Study and Analysis of a Designed F1 Halo Safety System According to FIA

Smit Shendge[1], Yash Shinde[2], Heet Patel[3]

[1,2,3]U.G. Student from the Department of Automobile Engineering at University of Wolverhampton, India

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Abstract -*In this study a deep research on Halo safety device is carried out to get a sound knowledge of it. After getting to know various aspects like design, strength, weight, compact, etc. which are considered to make a Halo a CAD model of Halo is made on a CAD tool/software Onshape. The design also contains aero wing considering aerodynamics point of view on the top of the Halo. This made halo is then Imported to an analysis tool to carry out three various type of analysis to validate the made geometry and assigned material if it is safe and good option to fit in a F1 race car. Material assigned for the Halo is Grade 5 Titanium which weighs approx. 7 Kgs. Three carried out analysis are static analysis on the u-tube and V-transition, modal/frequency analysis after applying three fixed support as a boundary conditions and dynamic analysis by colliding the Halo to a concrete wall from a particular distance at 200 Kmph. Got the results of static analysis with max 18 mm displacement for force on u-tube and max 19.5 mm displacement in v- transition, for modal/frequency analysis calculated 20 modes with max 16.6 mm displacement and for dynamic analysis got a max displacement of 1.25 mm. the found out results are within the yield strength of the Grade 5 Titanium validating the made Halo is safe to use real life application.*

Key word: Halo, F1 safety system, FEA, aerodynamics, FIA, Grade 5 Titanium.

1. Introduction

In F1 racing Championship the vehicle used are of very light weight and have an open cockpit which can be dangerous as the racer drive the vehicle which ranges at very high speed approximately 250 kmph to 300 kmph. If accident at this speed takes place there can be many possible cases of head injury to the driver can happen by many reason like debris like tyre or impacting on the side barrier or many more reasons due to open cockpit of F1 race car and there already have been such accidents in f1 history due to which driver have died or have been through very serious injury which is a permanent injury. To tackle any debris or impact to head of the driver FIA did a research which started in the year 2016 to develop a device to keep driver's head safe. And that's when Halo came to existence which is a solid Titanium bar which can easily withstand 12 tonnes of load on it and weighs around 9 Kgs. In other racing like IndyCar Series there was another safety device which is called aero screen in the form of curved windshield made from aerospace-spec polycarbonate which has a very good strength and elasticity to it which can handle good impact just like a Halo bar to save driver's head. Three companies are directed by FIA to manufacture a Halo for the f1 racing teams. FIA has carried out simulation of past crash considering a Halo in the crash scenario which gave results of saving the driver by 17% which is a good indication to use Halo as a head safety device. After carrying out many research and testing FIA made it mandatory to use a Halo bar or aero screen in the year 2018 as their new rules and regulations. Using a Halo in f1 car was a right decision made by the FIA with a proper design characteristic and use of very good impact strength material. In the year 2020 this Halo even showed its strength when Romain Grosjean met with an accident making his car colliding to the side barrier at the speed of 200 kmph which even had a blast of fire after collision and later after analysing the crash it was acknowledged that the Halo bars of the car saved him from hitting on to the barrier at so high speed and he was left with very minor injuries and this accident among the f1 fans was spread widely with a context Halo saved Grosjean's life which could have ended bad without it. [1]–[3]

1.1 Background

Halo is a safety device that is been used in F1 racing. This Halo was in a research and development process since a very long-time considering safety of the driver as the cockpit of F1 is open and can be fatal if any accident takes place as in history of f1 there are many drivers who have lost their life due to head injury like Jules Bianchi in the year 2014 lost his life due to an accident in which he collided the side barrier at 220 kmph and got into very serious head injury which lead to his death. FIA on the note of seeing so many head injury taking place they decided to avoid this by taking an action to make a safety device which will save driver's head. A first Halo was tested in the year 2016 and also later in 2017 to get to know its design and material used strength if it goes through any such accident. Later in the year 2018 FIA (Fédération Internationale de l'Automobile) gave permission to implement Halo in various racing like Formula 1, Formula 2, Formula 3, Formula 4 and Formula E with a proper rules and regulations for its design and the material used to manufacture it. Also, other well-known racing championships and series like Super Formula, IndyCar Series and Australian S5000 Championship implemented a halo as a safety device due to open cockpit. A halo is a circular bar with a support from middle of the circular bar to prevent any direct hit to a driver from front and it has three mounting points which fix the Halo to Chassis. This Halo weigh nearly about 9 kilograms and is made from titanium which provides all the strength to the designed Halo which can handle about 12 tonnes of load as approved by the FIA testing team. This Halo System is not manufactured by the teams but by three external manufacturer which design and manufacture the Halo as directed by FIA and the manufacturer have specifications of all the racing teams to design the Halo and fit in each and every vehicle even if its unique in some or the other way. Testing like destructive and non-destructive testing was carried to validate the how strong is the made halo. In destructive testing a debris test was conduct with a 20 kg tyre ejected directly on Halo at 225 kph speed which didn't harm the driver according to attach sensor setup leaving driver without any injury. A non-destructive testing like, x-rays for any cracks and some strength test are conducted after manufacturing a Halo for validation purpose. [4]–[7]

