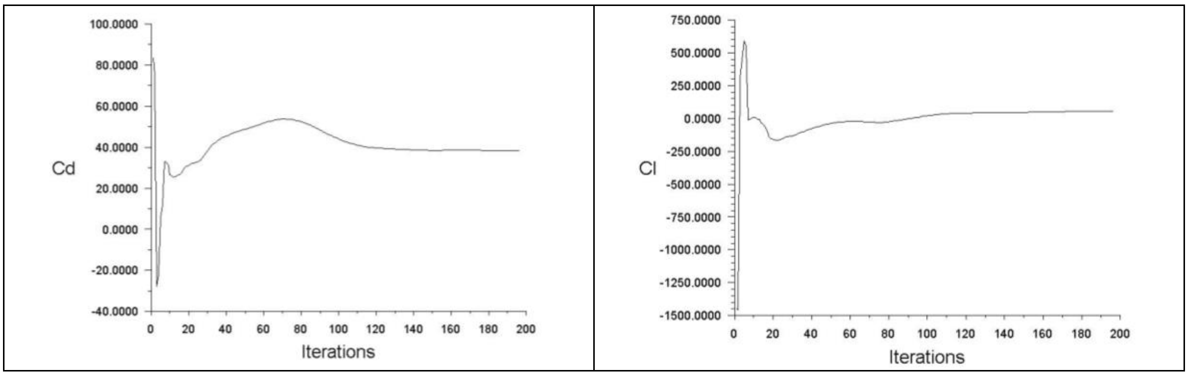
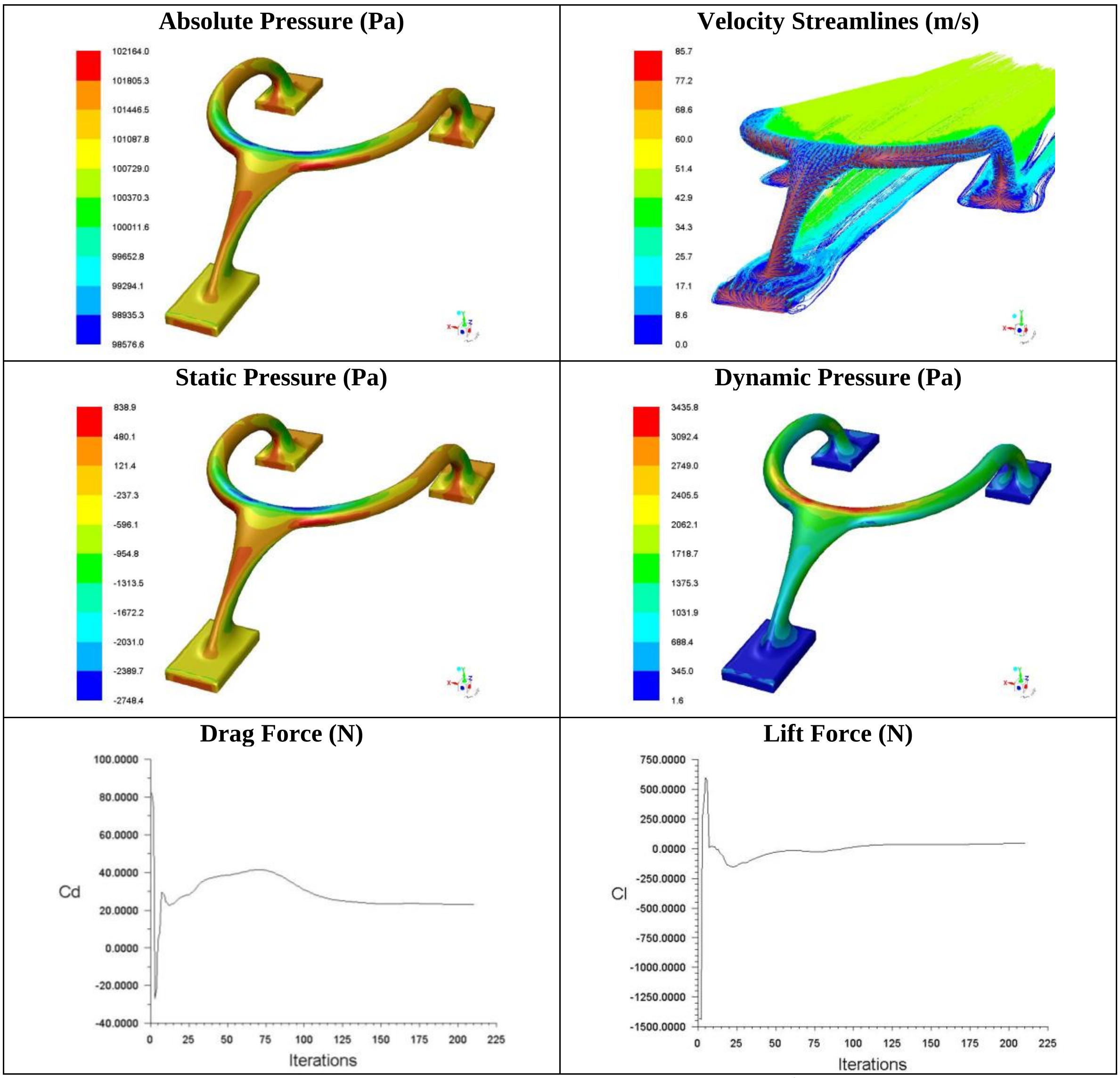


Figure 5: Pressure and Force Summary on Halo frame for "5^0" Incident angle


Absolute Pressure (Pa)

Velocity Streamlines (m/s)

Static Pressure (Pa)

Dynamic Pressure (Pa)

Drag Force (N)

Lift Force (N)

Figure 6: Pressure and Force Summary on Halo frame for "10^0" Incident angle

Table 1: Pressure and Force Summary

Incident Angle	Absolute Pressure (Pa)	Static Pressure		Dynamic Pressure (Pa)	Max Velocity stream (m/s)	Drag Force (N)	Lift Force (N)
		Positive gauge Pressure (Pa)	Negative gauge Pressure (Pa)				
0	103189	1864	4136	5660	90.94	56.5	77.8
5	102542	1216.9	3314	4592	80.46	38.4	56.5
10	102164	838.9	2748	3435	85.7	23.1	42.2

5. Conclusion

In this study, the aerodynamic effects of the halo protection device on a 2019 Formula 1 racecar are analyzed using Computational Fluid Dynamics (CFD). The study focuses on understanding how the halo influences key aerodynamic parameters, based on data collected across various speeds. The findings indicate three significant impacts of the halo protection device.

1) **Reduction in Rear Wing Downforce**: The halo device decreases the downforce generated by the rear wing. This reduction in downforce affects the rear wheels' traction, which is crucial for maintaining stability and control, especially at high speeds.
2) **Decrease in Engine Intake Mass Flow**: The halo also impacts the air intake for the engine. By redirecting airflow away from the engine's air intake, the halo leads to a lower mass flow rate into the engine. This decrease directly correlates with a reduction in the engine's power output, potentially affecting the car's overall performance.
3) **Effect on Vehicle Stability During Turns**: In scenarios involving vehicle yaw - when the car turns - the halo plays a critical role. The study's yaw simulations reveal that the halo reduces the downforce provided by the rear wing during turns. This reduction can lead to rear - end instability, particularly in situations where the Drag Reduction System (DRS) fails. Such instability can pose challenges in handling and maneuvering the car effectively in turns.

Overall, while the halo protection device is integral for driver safety, its presence distinctly alters the aerodynamic behavior of the racecar, impacting aspects like downforce, engine efficiency, and vehicle stability during turns.

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