High - Speed Savior: Exploring Formula One's HALO Frame using Impact Simulations

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Abstract: ***The relentless pursuit of speed in Formula One racing often collides with the paramount concern for driver safety. The sport has witnessed devastating accidents throughout its history, prompting continuous advancements in car design and safety regulations. The introduction of the Halo frame in 2018 marked a significant watershed moment, ushering in a new era of driver protection against potentially fatal head injuries. Central to this research is an extensive examination of the Halo frame, specifically designed to shield drivers from debris during collisions. We meticulously analyze the frame's structural integrity under conditions of high - speed impact, utilizing advanced simulation techniques. The core of our analysis involves the use of ANSYS for structural assessment, where we simulate debris impacts on the Halo at a velocity of 225 Kmph. This approach allows us to measure the frame's deflection and stress responses under such extreme conditions. This paper aspires to influence future safety regulations and car design in the sport by aligning the high - speed demands of Formula One racing with robust safety mechanisms. The goal is to ensure that the relentless pursuit of speed does not compromise the paramount concern of driver safety.***

Keywords: Formula One, Safety Regulations, Halo Frame, High-Speed Impact Simulation, ANSYS Structural Assessment

1. Introduction

In 2015, the Formula - 1 community was stunned by the death of Jules Bianchi following a catastrophic head injury suffered during the 2014 Japanese Grand Prix. While the cause of Bianchi’s accident may be debatable, the mechanism of his injury was clear; a high - speed impact to his head [1]. Over the past fifty years, more than 30 fatalities occurred in F1 racing events [2]. In 2018, the halo frontal cockpit protection system was introduced into Formula - 1 by the Fédération Internationale de l’Automobile (FIA) [1]. Since its debut in Formula - 1 in 2018, the Halo has been adopted across various single - seater motorsport categories, including Formula E, F2, F3, Euroformula Open, and Super Formula. The Halo, a tubular structure made of titanium with three prongs, encircles the cockpit of a Formula - 1 car. Its purpose is to serve as a protective barrier, either deflecting or absorbing the forces encountered during accidents [3]. This groundbreaking safety device has proven instrumental in safeguarding drivers, significantly reducing the risk of severe injuries, and saving numerous lives in the sport.

Tests of the Halo continued to prove successful. Centering on three significant major risk types, car - to - car contact, car - to - environment contact, and external objects, tests revealed that in the case of car - to - car incidents, the Halo was able to withstand 15x the static load of the full mass of the car and was able to significantly reduce the potential for injuries [4]. This HALO frame design protects the drivers from flying objects in the race. The F1 Car Cockpit Standard Test picture is shown in Figure 2: A Comprehensive Guide to the Physical Testing Criteria for Formula 1 Cockpits [5]. This paper analyzes a load case that mimics the cockpit protection test of a flying object hitting the HALO frame and its design effectiveness. This paper analyzes a load scenario replicating the cockpit protection test, focusing on the impact of a flying object on the HALO frame and assessing its design efficiency. The primary focus of this research is on the impact analysis of the HALO frame using debris. For insights into the aerodynamic aspect of the HALO frame is discussed in reference [6].

Injury Risk	Mechanism of Protection	Performance
Car-to-car	Withstand 15x static load of full car mass	Significantly reduce injury potential
Car-to-environment	Prevent helmet contact with wall/barrier	Successfully prevention in recreated incidents
External objects	Deflect large objects from cockpit and protect against small debris	Significantly increased protection from small and large debris

Figure 1: Summary of HALO frame protection performance [7].

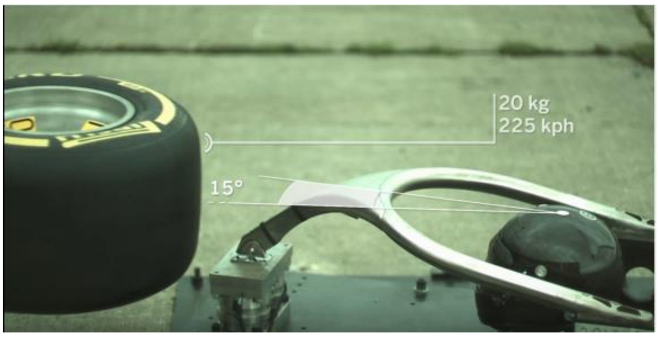

Figure 2: HALO Frame design verification test setup [4], [5]

2. Methodology

In this case study, within a high - speed environment, simulating the effectiveness of the halo frame design against debris impact, aiming to understand the critical dynamics and resilience of this safety feature under extreme conditions.

3.1. Design

The Halo, crafted from high - strength titanium, resembles a U - shaped frame encircling the driver's cockpit. Its seemingly simple design belies a complex engineering marvel. It efficiently distributed impact forces across the entire structure. Solidworks is used to design this HALO Frame.

