iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 Issue: VI Month of publication: June 2022

DOI: https://doi.org/10.22214/ijraset.2022.44027

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VI June 2022- Available at www.ijraset.com

Modal and Explicit Analysis of Formula 1 Halo

Dattaraj Raikar
Undergraduate from Department of Automotive Engineering, University of Wolverhampton, India

Abstract— Formula 1 cars are one of the finest track machines, they can travel at speeds up to 375 km/h, at such speed the car may lose traction or due to any other conditions there can be prospects of a crash. To protect the driver from such high-speed crashes, head protection Halo devices can be used to protect the upper portion of the driver which includes the head, neck, and thorax. In this study, a Halo device which is an official Formula 1 safety device is studied and numerous analyses are performed on it. Furthermore, a Halo design is structured and modeled in SolidWorks by taking the best material suitable for the Halo device. The analysis is performed on the ANSYS software where all the results are evaluated, by performing Explicit Dynamics analysis, Modal Analysis, and Static structural analysis after positive results are gained from the analysis, it was concluded that Titanium of Grade 5 was the best suitable material for the Halo device.
Keywords— Explicit Dynamics, Halo, Formula 1, Crashworthiness, Modal, FEA

I. INTRODUCTION

The research program for driver cockpit safety was initiated in early 2011 where more than 10 safety devices were tested and studied by FIA and their research team. Initially, 3 designs were shortlisted which were Aero-screen, Halo, Shield, etc. The main goal of Halo is to deflect large objects far away from the driver's head area. In F1 a separate cockpit is developed in which the Halo device is bolted to form a rigid structure. Initially, full-scale tests were conducted wherein an F1 wheel was forced towards frontal safety devices at a speed of 225 km/h, and the safety devices should be able to deflect the wheel away from the driver as well as Halo. The following test was conducted on all designs, wherein Halo passed the test and got selected. Before considering the material, for analysis, high-speed cameras were utilized and recording was taken off the accidents [1]. Many risk factors were recognized mostly the vehicle-to-vehicle collision, vehicle to surrounding collision, and collision with external objects like flying tires or any aero part of the car, the research team at FIA studied each of the cases. From this study, Halo was optimized and design changes were made by keeping in mind all the parameters [2].

II. LITERATURE REVIEW

[3] After FIA research for driver cockpit protection device, a Halo device was considered, Mercedes gave an idea of new Halo of steel material which was tested for static RAF analysis, wherein a 20 Kg of the tire was fired at the structure from a nitrogen power cannon achieving a speed of 225 Km/h. A steel Halo structure with carbon fiber was tested by Ferrari in the year 2016. Later in Austria GP a titanium material was used for the Halo, major changes were done in the design, and the arc of the Halo was made wider for better visibility and to avoid the driver's head from contacting the Halo in case of an accident. For extrication purposes, many trials were conducted.

[4] This article indicates that the Halo structure proves to be effective for driver protection, but it disturbs the airflow to the rear wing. To improvise on that, many F1 teams placed fairings boomerang-shaped deflectors on their curved hoop bars of titanium. These changes were to be done by keeping a 20 mm distance from the Halo structure, as regulated by the FIA. These gap changes are mandatory as they can affect the Halo structure when an accident occurs. The gaps are also maintained so that a specific amount of air can pass through them.

[1] According to FIA, there were many selections and trials made for the cockpit protection for F1 Aero-screen, Halo, and the Screen, they were the initial shortlisted designs. Many tests were considered for them, in which Halo was selected due to its strength. The safety of the driver was considered by working on aspects like driver extrication, in case of an accident the driver must pull himself out, by increasing the hoop diameter, the design changes were made. Visibility was a concern, initially, drivers observed effects of claustrophobia but were comfortable on the track, to improve visibility, the center structure was made narrow by about 4mm.

