DESIGN AND OPTIMIZATION OF SUPPORT STRUCTURE OF A SENSOR IN SPACECRAFT

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Abstract: *In this project, the design and optimization of aerospace brackets and their manufacturing processes was going to be carried out. In the design of aerospace structures, lightweight and high-performance structures were essential because spacecraft often operate in harsh conditions. By Topology optimization, a lightweight aerospace bracket that supports spacecraft sensors was designed which must ensure stiffness, strength and quasi static load requirements. The model of the bracket, we designed should be 3D printed. The additive manufacturing process has evolved dramatically over the past few decades, has found application in many areas, including the aerospace industry where a wide range of material properties was required. Materials should be selected based on it. In spacecraft construction mass reduction was very important. For stiffness requirement, the bracket has to meet the fundamental frequency of >80Hz, when the bracket base was fixed and also the bracket (with sensor) must be able to withstand a quasi-static load of 20g in all directions. In the project, materials with the required properties were selected, as well as design and analysis procedures were carried out in commercial software, to ensure that the design meets the task objectives and results were obtained.*

Keywords: *Aerospace Bracket, Aerospace structures, 3D printing*

1. INTRODUCTION

Throughout the aerospace industry, spacecraft were subjected to many harsh conditions in various environments, so a major requirement was to design and optimize structures to cope with these harsh conditions. Our paper presents the design and manufacture of a lightweight sensor support structure using additive manufacturing. Aerospace structures need to be lightweight and high-performing due to the harsh environment in which they were operated. Aerospace brackets were connector pieces or support structures with many cutouts to connect with fixtures [1]. A lightweight aerospace bracket that supports spacecraft sensors was designed and tested to meet the requirements for stiffness and quasi-static load. Over the past few decades, additive manufacturing has developed dramatically, with applications in a wide range of industries, including aerospace, where a wide range of material properties were needed. Materials should be selected based on it. The reduction of mass was one of the key factors to be considered in spacecraft structures. For stiffness requirement, the bracket has to meet the fundamental frequency, when the bracket base was fixed and also the bracket (with sensor) must be able to withstand a quasi-static load in all directions to satisfy the Margin of Safety. In this project, materials with the required properties had been selected, as well as design and analysis procedures were carried out in commercial software, to ensure that the design meets the task objectives and results were obtained.

2. METHODOLOGY

Often, aerospace components need to be fabricated or machined to meet exceptionally high performance, strength, or heat resistance requirements, stiffness, strength to weight ratio which could entail considerable cost [2]. Material engineering was an important area within aerospace engineering, and defined by the international standards bodies that set standards for the materials and processes involved, such as ASTM, AMS, or company specifications [2]. So, the material for the whole project was selected as per the requirement first of all. To begin with, the materials for the entire project were selected based on the requirements and also must be 3D printed. From the author [3], the components weigh 35.98% less than components produced previously by subtractive manufacturing [3]. As per that, model we were going to design. In 3D printing, the Powder Bed Fusion type was selected for manufacturing. Powder Bed Fusion (PBF) was an additive type of manufacturing process. It was the addition of layers process. Hence, it would be able to manufacture all types of products used in automotive, aerospace, energy, and home appliances in the future [7]. In PBF, SLM process was selected. Using selective laser melting (SLM), metal powders were melted and fused to produce near net-shape parts with near full density, using a high power-density laser [8]. So, we could design complex shapes to model the support structure. Then, the project was designed in CATIA, where the plane where the sensor was to be mounted must be inclined at 67.5 degrees from the deck. Additionally, the plane should have five interfaces to connect the sensors, as shown in Figure 1 & Figure 2. Then the model would be analyzed in ANSYS to check whether the designed model survive all the given loads and satisfy the stiffness and Margin of Safety requirement.