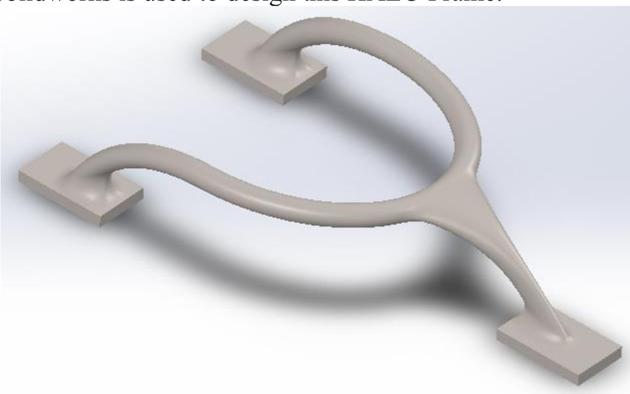

Table 1: CAD Model of HALO Frame

3.2. Material

The titanium alloy chosen offers an exceptional strength - to - weight ratio, crucial for minimizing weight addition while guaranteeing robust protection. Material properties for both HALO frame and stainless steel ball are summarized in

Table *2*.

Table 2: Material Properties

Material Properties		
	Titanium	**SS304**
Density (Kg/m^3)	4.51E+03	7.90E+03
Volume (m^3)	5.72E - 03	4.19E - 03
Mass (Kg)	25.804	33.091
Modulus		
Specific Heat (J/ (Kg. C)	500	423
Yield stress (Pa)	8.50E+08	3.40E+08
Ultimate stress (Pa)	1.45E+09	2.50E+09

3.3. Finite Element Analysis:

To comprehensively understand the Halo frame's performance, conducted simulations where a 33 kg steel ball impacts the frame at a speed of 225 km/h, mimicking the conditions experienced by a racing car. These crash simulations are employed to assess the frame's durability and effectiveness under extreme stress. " Ansys workbench is used to perform this impact simulation. HALO frame is discretized into second - order tetra elements. Finite Element discretized model is shown in

Figure 3.

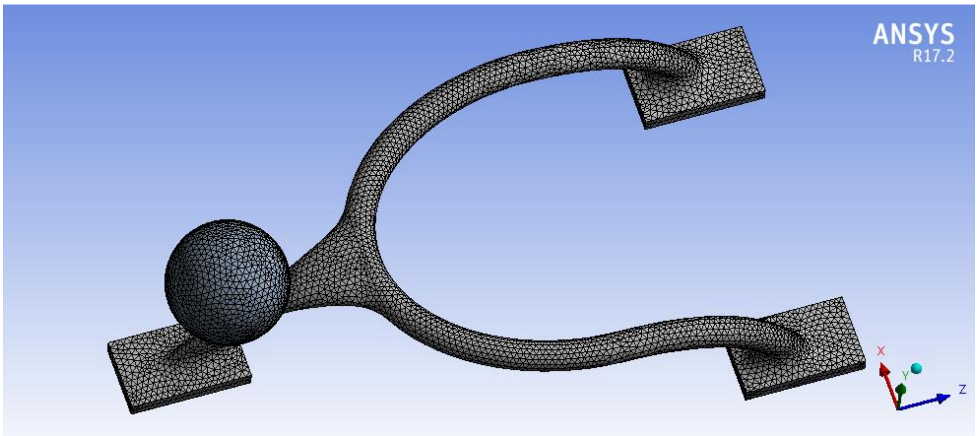

Figure 3: Finite Element discretized model

Boundary Conditions

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HALO frame base sections are constrained with Fixed DOF at its three legs. The initial velocity of the steel ball is 62 m/s with a mass of 33 kg as shown in Figure 4.

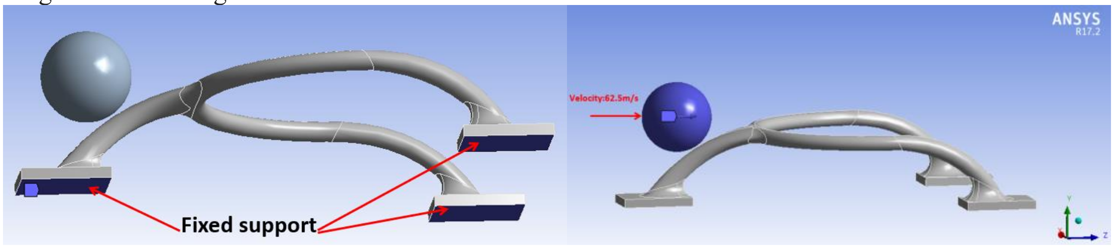

Figure 4: Boundary conditions

3. Results and Discussion

The primary objective of the impact analysis of the Halo frame in Formula One racing cars study was to evaluate the structural integrity of the Halo frame under high - speed impact conditions, using Ansys specifically considering its ability to withstand forces without compromising driver safety.

