STRUCTURAL ANALYSIS AND OPTIMIZATION OF HYPERLOOP POD CHASSIS

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ABSTRACT

This paper aims to design, optimize and analyze the structure of the Hyperloop pod, designed for Hyperloop Pod Building Competition organized by SpaceX. To reduce the aerodynamic drag, Hyperloop uses a partially evacuated tube, for running the pod. The design of the structure of hyperloop pod is very critical due its high speed, vibrations induced due to it and critical dynamic conditions. Also, in today's world of mass production, we cannot keep the factor of safety unnecessarily greater than needed. Also, while maintaining the safety we also must consider the material costing. Sometimes we use exotic materials like titanium for building the structure, as their supply is limited their value also increase with time, so it is very necessary to analyze for stresses and according to optimize it. So, in this paper, we discuss various forces coming onto the structure of hyperloop pod chassis and accordingly optimizing the structure for greater stiffness and lighter weight. We are using SolidWorks for modelling the structure, structural optimization is done using SolidThinking INSPIRE and analysis is done using the same.

Keywords*: Chassis, Finite Element Analysis, Hyperloop, Structure, Topology Optimization.***

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1. INTRODUCTION

Hyperloop, a concept devised by SpaceX, is a fifth mode of transportation [1]. In Hyperloop, a pod will travel in a vacuum tube at high speeds as high as 1130 kph, as proposed in the white paper of hyperloop alpha. To propagate and develop the concept, SpaceX organized a competition to design and build the pod and a select few teams get a chance to have a test run in California situated 1:2 scaled test track. “Hyperloop One” successfully tested its XP-1 passenger pod, reaching speeds of up to 192 mph (309 km/h) [2].

In the lieu of the competition [3] we developed a pod that can travel up to the maximum speed of 360 km/h. . The architecture of the pod is shown in Fig. 1. The pod is initially propelled with the help of Brushless DC (BLDC) motors (1) up to the speed of 44 m/s, after that a Halbach array of magnets (2) are lowered. They, then provide the upward force required to levitate the pod. As the levitation starts, the pod is propelled further with the help of cold gas thruster system (3). After achieving the predetermined braking conditions, the pod is braked with the help of Eddy current brakes (4). Throughout the journey the attitude of the pod is maintained by stability mechanism (5) as well as adjusting the position of levitation magnets. All the mechanisms are mounted on the chassis (6).

The chassis endures all the loads by the mechanisms, dead load, dynamics loads and vibrations; and thus needs to be sufficiently rigid. For accurate operation of all the mechanisms, their relative position with the track is essential. Thus, the deflection of chassis upon application of loads and stiffness are crucial design parameters. Furthermore, the chassis needs to be lightweight to reduce the inertia of the system and achieve the target speed. For this, the advantages and disadvantages of various chassis architecture as well as various materials to build one, were investigated.

2. LITERATURE REVIEW

Various types of chassis depending upon the structure that were discussed by John Robertson, et al. [4] are: 1) Ladder frame 2) Cruciform frame 3) Torque tube backbone frame 4) space frame 5) Integral structure and a combination of two or more of them. The advantage of ladder frame is its versatility of accommodating various body shapes. Regrettably its torsional stiffness is very less. This can be overcome using a cruciform frame. No member in cruciform frame is loaded in torsional stress even on twist loading.