III.METHODOLOGY

Every F1 team had a safety and crash department, and a lot of research work is done. From the above-obtained information, it was concluded that the Halo design should be selected for its unique properties as it is rigidly connected at 3 points to the passenger cockpit of an F1 car. Halo is made from 5 elements the 2 rear pillars, a center pillar, and two quarter-circle rings on the top which are further defined into sections such as -

Main Hoop – A C-shaped tube that connects to the center pillar.

Rear Brackets – It connects the rear pillars to the body.

Central Pylon – The frontal section of the Halo including the center pillar.
V-transition – The area where the Hoop and the center pillar connect.
Front fixing axes – The front pillar mount.

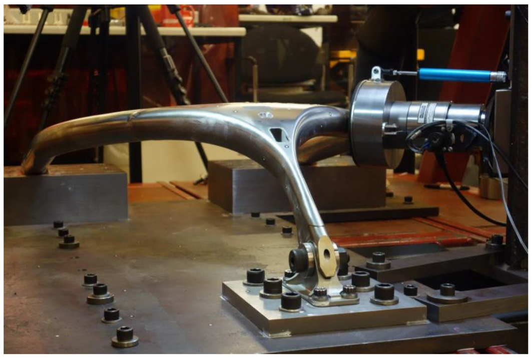

Fig. 1 Example of an unacceptable low-resolution image

The Halo should be made from a stiffer material to resist forces from the other vehicle, environment impact, and flying objects. Many materials like steel, mild steel, titanium, etc. were tested, the tire test was performed where a tire was forced against the Halo structure and Titanium showed good results when deformation was considered. Therefore the selected material for this Halo model is Titanium of grade 5 Ti-6Al-4V, which is an aerospace quality grade [1].

A. Halo Design:

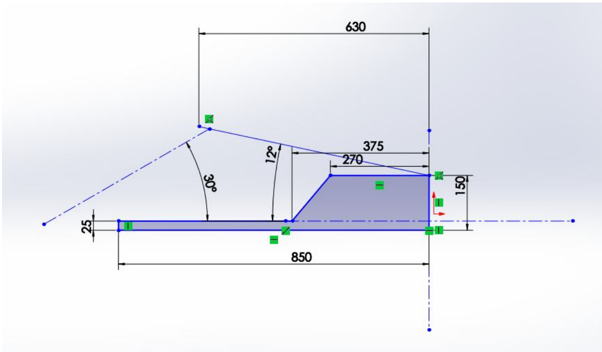

Fig. 2 Sketch made on Right Plane

This sketch is the foundation sketch that defines the structure, angle, and basic parameters of the halo, in SolidWorks this sketch is drawn on the right plane.

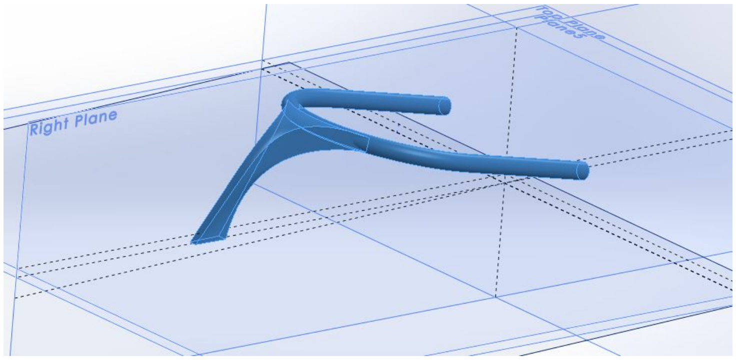

Fig.3 Combining two Lofts

For making the hoop, the Loft feature was used in which the guide curve and profile were formed according to the FIA design structure. The same method was used to generate the center pillar by creating a guide curve and profile. A 3D sketch tool was used to create a 3D drawing. The two created Loft are then combined by using the Combine tool, this tool is used to connect two components to form one part.

Fig.4 Halo Cockpit Safety Device for F1

The loft mounts are generated, on the left, the center pillar mounts are created with custom dimensions and on the right, the dual rear pillar mounts are created with all mounting criteria. The final product made is then added with material that is mandatory according to FIA results.