4.1. Total Deformations:

The maximum deformation observed across the entire structure of the Halo frame was measured at 48 mm to the side rails of the Halo frame. More critically, at the central location of the Halo frame, which is considered a vital point due to its proximity to the driver's head, the maximum deformation was remarkably low, measured at just 0.74 mm. This minimal deformation at such a crucial point is a testament to the frame's robust design and efficiency in absorbing and distributing impact forces. It indicates that even under severe collision scenarios, the structural design effectively safeguards the driver by maintaining the Halo's shape and position, thereby greatly reducing the risk of injury.

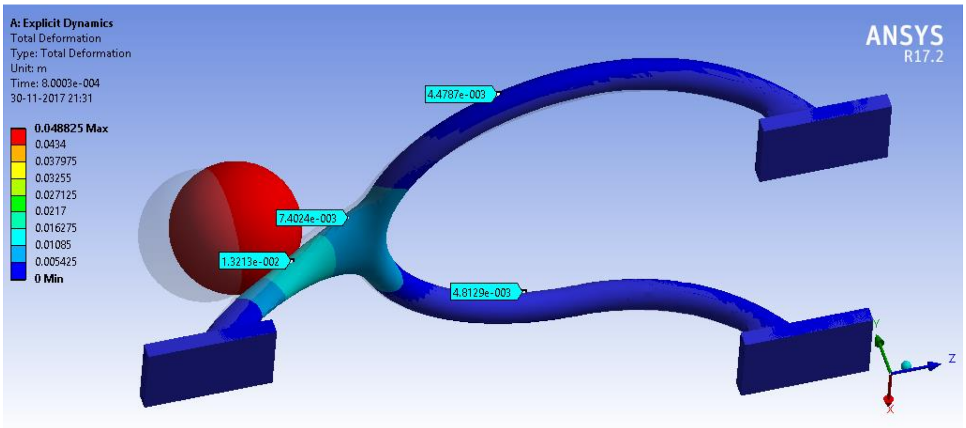

Figure 5: Total deformation of HALO Frame

4.2. Von Mises Stress:

von Mises stress and total Logarithmic strains give an idea of the Halo frame structural strength. A key finding was that the maximum von Mises stress recorded at the front rail of the Halo frame remained below the ultimate stress threshold of the material used. This result is particularly significant considering that the primary purpose of the high - speed impact test is to evaluate cockpit protection. This characteristic is essential for ensuring the frame's durability and effectiveness in protecting the driver during high - impact scenarios in Formula One racing. Interestingly, the frame exhibited some degree of plastic deformation under high - stress conditions. However, this deformation did not compromise the frame's overall integrity. In practical terms, this means that while the frame may bend or change shape to some extent under extreme forces, it is not expected to fracture or shatter. This characteristic is vital for preventing additional injuries to the driver from the frame itself in the event of a collision.

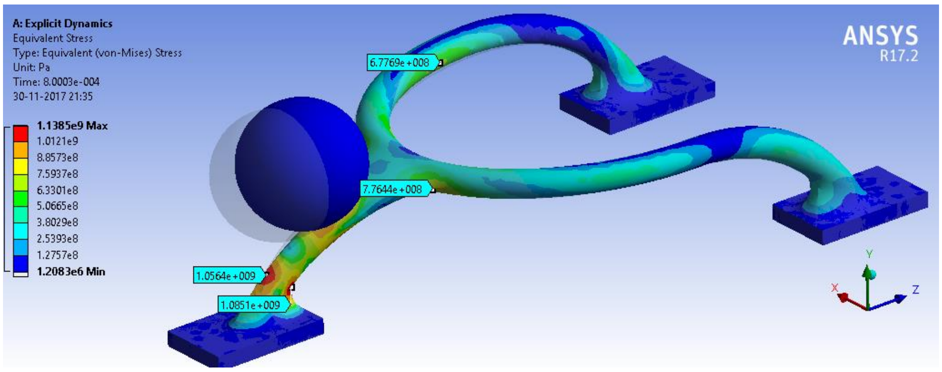

Figure 6: von - Mises stress plot of HALO Frame

4. Conclusion

In conclusion, the case study detailed in this paper highlights the Halo frame's pivotal role in safeguarding the cockpit of Formula One cars. This research has demonstrated that the Halo frame is a significant breakthrough in the realm of motorsport safety technology. Its robust design ensures that it can endure severe impacts while preserving its structural integrity, a key factor in protecting drivers from the risk of head injuries. Such protection is crucial in the high - speed, high - risk environment characteristic of Formula One racing.

Overall, the findings from this study reinforce the Halo frame's status as an essential safety feature in Formula One cars, effectively combining resilience and controlled deformation to offer maximal protection to drivers in the face of extreme racing conditions.

References

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