# PRATHAM
# IIT BOMBAY STUDENT SATELLITE

## Report
## Structures

By

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# Chapter 1

# Introduction

In this chapter, we will give a brief introduction to the concept of Student Satellite and the work of the System Engineer.

## 1.1 Vital Statistics about Pratham

Pratham is the first Student Satellite being built under the IIT Bombay Student Satellite Project. Some of the vital statistics about the Satellite are as follows:

- Weight: 10.04 kg (without FE Ring of mass 0.6 kg)
- Size: 29.4 cm X 31.5 cm X 46.0 cm cube
- LVI from VSSC (IBL230V2)
- Solar Panels (4 sides)
- Orbit – 10:30 polar sun-synchronous
- Material of side panel is AL6061-T6
- 3 pre-deployed monopoles (outside the 26 cm cube)
- Downlink at frequency 437.455 MHz
- Beacon at frequency 145.98 MHz
- Uplink at frequency 437.455 MHz
- Completely autonomous (except reset and kill switch)

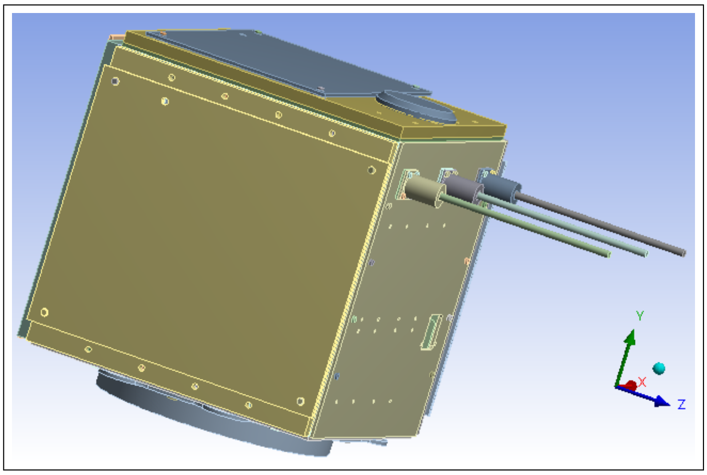



Figure 1.1: Pratham's Engineering Drawing

| Axes | Simulation | Testing |
| --- | --- | --- |
| X | Lagging to Leading | Leading to Lagging |
| Y | Nadir to Zenith | Anti-sunside to Sunside |
| Z | Sunside to Anti-sunside | Nadir to Zenith |

Table 1.1: Axis Definition

## 1.2 Mission Statement and Success Criterion

The Indian Institute of Technology Bombay, Student Satellite Project has an overall plan to launch atleast 5 satellites into orbit within the next few years. The objective of this Project is to make IIT Bombay a respected center for advancement in Satellite and Space Technology, in the world. These Satellites could be test-beds for new technology that is being developed in the institute and need space qualification.
The Student Satellite named Pratham being currently made is the first of this series. After months of literature survey, a Payload was chosen which was deemed fit for the first satellite.
The Mission for Pratham, IIT Bombay's First Student Satellite is:

1. Acquiring knowledge in the field of Satellite and Space Technology
2. Have the Satellite entirely designed by the student body of IIT Bombay
3. Have the satellite launched, Measure TEC of the Ionosphere above IITB
4. Involve students from other universities in our Satellite project

When all the 4 mission statements are fully satisfied, we can call our satellite to a complete success (100%). The IITB Student Satellite Team has attached a lot of importance to all the mission statements. The Success Criterion for the Project is shown in table 1.2.

| Description | Mission Success |
| --- | --- |
| Flight Model ready | 85% |
| Beacon Signal received | 90% |
| TEC measurements at IITB | 95% |
| Satellite functional for 4 months | 100% |

Table 1.2: Success Criterion

## 1.3 Structures Subsystem

The requirement that the structure must satisfy is that it must house all the components and ensure that it does not fail during the lifetime of the satellite. During the lifetime, the satellite will undergo various types of loading. Structural subsystem should ensure that satellite structure is able to withstand the loading and no component should fail due to structural loading.

The design of satellite structure is dependent on many factors. Some of the most important factors are placement of components and the material properties of components. The design approach that is followed in this satellite is first system engineering team prepares a configuration layout and structures team analysis it and decides the parameters like material of satellite body and thickness of the material. The analysis is given to system engineering team and if there is some flaw in the system, system engineering team prepares a modified configuration layout. This iterative process is followed till a design satisfying both system engineering and structural requirements is obtained. The various parameters that can be changed by structural subsystem are material properties of structure, geometric parameters like thickness of the structure and joining mechanisms.

Finite element software ANSYS is used for structural analysis. A structural model is prepared and meshed to get the finite element model. Various static as well as dynamic analysis are performed on this finite element model to get the response of the structure to various types of loading. ANSYS can be used to perform both static as well as dynamic analysis on the structure.

Validation of the results obtained using ANSYS is done by first validation of the finite elements and geometry by comparing results with theoretical results and then by analysis of individual structural element in ANSYS isolated. This approach was giving a good match between the results obtained from finite element analysis and theoretical results as well as between individual element and entire structural model. The results obtained using FEA suggest that satellite will be above the failure stresses and strains when specified loads are applied and no component on the satellite fails due to these loads.

## 1.4 Overview of the report

In chapter 2, requirements and constraints are given. Chapter 3 describes the configuration and interfaces. In chapter 4, all the simulations that have been performed are described. Validation of the design and analysis and the qualification and testing plan are described in chapter 6. Chapter 7 deals with the placement of handle and the simulations regarding the stresses developed when the satellite is being carried.

# Chapter 2

# Requirements and Constraints

The following section details the requirements imposed on the Structural Subsystem by the other subsystems of the satellite and the constraints under which the Structural Subsystem needs to design the satellite. It gives a broad look at the various tasks handled by the subsystem and their significance in the overall scheme of the satellite.

## 2.1 Launch Vehicle Placement Requirements

The satellite is launched into Low Earth Orbit by the Polar Satellite Launch Vehicle. The launch vehicle interface to be used is the IBL230V2, to be provided by VSSC.

1. Launch vehicle interface requires 8 no's M6x1, 9mm long helicoil inserts at 230mm PCD on bottom deck of the satellite.
2. There should not be any interference in the joint from the satellite to the launch vehicle body.

## 2.2 Launch Loading Requirements

The satellite is carried to its orbit by a launch vehicle in a flight lasting about 17 minutes. During this period, the vehicle experiences high levels of acceleration, vibrations and shocks which are transmitted to the payloads attached to the flight decks of the vehicle. Launch loads experienced include static loads, vibration loads, acoustic loads and shocks and impose certain strict requirements on the structure of the satellite. Satellite structure should be able to withstand these loads during launch. All the components should be safe and working after the launch. The loading specification for which the launch vehicle interface is tested is assumed to be the loading data for the satellite during launch.

### 2.2.1 Static Loading

Static loading occurs on the satellite during launch as a result of the accelerations experienced during flight. The static loads that are used for testing verify the design and ensure that structure meets the safety margins are as listed in Table 2.1.

| **Direction** | **Loading** |
|---|---|
| Longitudinal | 3.5g Tensile, 7g Compressive |
| Lateral | 6g Tensile/ Compressive |

Table 2.1: Static Loading

Lateral loads are considered to act simultaneously with longitudinal loads. All loads apply at every element of the satellite as body forces.

### 2.2.2 Harmonic Loading

The levels defined for qualification and acceptance in the sinusoidal vibration sweep test are as given in table 2.2. The satellite is tested in conjunction with its launch interface on the shaker table. Here, the 'Qualification level' is used to prove that the structure can withstand loads, which are a factor greater than the expected flight limit loads (qualification loads), while the 'Acceptance level' is used to discover production deviations, not discovered during inspection. The applied loads are equivalent to the flight limit loads.

| | **Frequency range(Hz)** | **Qualification level** | **Acceptance level** |
|---|---|---|---|
| Longitudinal axis | (i)5-8 | 34.5 mm(DA) | 23 mm (DA) |
| | (ii) 10-100 | 4.5g | 3g |
| Lateral axis | (i)5-8 | 34.5 mm(DA) | 23 mm(DA) |
| | (ii) 8-100 | 3g | 2g |
| Sweep rate | | 2 oct/min | 4 oct/min |

Table 2.2: Sine sweep tests for qualification

These levels are defined at the interface of the satellite with the deployer. The test is to be carried out along all three axes of the satellite, on the flight model.

### 2.2.3 Random Loading

The conditions for testing for random and acoustic vibrations are the same as that of sinusoidal vibration testing. The test levels for Random and Acoustic vibrations are given in Table 2.3 and in Table 2.4. The Shock SRS levels are given in Table 2.5

| | **Qualification** | **Acceptance** |
|---|---|---|
| **Frequency(Hz)** | **PSD($g^2$/Hz)** | **PSD ($g^2$/Hz)** |
| 20 | 0.002 | 0.001 |
| 110 | 0.002 | 0.001 |
| 250 | 0.034 | 0.015 |
| 1000 | 0.034 | 0.015 |
| 2000 | 0.009 | 0.004 |
| g RMS | 6.7 | 4.47 |
| Duration | 2 min/axis | 1 min/axis |

Table 2.3: Random vibration test levels

| **Octave Band center Frequency (Hz)** | **Sound pressure level in dB** | |
|---|---|---|
| | **Qualification levels** | **Acceptance levels** |
| 31.5 | 128 | 124 |
| 63 | 130.5 | 126.5 |
| 125 | 134 | 130 |
| 250 | 140 | 136 |
| 500 | 144 | 140 |
| 1000 | 139 | 135 |
| 2000 | 132 | 128 |
| 4000 | 129 | 125 |
| 8000 | 126 | 122 |
| Overall level in dB | 147 | 143 |
| Duration | 2 minutes | 1 minute |

Table 2.4: Acoustic levels

| **Frequency(Hz)** | $\mathbf{g}_{peak}$ |
|---|---|
| 100 | 20g |
| 1000 | 1000g |
| 5000 | 1000g |

Table 2.5: Shock SRS levels

According to the instructions given by Dr. Muralidhar the shock and acoustic loads would not have a considerable influence on the structure

## 2.3 Stiffness Requirements

The requirements for stiffness of the satellite are such that there should be no component onboard the satellite which is free to vibrate at a natural frequency below the specified limits. This implies that all extended structures must thus comply with the stiffness requirements, as well as the structure as a whole.

| | |
|---|---|
| Global fundamental frequency in longitudinal mode | >90Hz |
| Global fundamental frequency in lateral mode | >45 Hz |

Table 2.6: Stiffness requirements

# Chapter 3

# Configuation and Layout

The internal and external configuration of the satellite is shown in Figure 3.1 and Figure 3.2 respectively.

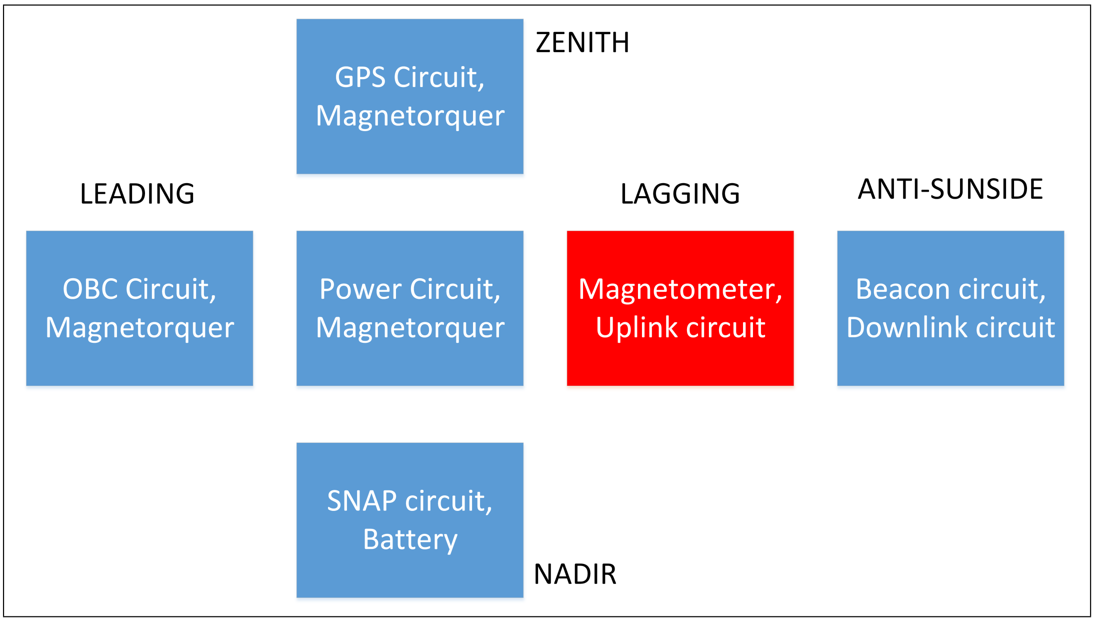



Figure 3.1: Internal Configuration Layout

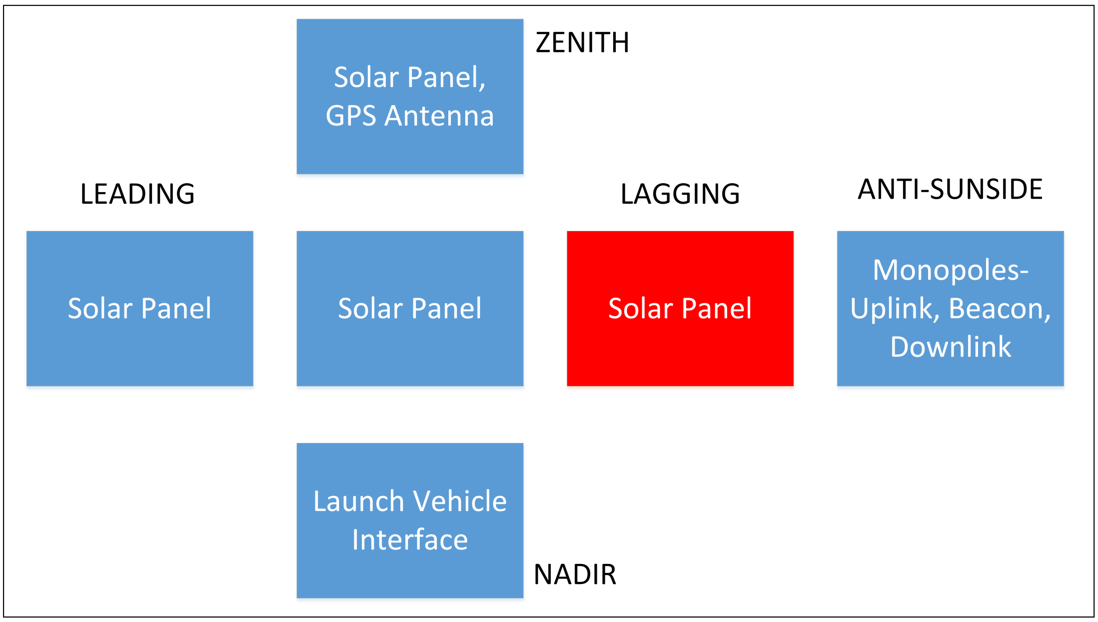



Figure 3.2: External Configuration Layout

The entire satellite structure was modeled in CAD software. The entire model is shown in Figure 3.3 and the inside view is shown in Figures 3.4 and 3.5.

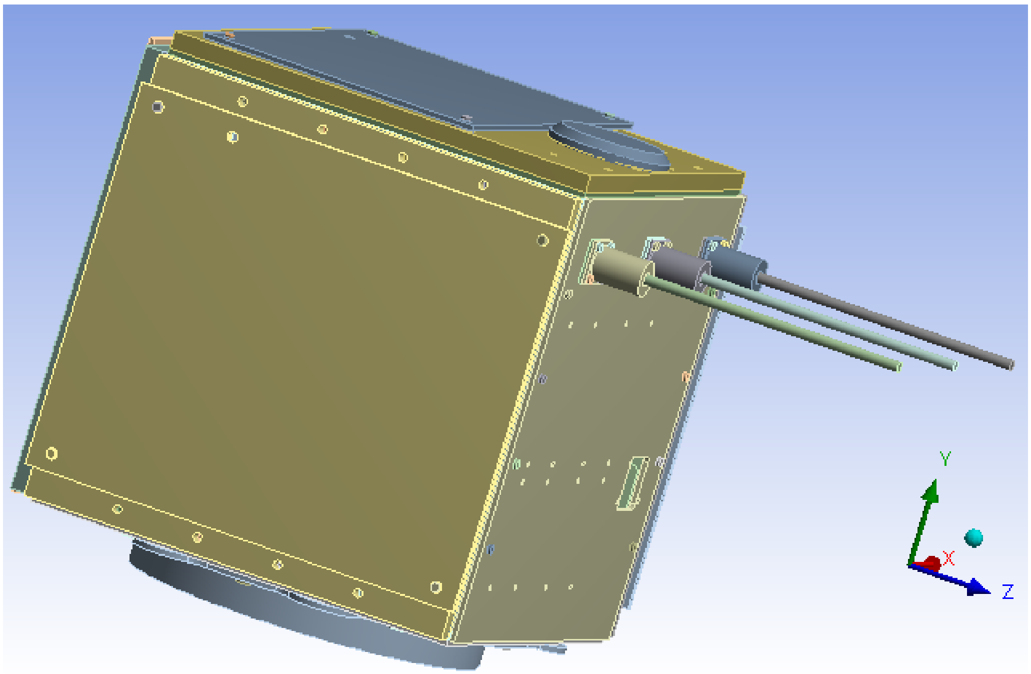



Figure 3.3: Satellite Model

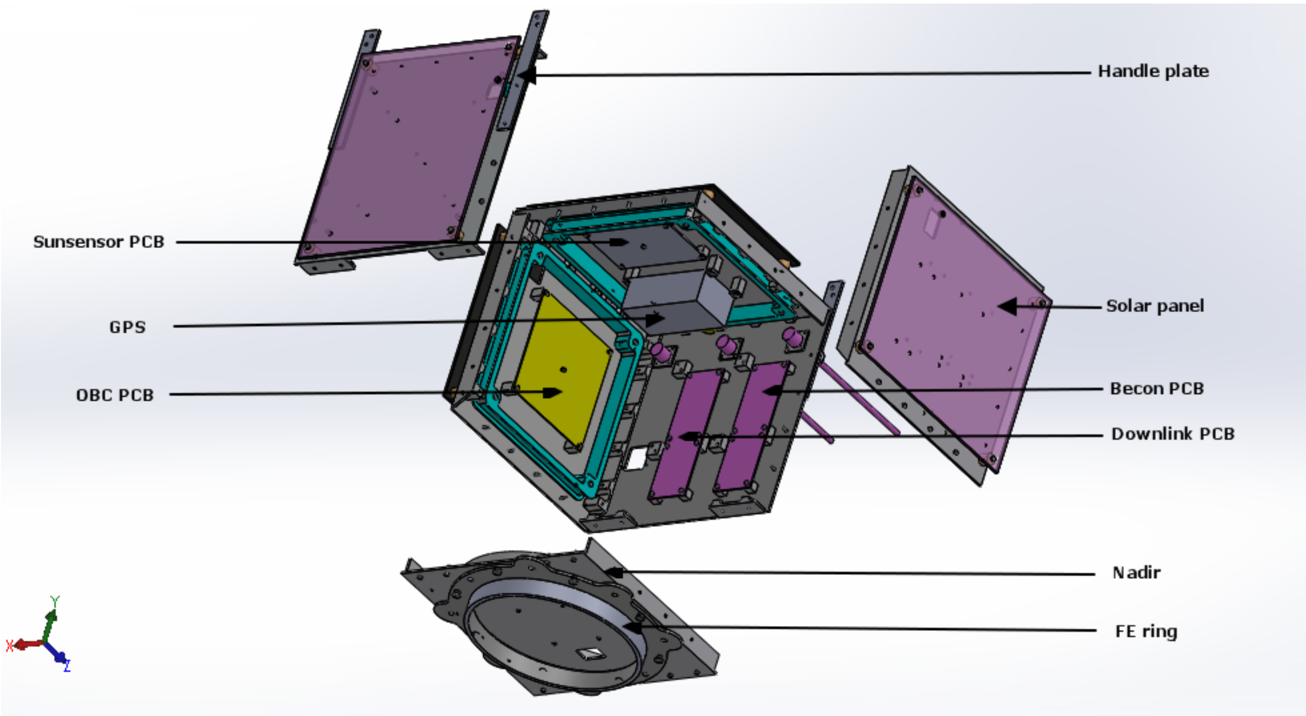



Figure 3.4: Satellite Model: Exploded View

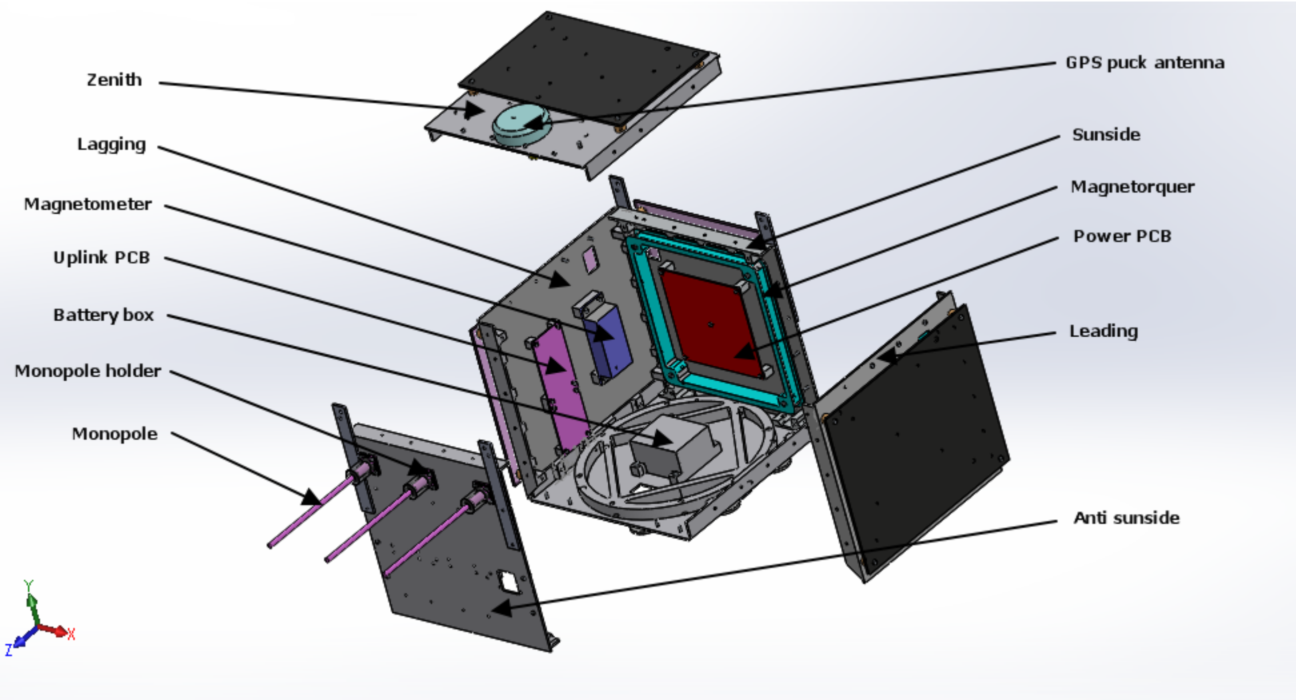
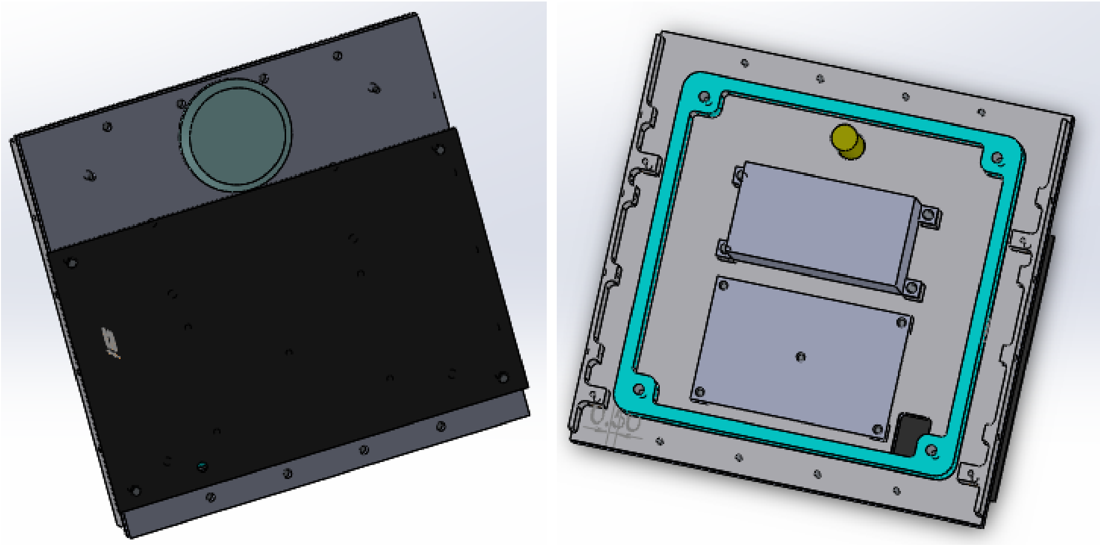



Figure 3.5: Satellite Model: Exploded View

## 3.1 Full Configuration Layout

### 3.1.1 Zenith

The zenith is the side of the satellite which always faces away from the earth. The Zenith side of Pratham incorporates one of the solar panels and the GPS antenna along with GPS circuit and a magnetorquer.