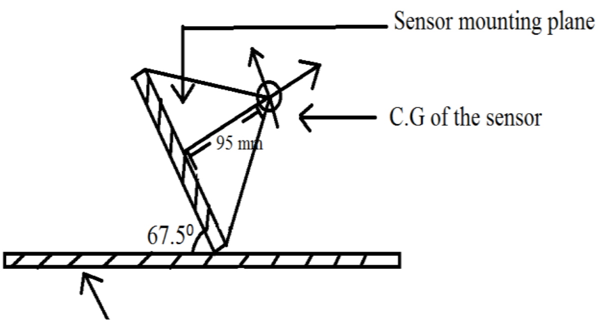

Figure 1: Overall Configuration

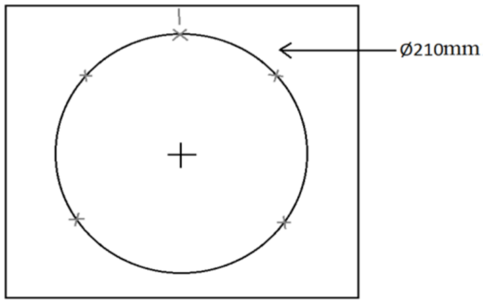

Figure 2: Top View

3. MATERIAL SELECTION

As per the requirement, the material we should select for the bracket must be space grade and 3D printable. In accordance with these conditions, Ti6Al4V, Inconel 625, and Inconel 718 were shortlisted. Ti6Al4V was considered being the most lightweight material for spacecraft structures because of its combination of high strength, low density, high modulus, low coefficient of thermal expansion, and high thermal conductivity [4].Inconel 625 (IN625) was a high-strength and fatigue-resistant alloy that was highly resistant to creeping and creeping fatigue under high-temperature and high-pressure conditions, making it one of the critical materials used for aero-engine bearing parts [5].Inconel 718 nickel alloy, another high-temperature alloy, was also widely applied to the aerospace industry. Because Inconel 718 has excellent mechanical properties and excellent oxidation resistance at high temperatures, it was an ideal material for using in high temperature areas of aero engines and gas turbines [6]. But for this model, Ti6Al4V material has been selected. Because it was space grade material and due to the fact that it can be easily printed through 3D printing.

Ti6Al4V CONTENT	
C	<0.08%
Fe	<0.25%
N_2	<0.05%
O_2	<0.2%
Al	5.5-6.76%
V	3.5-4.5%
H_2(sheet)	<0.015%
H_2(bar)	<0.0125%
H_2(billet)	<0.01%
Ti	Balance

Table 1: Composition of TC4

4. DESIGN

This project was completely a design based one here to design an aerospace bracket which should withstand the structural loads and it should satisfy stiffness with fundamental frequency above 80Hz and also must survive quasi static load of 20g in all direction individually and Margin of Safety ratio must be above 0.5 in all three axes. As per the given conditions in Figure 1 and Figure 2, the model has been designed in CATIA as it was best for sheet metal design

4.1. DESIGN DESCRIPTION

- The sensor has to sit on a deck making 67.5-degree angle with the deck (refer Figure 1).
- Mass of the sensor was 3 kg. CG of the sensor was 95mm from the mounting plane in perpendicular direction (Figure 1). Sensor has 5 interfaces with the mounting plane of the bracket with PCD of 210mm (Figure 2).
- Mass moment of inertia of the sensor about its CG: I_1=0.004 kg-m^2, I_2=0.004kg-m^2, I_3=0.0075kg-m^2 (Refer Figure 1 for local coordinate system).
- The mass of the sensor bracket has to be less than 0.5kg. Mass reduction in spacecraft structures was very important.
- The bracket should meet stiffness requirement with fundamental frequency >80Hz, when base of the bracket was fixed. This requirement was necessary to keep the bracket away from spacecraft major modes.
- The bracket (with sensor) has to withstand quasi-static load of 20g in all directions individually, i.e. (20g,0,0), (0,20g,0), (0,0,20g) load cases. The margin of safety for stress for these load cases were to be verified.

4.2. FINAL DESIGN PROCESS

4.2.1. Final Model

The above 3 parts were assembled as a single part as a final model which satisfied the design requirements as per the design description. The final model of the project as follows in Figure 3.