2. Literature Review

Yasmine Phillips in this case study it is said that a Halo is a very good device/part for protection of the driver in case of any accident but in terms of driving conditions for the driver it can be an obstacle in their field of view as there is a support bar from front in a Halo which is mandatory in Halo design for support as well as for frontal protection to the driver. This support bar can make the driver lean or stretch the neck which can cause neck and eventually spinal misalignment in a long-term factor. To avoid this, special ergonomically changes need to be done in the seating position of the driver to make sure no stress and fatigue is developed due to this Halo safety system eventually leading to lose focus and can even lead to crash due to this. It is also said that due to a Halo in the field of vison can result to inaccuracy of turning to all the drivers new and experienced drivers and to get used to it the driver needs to practice and get used to this Halo which will not disturb while actual racing. Though there are side effects from this Halo it will keep the driver's head safe from direct hit in crash. [8]

Gemma Hatton et al. This study is of SST which is one out of three manufacturer of Halo safety device assigned by the FIA and provide the made Halo to various F1 teams according to their vehicle specifications. Considering crashes taken place in F1 history FIA got the idea of providing something like a Halo bar which later saved many drivers from direct head impacting on to other objects at high speed in any crash saving the driver's life and even avoiding any fatal injuries. SST went through very deep research and development to get this design and implement it on f1 race cars. Many tests were conducted while developing this Halo like force test from direction like vertically upward, sideways with a 125 KN of force to test the designed bar. A Halo bar is made from grade 5 titanium with different parts which are welded together to form a single part and during testing process there were failures found near the welding areas in which they did a lot of research to resolve that and make each and every Halo as strength full as required. This halo is 7 Kgs which is designed two with stand two African elephants' weights or 12 tonnes of load. After going through proper testing, research and developments a Halo was implemented on a F1 race car. When it comes to racing the aerodynamics should even be considered in which aero faring was provided on top of the Halo to curtail the aerodynamic drag. [9]

2.1 Aim: To carry out research study on a Halo safety system used in f1 racing and design a Halo on a CAD software/tool and performing three various types of analysis static, modal/frequency and dynamic analysis for validation of the made Halo geometry.

2.2 Objectives

- Do research on a Halo used in F1 racing for head protection
- Make a CAD model of the F1 Halo on any CAD tool
- Do a static, modal/frequency and dynamic analysis on the made Halo geometry.
- Get the results of the analysis and if it fails, first optimizing the design and doing the analysis again if it fails then lastly changing the material of the Halo.

Fig- 1: Various F1 team with their Personalized Halo

2.3 Regulation

From the year 2018 FIA made a rule to use a Halo in a f1 car and other racing championship like IndyCar Series to use Aero screen to avoid any head injury in case of accident. To implement Halo in a racing car FIA has a rules and regulations which needs to be followed by each and every motorsport racing team. Halo was started implementation in the year 2018 after carrying out many types of destructive and non-destructive testing by three manufacturer who have partnership with FIA and manufactures Halo as directed by FIA and no racing team are allowed to design the Halo and implement in their vehicle. Halo should be only made from grade 5 titanium which is mostly used in aerospace industry because it has high strength and stiffness compared to the whole weight of the made product. One of the first partnership to manufacture Halo system is CP Autosport Germany which is well-versed with such high-grade material used in aerospace industries. SST Technology, England and V System, Italy are the two other companies who got approval from FIA to provide Halo system to motorsport teams. Racing team members are free of choosing any of the manufacturer to fit the specific Halo in their racing vehicle. CP Autosport had given six-and-a-half weeks by FIA to prototype a Halo for testing purpose at Cranfield Technical Centre, UK in the year 2017 which passed the test and got approval from FIA and later 9 teams out of 10 teams of F1 partnered with CP Autosport for Halo safety device.