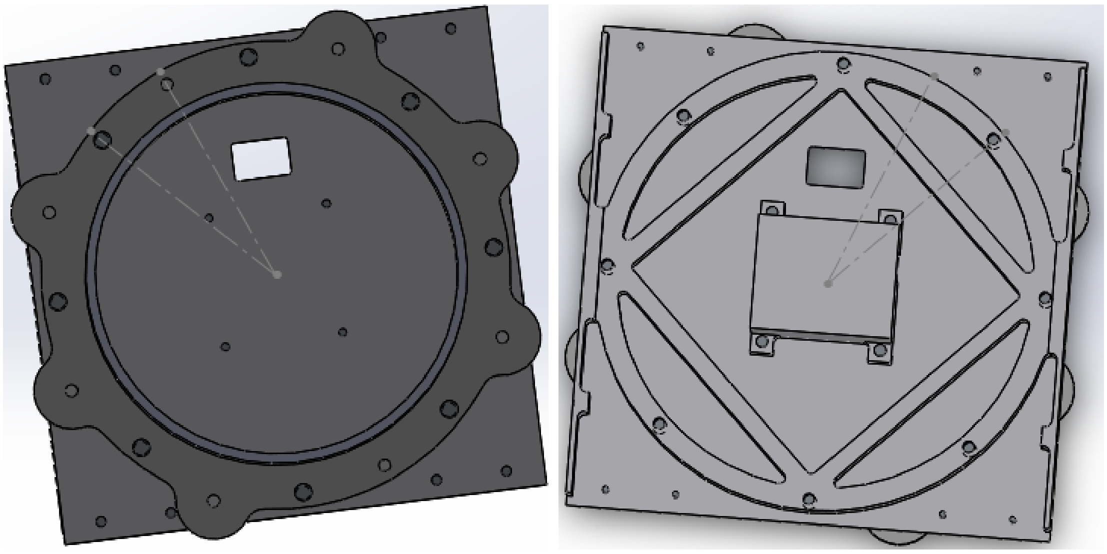


(a) Outer View (b) Inner View

Figure 3.6: Zenith

### 3.1.2 Nadir

The Nadir side always faces towards the earth. The Launch Vehicle interface which in our case is the IBL-230 V2 will be attached to Nadir side. It will also has a battery (battery pack and battery box)

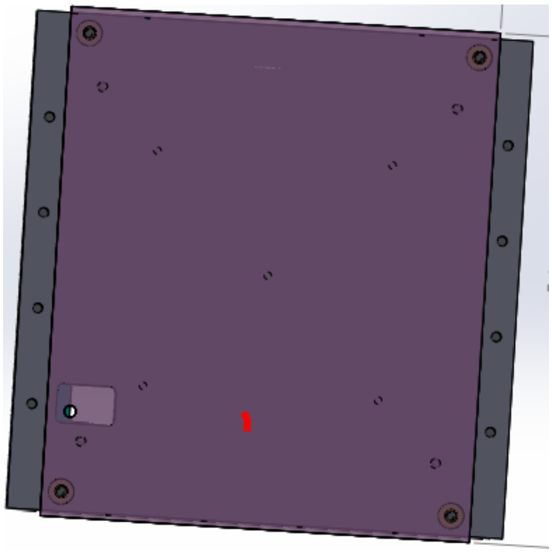


(a) Outer View (b) Inner View

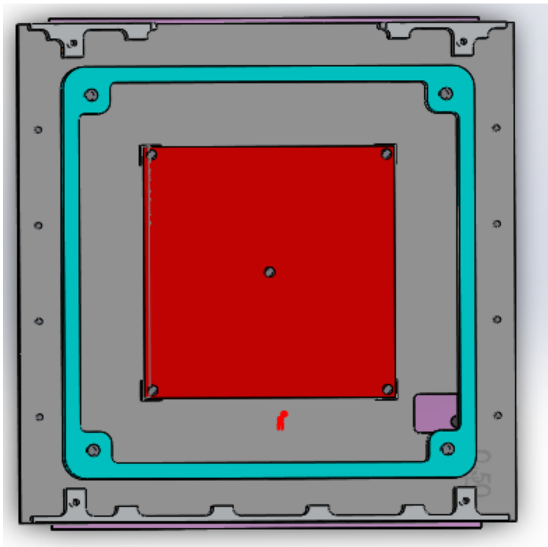
Figure 3.7: Nadir

### 3.1.3 Sun-side

As the name suggests, the sun-side faces the sun. Our sun-side has a solar panel mounted on it. From the inside, it has the power circuit and a magnetorquer.



(a) Outer View

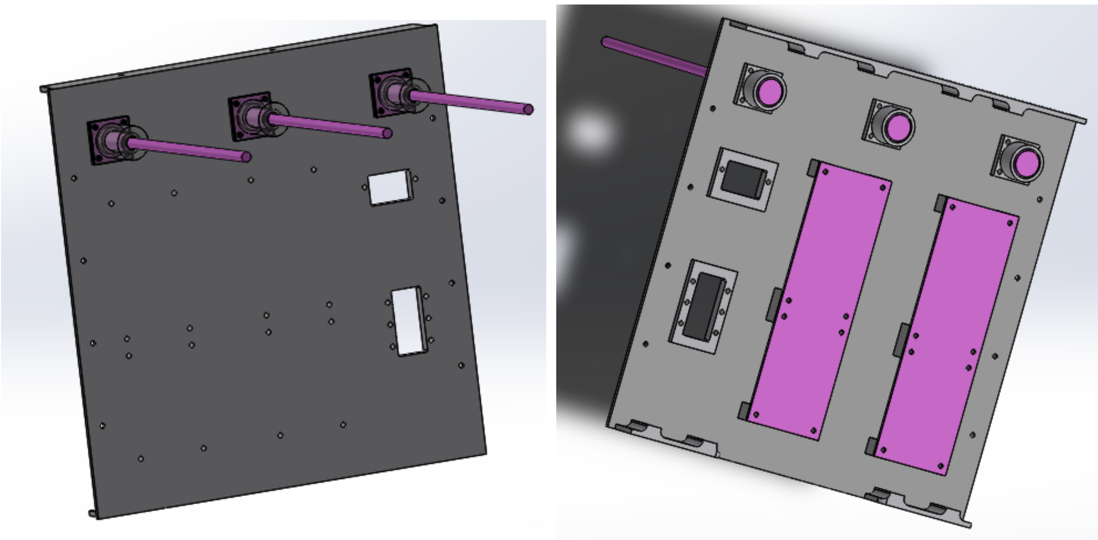


(b) Inner View

Figure 3.8: Sunside

### 3.1.4 Anti sun-side

It is the side opposite to the Sun-side. The monopoles are attached to the anti-sun side. It has the monopole circuit and the beacon circuit.



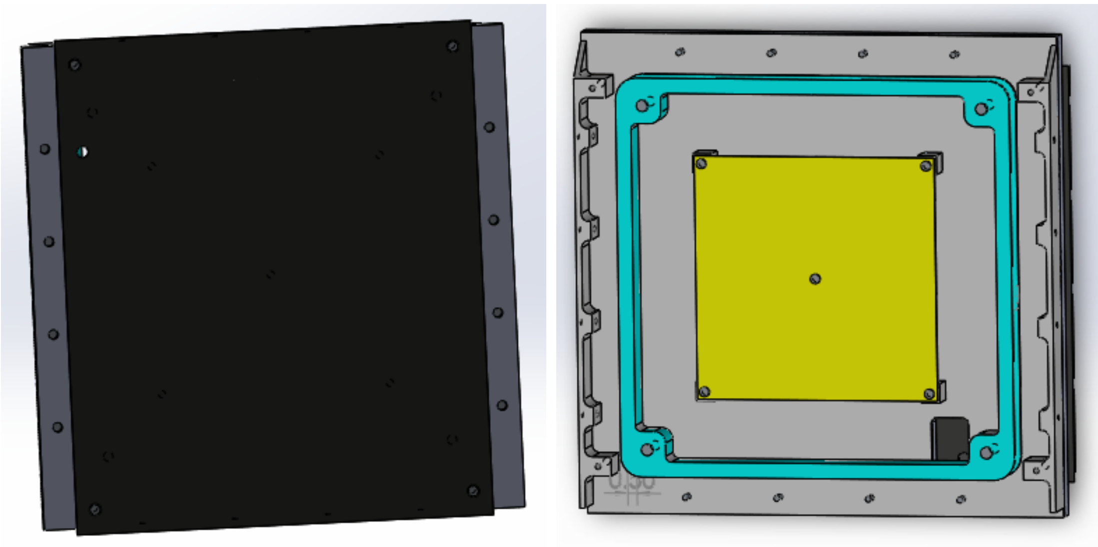
(a) Outer View

(b) Inner View

Figure 3.9: Anti-sunside

### 3.1.5 Leading side

The Leading side is normal to the direction of orbit of the satellite and has a solar panel mounted on it and has a magnetorquer and the OBC circuit.



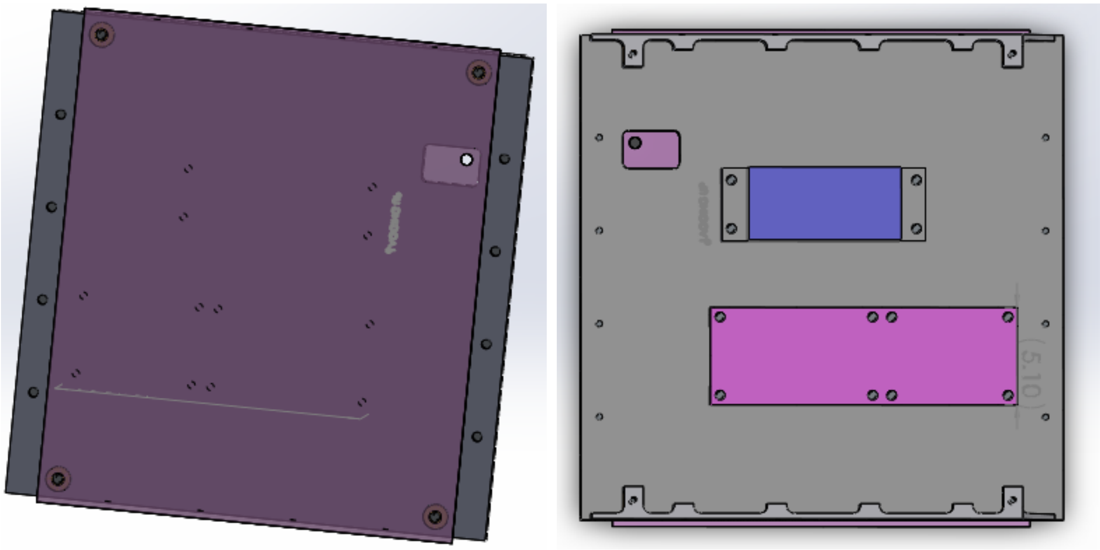
(a) Outer View

(b) Inner View

Figure 3.10: Leading

### 3.1.6 Lagging side

The Lagging side is opposite the leading side. It contains the magnetometer and a solar panel.



(a) Outer View (b) Inner View

Figure 3.11: Lagging side

# Chapter 4

# Analysis

## 4.1 Modeling

1. The entire satellite structure, including the body, panels and other components on-board, was modeled using CAD software.

2. The joints were modeled using the “mate” function. In this model, the contact were assumed only at the position of screws, but in actual case some portion around the screws is also coupled. This model provides a worst case representation of the structure.

3. Only the boards of the PCBs were modeled. The components on the PCBs were not modeled. The density of boards were changed to compensate for the mass

4. The co-ordinate system used in the analysis is the Cartesian co-ordinate system with origin at the base of the Nadir of the satellite. The longitudinal axis used for this analysis is along Y axis (axis joining Nadir and Zenith). X axis is from Lagging to Leading sides. Z axis is from Sun-side to Anti Sun-side

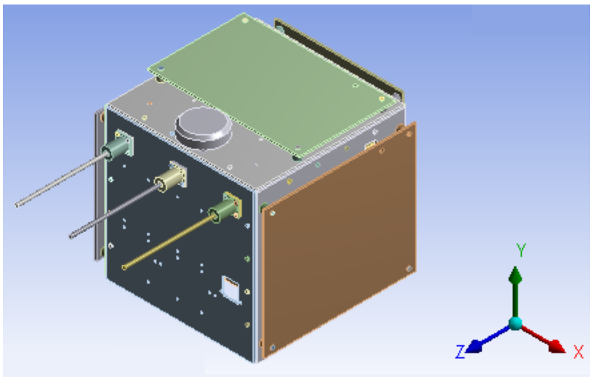



Figure 4.1: Satellite model in ANSYS

The types of Contacts and Joints used in simulating the loads are as follows

1. **Bonded Contacts:** - All degrees of freedom are constrained.

2. **Fixed Joint** - All degrees of freedom are constrained. But the bodies that are constrained needn't be in contact

Ansys has a Trim Tolerance of 1.16 mm i.e if any two surfaces are less than 1.16 mm apart then Ansys defines a contact between the two surfaces. By default Ansys treats all the contacts as Bonded.

## 4.2 Simulations and results

All simulations have been done on the following model-

1. In this model all the contacts were suppressed except those between GPS puck antenna and zenith and between battery pack and battery box.
2. All the screws were suppressed and the corresponding screw holes were joined by "Fixed Joint"
3. The remaining contacts have been suppressed.

Presented in the subsequent sections are the simulations and results of each of the above models

## 4.3 Static analysis

1. **Aim of analysis**: To determine the stress developed when a static load is applied.
2. **Type of analysis**: Static
3. **Material properties**: As given in section 8.1
4. **Constraints applied**: The FE ring, attached to the base of the Nadir was constrained for movement in all directions. All the screw joints are rigidly linked.
5. **Loads applied**: The loads as specified in table 2.1 were applied in different combinations on the model. The results are presented in tables 4.1, 4.3,

Top two values of stress at particular component is highlighted in the table below

| Sl. No. | Material | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Al 6061 T6 | | | | | | | |
| | Side Panel | | FE Ring | | Magnetorquer | | Monopole+Holder | |
| | Max Eq. Stress (MPa) | FOS | Max Eq. Stress (MPa) | FOS | Max Eq. Stress (MPa) | FOS | Max Eq. Stress | FOS |
| 1 | 15.925 | 17.331 | **55.179** | 5.002 | 0.788 | 350.298 | **5.939** | 46.474 |
| 2 | 17.651 | 15.637 | 48.739 | 5.663 | 0.797 | 346.386 | 5.805 | 47.544 |
| 3 | 11.114 | 24.834 | 38.153 | 7.234 | 0.517 | 533.436 | 4.199 | 65.733 |
| 4 | 10.530 | 26.211 | 42.806 | 6.448 | 0.511 | 540.012 | 4.332 | 63.712 |
| 5 | 34.547 | 7.989 | 32.689 | 8.443 | 0.647 | 426.782 | 4.004 | 68.933 |
| 6 | 41.189 | 6.701 | 31.789 | 8.682 | 0.588 | 469.627 | 3.932 | 70.193 |
| 7 | 41.189 | 6.701 | 31.789 | 8.682 | 0.588 | 469.627 | 3.932 | 70.193 |
| 8 | 34.547 | 7.989 | 32.689 | 8.443 | 0.647 | 426.782 | 4.004 | 68.933 |
| 9 | 46.846 | 5.892 | 27.230 | 10.136 | 0.845 | 326.666 | 4.191 | 65.857 |
| 10 | **49.066** | 5.625 | 28.795 | 9.585 | **0.969** | 284.756 | 4.259 | 64.805 |
| 11 | 41.522 | 6.647 | 41.522 | 6.647 | 0.711 | 387.918 | 2.147 | 128.575 |
| 12 | 41.568 | 6.640 | 21.938 | 12.581 | 0.587 | 470.027 | 2.107 | 130.979 |
| 13 | 42.383 | 6.512 | 55.518 | 4.971 | 0.976 | 282.816 | 5.903 | 46.758 |
| 14 | 49.145 | 5.616 | **55.914** | 4.936 | 1.158 | 238.404 | **5.975** | 46.192 |
| 15 | **51.768** | 5.331 | 52.589 | 5.248 | 0.779 | 354.300 | 5.679 | 48.597 |
| 16 | 49.544 | 5.571 | 49.462 | 5.580 | **1.206** | 228.856 | 5.841 | 47.253 |
| 17 | 42.037 | 6.566 | 39.403 | 7.005 | 0.926 | 297.960 | 4.233 | 65.200 |
| 18 | 46.478 | 5.938 | 42.142 | 6.549 | 0.629 | 439.001 | 4.198 | 65.742 |
| 19 | 41.664 | 6.624 | 43.670 | 6.320 | 0.881 | 313.458 | 4.368 | 63.182 |
| 20 | 38.137 | 7.237 | 43.323 | 6.371 | 0.867 | 318.523 | 4.296 | 64.247 |

Table 4.1: Static Simulation Results

| **Sl. No.** | **Material** | | | | |
|---|---|---|---|---|---|
| | **Al 6061-T6** | | **FR 04** | | **GFRP** |
| | **Solar Panel** | | **PCB** | | **Washer** |
| | **Max Eq. Stress (MPa)** | **FOS** | **Max Eq. Stress (MPa)** | **FOS** | **Max Eq. Stress (MPa)** |
| 1 | 30.448 | 9.065 | 7.087 | 17.639 | 0.005 |
| 2 | 30.202 | 9.138 | 6.975 | 17.921 | 0.005 |
| 3 | 30.257 | 9.122 | 6.833 | 18.294 | 0.004 |
| 4 | 30.379 | 9.085 | 6.846 | 18.260 | 0.004 |
| 5 | 35.156 | 7.851 | 7.339 | 17.033 | 0.004 |
| 6 | 37.415 | 7.377 | 7.343 | 17.023 | 0.004 |
| 7 | 37.415 | 7.377 | 7.343 | 17.023 | 0.004 |
| 8 | 35.156 | 7.851 | 7.339 | 17.033 | 0.004 |
| 9 | 31.831 | 8.671 | 6.962 | 17.956 | 0.005 |
| 10 | 40.744 | 6.774 | 7.588 | 16.474 | 0.005 |
| 11 | 38.506 | 7.168 | 7.316 | 17.087 | 0.004 |
| 12 | 34.048 | 8.106 | 6.805 | 18.369 | 0.004 |
| 13 | 32.228 | 8.564 | 7.107 | 17.589 | 0.005 |
| 14 | **41.903** | 6.587 | **7.890** | 15.842 | 0.005 |
| 15 | 32.950 | 8.376 | 6.975 | 17.922 | 0.005 |
| 16 | 39.606 | 6.969 | 7.851 | 15.921 | 0.005 |
| 17 | 37.378 | 7.384 | 7.595 | 16.458 | 0.005 |
| 18 | 35.179 | 7.846 | 7.069 | 17.682 | 0.005 |
| 19 | 39.656 | 6.960 | 7.617 | 16.412 | 0.005 |
| 20 | 32.944 | 8.378 | 7.082 | 17.649 | 0.005 |

| **Sl. No.** | **X (g)** | **Y (g)** | **Z (g)** |
|---|---|---|---|
| 1 | 6 | -7 | 0 |
| 2 | -6 | -7 | 0 |
| 3 | 6 | 3.5 | 0 |
| 4 | -6 | 3.5 | 0 |
| 5 | 6 | 0 | 6 |
| 6 | 6 | 0 | -6 |
| 7 | -6 | 0 | 6 |
| 8 | -6 | 0 | -6 |
| 9 | 0 | -7 | 6 |
| 10 | 0 | -7 | -6 |
| 11 | 0 | 3.5 | 6 |
| 12 | 0 | 3.5 | -6 |
| 13 | 6 | -7 | 6 |
| 14 | 6 | -7 | -6 |
| 15 | -6 | -7 | 6 |
| 16 | -6 | -7 | -6 |
| 17 | 6 | 3.5 | 6 |
| 18 | 6 | 3.5 | -6 |
| 19 | -6 | 3.5 | 6 |
| 20 | -6 | 3.5 | -6 |

Table 4.2: Simulation No. v/s Load

Note: The last 8 simulations corresponding to loads along all 3 axes are extreme case scenarios which hardly occur. But they have been included to show that, the satellite can sustain even these loads.