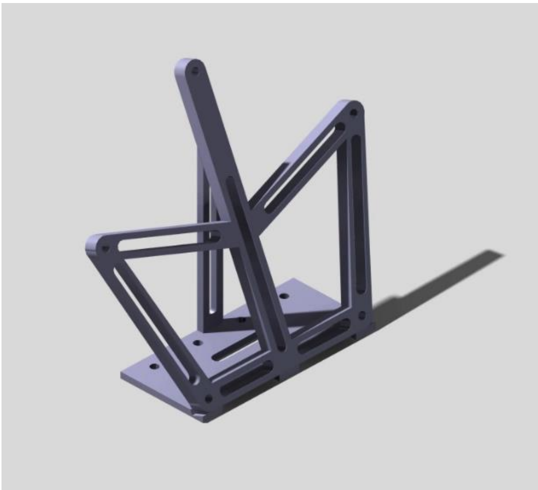

Figure 3: Final Model

In this work the support structure was designed into three parts

- Base part
- Support part
- Plane part.

4.2.2. Base part

The base part of the bracket was connected to the deck of the spacecraft and it was the bottom portion of the bracket as shown in Figure 4

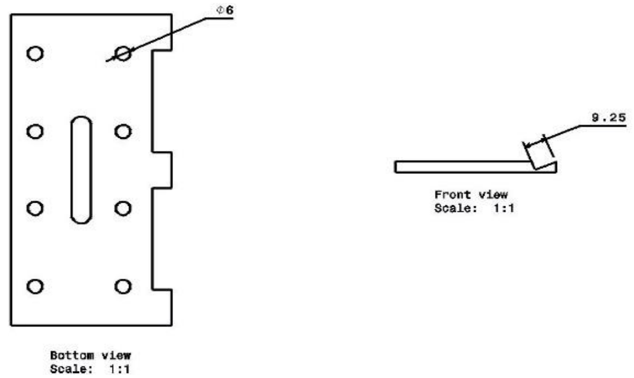

Figure 4: Base Part

4.2.3. Support part

The support part was help to connect the both base and interface part of the bracket. The support part attached at the C.G. point of the in their interface to archive high frequency as shown in Figure 5

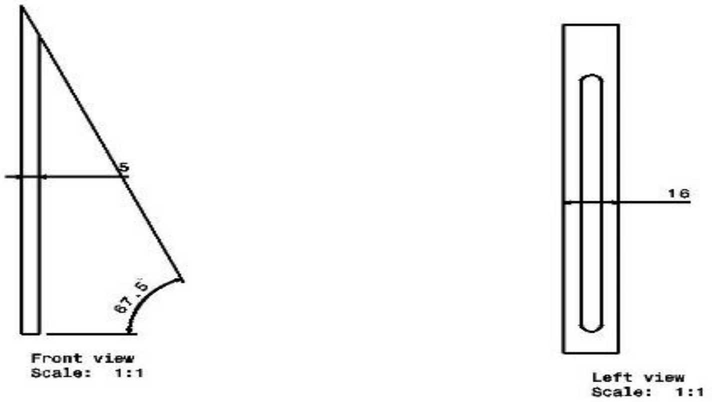

Figure 5: Support Part

4.2.4. Plane part

The interface part was the top view of the overall Figure 2. in which the sensor was going to mount or mounting plane. It has five interfaces to connect the sensor to the support structure as shown in Figure 6

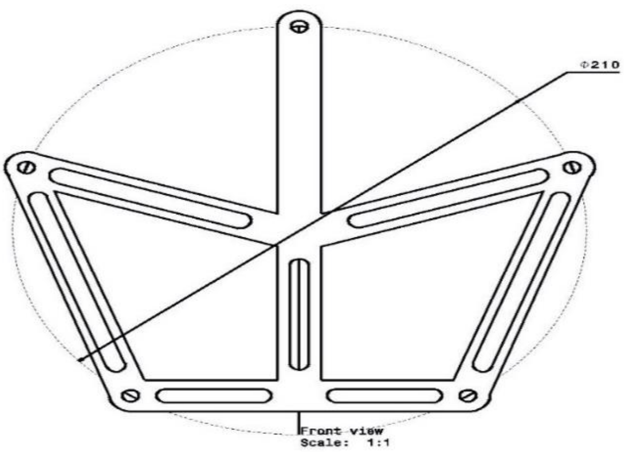

Figure 6: Plane Part

5. ANALYSIS

The model we designed must be tested to find whether it survive all loads in extreme harsh conditions in space. But we can give the loads and conditions in space as boundary condition in the commercial analysis software. Here we used commercially available ANSYS software to analyze the model we designed. This analysis process was carried out in three steps. First, we found the stiffness requirements with a fundamental frequency >80Hz when the base of the bracket was fixed. Fundamental frequency was the frequency of the model when the initial load was given. If it did, then we should move forward to find the Margin of safety when quasi static load of 20g was acting in all three axes individually. Quasi static load was the load where dynamic forces were negligible. Margin of Safety value must be above 0.5 in all three axes individually. Then finally the reaction force on the base was calculated to find whether M6 bolt was enough to connect the bracket with deck. The maximum allowable load for M6 bolt will be 1461.19 N. so the force on base must be less than mentioned value. The flow of the analysis process was given in Figure 7.