Fig- 2: Forces on Halo

3. Methodology

3.1 Research on Halo

Halo is a safety device/part which is used in a racing where a cockpit of the racing vehicle are open and this device/part is mandatory from the year 2018 according to FIA rules and regulations as there are many lives lost and fatal injury has taken place due to direct impact on driver head in the history of f1 and seeing this case there had to be some or the other safety feature for driver's head which will save him from any accident debris like tyre or even if it flips upside down and also the design should be in such a way that the driver can easily exit the cockpit of the vehicle in case of accident and the vehicle catches fire. After simulating all the accidents that happened in f1 history and using this device/part there is 17% chances of saving helping driver from any crash which will impact directly on the driver's head.

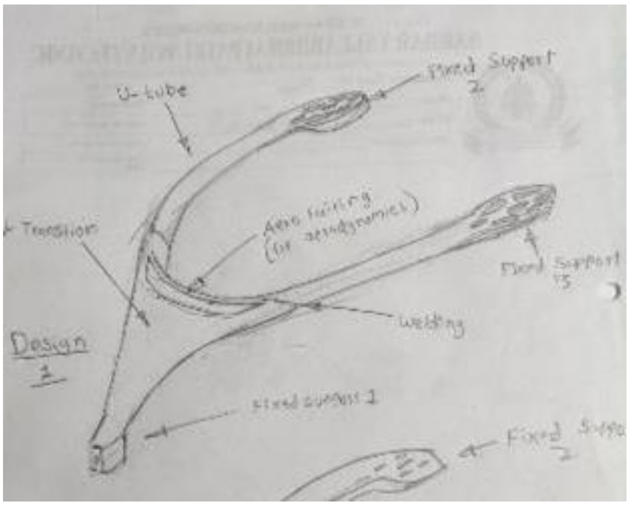


Fig- 3: Halo sketch design 2

Sketching a Halo

Sketched few halo designs to convert an imagination on to a paper and then creating a 3D modelling in a CAD software/tool instead of directly designing a CAD model which will even help if any optimizations in design is required for analysis.

3.2 3D modelling Halo on CAD tool

Made a CAD model of the Halo system according to sketch design 1 considering each and every rules and regulations set by FIA which covers parameters like strength, a pole at the center, thickness of Halo bar, visibility of the driver, etc. To make the designed Halo aerodynamic a small aero fairing is provided at the center of the Halo bar which even increase its aesthetics. Made Halo might not be according to the dimensions as they are designed according to the car dimensions and the dimensions for each and every f1car is different. For dynamic analysis a wall in front of the Halo is considered as shown in the below image.

3.3 CAD modelled Halo

Fig- 4: CAD modelled F1 Halo

3.4 Importing CAD model in analysis tool for FEA (Finite element analysis)

Imported the made Halo geometry in a Parasolid format to carry various FEA like static analysis, dynamics analysis and modal/frequency analysis. For static and modal/frequency analysis only a Halo is imported to carryout analysis both the type of type of analysis and for dynamic analysis a wall is considered at 1000 mm (3.3 feet) which is less because of considering the analysis time as the analysis time is defined by the distance between the Halo and the wall, greater the distance more the time taken to carry out analysis.

Further Methodology is divided in three different parts according to three different analysis

3.5 Assigning Material for static and modal/frequency analysis

ZMaterial assigned for the Halo is according to the FIA rules and regulation which is a grade 5 titanium which is widely used in aerospace industry.

Fig- 5: Halo Material properties according to FIA standards

Assigning material for dynamic analysis

Fig- 6: Wall material properties for dynamic analysis

Fig- 7: Halo Mesh

Material for Halo will be same grade 5 titanium and the wall considered in the halo is assigned as a concrete with a standard mechanical property.

3.5.1 Mesh for static analysis

A fine mesh is given to the Halo geometry with a 10-size fineness in automatic mesh sizing using a standard algorithm of a Simscale.

Mesh quality and event log for static analysis Average skewness – 0.1829, Average non-orthogonality – 20.015, Average aspectratio – 1.623, Average tetaspectratio – 1.623. According to event log and checking average from mesh quality the generated mesh is a good quality mesh.

3.5.2 Mesh generated for modal/frequency analysis

Mesh quality and event log for modal/frequency analysis Average skewness – 0.1820, Average non-orthogonality – 19.832, Average aspectratio – 1.615, Average tetaspectratio – 1.615. According to event log and average of parameters from mesh log its ca be said that the generated mesh is a good quality mesh.