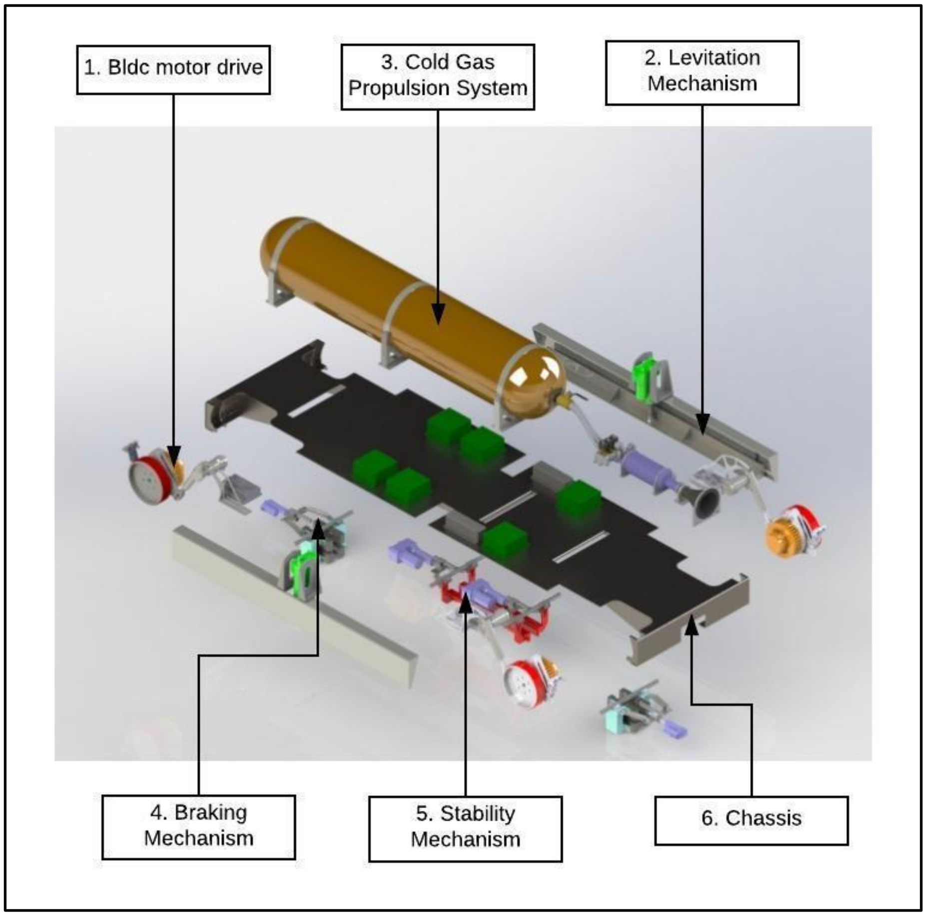

Fig. 1. COEP Hyperloop system architecture.

The Torque tube backbone chassis has transverse members joining the rear and front. The entire body is placed on this structure. However, due to no members on the sides, it does not provide any protection against side crashes. Space frames have triangulated structures of tubular members welded together. Thus sometimes the loads are borne by the welded joints. Though it is comparatively easy to build and lightweight, owing to the open apertures, imperative for accessing various components, makes this chassis less stiff. To get advantages of more than one of these chassis, an amalgamation of more than one was used in the design.

Another important aspect was the selection of material. To make the chassis, lightweight and stiff at the same time is a challenge. However, as the pod is going to operate in a partial vacuum, an important parameter is vacuum outgassing [5]. Certain materials out-gas upon exposure to vacuum. Steel and aluminum alloys along with other polymers and polymer coated metals were investigated by Erikson, E. D., et al. [6]. Aluminum alloys are found out to be more stable than steel alloys (Coated metals were rejected for economic reasons). Aluminum being significantly lightweight as well, the chassis was constructed using Aluminum alloys majorly along with occasional Steel, members as discussed in proceeding sections.

3. METHODOLOGY

The chassis supports all the components and maintains the relative position of the guiding and braking mechanisms with respect to the tracks and with each other. The Main chassis plate as well as side panels were made from formed Aluminum Sheet metal alloy 6061-T6, while the linear guides of the various mechanisms act as transverse ribs, are made of Stainless Steel alloy AISI 304. The properties of the same are summarized in Table I.

3.1 Modelling and optimization

The chassis is modelled using Solidworks and optimized using Solidthinking INSPIRE. The boundary conditions and the loading are as shown in the Fig. 3. The original mass of chassis was 60.4 kg. The chassis is optimized for maximum stiffness objective for 50% mass constraints.

TABLE I: Physical Properties of Aluminum Alloy 6061-T6 [7] and Stainless Steel AISI 304 [8]

	Value	
Property	**AA 6061-T6**	**AISI 304**
Density	2.7 g/cc	8.0 g/cc
Ultimate tensile strength	310.0 MPa	505.0 MPa
Modulus of Elasticity	68.9 GPa	193 GPa
Poisson's Ratio	0.33	0.29
Shear Modulus	26.0 GPa	77.0GPa

The Structure is modified according to the optimization results and analyzed for boundary conditions and loading as shown in Fig. 3 and Table II, using INSPIRE. The meshing for both the stages, optimization and static analysis, is done in Hypermesh.