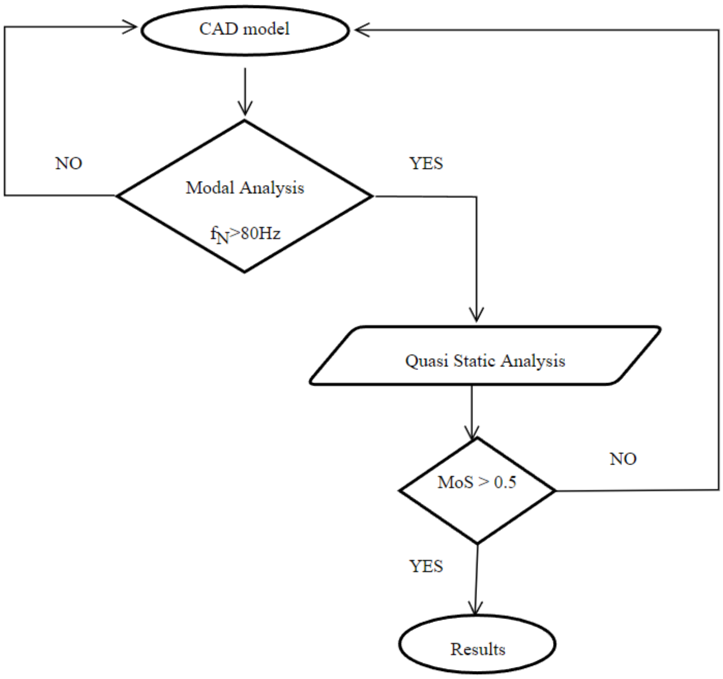

Figure 7: FLOW OF ANALYSIS

5.1. MESH OF THE MODEL

Meshing was the process in which your geometry was spatially discretized into elements and nodes. The stiffness and mass distribution of structures were mathematically determined by the mesh and material properties. The mesh of the model was shown in Figure 8.

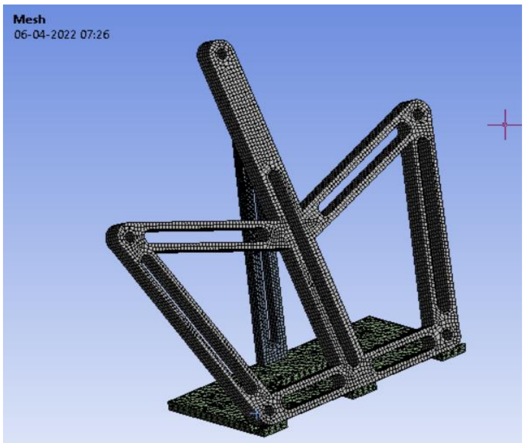

Figure 8: MESH OF THE MODEL

5.2. MODAL ANALYSIS

Modal analysis was a free vibrational test to find the fundamental frequency of the model. Here the base of the base was fixed and mass of the sensor 3kg was given as point load at 95 mm from interface part. And using mass moment of inertia value (I_1=4000 kg-mm^2, I_2=4000 kg-mm^2, I_3=7500 kg-mm^2) it considered as remote point. The above-mentioned boundary conditions were shown in Figure 9.

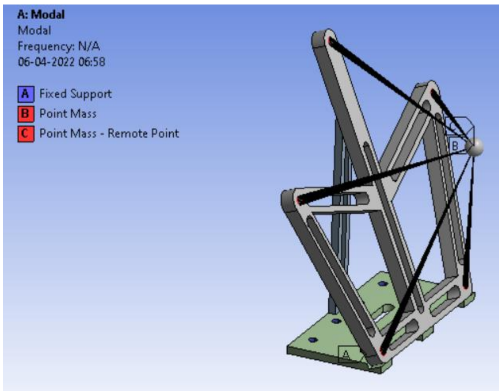

Figure 9: BOUNDARY CONDITIONS OF MODAL ANALYSIS

5.2.1. Modal analysis results

For the given boundary condition, the fundamental frequency of the model value when the base fixed will be **130.73 Hz**. And the mode shape for the fundamental frequency will be shown in Figure 10.

