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Design, Modeling and Analysis of Chassis for Human Exploration Rover

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Abstract

Human Exploration Rover is a human powered rover made in order to take part in 'NASA Human Exploration Rover Challenge' and among different parts of rover chassis is one of the most important analytical component for any vehicles like a rover. However, a perfect design of chassis depends on proper selection and uses of stiffness, low weight and low manufacturing cost. This paper presents about perfect design procedure of a human rover chassis and distribution of loads over the chassis at different conditions as well as impact of the loads on the chassis at different dynamic conditions. This paper also represents that design of rover is modeled according to the rulebook 2019 and is made suitable for one male and one female driver considering 70 kg (male) and 50 kg (female) weight. On the other hand, for material selection available light material selects is Alloy steel (SS) and the total weight of the chassis found is14kg and two different sizes of SS square pipes is used to make the frame so that it is stiffer. Moreover, for dynamic load analysis, it is calculated by multiplying static load factor with three.
Keywords: Chassis, Torsional stiffness, FEA, Stress, Displacement, Factor of Safety.

1. Introduction

Chassis is defined as a frame supported on suspension system and attached to the wheels, which hold the overall structure of the vehicle. Moreover, chassis is a French word and it is a frame used to hold the basic components and structure to obtain stability in both static and dynamic conditions of the vehicle [1]. However, chassis which is designed for Human Exploration rover also hold various important components, those are- manual drive train (chain sprocket mechanism, axles), suspension system (swing arms, bell crank, push rods, springs), steering system, two driver seats, clamps, hinges (as the rover is to be folded). On the other hand, a perfect design of chassis minimizes the weight, gives idea about how vehicle rolls, provide much stiffness, and provide much stability of the vehicle in both static and dynamic conditions. According to the rulebook 2019, in Human rover two symmetrical frames are needed to be joined with a hinge connection so the total vehicle can be folded to a (5*5 feet) cube.

2. Design Considerations

While designing the chassis various loads on chassis were considered, they are- vertical bending load caused by the driver, body and other components, loads acting on the chassis due to bumps, side forces those are acting due to steering, loads due to braking, loads due to paddling and vibration loads due to hinge connection. However, safety as per the rulebook 2019 was considered and those are-Stiffness (Usually, a human rover chassis should be stiff enough to withstand torsion and to rise the rover 5 feet (~1.5 of travel [2], this is to facilitate easier suspension tuning. Moreover, by increasing rear track while decreasing front track, both rear wheels are more equally weighted than the front wheels. For convenience, more weighted driver was placed in the rear of the chassis, volume constraints (the vehicle is to be fitted in the 5 x5 x5-foot volume constraint (a cubical space that is 5 feet wide (1.524meters) on each side) in the collapsed condition [2], weight (weight of the rover should be less than 210 pounds in order to get points). Therefore, the chassis is designed in such a way to achieve the required weights and according to the rulebook, vehicles that weight less than 130 pounds receive 5 points, vehicles that weight 131 to 170 pounds receive 3 points, vehicles that weight 171 to 210 pounds receive 1 point, vehicles weighing more than 210 pounds receive 0 point.), Unfold/Assembly(The design of the chassis should be so simple that it is to be assembled within two minutes for obtaining two points, four minutes for one points.), Clearance constraints(A rover with riders in position ready to ride should have no less than 12 inches(30.48 cm) clearance between the ground and the lowest part of the rover with which riders have contact. The rover seats, pedals, and steering controls are expected to be where the lowest point is found, but it is not limited to the components. The measurement is to be made between the ground and that part of the rover where a rider has their lowest point of contact with the rover [2].)