B. Halo Analysis

The analysis of Halo is carried out on Ansys Software, as stated above a Static Structural analysis, Modal analysis, and Modal (Vibration) analysis are performed and their results are presented based on the selected material. The geometry made on the SolidWorks and file type is changed to Parasolid format, then imported in Ansys software. In the design model part, the geometry is generated and updated.

1) *Meshing Static Structural :* Before meshing, Grade 5 Titanium alloy Ti-6Al-4V was the chosen material for the Halo, from the engineering data.

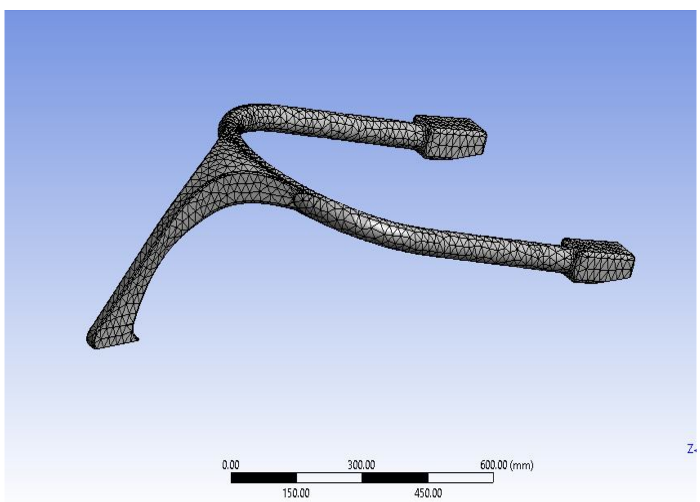

Fig.5 Body Sizing Meshing

In the Meshing section, a precise meshing was applied with the element size 70 and the body size to be kept at 20 mm. After applying the mesh, the quality of the mesh was checked to be precise for accurate results. The skewness was around 0.44558 along with the transition ratio of 0.272 with smooth transition inflation. The average aspect ratio was 20.364 which is considered decent.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VI June 2022- Available at www.ijraset.com

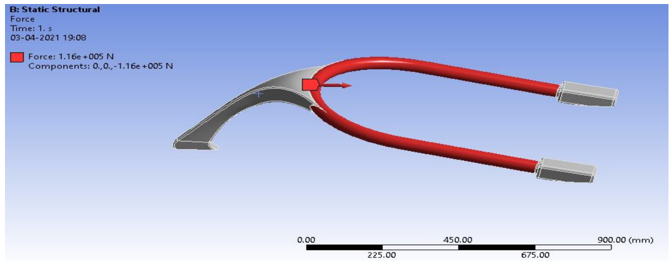

Fig.6 Force direction on Z-axis

For the structural analysis, the fixed support locations are selected, and the base of the Halo structure was best suitable for these fixpoints and is the same for all the further analysis methods. The forces that need to be applied were selected, -116 kN of the load was applied in the Z direction, and the location for the force was added at the Circular hoop to represent frontal impact.

2) Meshing Modal:

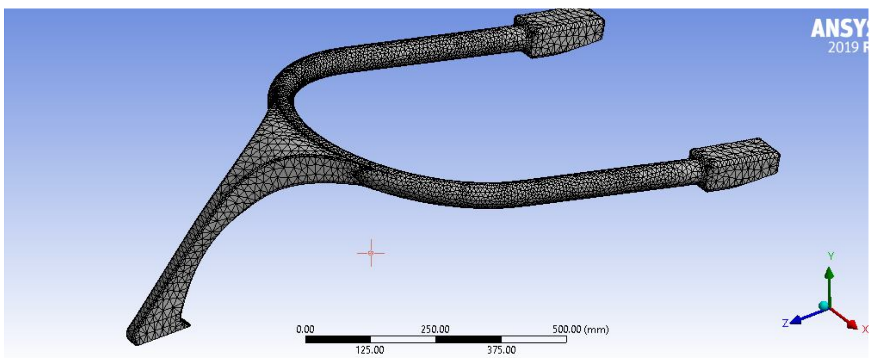

Fig.7 Meshing for modal analysis

When considering the Vibration analysis which is also called Modal analysis is performed with Meshing done with an element size set to 10mm for accurate results. The same geometry was used as of static structural model.