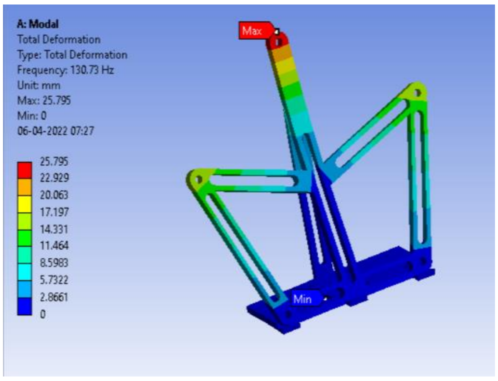

Figure 10: NATURAL FREQUENCY OF THE MODEL

5.3. QUASI STAIC ANALYSIS

Here the quasi load 20g which was 20 times the acceleration due to gravity, was given as acceleration **196133 mm/s^2** in all three directions individually and here also the base had fixed. And the above-mentioned boundary conditions were given in Figure 11.

Figure 11: BOUNDARY CONDITIONS OF QUASI STATIC ANALYSIS

5.3.1. von-Mises Stress and MoS IN X direction

Margin of safety value was one value less than safety factor. And safety factor was the ratio between tensile yield strength of the material to Maximum von-Mises Stress. Tensile yield strength of the material was **880 MPa**. Then from the given boundary condition in X direction, the maximum value of von-Mises stress was **281 MPa**. Then Margin of Safety value on X-direction was 2.14.

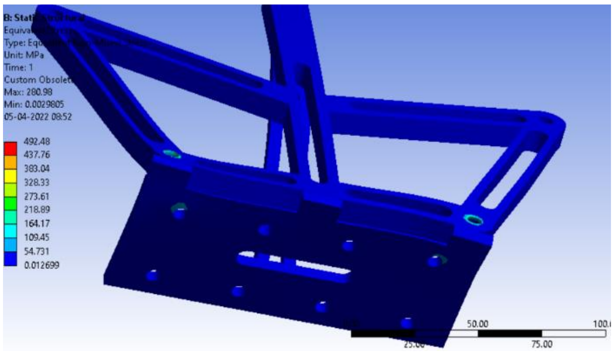

Figure 12: von-Mises Stress In X-Direction

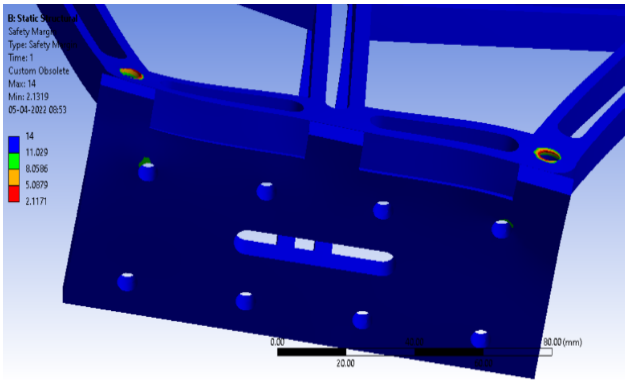

Figure 13: Margin of Safety X Direction

5.3.2. von-Mises Stress and MoS in Y direction

For the given boundary condition in Y direction, the maximum value of von-Mises stress was **492 MPa**. Then Margin of Safety value on X-direction was **0.79**.