Fig- 4: Halo with wall mesh for dynamic analysis

Mesh generated for dynamic analysis

Mesh quality and event log for dynamic analysis

Average skewness – 0.206, Average non-orthogonality – 17.951, Average aspectratio – 1.701, Average tetaspectratio – 1.701. According to event log and average of parameters from mesh log it can be said that the generated mesh is a good quality mesh.

4. Boundary conditions

Boundary condition is divided in three different part according to three different carried out analysis

4.1 Boundary condition for static analysis

There are two boundary conditions for a static analysis one is fixed support at the end of two Halo bar and at a support bar at front at its end. And another boundary condition is a force applied on Halo bar from 2 components i.e. Y and -Z which is from the front(Y) and side(-Z) of the Halo bar. The applied force is 147099 N (15,000 Kg) which is more than the FIA permissible limit which is nearly 12 tonnes showing that the analysis has factor of safety beyond 12 tonnes of force and is safe.

4.2 Boundary condition for modal/frequency analysis

For modal/frequency analysis only 1 boundary condition is provided which a fixed support at the two Halo bar and at the center support of the Halo bar

Boundary condition for dynamics analysis

In dynamic analysis three boundary conditions are provided two fixed supports for the wall and the Halo and the third boundary condition is initial velocity for the Halo colliding the wall at 70 m/s or 252 km/hr velocity.

5. Results

Results are divided in three parts just like boundary conditions i.e. static analysis, modal/frequency analysis and dynamic analysis

5.1 Static analysis for Halo

Max legend value for static analysis of von mises stress is 1e+9 Pa or 1000 MPa for Halo which is under the yield strength indicating Halo is safe under 12 Kg of loading condition.

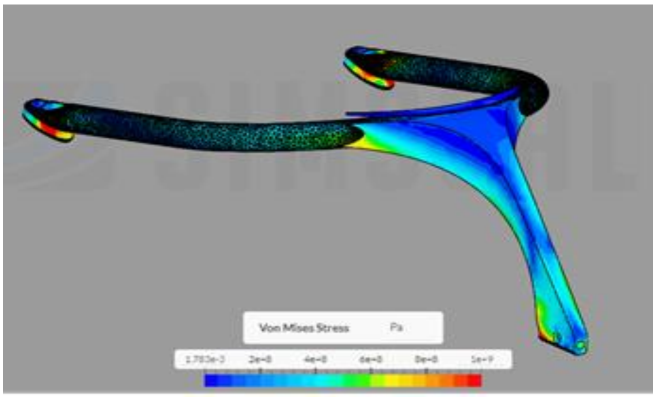


Fig- 9: Von mises stress contour plot when force is applied on U-tube Halo

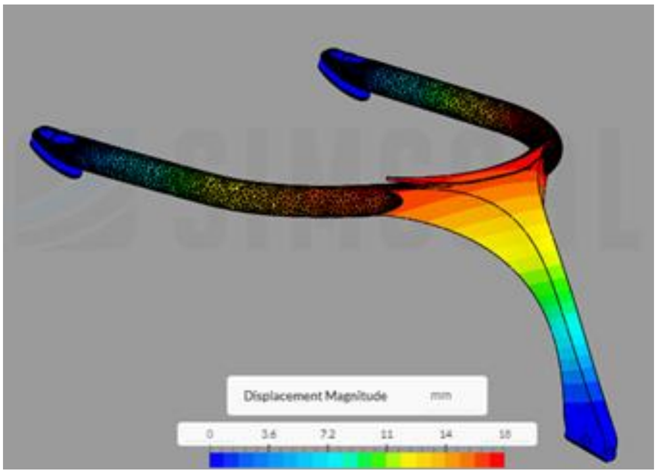


Fig- 50: Displacement magnitude contour plot when force is applied on U-tube Halo

Less than 18 mm of displacement will take place if 15 Kg of load is applied on curved Halo bar

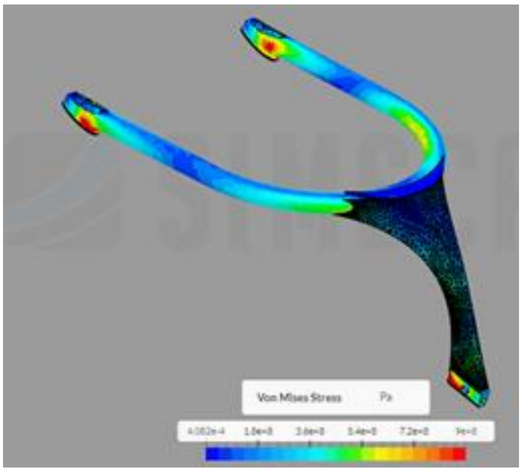


Fig- 11 Von mises stress contour plot when force is applied on V-transition of Halo

When 12 Kgs of load is applied on Halo support bar, 9e+8 Pa OR 900 Mpa of Von-mises stress is applied on Halo body shown as red in contour plot.