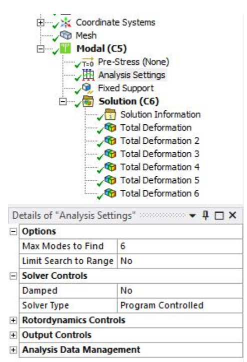

Fig.8 Max Modes set to 6

To get the exact results 6 modes were used, each mode resembles a natural frequency, the different model number represents different modes shapes. The total deformation at model frequencies is presented.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VI June 2022- Available at www.ijraset.com

3) Meshing Explicit Dynamics:

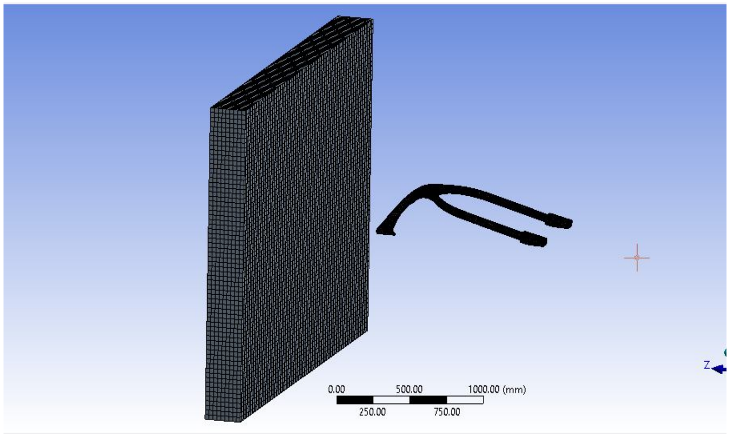

Fig.9 Meshing for Explicit Dynamics

To perform an explicit dynamic analysis the wall structure was meant to collide with the Halo structure, the gap between them was set to 600 mm. In the analysis, setting the end time was set to 0.0179 s and the Maximum number of the cycle was kept at 10000000. The Halo structure is considered flexible to show deformation and the wall is set to be rigid, the material used is concrete for the wall. In this analysis velocity of 320 Km/h was applied to the wall and the Halo structure was kept stationary by applying fixed supports at the mounting points. The element size was kept at 30 mm and the body sizing of the Halo was set to 10 mm, the Halo is kept flexible and applied with a fixed support at the mounts. The number of nodes set was 84555 and elements were set at 134715.

IV. RESULTS AND DISCUSSION

Post Processes

A. Static Structural

The statics structural analysis results were calculated, and the results are displayed below-