**Screenshots of Simulations:**

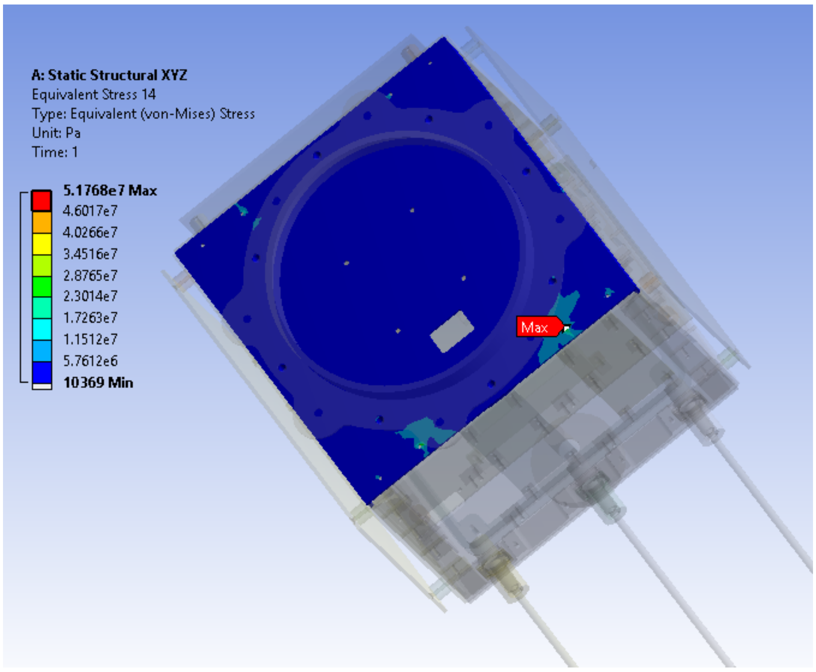



Figure 4.2: Max Eq. Stress on Nadir for loading -6g(X), -7g(Y), 6g(Z)

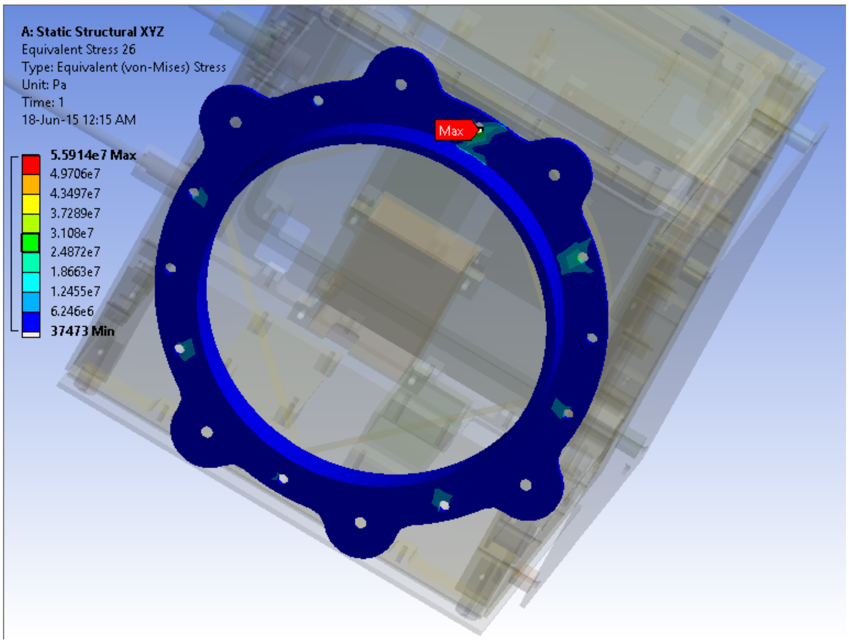



Figure 4.3: Max Eq. stress on FE Ring for loading 6g(X), -7g(Y), 6g(Z)

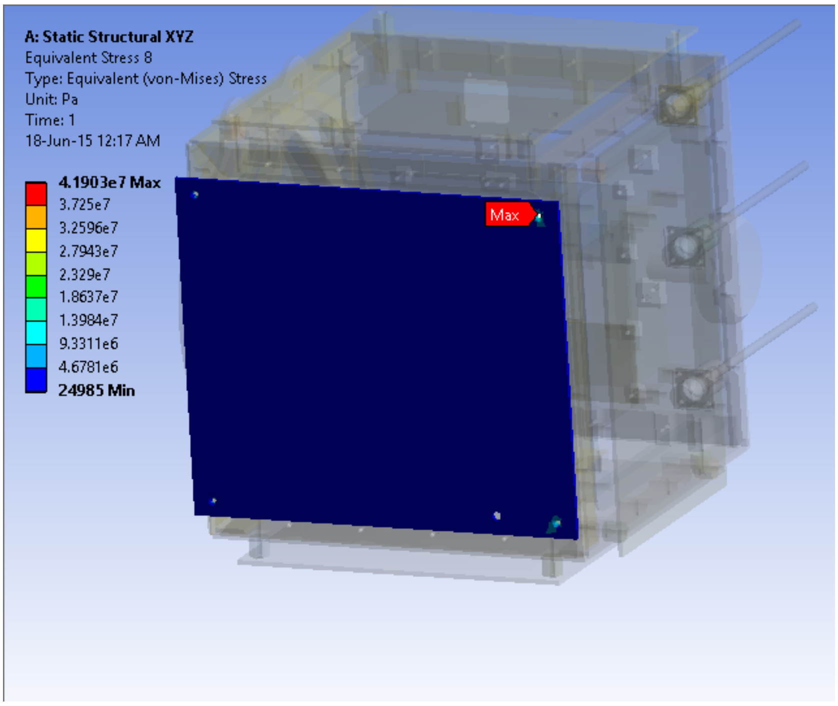



Figure 4.4: Max Eq. stress on Sunside Solar Panel for loading 6g(X), -7g(Y), -6g(Z)

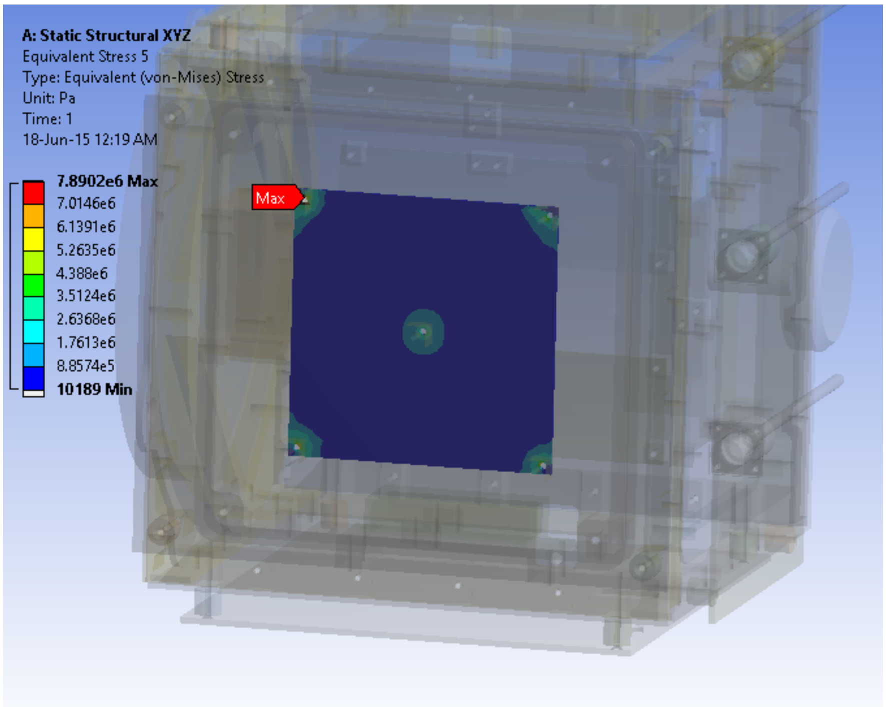



Figure 4.5: Max Eq. Stress on Power PCB for loading 6g(X), -7g(Y), -6g(Z)

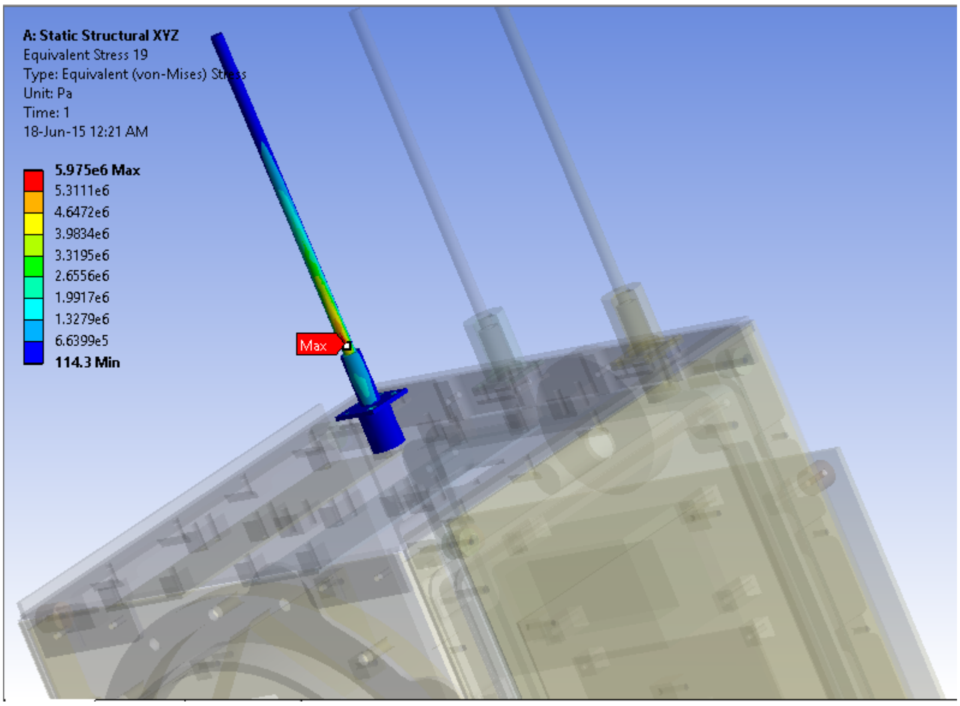



Figure 4.6: Max Eq. stress on Monopole for loading 6g(X), -7g(Y), -6g(Z)

**Interpretation of results:**

1. The maximum stress on the Side panels is 51.768 MPa (FOS: 5.3)
2. The maximum stress on the FE ring is 55.914 MPa (FOS: 4.9)
3. The maximum stress on the Solar Panel is 41.903 MPa (FOS: 6.5)
4. The maximum stress in the PCB is 7.890 MPa (FOS: 15.8)
5. The maximum stress on monopole is 5.975 MPa (FOS: 46.1)

The maximum stress-points observed in the simulation is located near the hole in majority of cases. Since washer is not taken into account in the simulation. Therefore we need to observe the stress outside the 6 mm diameter circle concentric to holes. Observed stress values in mentioned location is much less than the max stress value mentioned in the table.

**Conclusion:** Simulations for all possible worst case scenarios of static loading has been done. Stresses developed in these simulations are well within yield limit with high factor of safety. Stress values mentioned in above interpretation is of the simulation in which static load in all the directions are applied simultaneously. Since such case of loading is very unlikely during launch, therefore this design is safe for static loading.

## 4.4 Modal Analysis

Two kinds of Modal analysis have been done. One with heavy point mass attached on FE ring and other with constraining bottom of FE ring as fixed. The first kind of Modal analysis is used for Harmonic simulation. As suggested by Murali sir second kind of Modal simulation is the more accurate.

1. **Aim of analysis:** To determine the fundamental frequencies of the structure.
2. **Type of analysis:** Modal
3. **Material properties:** As given in section 8.1
4. **Constraints applied:** The FE ring, attached to the base of the Nadir was constrained for movement in all directions. All the screw joints are rigidly linked.
5. **Loads applied:** NIL
6. **No. of modes extracted:** 80

**Screenshots of Simulations:** The images given below is only useful to observe the mode shape. The given deformation values are not to the scale.

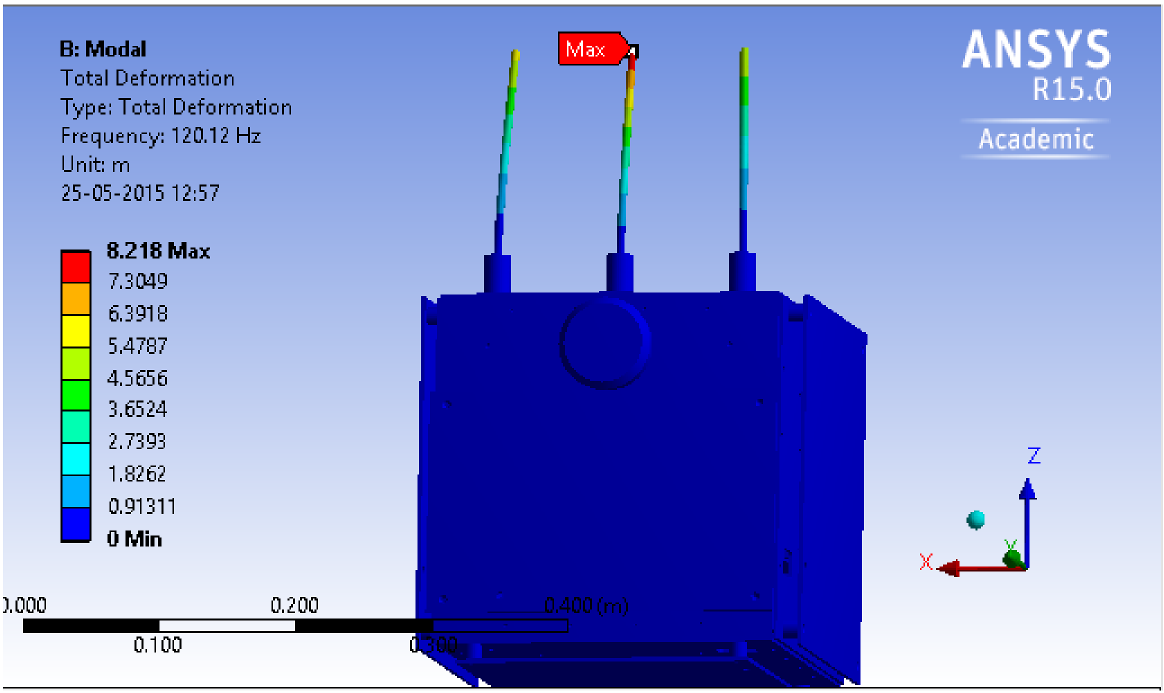



Figure 4.7: 1st mode of satellite (antenna mode)

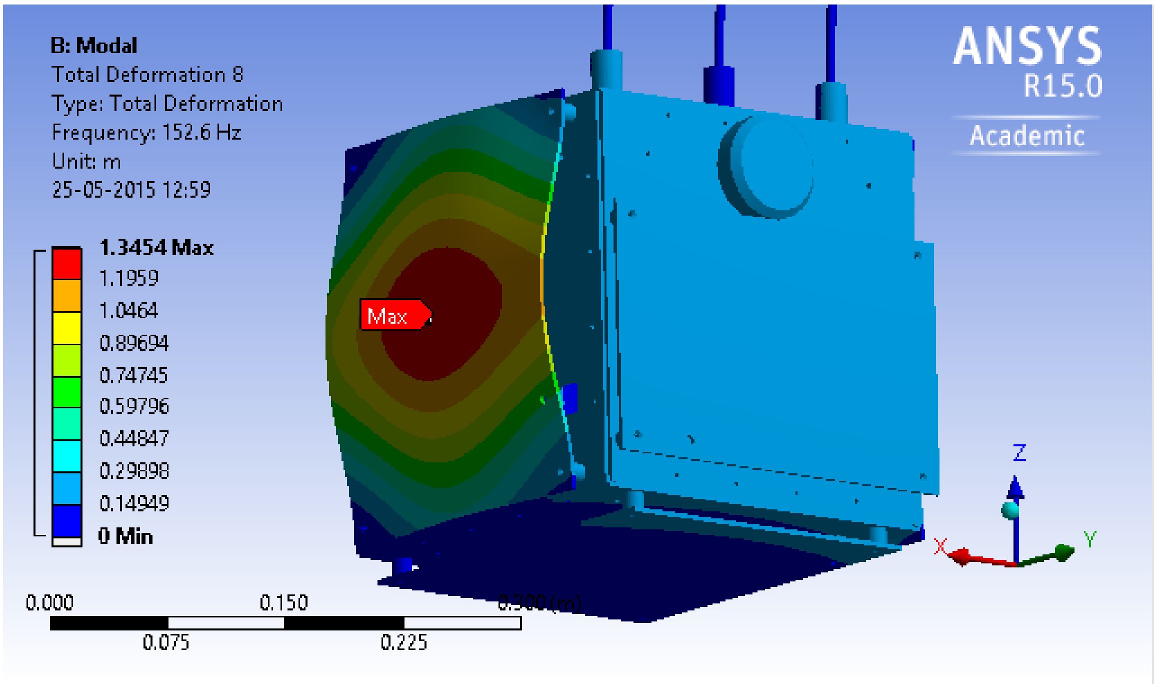



Figure 4.8: 7st mode of satellite (solar panel mode)

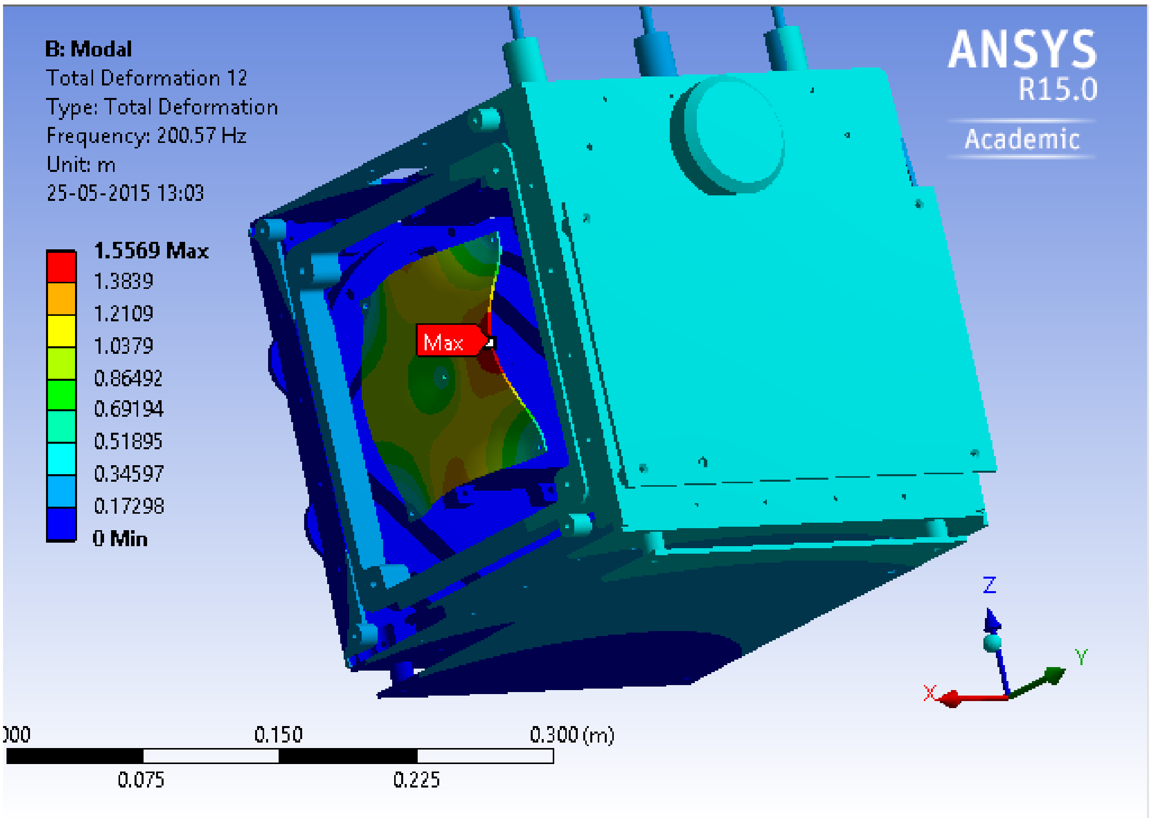



Figure 4.9: 11st mode of satellite (PCB mode)

| Mode | Frequency (Hz) | Mode | Frequency (Hz) |
|---|---|---|---|
| 1 | 120.12 | 41 | 493.56 |
| 2 | 123.86 | 42 | 497.81 |
| 3 | 124.9 | 43 | 499.29 |
| 4 | 126.28 | 44 | 509.21 |
| 5 | 126.53 | 45 | 521.85 |
| 6 | 127.22 | 46 | 557.13 |
| 7 | 129.78 | 47 | 564.19 |
| 8 | 152.6 | 48 | 575.28 |
| 9 | 160.47 | 49 | 581.01 |
| 10 | 166.91 | 50 | 583.07 |
| 11 | 187.99 | 51 | 583.39 |
| 12 | 200.57 | 52 | 590.06 |
| 13 | 231.5 | 53 | 593.74 |
| 14 | 239.01 | 54 | 598.37 |
| 15 | 251.83 | 55 | 604.87 |
| 16 | 252.35 | 56 | 608.45 |
| 17 | 253.02 | 57 | 610.07 |
| 18 | 254.09 | 58 | 618.42 |
| 19 | 266.58 | 59 | 634.32 |
| 20 | 267.6 | 60 | 636.06 |
| 21 | 277.72 | 61 | 640.93 |
| 22 | 280.48 | 62 | 656.12 |
| 23 | 280.57 | 63 | 663.5 |
| 24 | 283.08 | 64 | 666.74 |
| 25 | 308.24 | 65 | 677.56 |
| 26 | 319.61 | 66 | 682.67 |
| 27 | 321.92 | 67 | 688.04 |
| 28 | 327.61 | 68 | 697.66 |
| 29 | 330.5 | 69 | 708.06 |
| 30 | 338.19 | 70 | 710.09 |
| 31 | 356.14 | 71 | 720.61 |
| 32 | 357.04 | 72 | 724.08 |
| 33 | 357.05 | 73 | 733.08 |
| 34 | 402.15 | 74 | 735.37 |
| 35 | 423.66 | 75 | 737.08 |
| 36 | 442.04 | 76 | 742.92 |
| 37 | 444.58 | 77 | 752.15 |
| 38 | 457.55 | 78 | 755.48 |
| 39 | 462.14 | 79 | 757.1 |
| 40 | 490.37 | 80 | 776.42 |

Table 4.3: Result of Modal Analysis: Fixed FE Ring

| **Mode** | **Frequency [Hz]** | **Mode** | **Frequency [ Hz]** |
|---|---|---|---|
| 1 | 0 | 41 | 423.63 |
| 2 | 9.35E-08 | 42 | 440.04 |
| 3 | 3.52E-07 | 43 | 444.31 |
| 4 | 9.33E-04 | 44 | 456.51 |
| 5 | 9.36E-04 | 45 | 457.48 |
| 6 | 1.05E-03 | 46 | 490.08 |
| 7 | 121.50 | 47 | 493.32 |
| 8 | 122.73 | 48 | 497.79 |
| 9 | 124.87 | 49 | 499.24 |
| 10 | 126.25 | 50 | 508.87 |
| 11 | 126.42 | 51 | 521.81 |
| 12 | 127.05 | 52 | 556.97 |
| 13 | 128.39 | 53 | 564 |
| 14 | 146.36 | 54 | 574.97 |
| 15 | 160.47 | 55 | 580.82 |
| 16 | 166.18 | 56 | 582.99 |
| 17 | 186.22 | 57 | 583.28 |
| 18 | 186.64 | 58 | 589.86 |
| 19 | 230.9 | 59 | 592.67 |
| 20 | 236.57 | 60 | 593.79 |
| 21 | 251.83 | 61 | 604.25 |
| 22 | 252.15 | 62 | 608.36 |
| 23 | 252.95 | 63 | 609.67 |
| 24 | 254.08 | 64 | 617.81 |
| 25 | 260.74 | 65 | 632.8 |
| 26 | 266.59 | 66 | 635.73 |
| 27 | 267.61 | 67 | 639.92 |
| 28 | 280.46 | 68 | 656.01 |
| 29 | 280.52 | 69 | 663.47 |
| 30 | 282.43 | 70 | 666.67 |
| 31 | 307.85 | 71 | 676.43 |
| 32 | 319.52 | 72 | 682.45 |
| 33 | 321.54 | 73 | 687.81 |
| 34 | 324.16 | 74 | 697.24 |
| 35 | 330.03 | 75 | 707.88 |
| 36 | 338.09 | 76 | 709.95 |
| 37 | 350.71 | 77 | 720.57 |
| 38 | 356.14 | 78 | 723.93 |
| 39 | 356.99 | 79 | 732.33 |
| 40 | 357.05 | 80 | 734.84 |

Table 4.4: Results of Modal Analysis: Remote Point

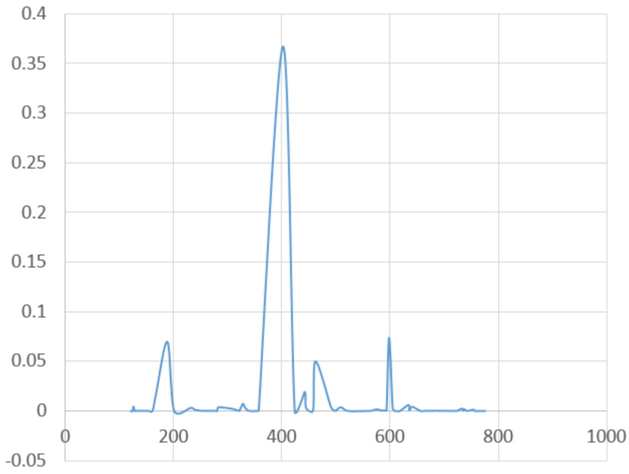



Figure 4.10: Effective Mass Participation Vs Frequency Response in X-direction

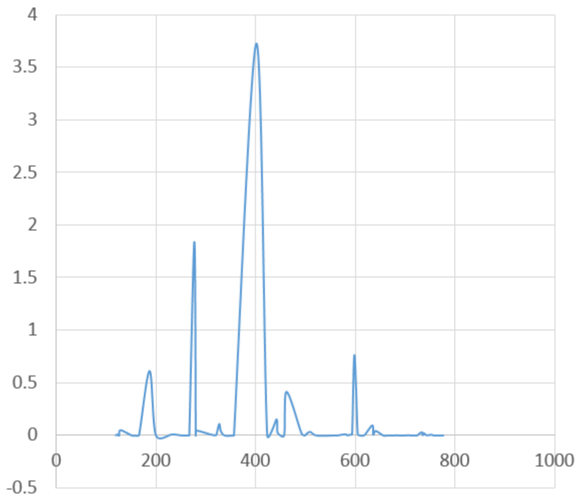



Figure 4.11: Effective Mass Participation Vs Frequency Response in Y-direction

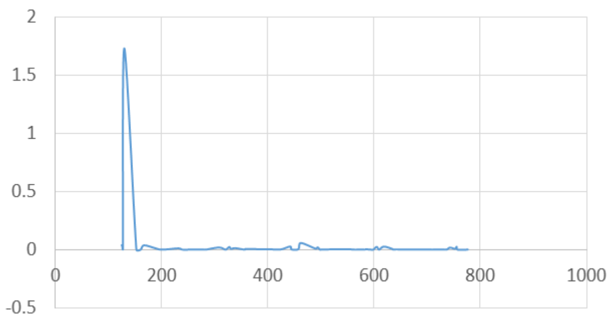



Figure 4.12: Effective Mass Participation Vs Frequency Response in Z-direction

**Interpretation:** Graphs plotted for modal frequency vs effective mass participated in all three direction. The peak in the graphs show the different modal frequencies in separate directions.