3. Modeling of Chassis

In order to model the chassis, the first thing, which was considered, was the wheel base and the track width. The track width was considered as 4.8 feet and the wheel base was considered 4.6 feet. Triangulation was maintained in the chassis to make it stiffer and for this; the chassis was shaped triangular in structure with all the joints at nodal points. Stiffness was considered and for this, two types of square pipes were used. All the reference pipes were made off with 1.25*1.25 inch square pipes and the other supporting square pipes were of .75*.75inch dimension. The width of the frame was kept 1 inch for convenience and the total length of the frame was kept (1.5+1.5=3 feet) in order to fold the truss within 5 feet as per the rulebook. The middle portion of the frame was made rectangular in geometry in order to set a hinge joint between the two frames so that it can be folded easily. The truss was designed considering enough clearance for the drive train (chain sprocket mechanism, shafts etc.) which was to be placed inside the frame. For the availability, the cost efficiency and less weight we used Alloy Steel (SS) as a material in the design. The design was done using Solid works software.

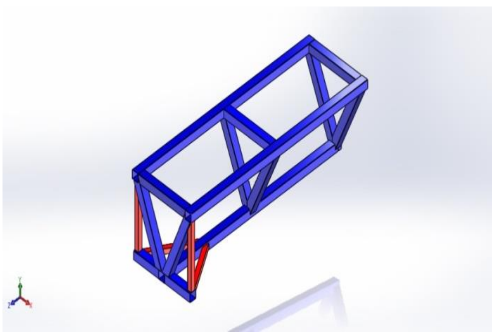

Fig.1. Design of a symmetric portion of frame

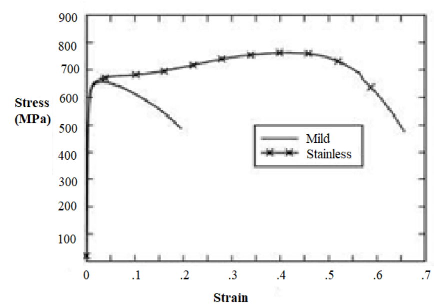

Fig.2. Property curve for steel specimens

While selecting the material comparison between the material properties of Mild Steel and Stainless Steel were done as they are the most available steels. In the comparison, it was obtained that the yield stress and ultimate tensile strength for the mild steel are 407 MPa and 657 MPa. The stainless steel has a higher yield stress and ultimate tensile strength of 539 MPa and 766 MPa, respectively and the fracture strain for stainless steel was 0.66 and 0.2 for mild steel [5].Besides, it is cheap and has much more stiffness. Therefore, Alloy Steel (SS) was chosen. For better rigidity all the reference pipes with same dimensions were used. The material property for Alloy Steel (SS) is tabulated below.

Table 1. Mechanical properties of chassis material

Name:	Alloy Steel (SS)
Model type:	Linear Elastic Isotropic
Default failure criterion:	Max von Mises Stress
Yield strength:	6.20422e+008 N/m^2
Tensile strength:	7.23826e+008 N/m^2
Elastic modulus:	2.1e+011 N/m^2
Poisson's ratio:	0.28
Mass density:	7700 kg/m^3
Shear modulus:	7.9e+010 N/m^2
Thermal expansion coefficient:	1.3e-005 /Kelvin

4. Results and Discussion

All analysis of chassis can be classified into the five classifications. They are- Vertical loadings, Front impact analysis, Lateral impact analysis, Torsion test, and Vibration analysis. In case of vertical loadings two ends of the frame was supported and the total weight of the driver including other components were placed. In this case the analysis was done with half portion of the frame. The total load was calculated to be 980 Newton. The frame and collect the result of Stress, Displacement and Safety factor were meshed and all the results obtained were satisfactory. The analysis result is cited in the Fig.3, Fig.4 and Table 3.

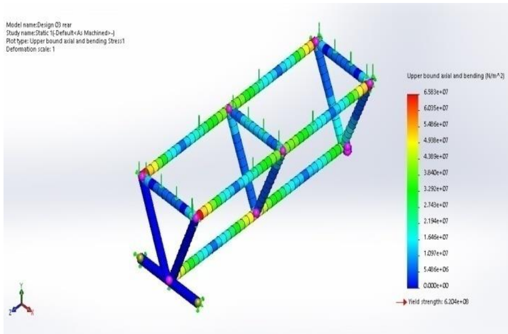

Fig. 3. Static Stress result.