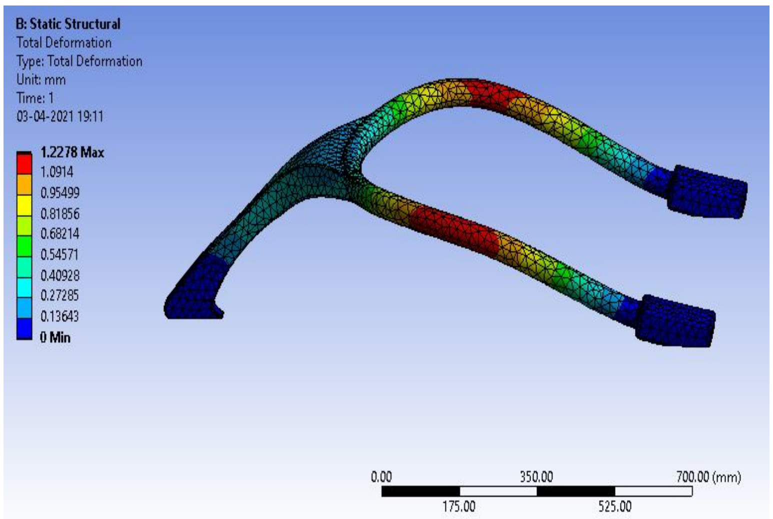

Fig.10 Total Deformation for Static load

In the total deformation test, the Halo was successful as the material used was of titanium grade 5, the results showed that after applying 116 kN of load on the halo from the front direction the maximum deformation calculated was just about 1.223 mm. This shows that the material chosen was capable to be used in a safety and protection device.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue VI June 2022- Available at www.ijraset.com

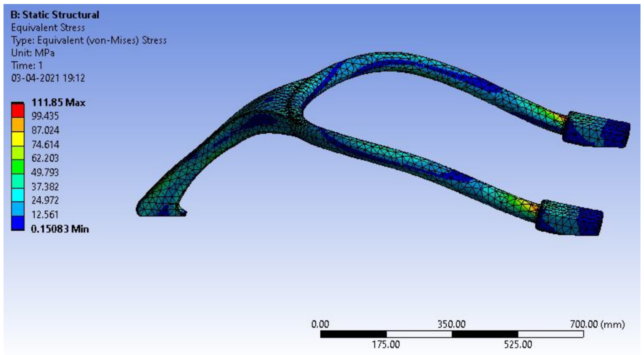

Fig.11 Equivalent Stress at Static Load

The maximum equivalent stress calculated at this Halo structure is 111.85 Mpa when the load of 116 kN is added to the structure along with 43.36 Mpa as the average stress calculated. When compared to the material allowable tensile strength of 1170 Mpa, the Halo has passed the test as its maximum working stress calculated is 111.85.

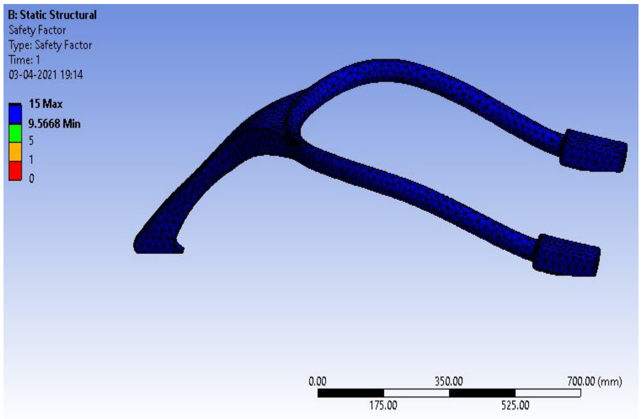

Fig.12 Factor of Safety

This figure shows that the factor of safety calculated at the structure is 15 which is the maximum value, and the average value is about 10.67. Thus, it can be said safe.

B. Modal

The total deformation Modal analysis results were calculated, and the results are displayed below-