Max 1.9 cm of deformation will take place in few regions as shown as red in contour plot if 15 Kgs of load is applied on the Center Halo support

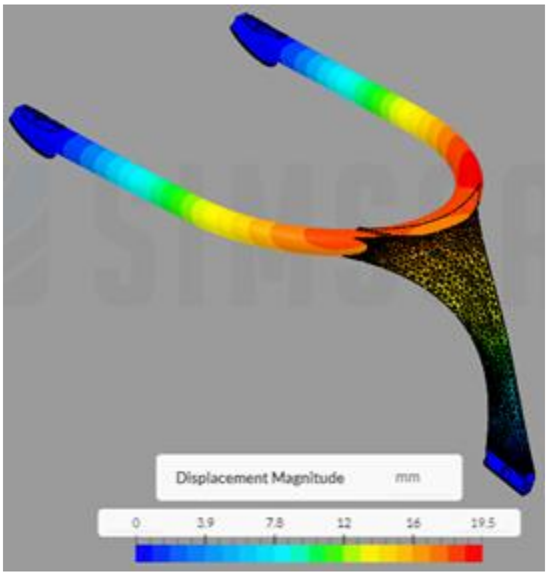


Fig-12: Displacement magnitude contour plot when force is applied on V-transition of Halo

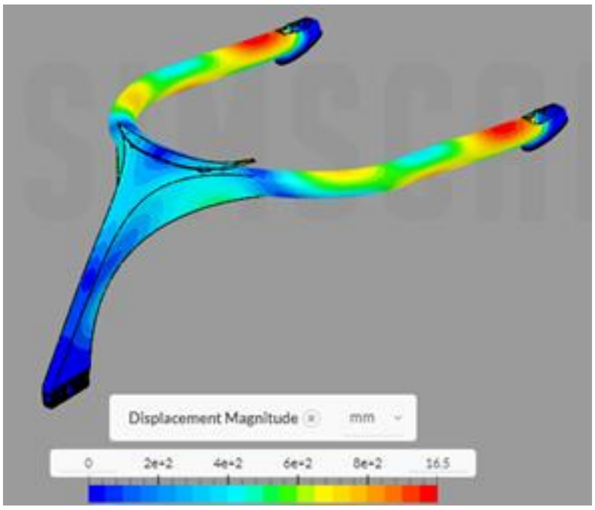
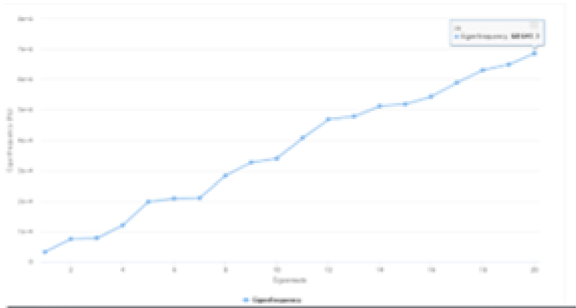


Fig- 13: Contour plot for modal/frequency analysis for Displacement magnitude of Halo

5.2 Modal/frequency analysis for Halo

In vibration analysis Max 16.5 mm or 1.65 cm of displacement will take place near to curved Halo bar's fixed end. For the analysis considered 20 Modes for frequency calculation.



EIGENMODE	EIGENFREQUENCY
1.0	3294.12
2.0	7458.75
3.0	7769.74
4.0	11996.6
5.0	19780.7
6.0	20804.4
7.0	21043.1
8.0	28289.3
9.0	32616.5
10.0	33925.1
11.0	40750.5
12.0	46797.4
13.0	47823.5
14.0	51216.5
15.0	51861.1
16.0	54378.7
17.0	58973.4
18.0	63107.8
19.0	64949.5
20.0	[illegible]

Fig- 14: Eigen frequency plot for 20 modes of modal/frequency analysis

Following is an Eigen frequency graph and table for Halo with 20 modes

5.3 Dynamic analysis for Halo

For dynamic analysis of a Halo max 1e+6 Pa or 1 Mpa of Von-mises stress is exerted on the red region of the Halo as shown below in contour plot