1. 1st peak in the graph for X direction shows the global mode for X direction is around **150 Hz**.
2. 1st peak in the graph for Y direction shows the global mode for Y direction is around **120 Hz**.
3. 1st peak in the graph for Z direction shows the global mode for Z direction is around **180 Hz**.

Modal analysis is done for 80 modes and mass participation for different direction is given in the table below

| **Direction** | **Mass Participation (%)** |
|---|---|
| X | 86.02 |
| Y | 94.50 |
| Z | 87.10 |

Table 4.5: Mass Participation for Modal Analysis of first kind

Mass participation table for X, Y and Z are given in the appendix.

**Interpretation of results:**

1. Modal analysis of first kind
   (a) The $1^{st}$ mode of the satellite is 120.12 Hz.
   (b) 1-6 modes are antenna modes.
   (c) The $1^{st}$ Solar Panel mode is the $7^{th}$ mode of satellite i.e 160.64 Hz.
   (d) The modes of the PCBs start from the $11^{th}$ mode of the satellite i.e 229.83 Hz.
   (e) No dominant side modes within the first 34 modes of the satellite(440.04 Hz).
2. Modal analysis of second kind
   (a) $1^{st}$ six modes are rigid body mode. Therefore, they are approximately zero.
   (b) This result will be used for Harmonic Analysis because it helps us to analyze more actual scenario by assuming PSLV as point mass.
   (c) Mass Participation values for this kind is not valid, since first six modes are rigid body mode.

**Conclusion:** There is no satellite mode below 90 Hz as required according to PSLV manual. First mode of the satellite should be antenna mode, which can be easily verified as the monopoles are the only part of satellite similar to cantilever. Solar panels, PCBs and satellite sides are like plate. Solar panels and PCBs are connected at four corners by screws whereas satellite sides are connected by flanges. So, Solar panels and PCBs have lower mode than satellite sides, but higher than antenna.

## 4.5 Harmonic Response

Harmonic Simulation is done separately for three directions and also for combined loading taken two directions at a time.

1. **Aim of analysis:** To obtain the stress developed and frequency response of the structure when subjected to sinusoidal loads.
2. **Type of analysis:** Harmonic
3. **Material properties:** As given in section 8.1
4. **Constraints applied:** The base of the FE ring is rigidly attached to a heavy point mass of $10^8$ kg.
5. **Loads applied:** The harmonic loads are taken from the PSLV manual. To simulate the base acceleration part, a heavy point mass was rigidly attached to the base of the FE ring and a remote force was applied on the point mass that gives the required acceleration

| Sl. No. | Material | Component Type | Component | X= 3g, Y= 0, Z= 0 | X= 0, Y= 4.5g, Z= 0 | X= 0, Y= 0, Z= 6g |
|---|---|---|---|---|---|---|
| | | | | Max (MPa) | Max (MPa) | Max (MPa) |
| 1 | | | Whole body | 12.728 | 24.004 | 12.989 |
| 2 | FR 04 | PCBs | Downlink | 0.1748 | 0.95811 | 0.9978 |
| 3 | | | Beacon | 0.1183 | 0.891 | 0.9145 |
| 4 | | | Uplink | 0.8162 | 0.6956 | 0.1957 |
| 5 | | | Power | 0.3504 | 0.6788 | 2.3263 |
| 6 | | | OBC | 2.2285 | 0.6971 | 0.4227 |
| 7 | | | Sunsensor Board | 0.1697 | 2.5041 | 0.7414 |
| 8 | Al 6061-T6 | Solar Panel | Solar Panel Sunside | 0.3848 | 6.5617 | 12.989 |
| 9 | | | Solar Panel Lagging | 12.728 | 1.7201 | 1.0338 |
| 10 | | | Solar Panel Leading | 11.311 | 1.7061 | 0.5479 |
| 11 | | | Solar Panel Zenith | 1.1918 | 24.004 | 2.4473 |
| 12 | | Side Panels | Sunside | 0.7674 | 5.526 | 1.2056 |
| 13 | | | Leading | 1.1017 | 7.0665 | 0.411 |
| 14 | | | Nadir | 0.4518 | 21.768 | 1.335 |
| 15 | | | Lagging | 1.428 | 6.1221 | 0.3327 |
| 16 | | | Antisunside | 0.7068 | 6.7205 | 1.857 |
| 17 | | | Zenith | 2.1166 | 5.431 | 2.4306 |
| 18 | | Monopole Holder | Outercover+ Antenna(leading 1st) | 2.0617 | 8.5901 | 5.3029 |
| 19 | | | Outercover+ Antenna(lagging 1st) | 2.0098 | 8.6115 | 5.1472 |
| 20 | | | Outer cover +Antennna( middle) | 0.7826 | 8.6474 | 6.0691 |
| 21 | | Battery | Battery Box | 0.2478 | 0.2033 | 0.22465 |
| 22 | | Torquer | Torquer sunside | 0.03028 | 0.4884 | 0.1002 |
| 23 | | | Torquer Leading | 0.0504 | 0.4859 | 0.0327 |
| 24 | | | Torquer Zenith | 0.0321 | 0.2528 | 0.03887 |
| 25 | | FE Ring | FE Ring | 0.1589 | 9.3578 | 0.21998 |
| 26 | GFRP | Washer | All washers | 0.000394 | 0.00261 | 0.000597 |

Table 4.6: Harmonic Simulation Results for Loads in Separate Direction

6. **Screenshots of simulation:**

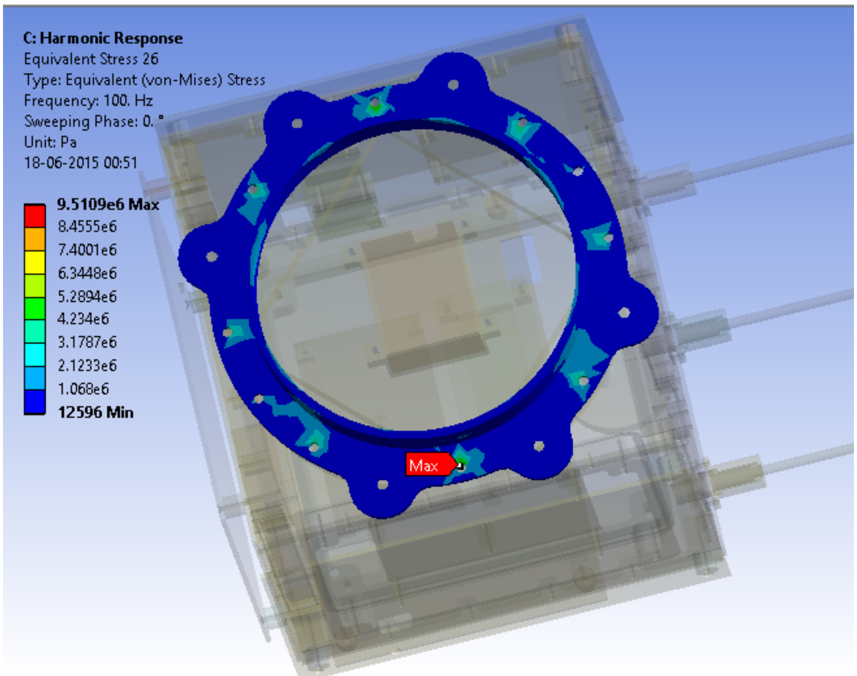



Figure 4.13: Max Eq. Stress: FE Ring (Combined X, Y Harmonic)

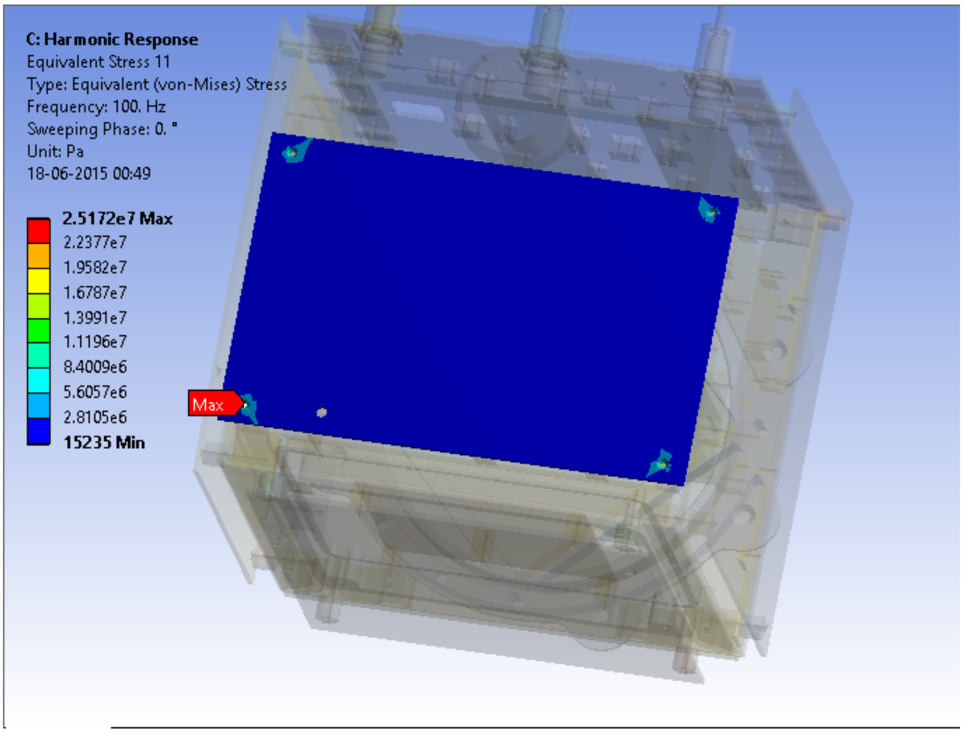



Figure 4.14: Max Eq. Stress: Zenith Solar Panel (Combined X, Y Harmonic)

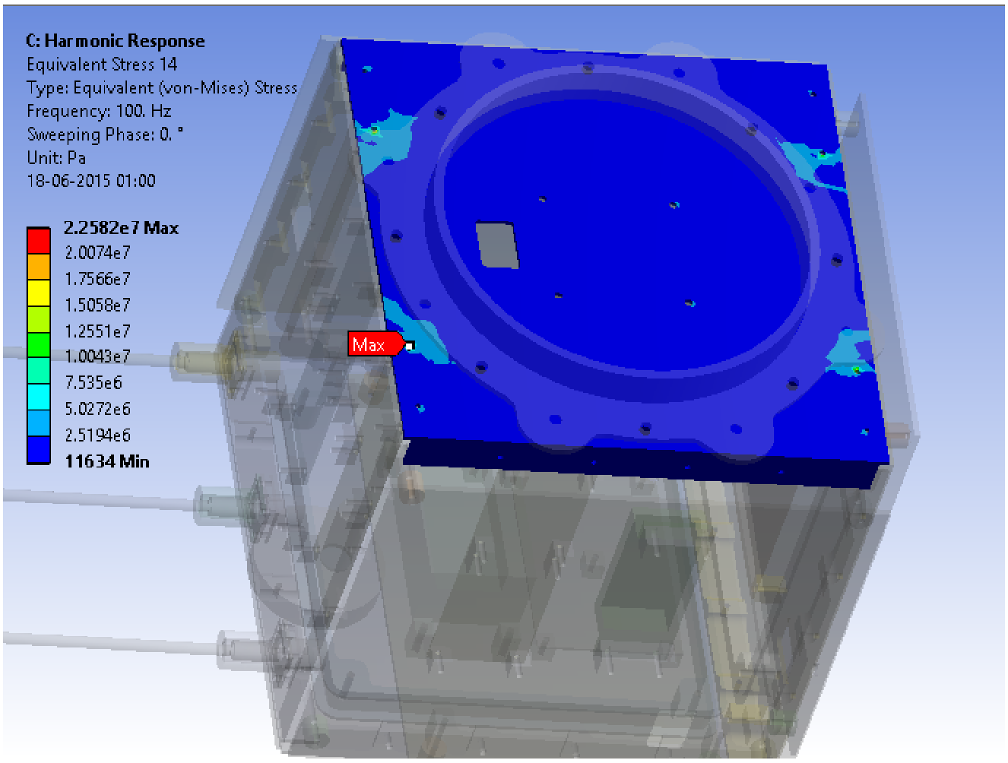



Figure 4.15: Max Eq. Stress: Nadir Side Panel (Combined Y, Z Harmonic)

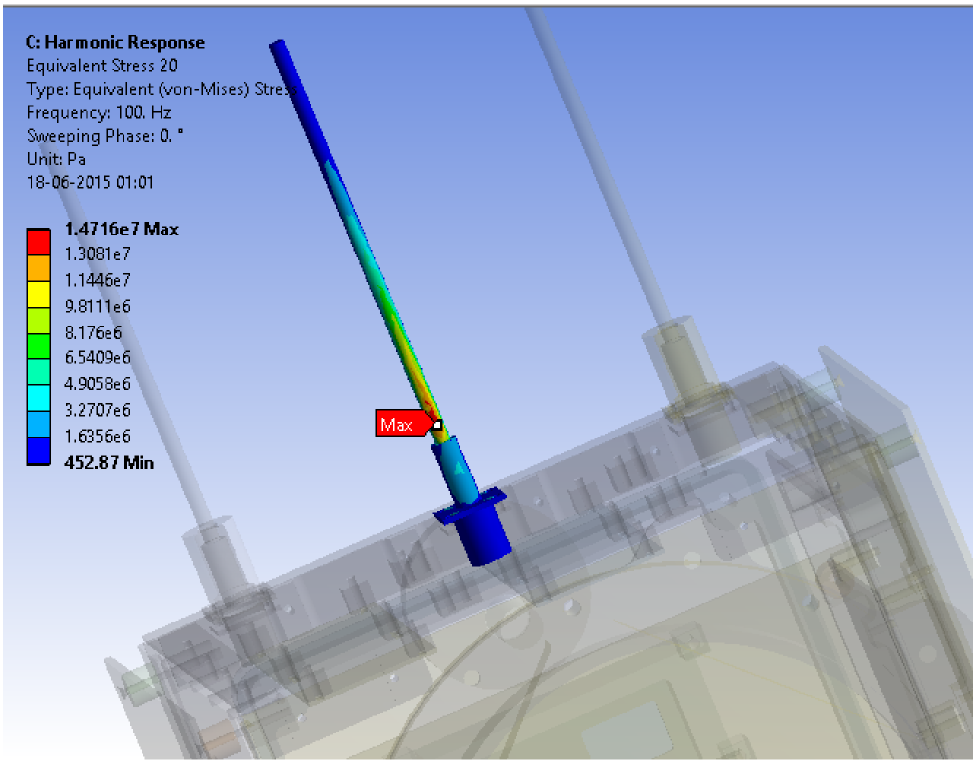



Figure 4.16: Max Eq. Stress: Middle Antenna (Combined Y, Z Harmonic)

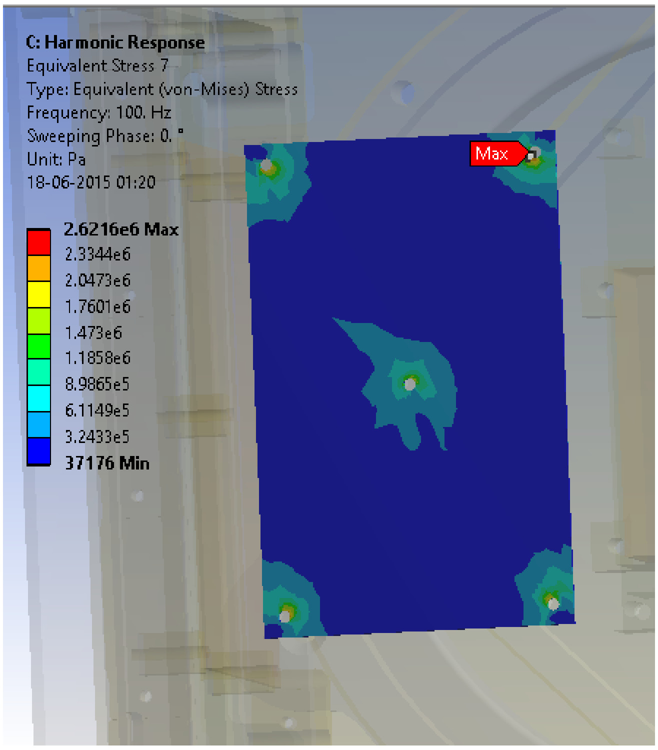



Figure 4.17: Max Eq. Stress: Sunsensor Board (Combined X, Y Harmonic)