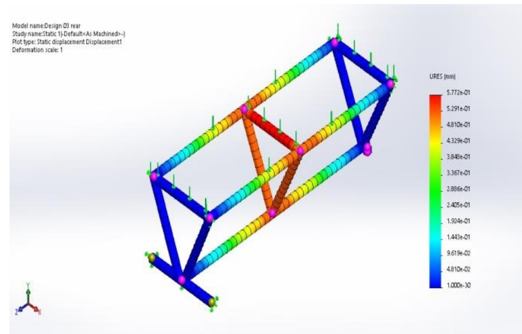

Fig. 4. Static Displacement Result.

In case of front impact analysis, it is considered that the vehicle is in static condition and rear side of the vehicle is in contact with a rigid wall and at that instant of time, another vehicle having the same mass will hit the vehicle at a speed of 15km/hr [3]. The final velocity is zero. For this purpose, the total mass of the vehicle was estimated and it was 79 kg. The maximum speed will be 15 km/hr and the time to impact is .2 sec. Therefore, the acceleration is 20.8333 m/sec square. So the maximum force is 1645.833 N. The results of the analysis are given in the figure Fig 5, Fig 6 and Table 3.

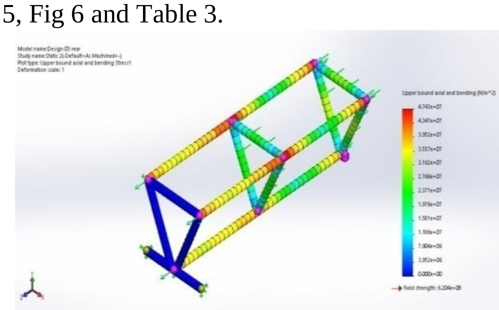

Fig.5. Static Stress Result

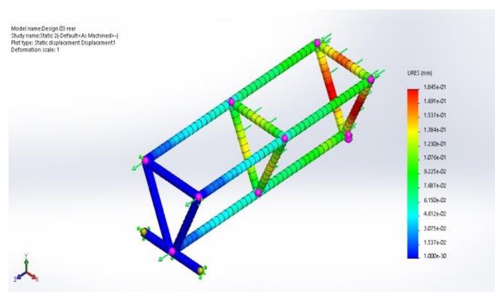

Fig.6. Static Displacement Result.

In case of lateral impact analysis, the total mass of the vehicle was taken as 79 kg. As per calculation, it was estimated that the total lateral force acting on the vehicle would be 900 N. considering this lateral impact simulation is done to the vehicle keeping both the ends steady. The results are provided in the figure Fig 7, Fig 8 and Table 3.

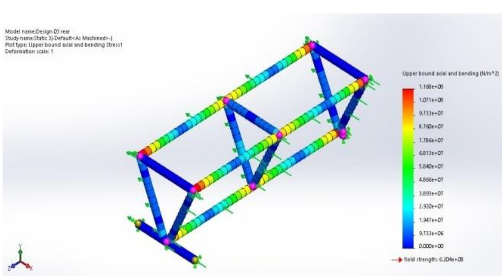

Fig.7. Static Stress Result.

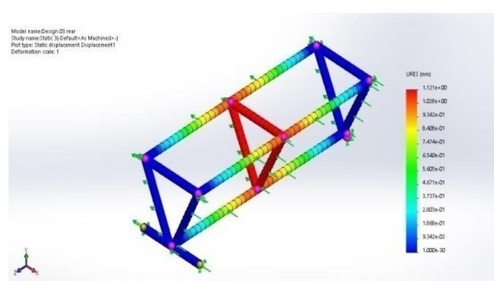

Fig.8. Static Displacement Result.