3.2 Boundary conditions

The forces acting on the chassis are, as shown in figure-2, due to the braking mechanism, magnetic and lateral stability mechanism, the inertial forces acting due to the deceleration of 24 m/s2 due to braking, and the actuator forces due to the active suspension system (1) figure 1.

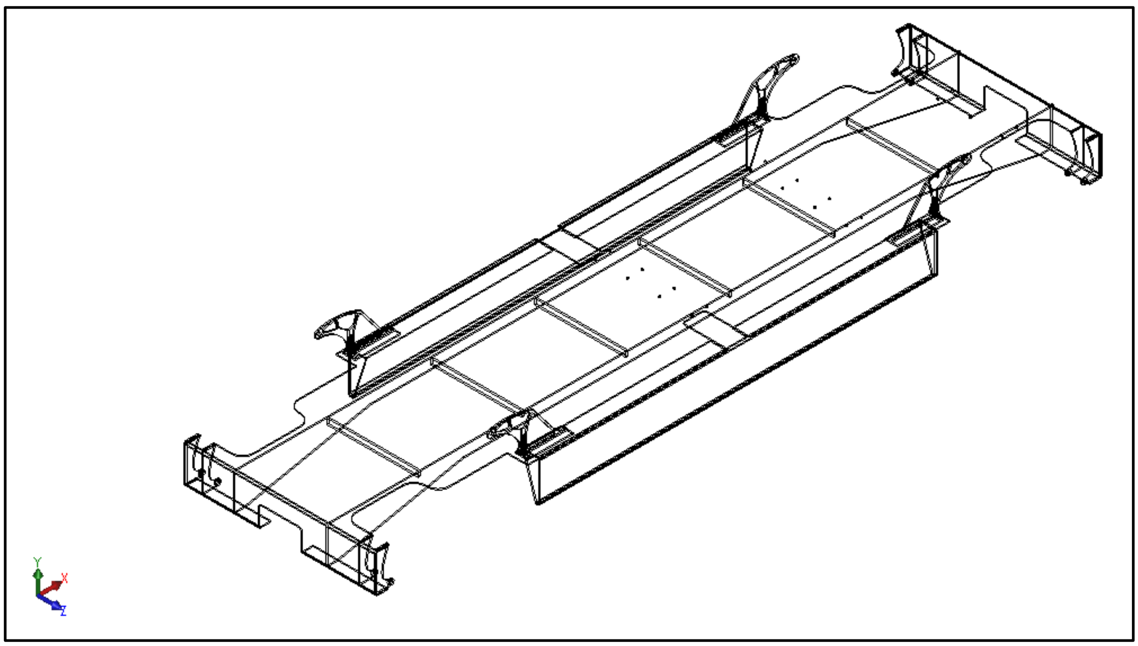

Fig. 2. Original Chassis Design

The gravity is 9.8m/s2 in negative Y direction. The wheels are approximated as pin joints. The magnitudes and directions of the forces are summarized in table II. Separate load cases for 1. Dead loading 2. Braking and 3. Operation of cold gas thruster system are considered. For the braking case, the inertial load as per Newton's second law was applied to the entire chassis as well as components in opposite direction, while for the cold gas thrusters it was applied in the direction of motion itself.