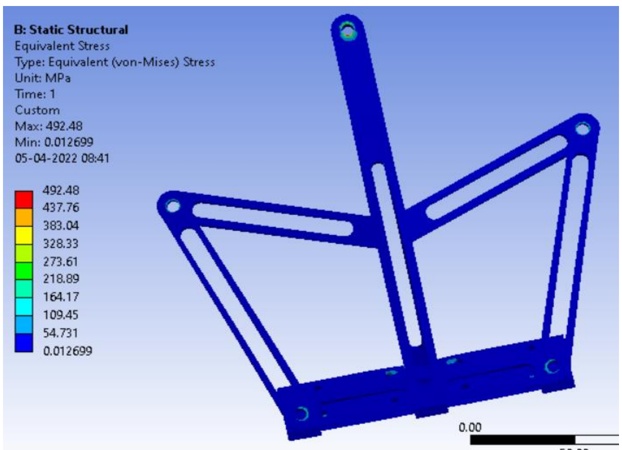

Figure 14: von-Mises Stress In Y-Direction

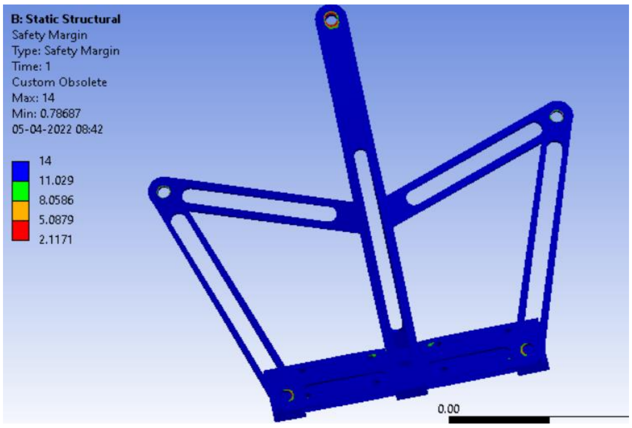

Figure 15: Margin of Safety in Y Direction

5.3.3. von-Mises Stress and MoS in Z direction

For the given boundary condition in Y direction, the maximum value of von-Mises stress was **146.19 MPa**. Then Margin of Safety value on X-direction was **5.02**.

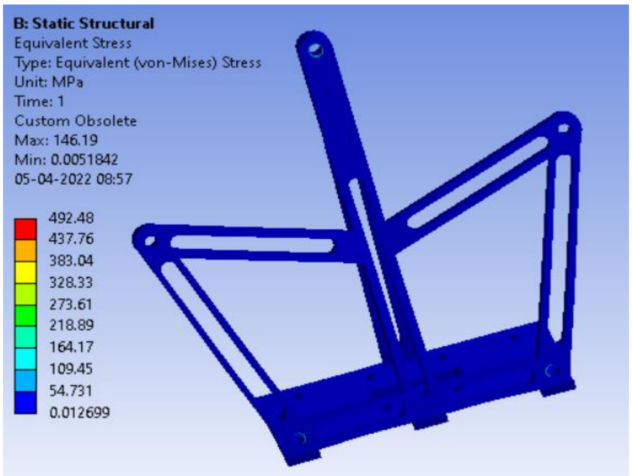

Figure 16: VON-MISES STRESS IN Z-DIRECTION

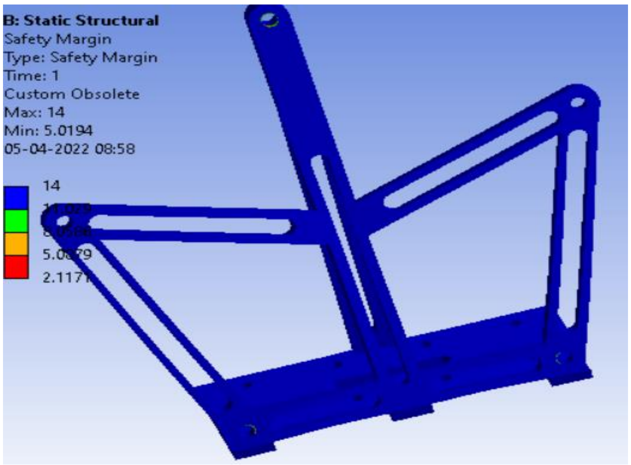

Figure 17: MARGIN OF SAFETY IN Z DIRECTION

5.4. REACTION FORCE ON BOLT

A reaction force acts in the opposite direction of an action force. As per that the reaction force of the bracket on bolt surfaces were calculated. As per our analysis result, maximum force value was 684.97 N. For this requirement M6 bolt was enough to carry the maximum force as its maximum allowable load was around 1461.19 N.