**Frequency Response at different locations and its direction:**

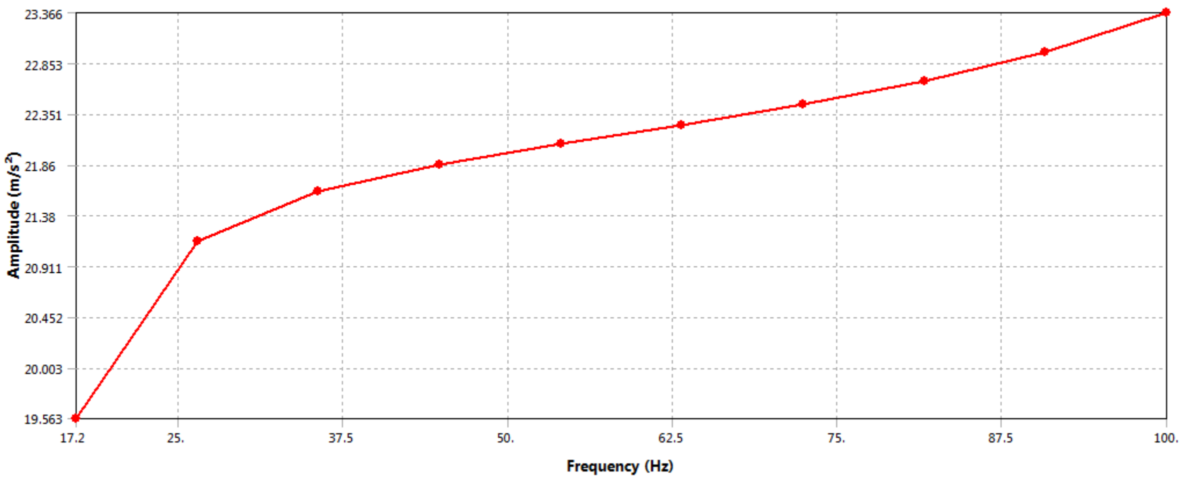



Figure 4.18: Bottom of Anti-sunside in Z-direction

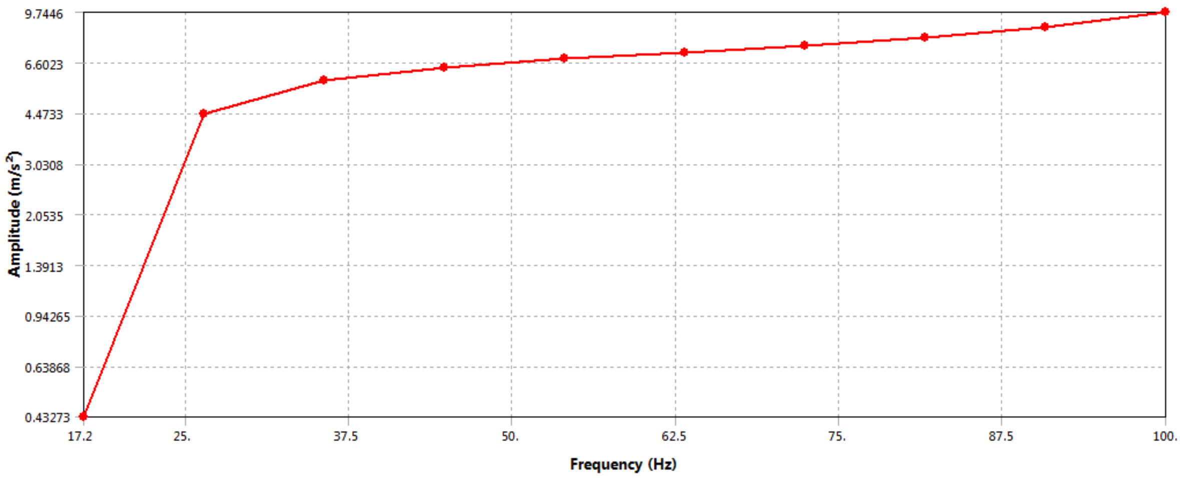



Figure 4.19: Top of Anti-sunside in Z-direction

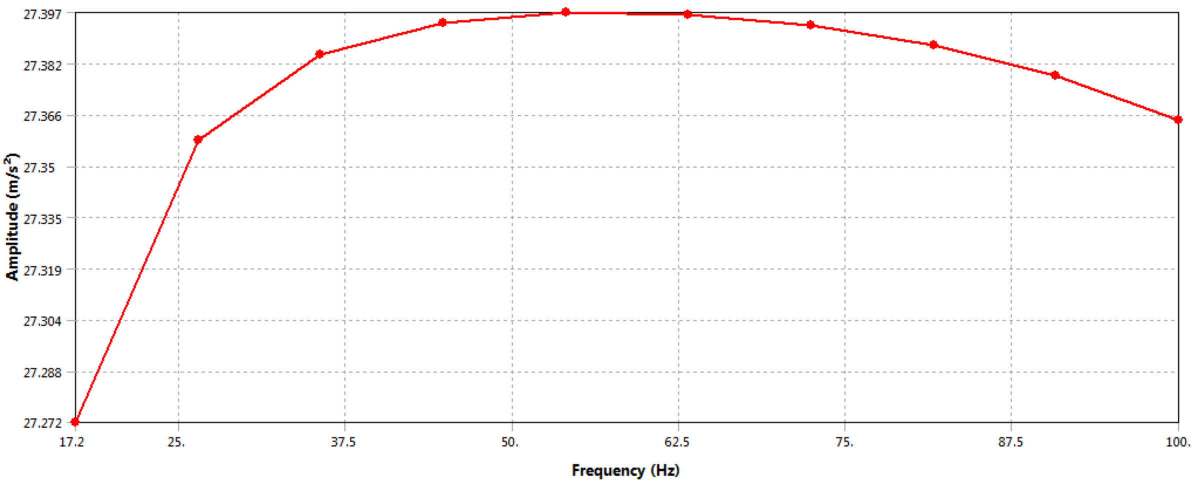



Figure 4.20: On Fixture near Leding Side in X-direction

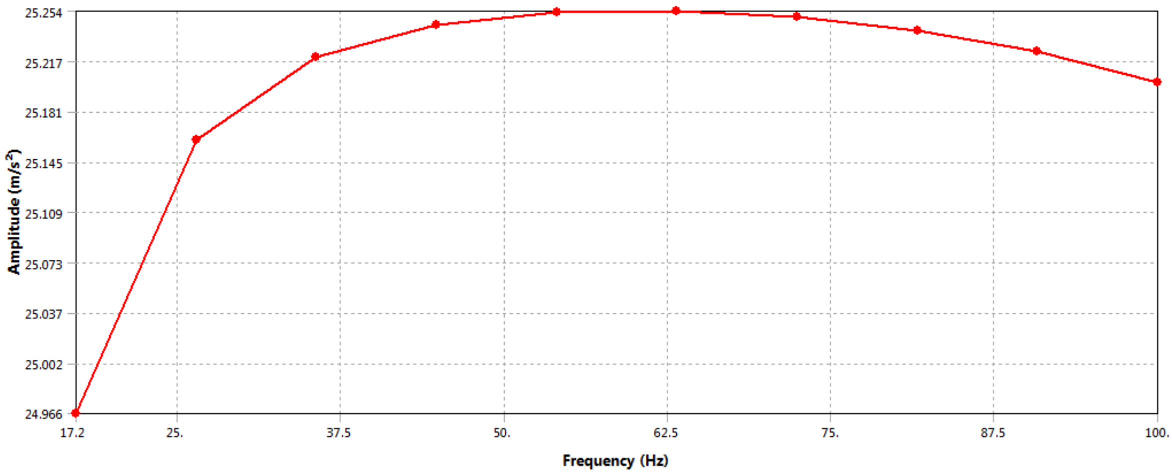



Figure 4.21: Bottom of Leading Side in X-direction

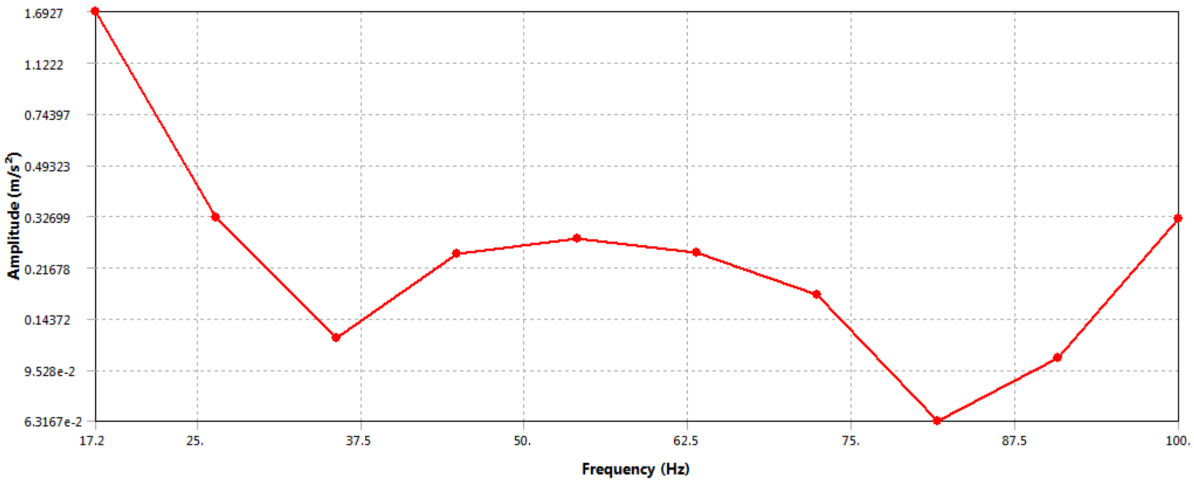



Figure 4.22: Top of Leading Side in X-direction

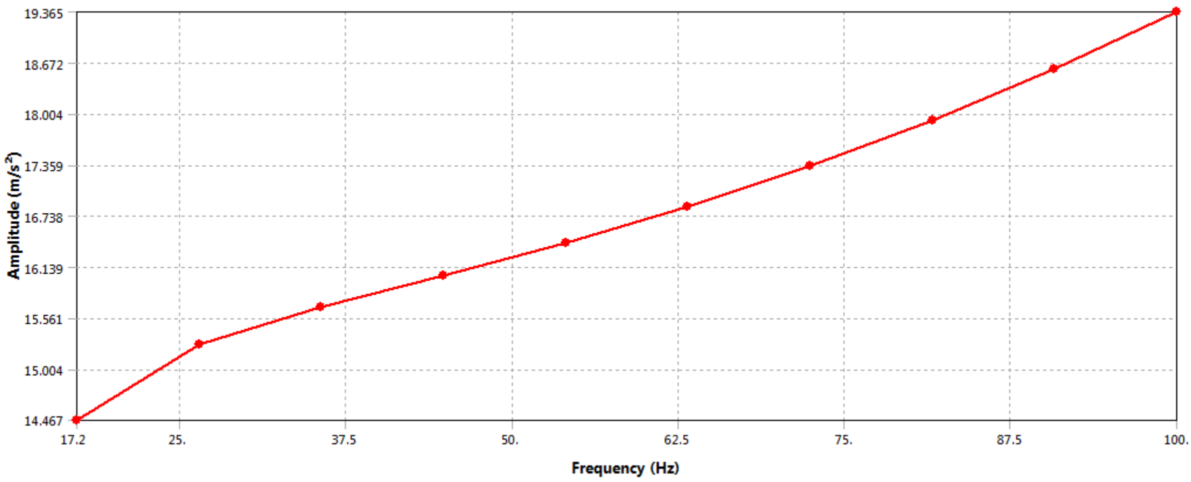



Figure 4.23: OBC Board in X-direction

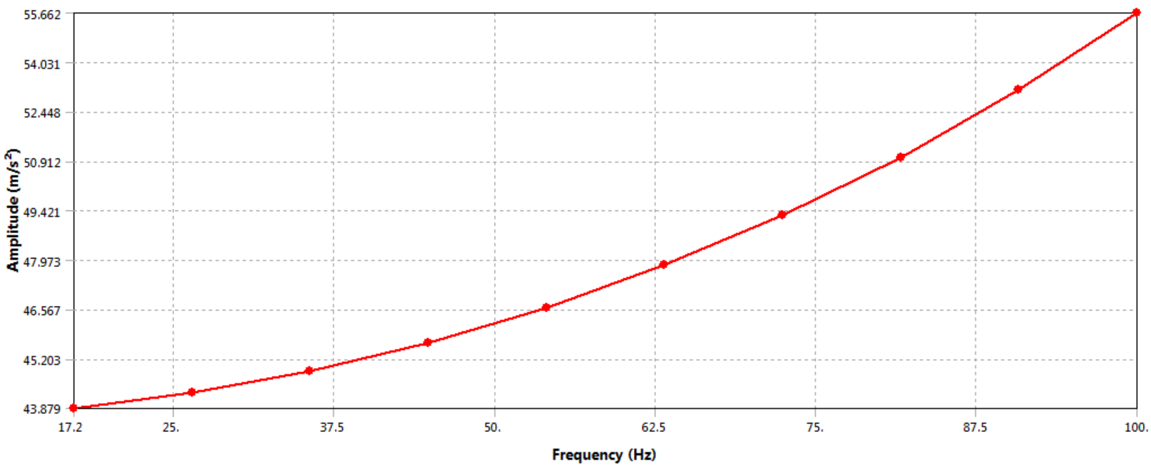



Figure 4.24: Sun-sensor Board in Y-direction

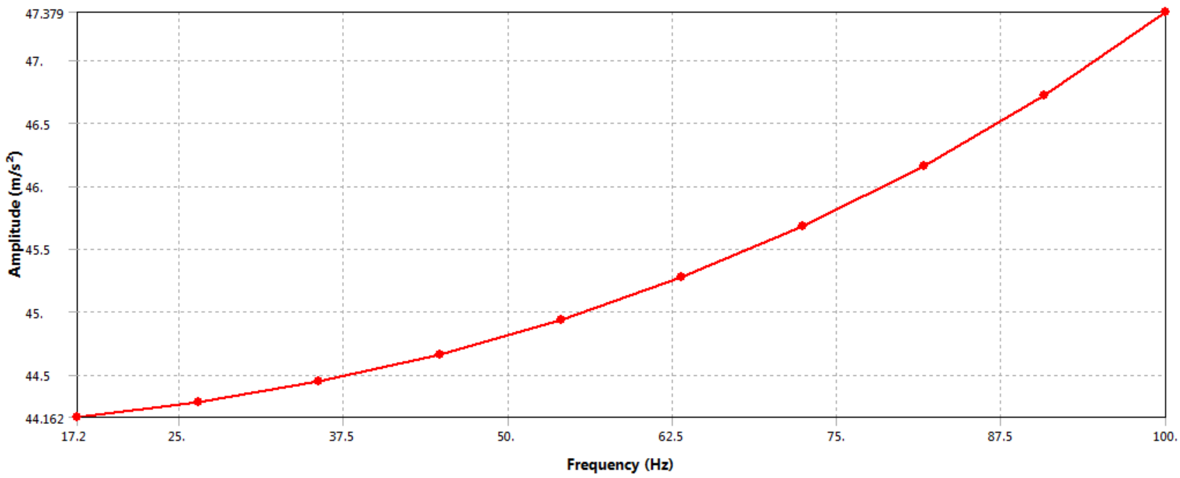



Figure 4.25: On Fixture near Leading Side in Y-direction

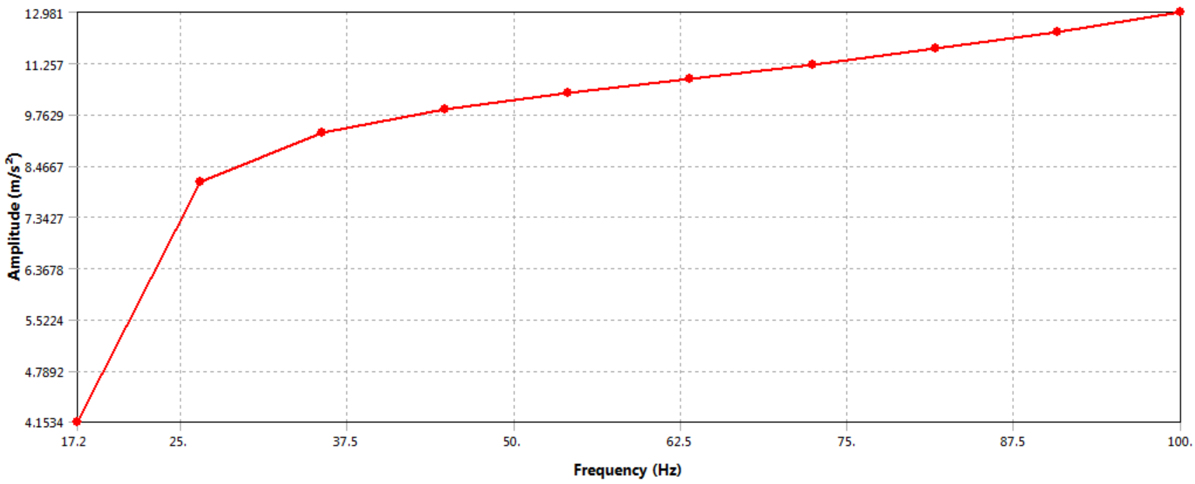



Figure 4.26: Power Board in Z-direction

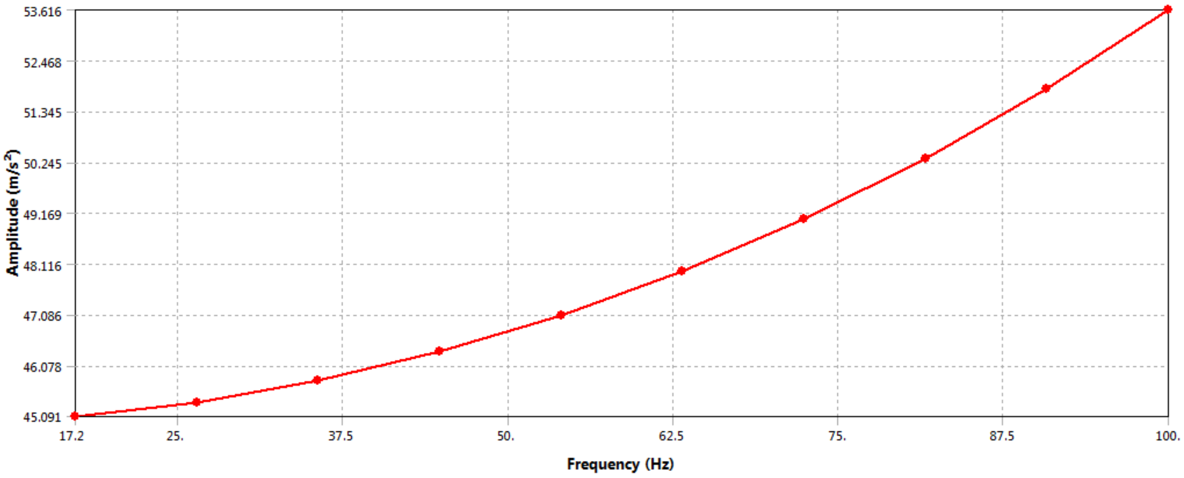



Figure 4.27: Zenith Side Panel in Y-direction

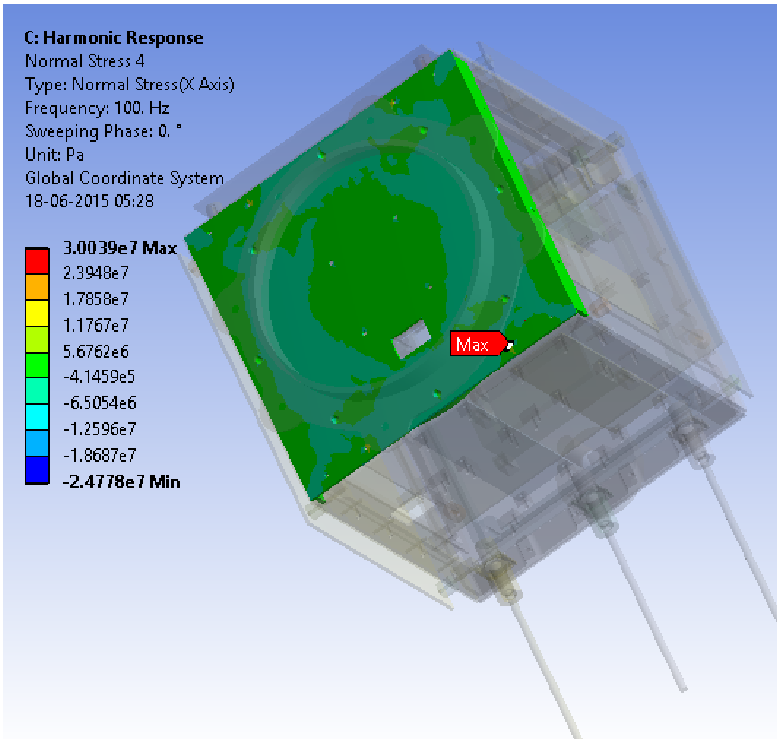



Figure 4.28: Max Normal Stress: Nadir Side Panel (Harmonic Loading in X)

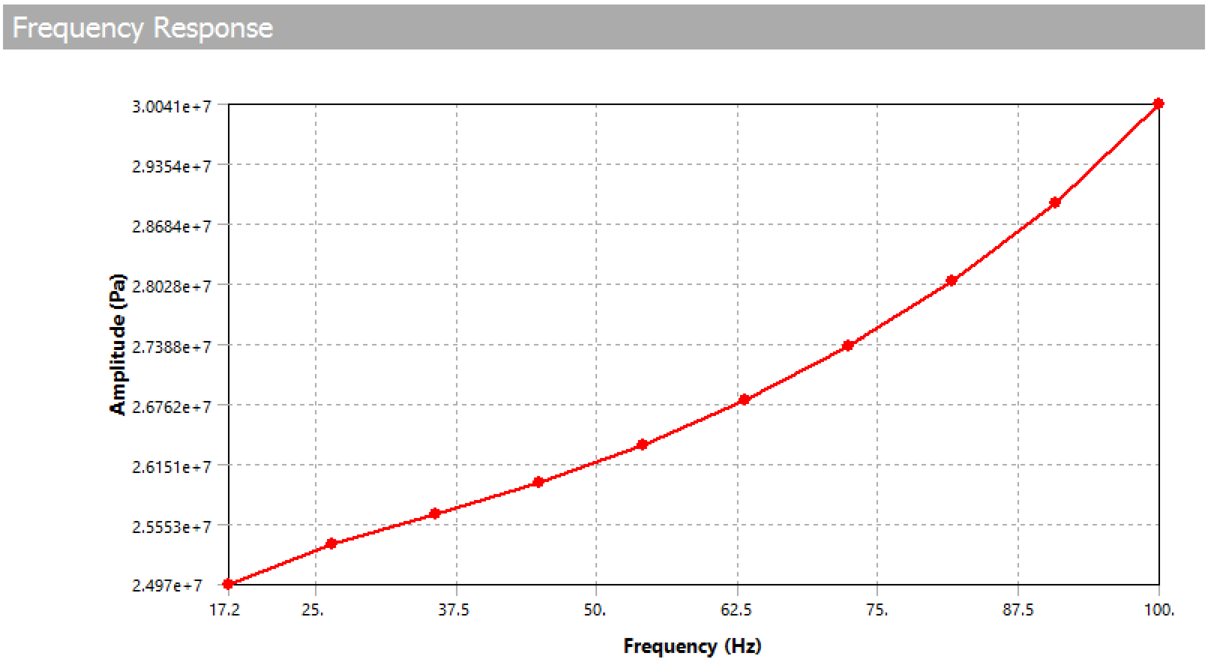



Figure 4.29: Frequency Responce: Normal Stress in X-direction (Harmonic Loading-X)

7. **Interpretation of results:**

   (a) The maximum stress in PCBs is 2.5014 MPa (FOS: 50)

   (b) The maximum stress on Solar Panel is 24.004 MPa (FOS: 11.5)

   (c) The maximum stress on Side Panel is 21.7680 MPa (FOS: 12.7)

   (d) The maximum stress on Monopole+Holder is 8.6474 MPa (FOS: 32)

   (e) The maximum stress on FE Ring is 9.3578 MPa (FOS: 29.5)

   Frequency Response of normal stress for Harmonic loading is continuously increasing in range 8-100 Hz and max value of stress is at 100 Hz. Therefore, there is no fundamental mode in between these range. The image above frequency response shows the corresponding normal stress plot on the body.

   **Conclusion:** No peak in the frequency range (5-Ö100 Hz) specified by PSLV manual shows no failure of satellite.

## 4.6 Random Vibration Analysis

1. **Aim of analysis:** To determine the stress developed and PSD response when structure is subjected to Random loading.

2. **Type of analysis:** Random

3. **Material properties:** As given in structures report 8.1

4. **Constraints applied:** The modal analysis results with fixed constraint on FE RING is used.