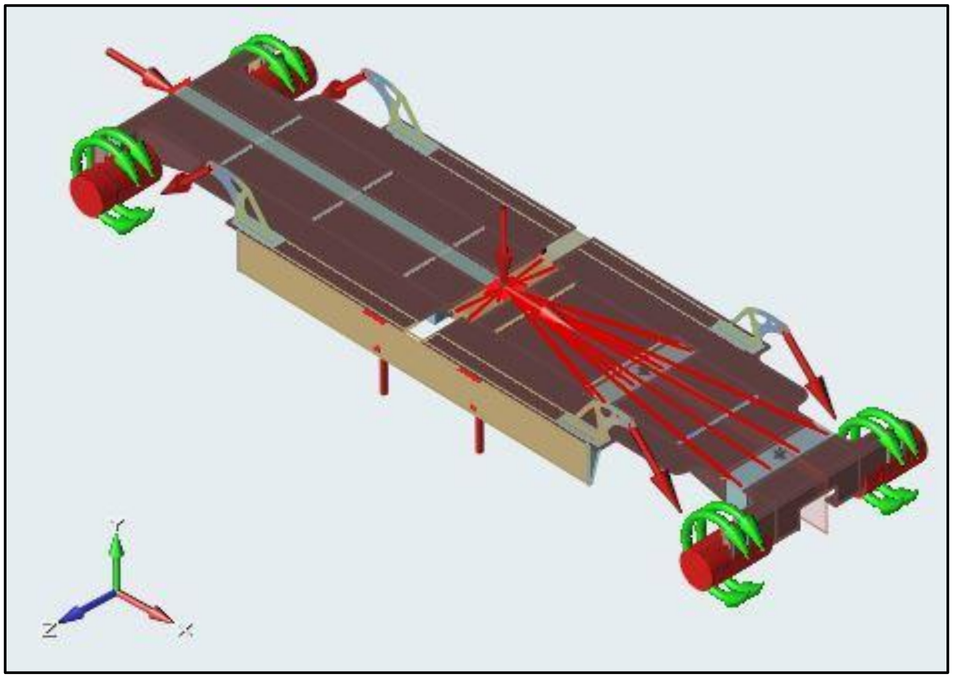

Fig-3. Free body diagram of the chassis

Table II: Forces acting on the Chassis

Description	**Forces**	
	Magnitude (N)	Direction Vector
Active suspension actuator (front)	2000	(0.707,-0.707,0)
Active suspension actuator (Rear)	2000	(-0.707, -0.707,0)
Weight of components	4000	(0, -1, 0)
Inertial force (braking)	8300	(0,-1,0)
Inertial force (Gas Thrusters on	2700	(0,-1,0)
Stability Mechanism down force	3500	(0,-1,0)
Braking Mechanism Down Force	200	(0,-1,0)
Levitation Lift	4700	(0,1,0)
Cold Gas Propulsion Thrust force	3000	(1,0,0)

4. ANALYSIS

The analysis of the entire chassis upon application of the boundary conditions and loads was done in INSPIRE and the entire based upon the result the optimization was done for maximum stiffness condition as discussed in previous sections.The mounting points of various mechanisms and boundary conditions were excluded from the design space. The optimized topology of the chassis is shown in Fig.4 A validation analysis was done, the results of which are summarized in Fig. 5-6. The weight of the chassis was reduced to about 65% from 60 kg to 38.4 kg. The modes of oscillations are listed in Table. III