In case of torsion analysis, one end of the frame was fixed and a force of double the mass of the vehicle was applied on each vehicle [3]. As the mass of the vehicle is 79 kg, force can be easily calculated. The required force is

1548.4N and as the frame width is 1ft and the couple is 471.952 Nm. Torsion analyses is too much important for observing the stiffness of the space frame. The result of the analysis is given in the figure Fig.9, Fig.10 and Table 3.

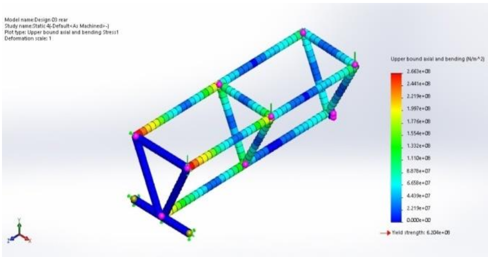

Fig. 9. Static Stress Result

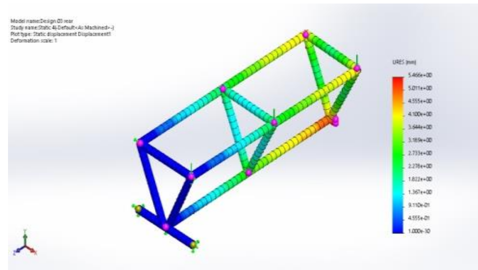

Fig. 10. Static Displacement Result.

In case of vibration analysis, the natural frequency & mode shapes of the chassis by fixing one end-supporting member's acting under the effect of gravity was found [3]. The analysis provided in the Fig.11, Fig.12 and Table 2 is obtained from the vibration analysis with several frequencies that are done with Solid Works software.

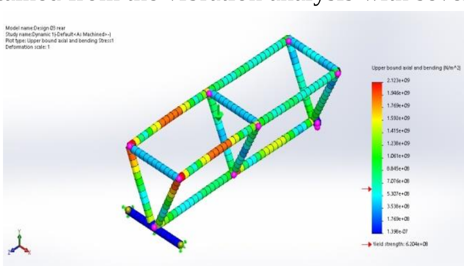

Fig. 11. Dynamic Stress Result.

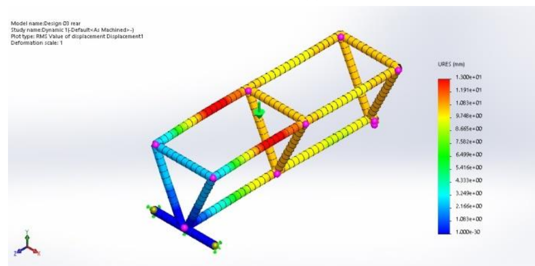

Fig. 12. Dynamic Displacement Result.

The analysis results for vibration analysis for sever frequency are cited in the table below.

Table 2: Table for vibration analysis

Mode Number	Frequency(Hertz)	X direction	Y direction	Z direction
1	31.503	0.61262	5.8997e-08	1.0559e-08
2	39.86	6.739e-08	0.58244	0.052616
3	95.412	0.0026248	9.7714e-10	6.3406e-10
4	185.86	0.19911	8.2914e-09	5.5174e-08
5	199.53	9.5156e-09	0.12141	0.41551
6	245.82	8.7897e-10	0.012569	0.23022
7	284.77	0.0013515	7.0552e-10	3.9666e-09
8	366.98	0.031851	1.2177e-10	9.4831e-12
9	423.59	0.0016468	1.0231e-11	1.1587e-10
10	666.57	5.9479e-15	0.0076451	0.0021841
11	708.28	0.00034293	2.9124e-10	4.3492e-08
12	710.88	6.5946e-10	0.00045018	0.0013323

Mode Number	Frequency(Hertz)	X direction	Y direction	Z direction
13	875.8	0.0094773	5.0576e-08	6.7521e-08
14	889.73	2.1716e-08	0.018707	0.00023611
15	899.48	5.6056e-09	0.0020349	0.00045595
		Sum X = 0.85903	Sum Y = 0.74526	Sum Z = 0.70256

All the analysis data are rearranged in the following table.