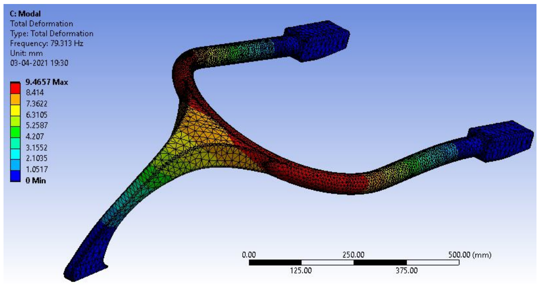

Fig.13 mode 1

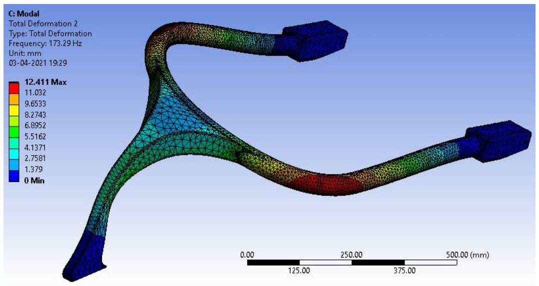

Fig.14 mode 2

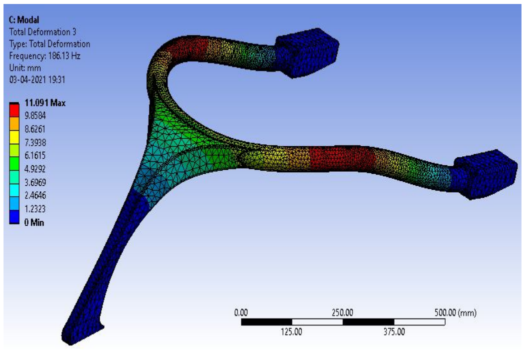

Fig.15 mode 3

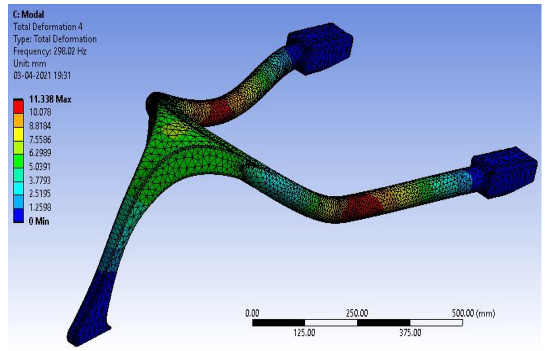

Fig.16 mode 4

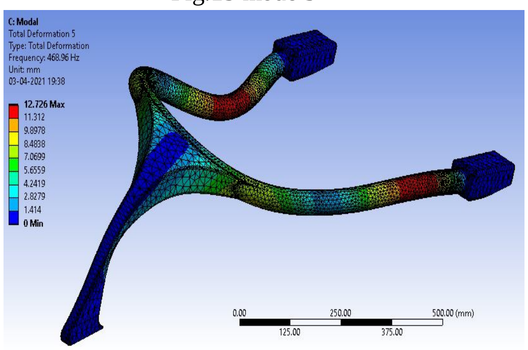

Fig.17 mode 5

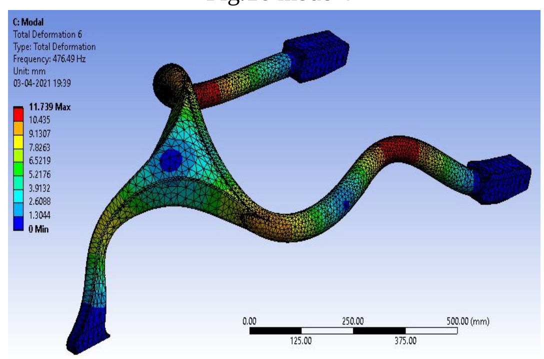

Fig.18 mode 6

These post-processed results present the 6 total deformations of Halo at various frequencies. In these results deformation mode 5 records maximum deformation of 12.76 mm at 468.96 Hz and deformation mode 1 records minimum deformation of 9.46 mm at 73.31 Hz.

C. *Explicit Dynamics*

The Explicit Dynamics analysis results were calculated, and the results are displayed below-