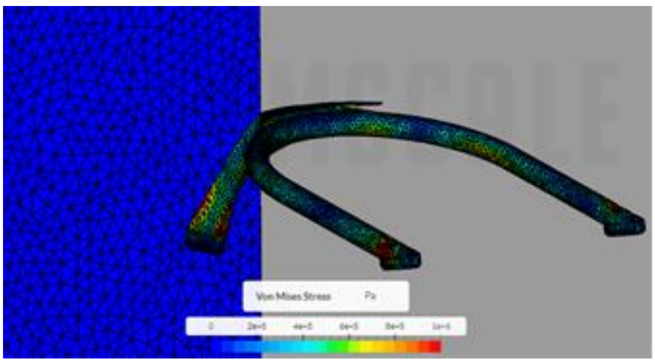


Fig- 15: Dynamic analysis contour plot for Von mises stress on Halo

Max 1.25 mm of displacement will take place in some portion of Halo at the center Halo curved bar and near the center support joint of Halo as shown in contour plot below.

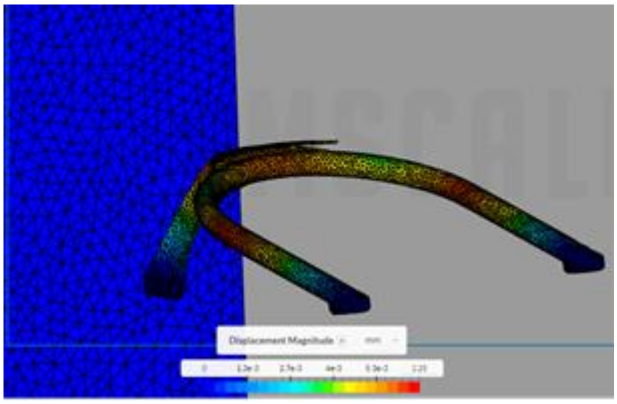


Fig- 16: Dynamic analysis contour plot for displacement magnitude of Halo

Following is the Residuum convergence plot from the dynamic analysis on a Halo colliding at a wall with nearly a speed of 200 kmph

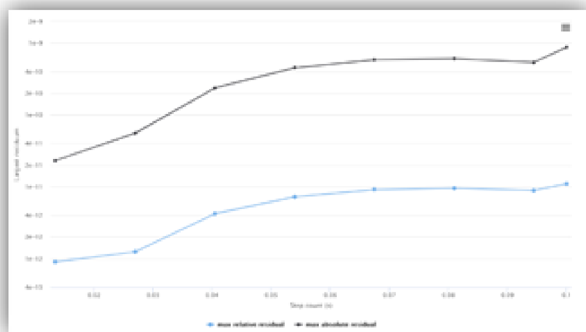


Fig- 17: Residuum convergence plot for dynamic analysis of halo

5.4 Result table

Table 1- FEA results for Halo according to FIA standards

Result	Static analysis		Modal/frequency analysis	Dynamic analysis
	V-transition	U-tube		
Von Mises stress (Mpa)	900	1000	-	1 Mpa
Displacement magnitude(mm)	19.5	18	16.5	1.25
Eigen modes	-	-	20	-

6. Conclusion & discussion

According to the results max displacement in static analysis on halo while application of load on u-tube and v-transition is 18 mm and 19.5 mm respectively which is very less, max displacement value for modal/frequency analysis is 16.5 mm which is even less and the ma displacement value for dynamic analysis is 1.25 mm. After designing a Halo with a grade 5 Titanium material and carrying out three various types of analysis like static, modal/frequency and dynamic analysis the results shows that the found values are within the yield limit of the used material grade 5 titanium thereby validating that the made design is safe and can be implemented practically on a f1 race car.

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BIOGRAPHIES

Mr. Smit S. Shendge has pursued BE. Hons in Automobile engineering from University of Wolverhampton, India. Has completed Diploma in Automobile engineering from Sardar Vallabhbhai Patel Polytechnic (SVPP), Mumbai.

Mr. Heet B. Patel has pursued BE. Hons in Automobile engineering from University of Wolverhampton, India. Has completed Diploma from AutoInstitute, Thane.

Mr. Yash A. Shinde has pursued BE. Hons in Automobile engineering from University of Wolverhampton, India. Has completed Diploma in Automobile engineering from Sardar Vallabhbhai Patel Polytechnic (SVPP), Mumbai.