Table 3: Data of the analysis result.

Analysis name	Type	Minimum value	Maximum value
Vertical loadings	Stress	0.000e+00 N/m^2 Element: 52	6.583e+07 N/m^2 Element: 108
	Displacement	0.000e+00 mm Node: 1	5.772e-01 mm Node: 233
	Factor of Safety	9.424e+00 Node: 43	1.000e+16 Node: 56
Front impact analysis	Stress	0.000e+00 N/m^2 Element: 40	4.743e+07 N/m^2 Element: 195
	Displacement	0.000e+00 mm Node: 43	1.845e-01 mm Node: 8
	Factor of Safety	1.308e+01 Node: 1	1.000e+16 Node: 43
Lateral impact analysis	Stress	0.000e+00 N/m^2 Element: 215	1.168e+08 N/m^2 Element: 145
	Displacement	0.000e+00 mm Node: 1	1.121e+00 mm Node: 208
	Factor of Safety	5.312e+00 Node: 29	1.000e+16 Node: 214
Torsion test	Stress	0.000e+00 N/m^2 Element: 40	2.663e+08 N/m^2 Element: 158
	Displacement	0.000e+00 mm Node: 43	5.466e+00 mm Node: 214
	Factor of Safety	2.330e+00 Node: 55	1.000e+16 Node: 43
Vibration analysis	Stress	0.000e+00 N/m^2 Element: 240	2.123e+09 N/m^2 Element: 108
	Displacement	0.000e+00 mm Node: 56	1.300e+01 mm Node: 122

5. Modeling of Hinge

Both of the symmetric frames were made connected with two hinge joints. For this instance, two SS hinges were chosen and was welded with the two frames. The hinge was chosen in such a way so that it can withstand enough load and force due to vibrations. The CAD model of the selected hinge is provided in the Fig 13 and the modelling of hinge was done for selecting the hinge precisely so that it can fit to the rover and can carry the imposed load.

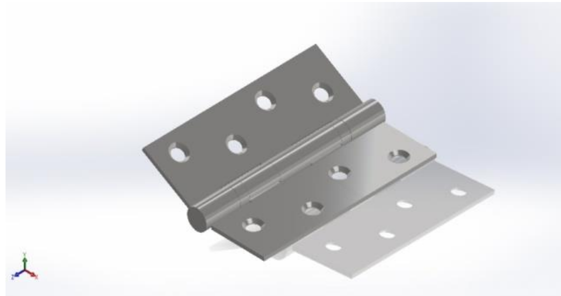

Fig. 13. Manufactured hinge

6. Chassis Manufacturing

While manufacturing Square SS pipes two dimensions is used as shown in Figure 14 and all the reference pipes are of 1.25*1.25 in dimension. However, the pipes are cut according to the cut list provided by the Solid works software and all the SS pipes are Gas welded at the nodes. Moreover, according to the geometry triangulation is maintained and two hinges is welded to make the frame so that it can easily fold and Figure 15 shows manufactured rover and manufactured chassis which maintain all design consideration.

Fig. 14. Manufactured chassis

Fig. 15. Manufactured rover

7. Conclusion

A human exploration rover an it's chassis has been manufactured with proper material selection ad the main purpose of the chassis is to hold the driver, the suspension system, the steering system, the drive train etc. Designing a full functioning chassis requires a series of analytical tests and our chassis crossed every analytical test successfully. All the rules associated in the rule book 2019, are maintained in the chassis to design the chassis much stiffer and simplifier. The entire chassis was only 14 kg in weight and it is much stiffer to carry required loads after manufacture.

8. References

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