5. **Loads applied:** PSD base excitation are taken from PSLV manual and simulated for all the three directions separately

6. **No. of modes used for analysis:** 300 modes - Till 2000 Hz

7. **Constant damping ratio:** 1%

8. **Scale factor:** 3 sigma

9. **Probability:** 99.73%

| Sl. No. | Material | Component Type | Component | X | Y | Z |
|---|---|---|---|---|---|---|
| | | | | Max (MPa) | Max (MPa) | Max (MPa) |
| 1 | | | All body | **266.55** | **194.28** | **102.71** |
| 2 | FR 04 | PCBs | Downlink | 13.907 | 75.863 | 19.435 |
| 3 | | | Becon | 11.79 | 36.466 | 16.375 |
| 4 | | | Uplink | 29.029 | 28.234 | 22.922 |
| 5 | | | Power | 21.696 | 39.604 | 31.337 |
| 6 | | | OBC | **103.42** | 31.787 | 27.245 |
| 7 | | | Sunsensor Board | 18.838 | **156.04** | **50.781** |
| 8 | AL 6061 T6 | Solar Pannels | Solar Panel Sunside | 22.652 | 131.46 | **102.71** |
| 9 | | | Solar Pannel Lagging | **266.55** | 69.292 | 35 |
| 10 | | | Solar Pannel Leading | 243.84 | 41.521 | 29.824 |
| 11 | | | Solar Pannel Zenith | 42.397 | **194.28** | 40.879 |
| 12 | | Side Pannels | Sunside | 33.177 | 52.962 | 26.682 |
| 13 | | | Leading | 49.607 | 55.565 | 34.28 |
| 14 | | | Nadir | **55.873** | **121.85** | **69.838** |
| 15 | | | Lagging | 38.639 | 59.635 | 29.26 |
| 16 | | | Anti-Sunside | 26.081 | 42.821 | 24.925 |
| 17 | | | Zenith | 18.002 | 98.51 | 27.362 |
| 18 | | Monopole+ Holder | Outercover-1+ Antenna(leading 1st) | 23.102 | 14.051 | 87.89 |
| 19 | | | Outercover-2+ Antenna(lagging 1st) | 25.118 | 14.272 | **88.248** |
| 20 | | | Outer cover-3+ Antennna(middle) | **25.863** | **21.953** | 75.522 |
| 21 | | Battery | Battery Box | 4.1955 | 10.365 | 4.2045 |
| 22 | | Torquers | Torquer Sunside | 8.2399 | 6.2715 | 6.3412 |
| 23 | | | Torquer Leading | 7.4512 | 5.5474 | 6.7048 |
| 24 | | | Torquer Zenith | 6.6203 | 5.2276 | 7.3923 |
| 25 | | FE Ring | FE Ring | **144.04** | **171.25** | **38.584** |
| 26 | GRPF | Washer | All washers | 0.0415 | 0.03831 | 0.03857 |

Table 4.7: Random Vibration Results

**NOTE:** The numbers shown in bold are higher stress values in the corresponding components.

10. **Screenshot of contour plot obtained:**

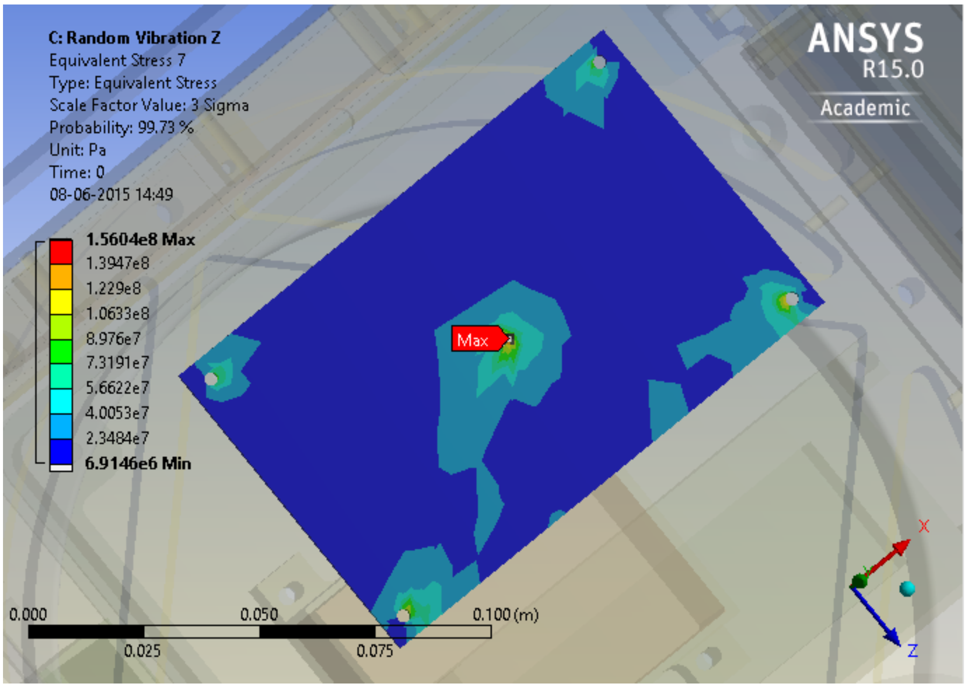



Figure 4.30: Max eq stress: Sunsensor PCB(Random Loading in Y)

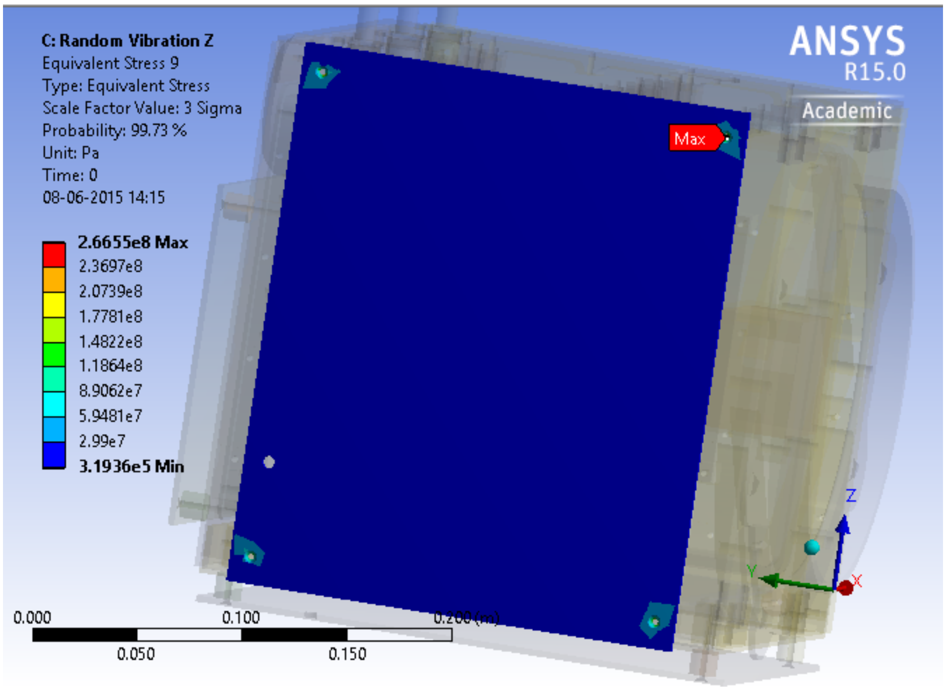



Figure 4.31: Max eq stress: Lagging Solar Panel (Random Loading in X)

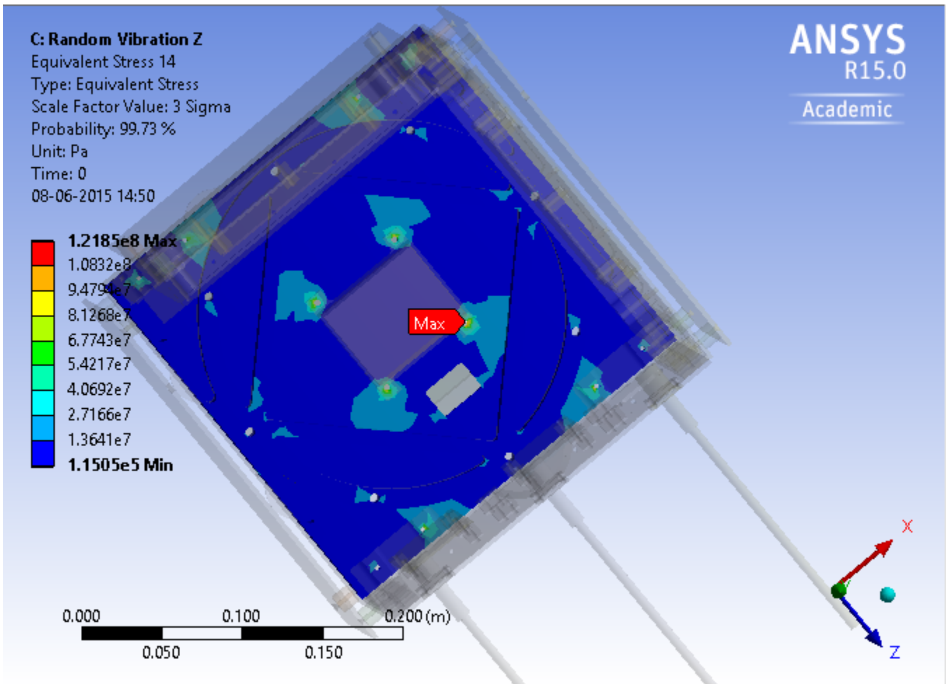



Figure 4.32: Max eq stress: Nadir Side Panel (Random Loading in Y)

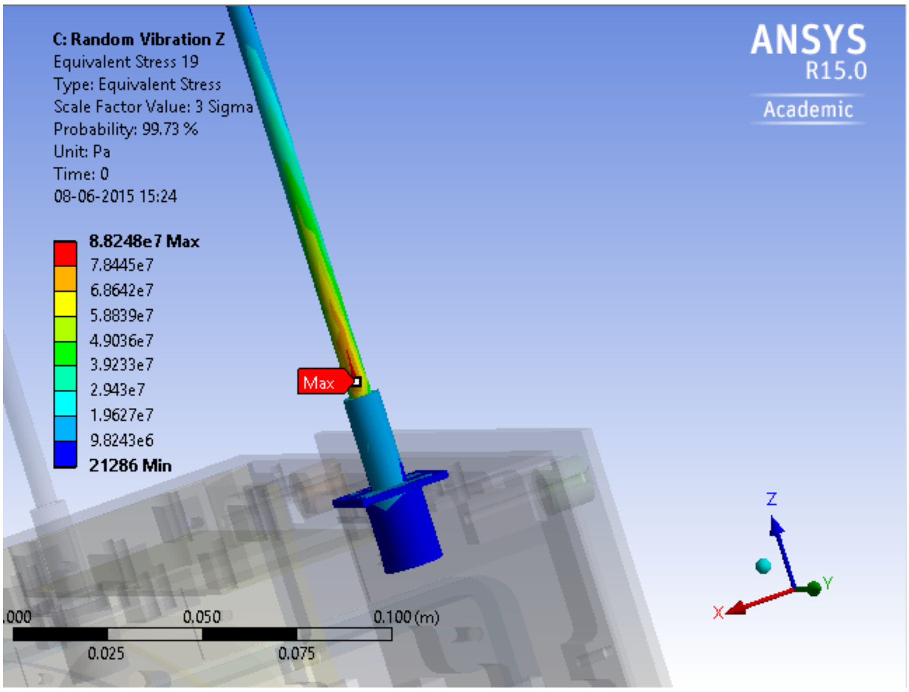



Figure 4.33: Max eq stress: Monopole+Holder (Random Loading in Z)

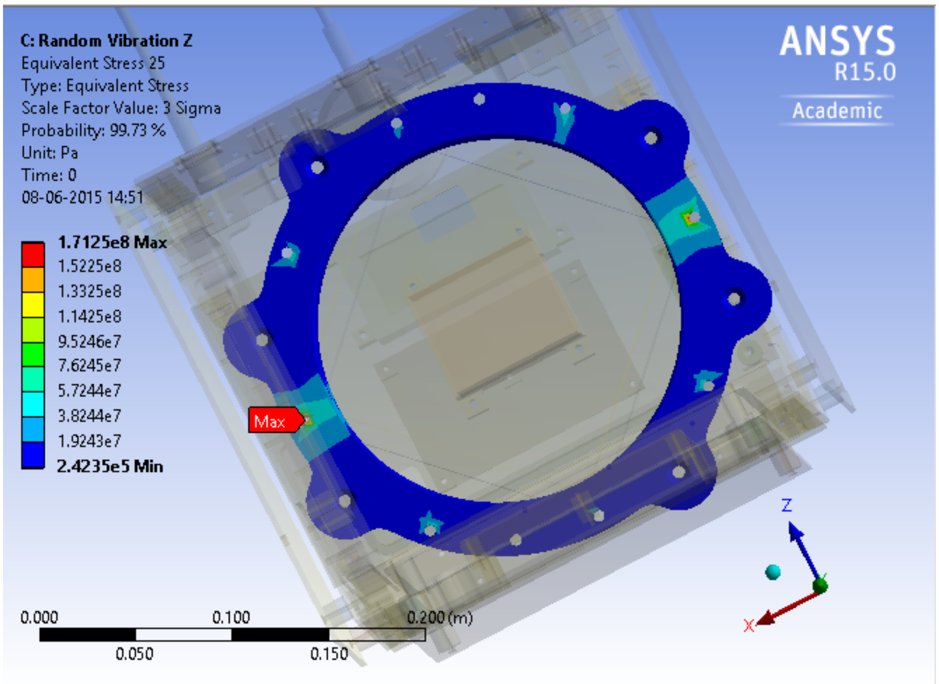



Figure 4.34: Max eq stress: FE Ring (Random Loading in Y)

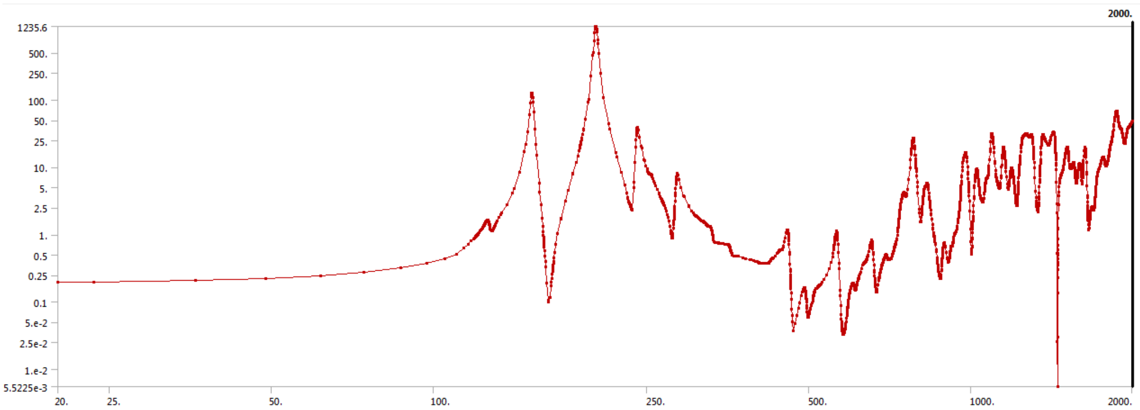



Figure 4.35: PSD Response Acceleration (X): Leading Side (Loading in X)

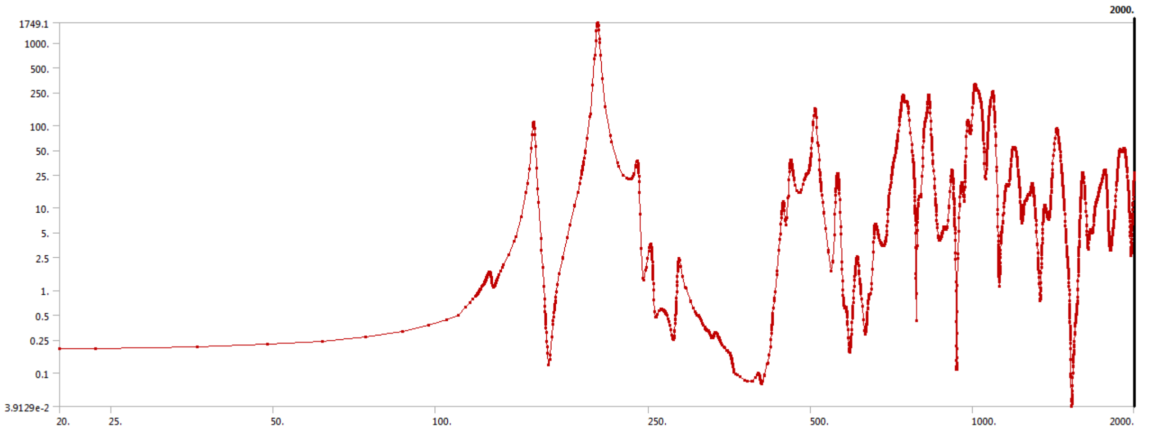



Figure 4.36: PSD Response Acceleration (X): OBC Board (Loading in X)

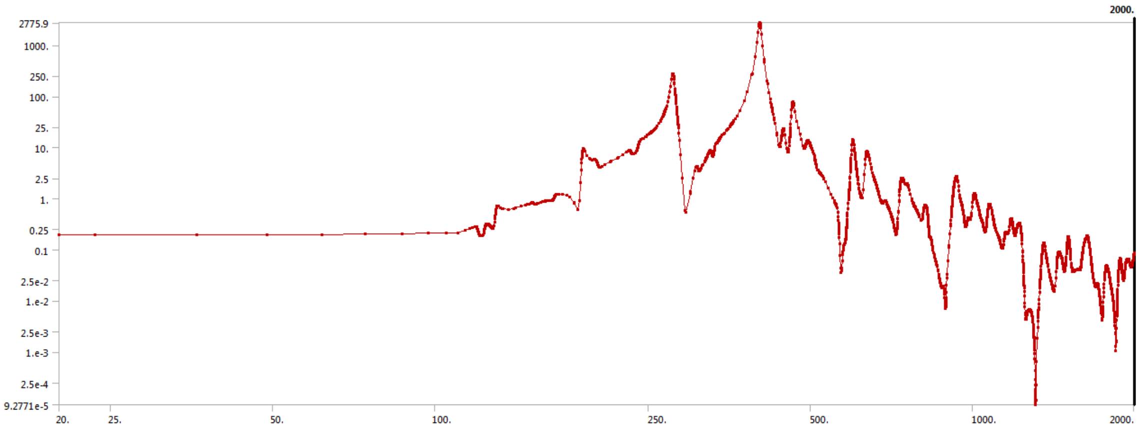



Figure 4.37: PSD Response Acceleration (Y): Power Board (Loading in Y)

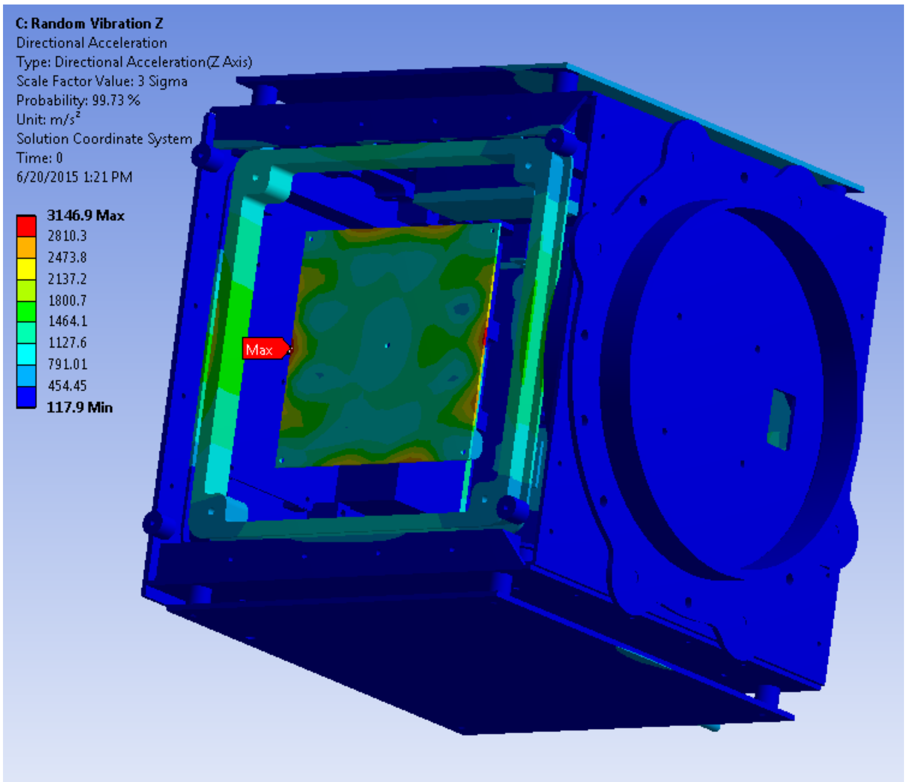



Figure 4.38: Directional Acceleration (Z) for Random Loading in Z

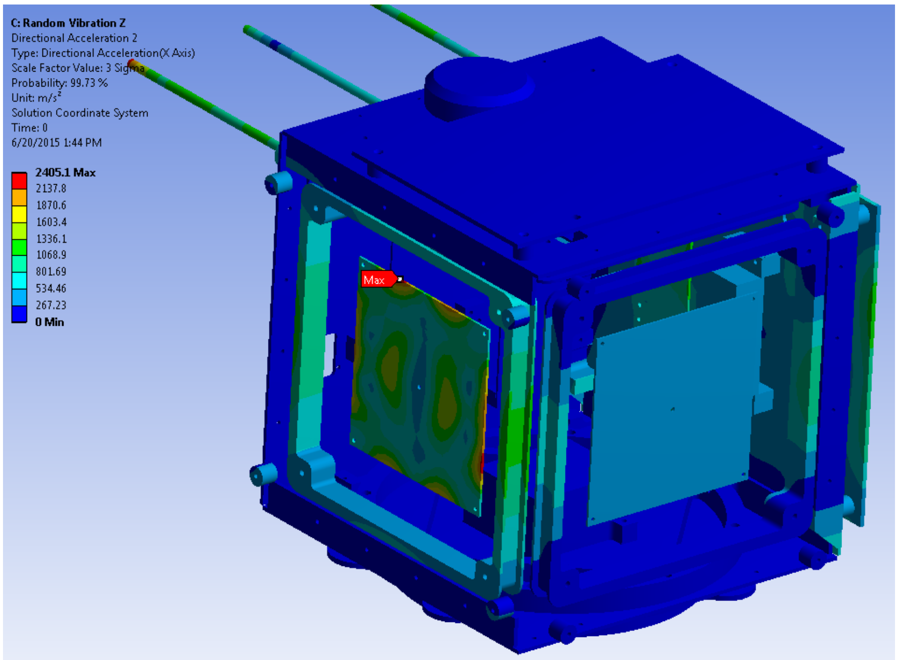



Figure 4.39: Directional Acceleration (X) for Random Loading in Z

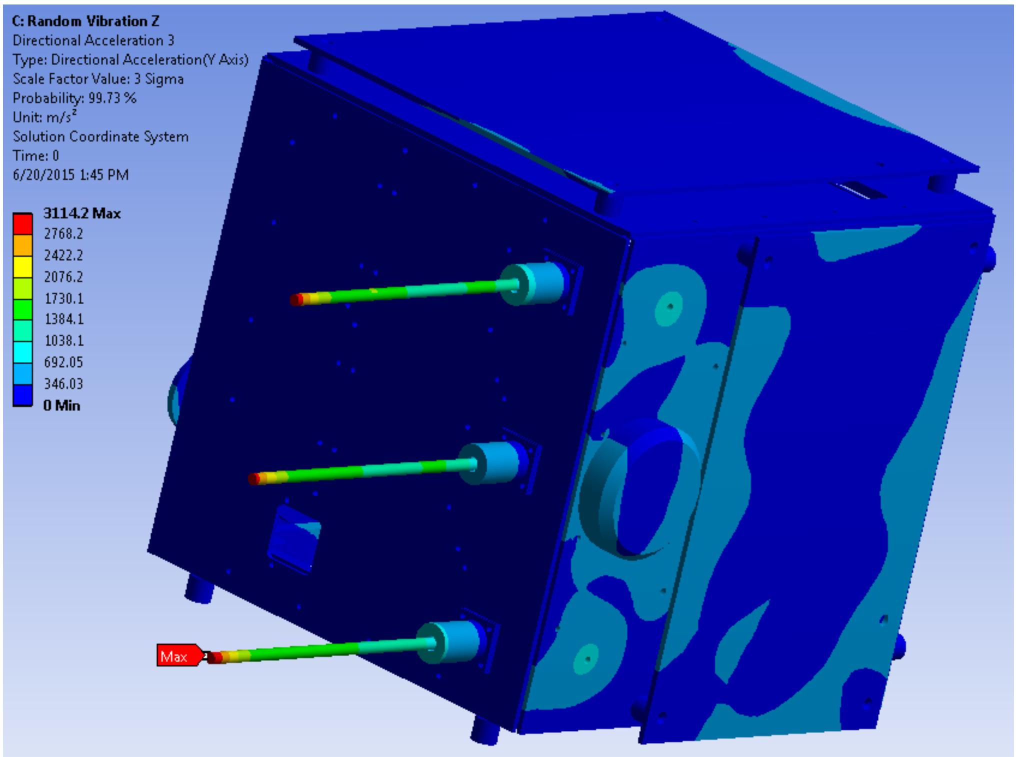



Figure 4.40: Directional Acceleration (Y) for Random Loading in Z

11. **Interpretation of results:** The maximum stress is obtained on a washer and is far less than the yield strength. Also, the total deformation is far too less for any contact between 2 surfaces to take place. Thus, the structure does not fail under random vibrations.

12. **Conclusion:** For all the above simulations FOS values for different material is greater than 1.