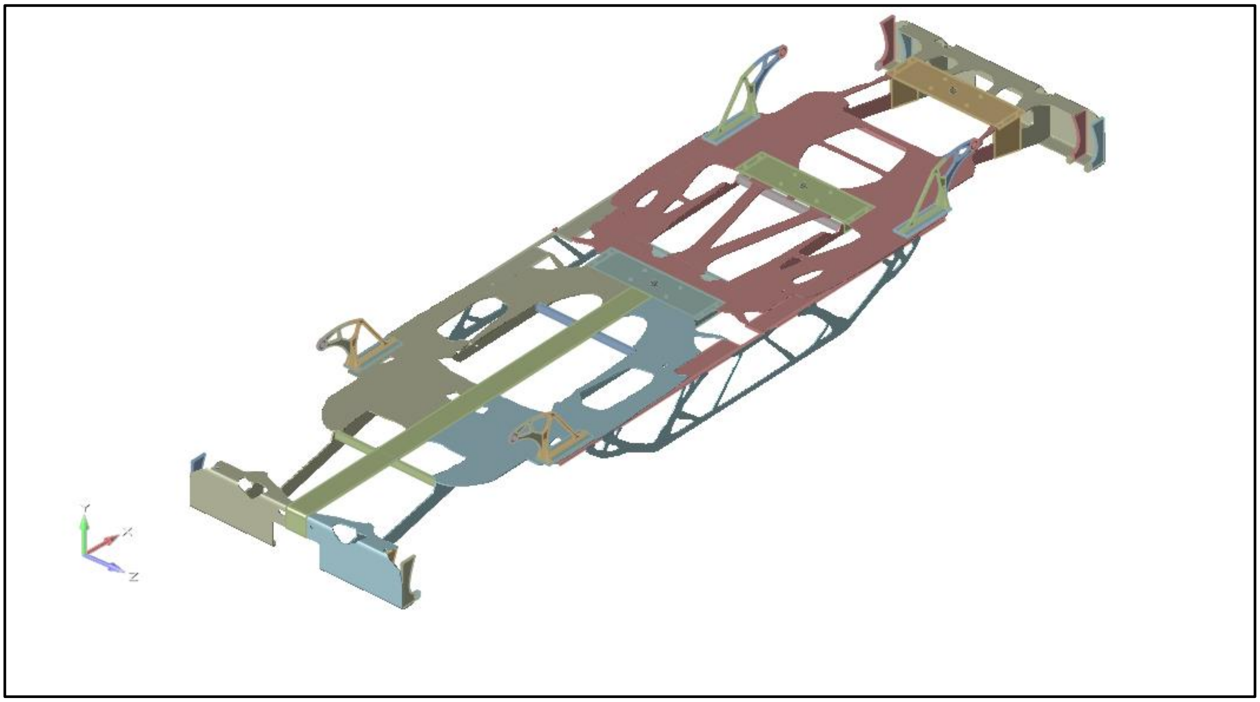

Fig. 4. Optimized Topology

5. RESULTS AND DISCUSSION

The Maximum deflection in the chassis is 5.743 mm in the region where the magnetic stability mechanism is mounted. The permissible deflection from the normal position is 12 mm for optimal operation of the mechanism, thus the chassis is safe. The maximum stress in the chassis is 99.81 MPa. The maximum stress concentration occurs at swing arm mounting points. With the help of structural optimization, the weight of the chassis is reduced by 35%. Modal analysis suggests that the minimum natural frequency of structure is 24 Hz.

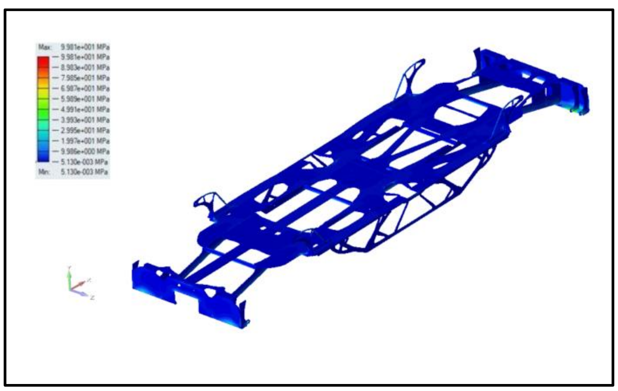

Fig. 5. Von Mises stress contour: optimized chassis

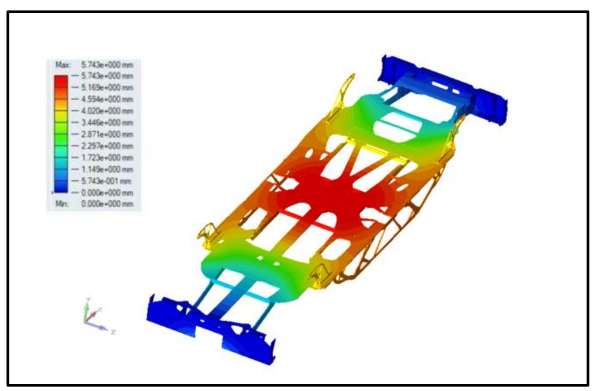

Fig. 6. Displacement contour: optimized chassis

Table III: Modes of Oscillation

Mode	Frequency (Hz)
1	24.503
2	25.3253
3	30.3874
4	39.7080

5	60.4771
6	82.1118

The actual deformations and stresses in the chassis will be lesser than the one obtained in analysis because, the external Propulsion apparatus and the stability system magnet array mounting members will provide the additional longitudinal stiffness.

6. CONCLUSION

From the optimized structure it can be seen that, the chassis has the prominent features of ladder frame, cruciform frame, torque tube backbone, space frame as well as integral structure. The longitudinal members and Linear guides (acting as transverse members)are characteristics features of ladder frame. The material removed in the main plates forms the Cross elements characteristic of cruciform frame. The region excluded from design space and propulsion apparatus acts like torque tube backbone, while the triangulated webs on side panels and main frame plate are characteristic to space frame. Thus, the virtues of all types of frames while, overcoming their limitations can be seen in the optimized structure of the COEP Hyperloop chassis.

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