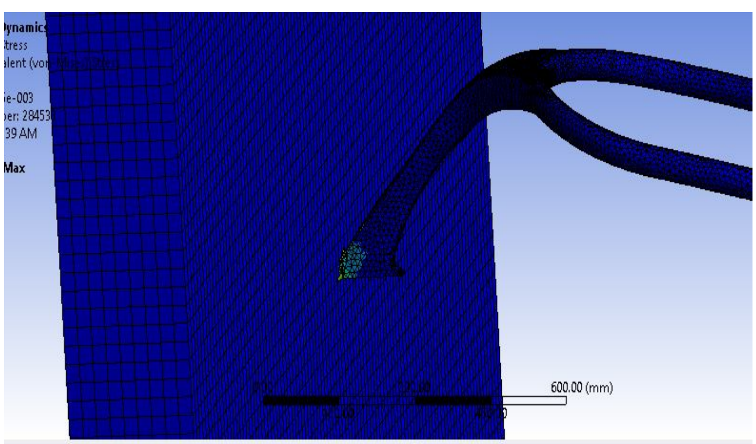

Fig.19 Equivalent stress (Von-Mises) stress Explicit Dynamics

In explicit dynamic analysis, two objects are meant to collide with each other to measure the physical ability of the target object, the wall here is the sample object and the Halo is the target object. The maximum equivalent stress measured in this analysis is 29782 MPa and the average stress measured is 610 MPa.

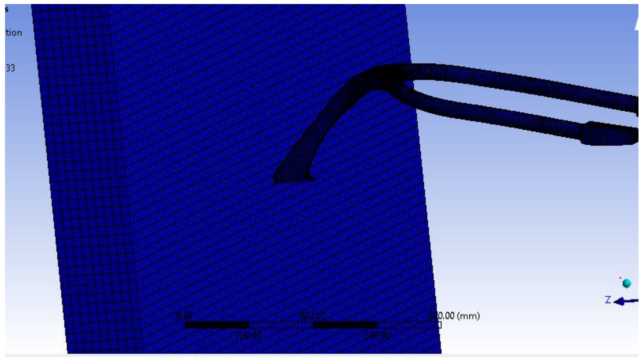

Fig.20 Total Deformation of Halo Explicit Dynamics

In this image, the frontal area of the Halo can be seen as deformed with a slight bend at the arc section, when the collision occurred at 320 km/h the Maximum total deformation achieved is 12.37 mm whereas the average deformation is 2.8 mm which explains that it is passed the test as the maximum deformation is not more than 20mm.

V. CONCLUSIONS

The Halo structure is a part of the driver's cockpit, when the F1 vehicle is severely crashed the whole cockpit along with the Halo is separated from the vehicle forming a rigid capsule. According to the report, a Halo device was designed on SolidWorks software and various Analysis was performed after finalizing the material for the Halo i.e., Grade 5 Titanium, which included Static Structural, Modal (Vibration), and Explicit Dynamic analysis. The results that are obtained in this analysis are considered satisfactory.

In structural analysis, the allowable stress of 1170 MPa is much greater than the working stress of about 111.85 MPa. In Modal analysis, the maximum deformation of the 5^{th} mode subjected at 468.96 Hz is 12.76 mm, which is proved to be safer as the deformation should not extend above 25 mm. In the Explicit Dynamics, the maximum deformation is recorded to be 12.37 when it collided with it at 320 Km/h which is considered safe. The Max Equivalent stress recorded is 29782 MPa when the wall is crashed against it.

Thereby, it is concluded that the proposed design and the material used are safer and can bear a much higher load which fits in the F1 standards.

REFERENCES

[1] FIA, *FIA - Presenting the facts behind Halo*, (Aug. 02, 2017). Accessed: Apr. 05, 2021. [Online Video]. Available: https://www.youtube.com/watch?v=AYkGjUHstKY

[2] C. Scarborough, "F1: 2018 TECHNICAL RULES AND TRENDS," *DriveTribe*, Mar. 02, 2018. https://drivetribe.com/p/f1-2018-technical-rules-and-trends-CJuaeKy2T4KbSutmGtc3dg (accessed Apr. 05, 2021).

[3] "All you need to know about Halo," *ESPN*, Jan. 30, 2018. https://www.espn.in/f1/story/_/id/22262498/all-need-know-halo-ahead-2018-f1-season (accessed Apr. 02, 2021).

[4] M. Delaney, "Tech F1i: How Formula 1 teams customized their Halo," *F1i.com*, Apr. 26, 2018. https://f1i.com/magazine/301561-tech-f1i-how-formula-1-teams-customized-their-halo.html (accessed Apr. 05, 2021).