## 4.7 Mock LVI Characterization

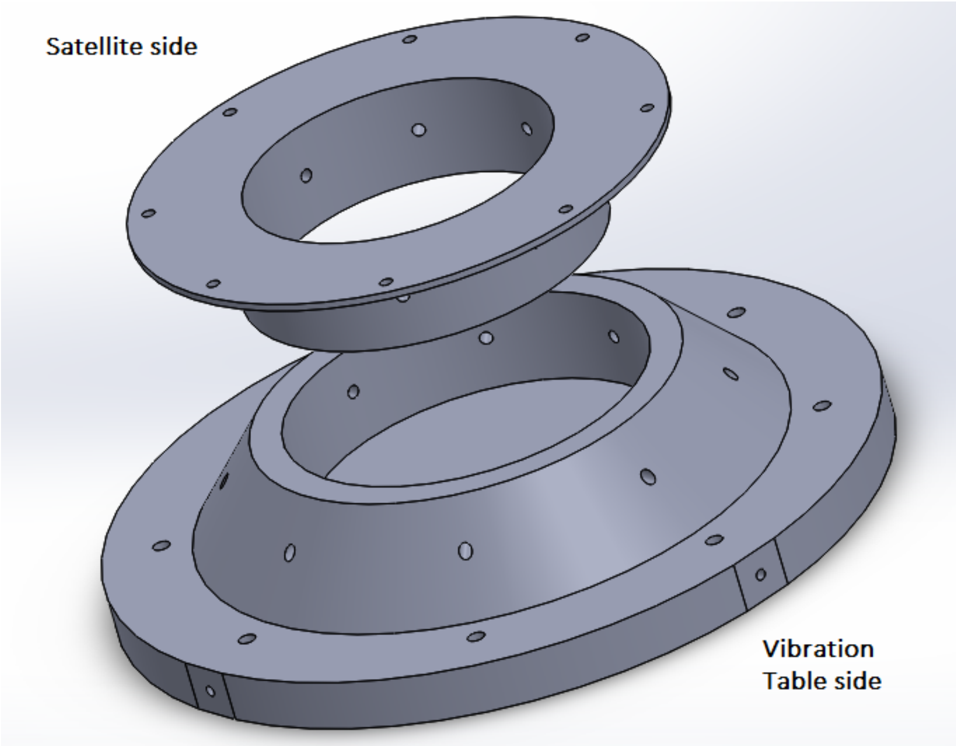



Figure 4.41: LVI Model

### 4.7.1 Static Simulations

1. **Aim of analysis**: To determine the stress developed and total deformation when a static load is applied.
2. **Type of analysis**: Static
3. **Model:**
   - **(a) Base height 24mm, upper plate height 3.5mm**
   - **(b) 8 holes are at 3.9 inch diameter and at 12 inch diameter each**
4. **Material used: Al 6061-T6**
5. **Constraints applied: The two LVI parts are attached by rigid links and one LVI part towards the vibration table is fixed.**
6. **Loads applied:Acceleration of -7g was applied in longitudinal direction and 6g in lateral direction.**

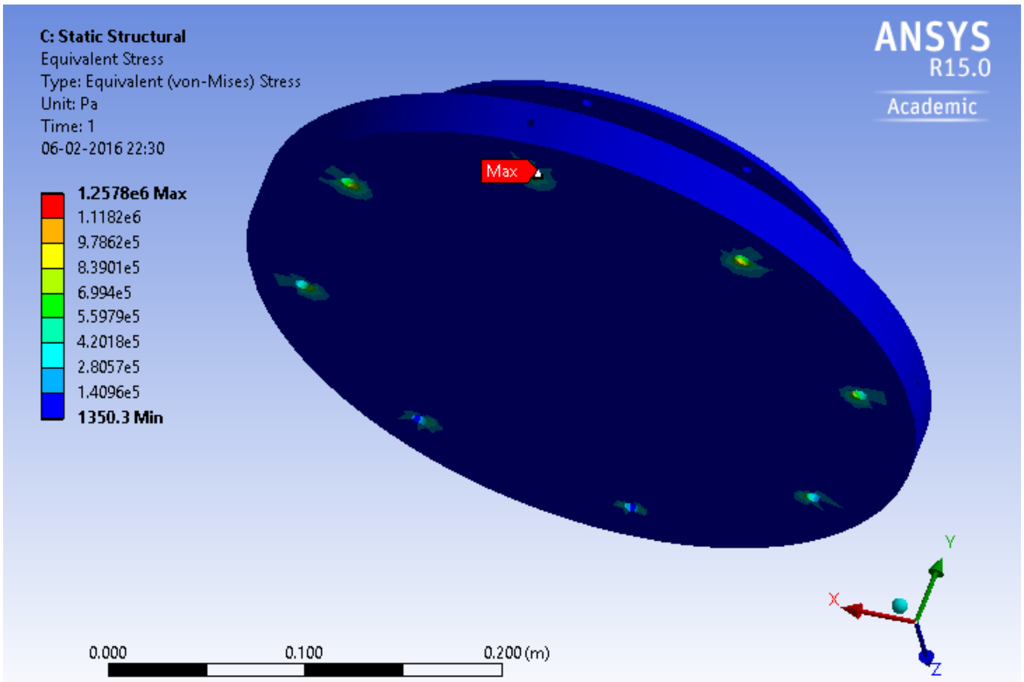



Figure 4.42: Static results- Equivalent Stress- LVI

7. **Interpretation of results: The maximum equivalent stress observed is** 1.2578 **MPa near the edge of a hole near satellite side. This is far less than the Yield strength of Al 6061-T6.**

8. **Conclusion: The model of the LVI can sustain the launch loads without yielding.**

### 4.7.2 Modal Simulations

1. **Aim of analysis**: To determine the fundamental and the subsequent resonance frequencies of the LVI.

2. **Material used**: Al 6061-T6

3. **Constraints applied**: Only the outer holes (12 inch) of the LVI and the Vibration table were attached by Rigid Link. The phase towards vibration table is fixed. Modal simulation is simulated for 10 modes.c Mass participation factor found was approximately 75% for all the directions.

| Mode | Frequency [Hz] | Mode | Frequency [Hz] |
|---|---|---|---|
| 1 | 2367.6 | 6 | 2910 |
| 2 | 2423.7 | 7 | 2941.6 |
| 3 | 2553.3 | 8 | 3042.3 |
| 4 | 2641.2 | 9 | 3415.8 |
| 5 | 2688.3 | 10 | 3544.2 |

Table 4.8: Modal Analysis Mock LVI

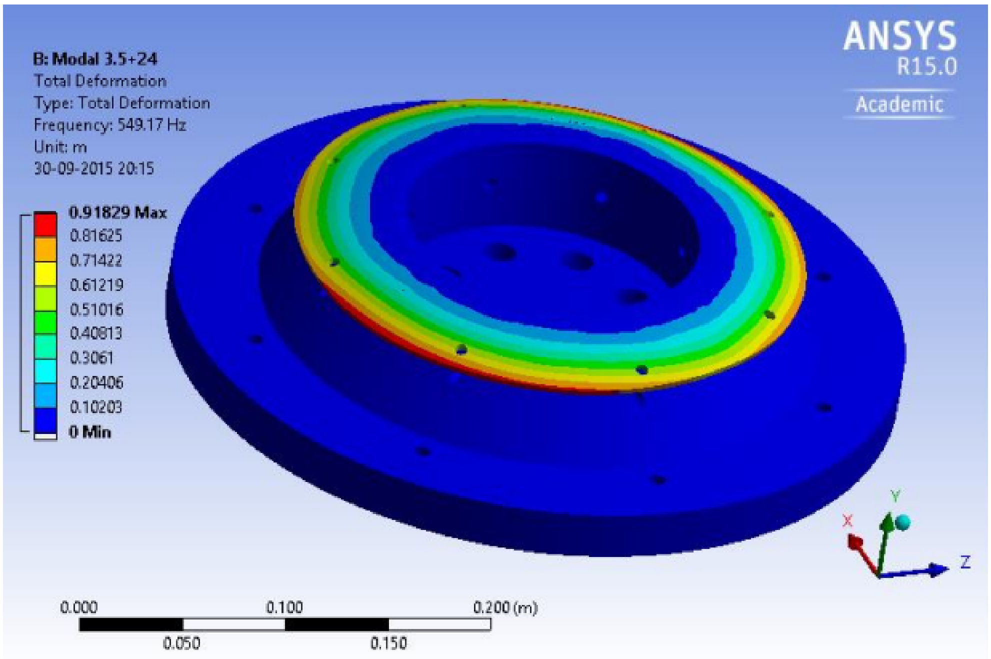



Figure 4.43: Modal results

4. **Interpretation of results:**The fundamental mode is at 2367.6 Hz. Since this is far more than the frequency range of loads, the structure will not fail.

‘

## 4.8 Mock LVI Characterization with Satellite as Point

### 4.8.1 Static Simulations

1. **Aim of analysis**: To determine the stress developed and total deformation when a static load is applied.
2. **Type of analysis**: Static
3. **Material used**: Al 6061-T6

4. **Constraints applied**: The holes of the LVI and the Vibration table were attached by Rigid Link. The phase towards vibration table is fixed. A point mass of 10kg as satellite is attached to upper plate as remote point.

5. **Loads applied**:Acceleration of -7g was applied in longitudinal direction and 6g in lateral direction.

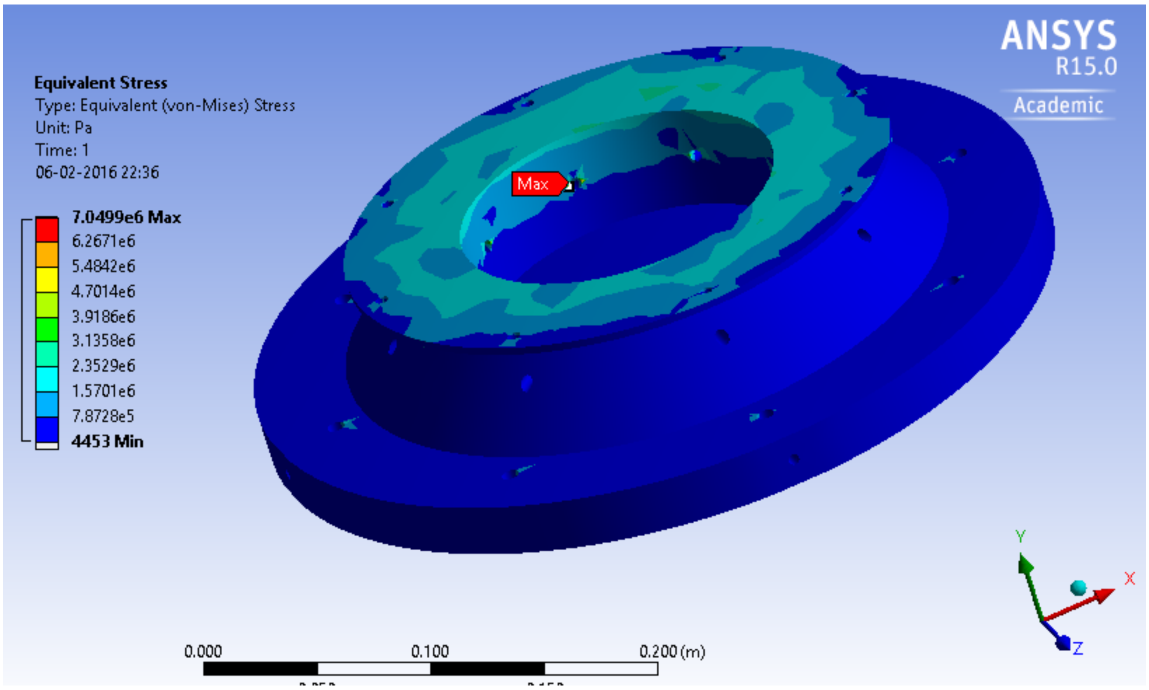



Figure 4.44: Static results- Equivalent Stress - LVI

6. **Interpretation of results:** The maximum equivalent stress observed is 7.0499 MPa near the edge of a hole. This is far less than the Yield strength of Al 6061-T6.

7. **Conclusion:** The modal of the LVI used can sustain the launch loads without yielding.

### 4.8.2 Modal Simulations

#### Model 1

1. **Aim of analysis**: To determine the fundamental and the subsequent resonance frequencies of the LVI.

2. **Material used**: Al 6061-T6

**Constraints applied**: Only the outer holes (12 inch) of the LVI and the Vibration table were attached by Rigid Link. A point mass of 10kg as satellite is attached to upper plate as remote point. The phase towards vibration table is fixed. Modal simulation is simulated for 10 modes.

| Mode | Frequency [Hz] | Mode | Frequency [Hz] |
|---|---|---|---|
| 1 | 549.17 | 6 | 2747.1 |
| 2 | 1535.6 | 7 | 2852.3 |
| 3 | 1550.8 | 8 | 2863.8 |
| 4 | 2625 | 9 | 2944.2 |
| 5 | 2667.1 | 10 | 3054.4 |

Table 4.9: Modal Results of LVI with Stellite as a Remote Point

Modal simulation is simulated for 10 modes. Mass participation factor found is approximately 75% for all the directions.

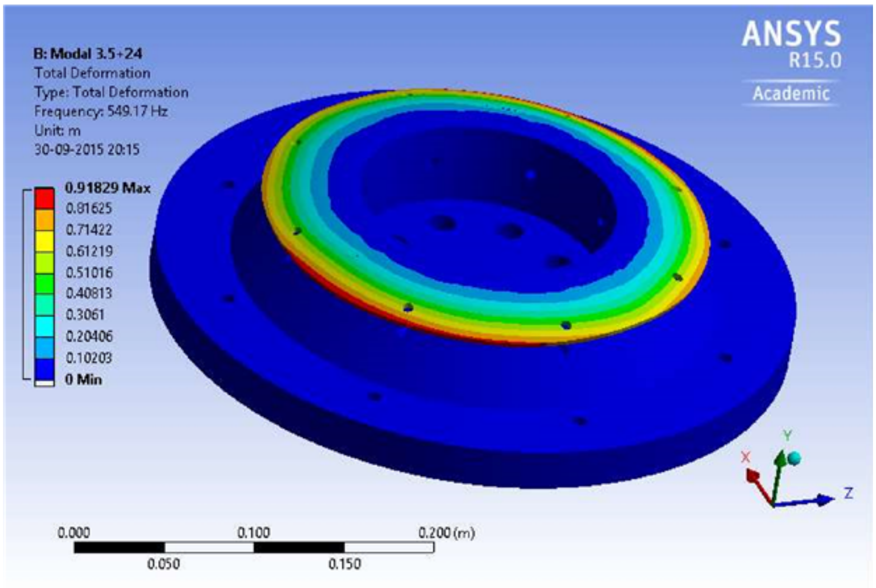



Figure 4.45: Modal results

**Interpretation of results:**The fundamental mode is at 549.17 Hz. Since this is far more than the frequency range of loads, the structure will not fail.

# Chapter 5

# Vibration Testing

## 5.1 Vibration Testing of Fixture

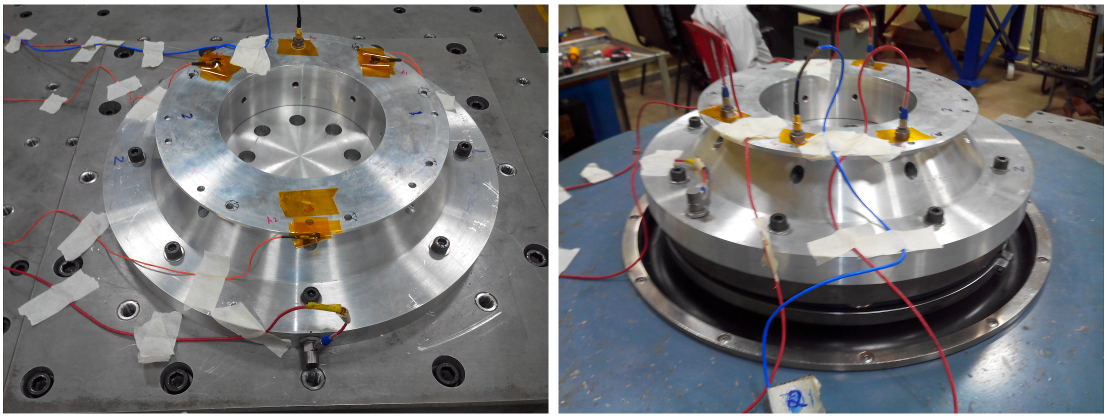


Figure 5.1: Vibration Testing of Fixture

Fixture with two rings one which will be attached to satellite nadir side and other which will be attached to shaker table is designed keeping in the point of integration difficulty during testing. Therefore the two rings will attached separately at its location and after that satellite is kept over the bottom fixture ring and screwed from sideways through M6 screws. The top ring weighs 1.1 kg and the bottom ring weighs 8.2 kg. This fixture is designed to be used only for vibration testing. The final LVI IBL230V2 will be provided by VSSC for flight model.

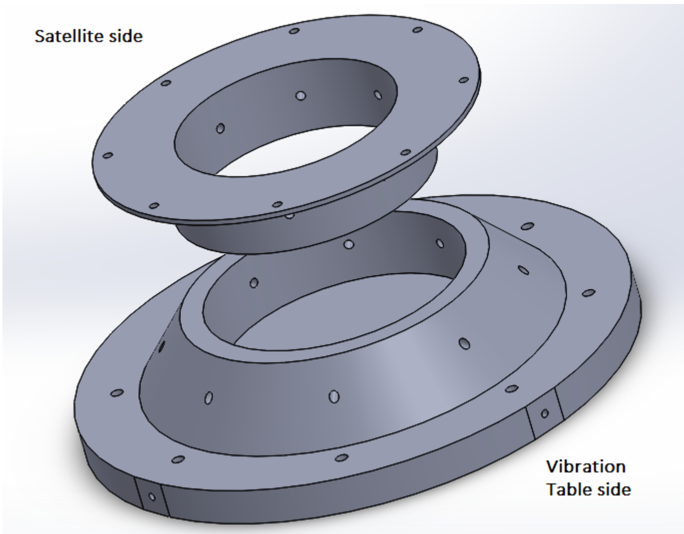



Figure 5.2: Z-direction set up

### 5.1.1 Testing Setup

The fixture is separately tested without satellite for low level random and sine test for two axis one for longitudinal and one for lateral. Since the fixture is symmetric only one lateral direction testing was sufficient. Four accelerometers were mounted on the top ring of the fixture and a controller mounted on the bottom bigger ring.

**Testing for Z axis (longitudinal):**

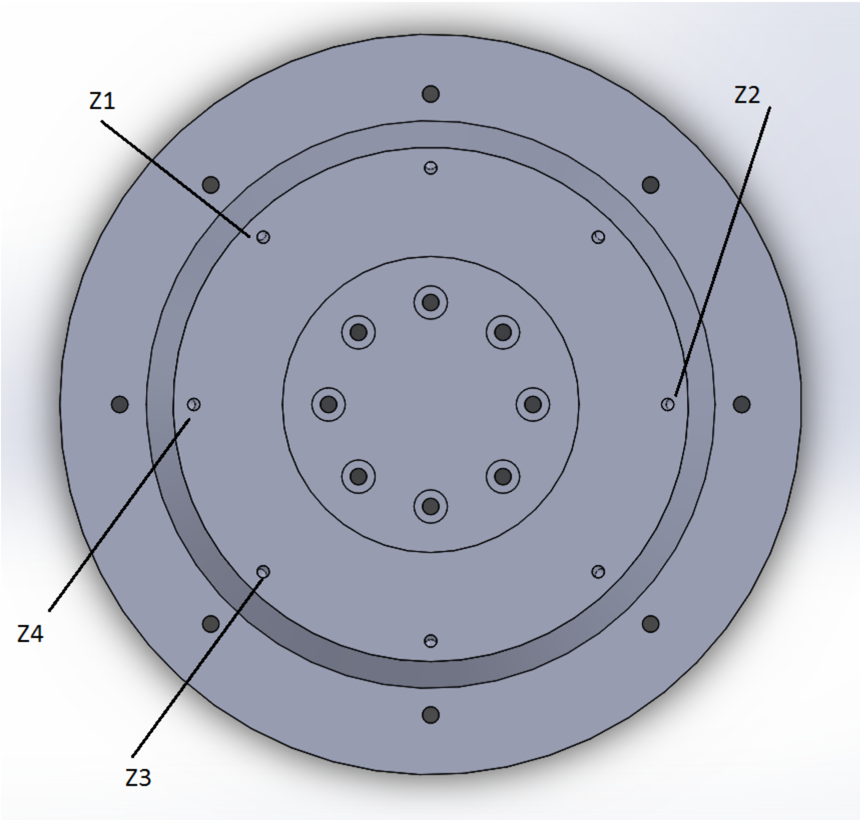



Figure 5.3: Z-direction set up

| Location | Accelerometer No. | Sensitivity (mv/g(rms)) | PB No. |
|---|---|---|---|
| Z1 | 173080 | 10.02 | 1 |
| Z2 | 71672 | 10.12 | 2 |
| Z3 | 169418 | 9.85 | 3 |
| Z4 | 169432 | 9.81 | 4 |
| Control on Fixture | 71815 | 103.3 | 5 |

Table 5.1: Location of accelerometer for Z-direction Testing

**Testing for Y axis (lateral):**

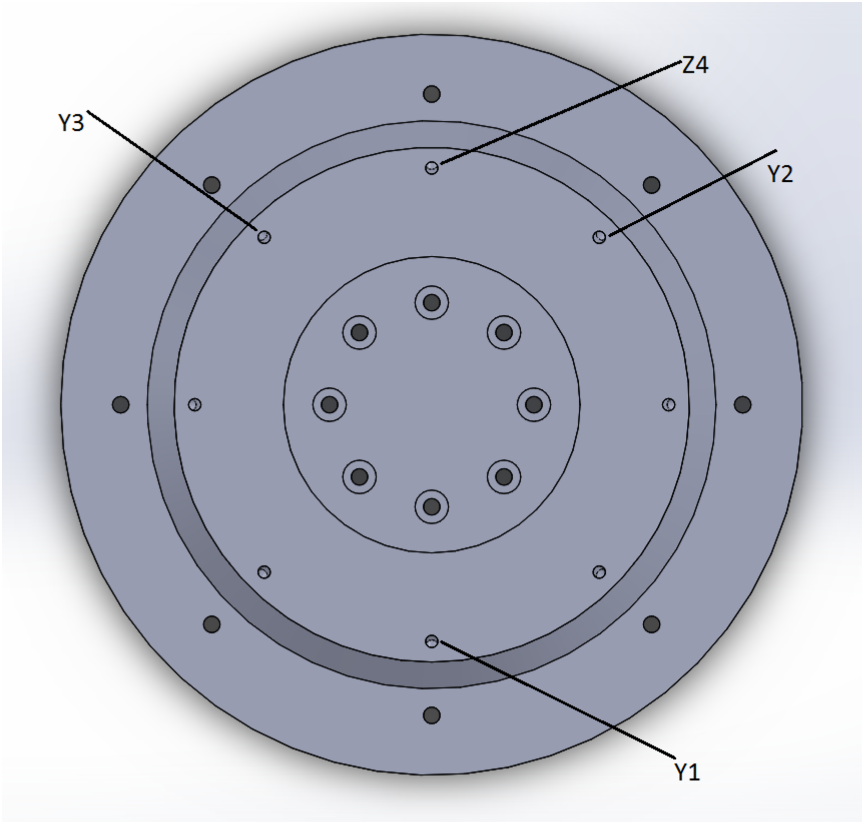



Figure 5.4: Y-direction set up

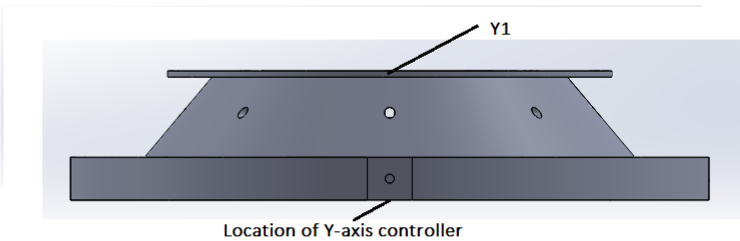



Figure 5.5: Y-direction set up

| Location | Accelerometer No. | Sensitivity (mv/g(rms)) | PB No. |
|---|---|---|---|
| Y1 | 50457 | 2.038 | 1 |
| Y2 | 55398 | 1.867 | 2 |
| Y3 | 55402 | 1.87 | 3 |
| Z4 | 169432 | 9.81 | 4 |