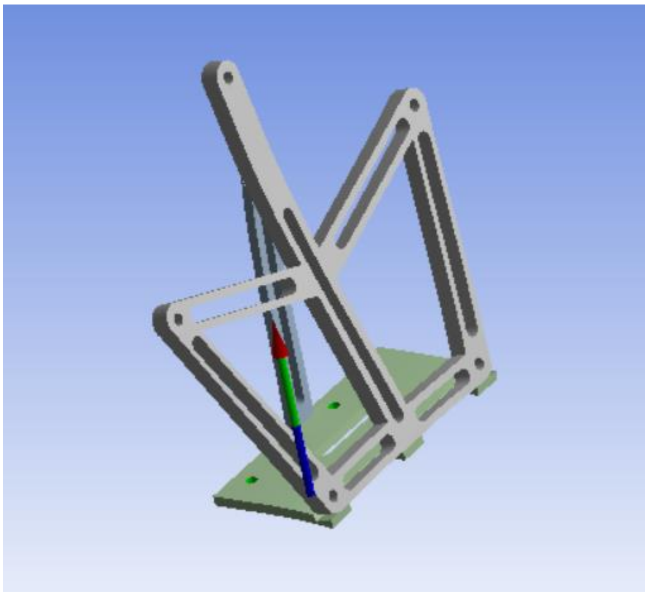

Figure 18: Force Reaction of The Model

6. RESULTS AND DISCUSSION

We designed the aerospace bracket that provides support to sensors in a spacecraft according to the requirements. In terms of material selection, Inconel 625, Inconel 718, and Ti6Al4V were considered. As it turns out, all of these materials met our requirements since they were space grade; however, Inconel was actually a heavy metal compared to Ti alloys, where it can be fabricated into thin sheets with high strength. But titanium alloy, **Ti6Al4V** was a lightweight material that was well suited to our design, and its mass was around **0.4959 kg**. Then the stiffness requirement with a fundamental frequency with base fixed must be above 80Hz, thus meeting the stiffness requirement for this bracket. It was nearly **130.73 Hz** in our case, indicating that our bracket was stiff enough to carry the sensor in space. In order to estimate the margin of safety, we must consider the quasi-static load of 20g, where g was the acceleration due to gravity constant loaded in each axis individually. We achieved a margin of safety ratio of minimum 0.5 in each of the three directions individually. So, our requirement for a margin of safety was also satisfied. Therefore, we have fulfilled all the requirements for the bracket design project and analyzed the design of the bracket to conclude that it was suitable to mount the sensor on the spacecraft.

S.NO	REQUIREMENT	RESULTS
1	Material should be space grade and 3D printable	Ti6Al4V was a space grade material [5] [10] and it was quite famous in 3D metal printing industry
2	Mass of the bracket must be below 0.5kg	Fulfilled. And the mass of the bracket was 0.4959 kg
3	Stiffness requirement with fundamental frequency must be greater than 80Hz	Fulfilled. And fundamental frequency value was 130.73 Hz
4	Margin of safety considering quasi static load cases must reach and should survive	Bracket can survive quasi static load cases and reached the required margin of safety

Table 2: Requirements and Results

7. CONCLUSION

The additive manufacturing technology provide a broad possibility for manufacturing and also weight reduction over other way of manufacturing. The optimization technology provides an important way to design high performance lightweight structure. The project proposed a combination of analysis and 3-D printing technology for designing and manufacturing of an aerospace bracket considering the structural performance. Due to its lightweight properties and ability to be 3-D printed, titanium alloy Ti-6Al-4V was considered the best material in all aspects including mechanical properties. Initially, the design of support structure has been designed as per the requirement such as mass below 0.5 kg and with 5 interface mounting location. Subsequently, using the 3-D CAD file the analysis process satisfied stiffness requirement with fundamental frequency above 80Hz and sustained 20g of quasi-static load in respect to all direction individually, these two-analysis carried out under the consideration of mass of sensor (3kg). The problem controls the structure with good safety margin results. Under the guidance, according to the structural optimization results the support structure of sensor was designed and fabricated by the SLM or EBM method. The vibration quasi-static loading test fulfills the structural specification proposed at the best building of the bracket design. This work indicate that the integration of the proposed structural optimization design method and additive manufacturing can be a powerful tool for the light weight design of aerospace brackets.

8. REFERENCE

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