Table 5.2: Location of accelerometer for Y-direction Testing

### 5.1.2 Results

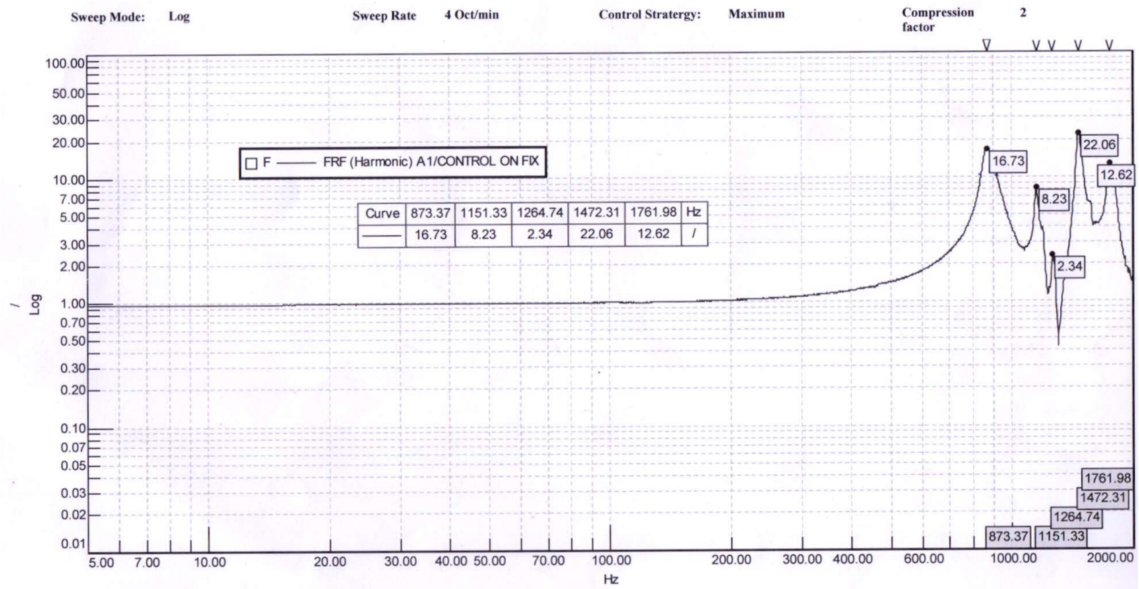



Figure 5.6: Frequency Response of Fixture during ZLLS on A1

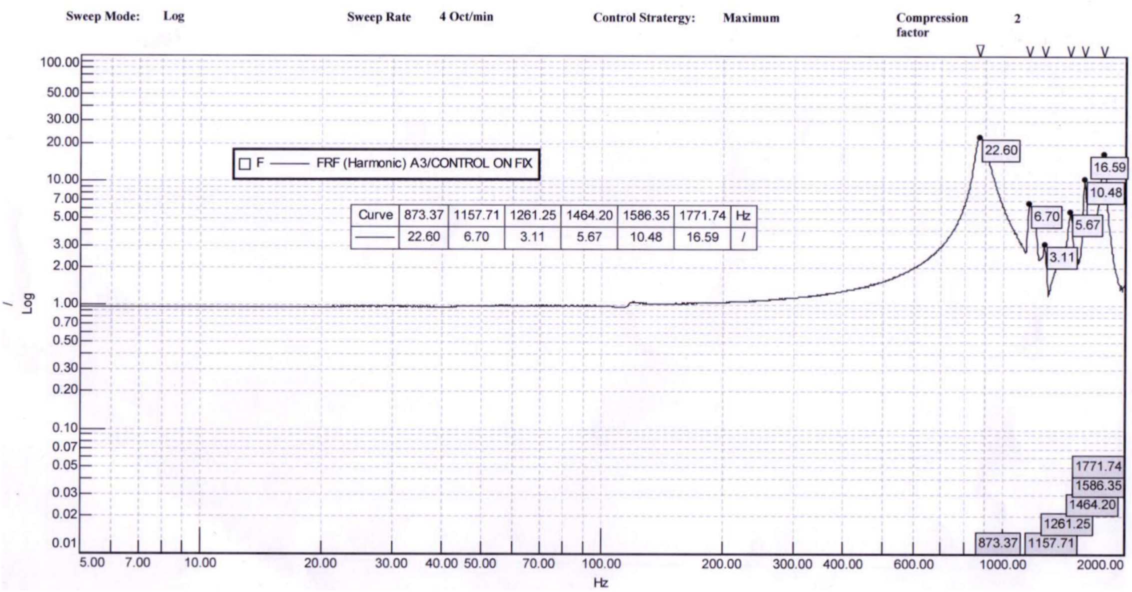



Figure 5.7: Frequency Response on Fixture during ZLLS on A3

### 5.1.3 Interpretation

Peak observed from both the above frequency response plot show the peak at frequency of around 873Hz. Which show the fundamental frequency corresponding to the fixture.

The aim of the fixture was to transfer the load to the satellite properly. The constraints which was set to have a fundamental frequency of fixture around and above 5 times the satellite frequency which is coming around 150 Hz(satellite frequency) * 5= 750 Hz. The frequency observed is 873 Hz which shows that no frequency of fixture will resonate during the testing for the satellite.

## 5.2 Vibration Testing of Satellite

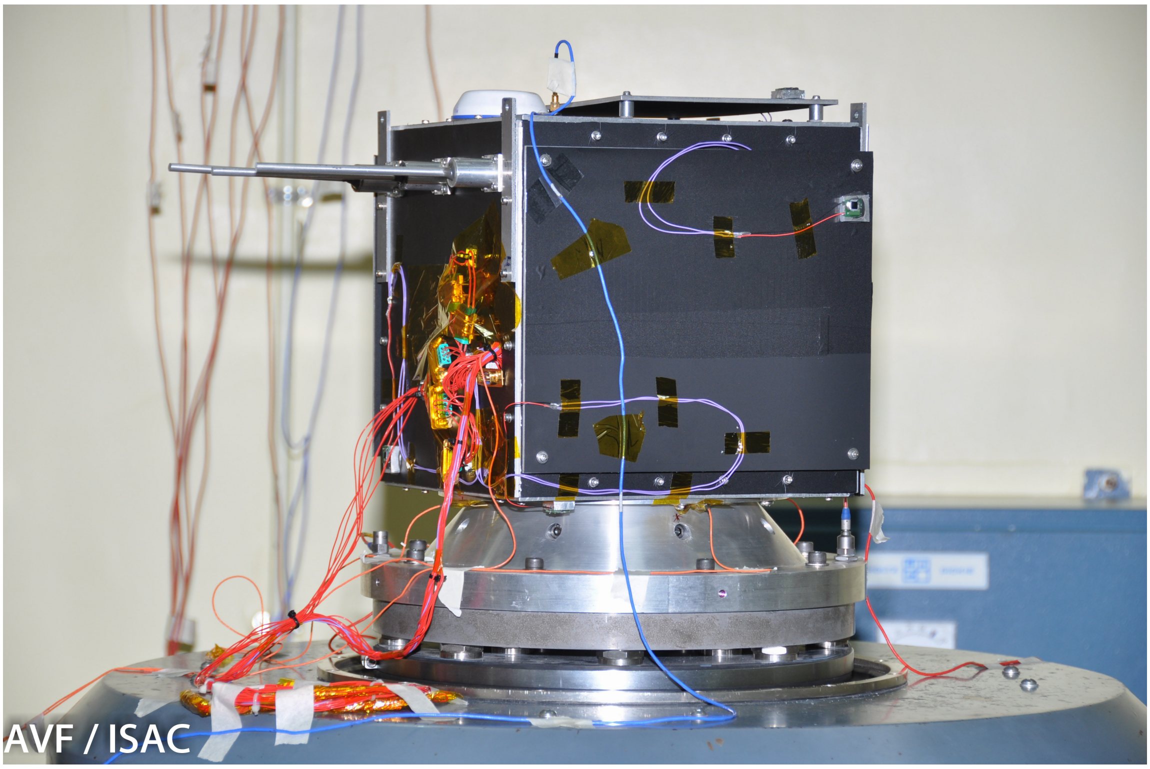



Figure 5.8: Vibration Testing of Satellite

### 5.2.1 Testing Setup

The bigger fixture ring is mounted on the shaker table. Complete integrated satellite along with the smaller LVI ring attached to the Nadir side of the satellite is mounted on it. The two rings are attached through sideways 8 M6 screws. In this way satellite is interfaced through the shaker table using fixture. Satellite is then separately tested for all three axis, one longitudinal and two lateral.
**Sequence of testing:**

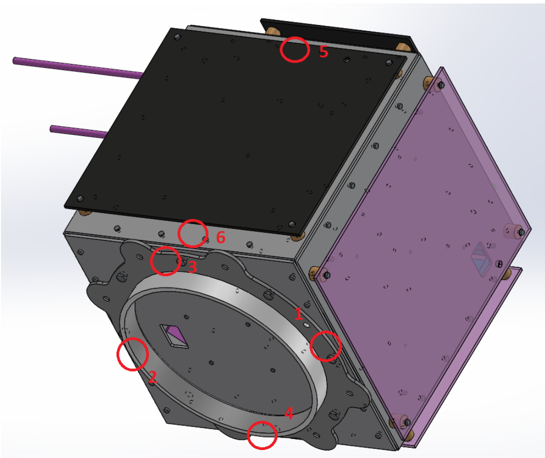
1. Low Level Random

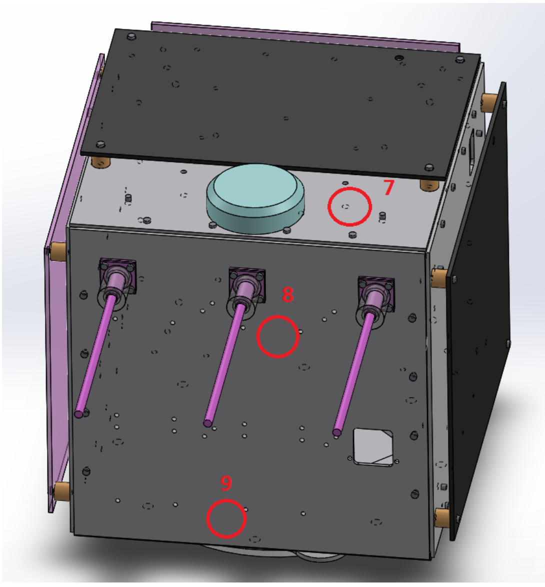
2. Low Level Sine

3. Qualification Level Sine
4. Low Level Sine (Post QLS)
5. Low Level Random (Post QLS)
6. Qualification Level Random
7. Low Level Random (Post QLR)

Similar sequence of testing is performed for all three axis. Applied loads are Qualification level loads according to the PSLV manual.

### 5.2.2 Location of Accelerometers



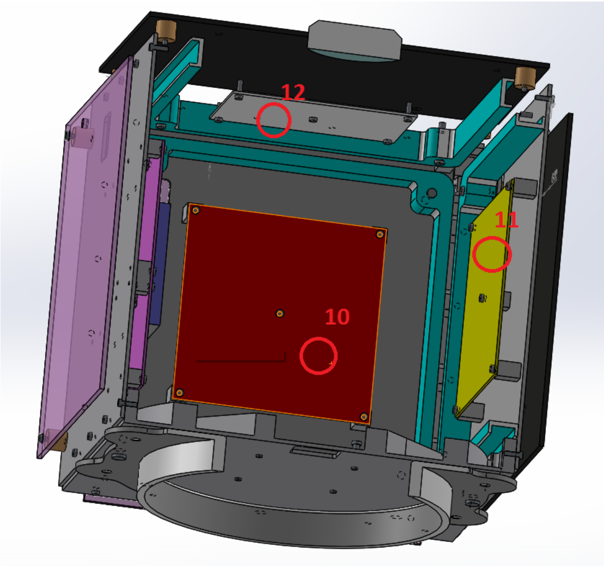



Figure 5.10: Location of accelerometer

**Note:** Red circles represents location of accelerometer

| SI. No. | External Location | Side Name | Testing Axis |
|---|---|---|---|
| 1 | FE Ring (towards Sunside) | Nadir | X,Y and Z |
| 2 | FE Ring (towards Anti-sunside) | Nadir | X,Y and Z |
| 3 | FE Ring (towards Leading) | Nadir | X,Y and Z |
| 4 | FE Ring (towards Lagging) | Nadir | X,Y and Z |
| 5 | Towards Zenith Side | Leading | X |
| 6 | Towards Nadir Side | Leading | X |
| 7 | Near GPS Antenna | Zenith | Y |
| 8 | Below Monopoles | Anti-sunside | Z |
| 9 | Towards Nadir side | Anti-sunside | Z |
| | **Internal Location** | | |
| 10 | Power Board | Sunside | X,Y and Z |
| 11 | OBC Board | Leading | X,Y and Z |
| 12 | ADC Board | Zenith | X,Y and Z |

| Location of Accelerometer | Accelerometer No. | Model No. | Sensitivity | P.B. No. | Direction of testing |
|---|---|---|---|---|---|
| ADC Board | 61246 | 4517002 | 10.25mv/gm | 6 | X,Y,Z |
| Power Board | 61239 | 4517002 | 10.2mv/gm | 7 | X,Y,Z |
| OBC Board | 61229 | 4517002 | 10.21mv/gm | 8 | X,Y,Z |
| On fixture near leading side | 55402 | 4517C003 | 1.87pc/gm | 1 | X,Y,Z |
| On fixture near anti-sunside | 61248 | 4517002 | 10.51mv/gm | 2 | X,Y,Z |
| On fixture near lagging side | 50457 | 4517C003 | 2.038pc/gm | 3 | X,Y,Z |
| On fixture near sunside | 61269 | 4517002 | 10.05mv/gm | 4 | X,Z |
| Zenith side | 71672 | 352C43 | 10.12mv/gm | 9 | Z |
| Control on fixture | 71805 | 352C33 | 102.3mv/gm | 5 | Z |
| Control on fixture (sunside) | 2015821 | 8704B500 | 9.838mv/gm | 10 | Z |
| Control on fixture (lagging) | 2014938 | 8704B500 | 10.28mv/gm | 5 | Y |
| Leading side top | 139248 | 352C43 | 9.894mv/gm | New PB | Y |
| Leading side bottom | 71672 | 352C43 | 10.12mv/gm | 9 | Y |
| Anti-sunside bottom | 139248 | 352C43 | 9.894mv/gm | New PB | X |
| anti-sunside top | 71672 | 352C43 | 10.12mv/gm | 9 | X |
| control on fixture (sunside) | 2014938 | 8704B500 | 10.28mv/gm | 5 | X |
| control on fixture (anti-sunside) | 2015821 | 8704B500 | 9.83mv/gm | 10 | X |
| On fixture near sunside | 50457 | 4517C003 | 2.038pc/gm | 3 | X |

Table 5.3: Deatails of Accelerometer Used during Vibration Testing

The accelerometer mounted at 7-8 different locations during the vibration testing. When testing is in Longitudinal direction accelerometer mounted on Zenith side and when in lateral direction 2 accelerometer mounted on the corresponding side panel (Leading in X direction and anti-sunside in Y direction). 3 accelerometer mounted inside the satellite on 3 PCB cards OBC,ADC,Power on three mutually perpendicular directions. Controller is also mounted on the bottom bigger fixture ring. Accelerometer mounted on the power card was not working during the testing done for Y axis. Therefore the results interpreted for Y direction testing is only through accelerometer response which are mounted on anti-sunside.

### 5.2.3 Results

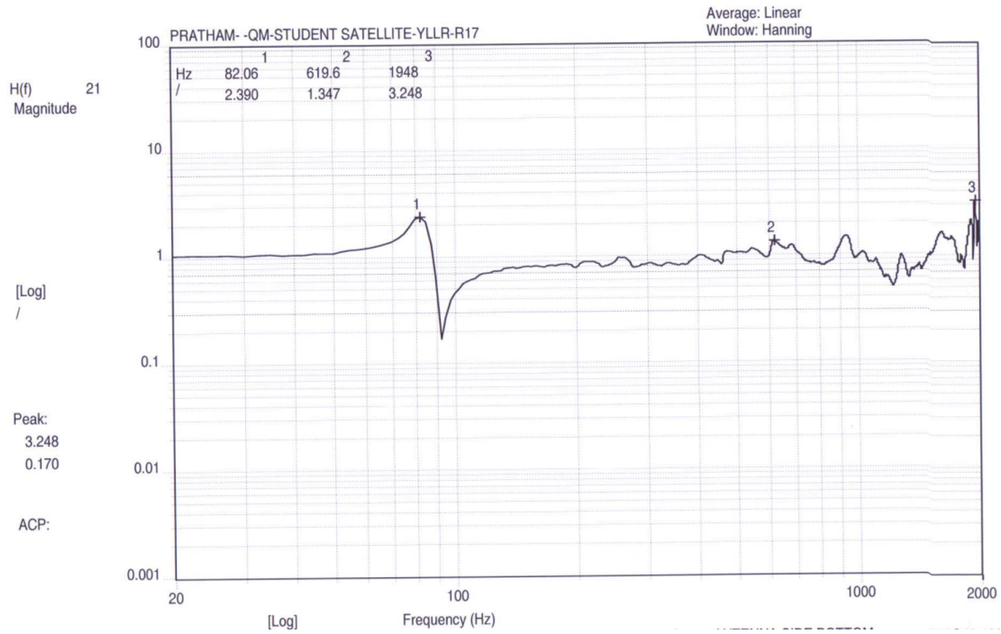



Figure 5.11: Frequency Response on Bottom of Anti-sunside during YLLR

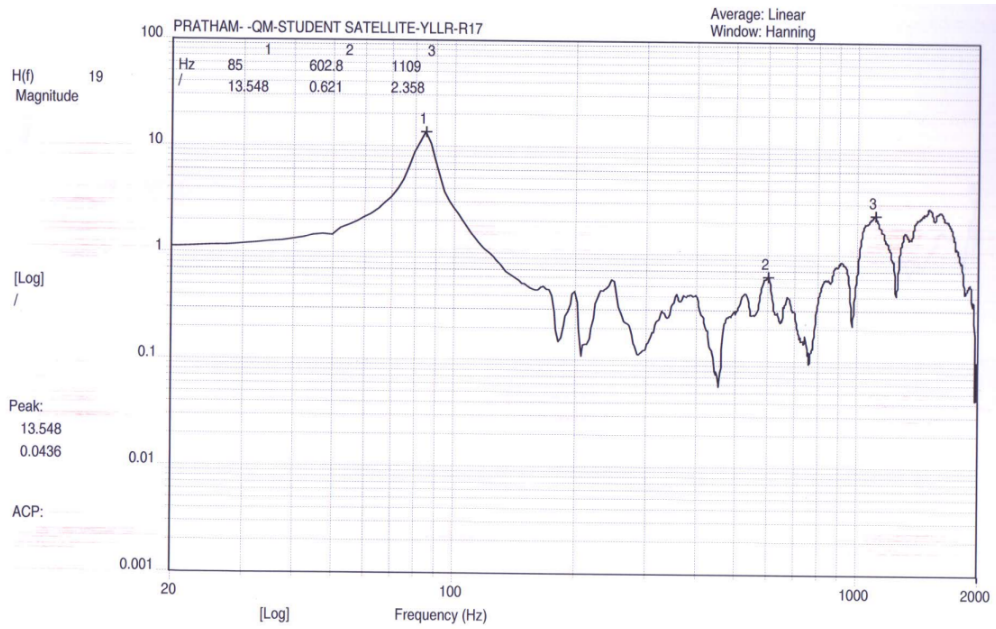



Figure 5.12: Frequency Response on Top of Anti-sunside during YLLR

From the above Low level random response for Y direction peak was observed at all locations around the frequency of 83Hz. Which shows the 1st global mode in Y direction.

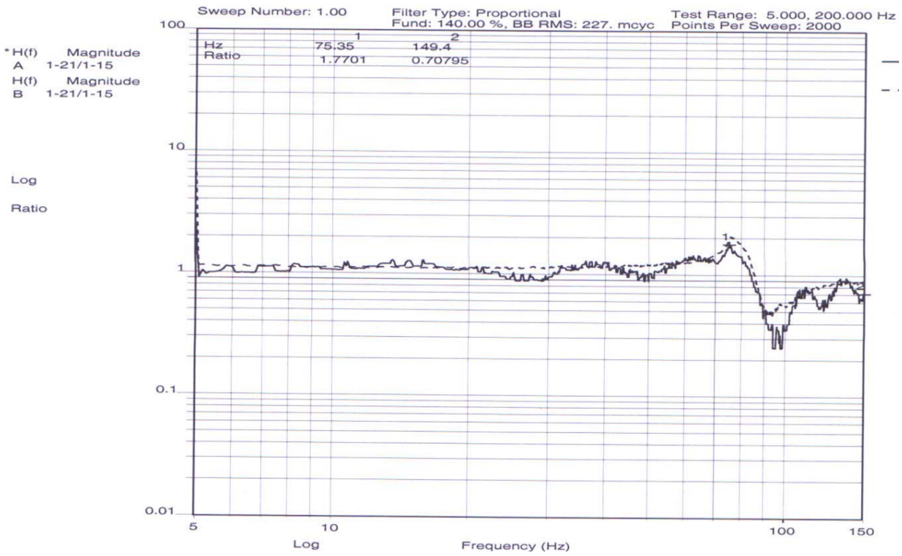



Figure 5.13: Frequency Response on Bottom of Anti-sunside during YLLS

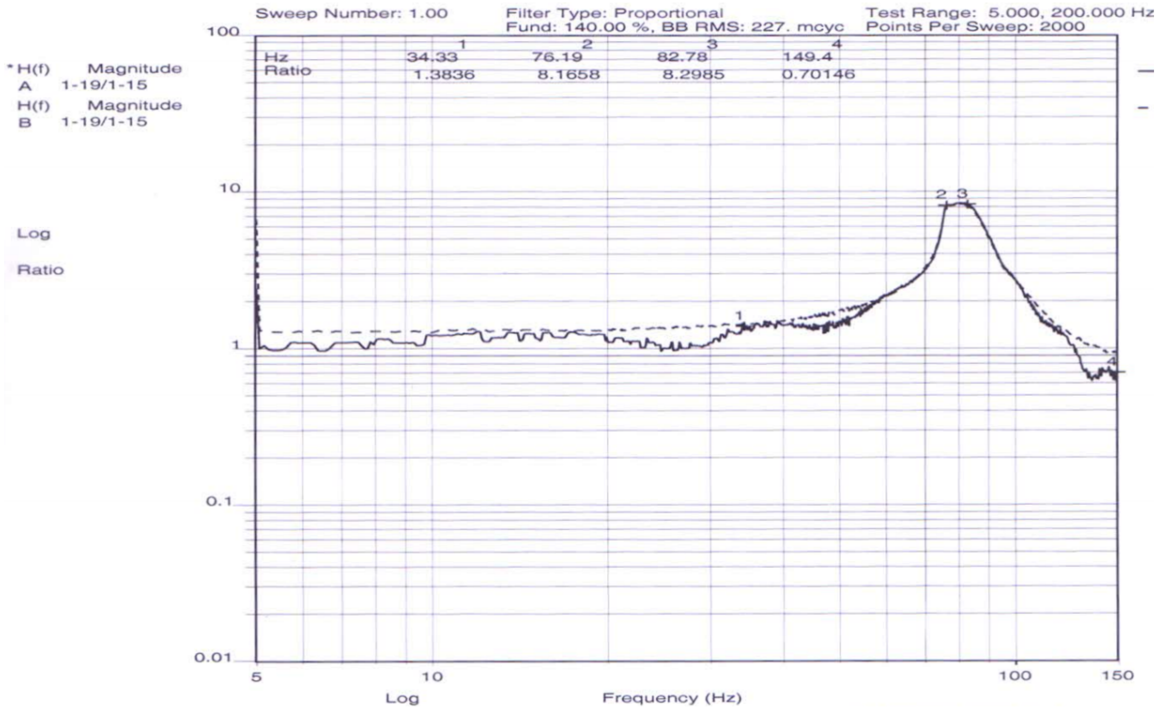



Figure 5.14: Frequency Response on Top of Anti-sunside during YLLS

From the above Low level Sine response for Y direction peak was observed at all locations around the frequency of 75Hz.

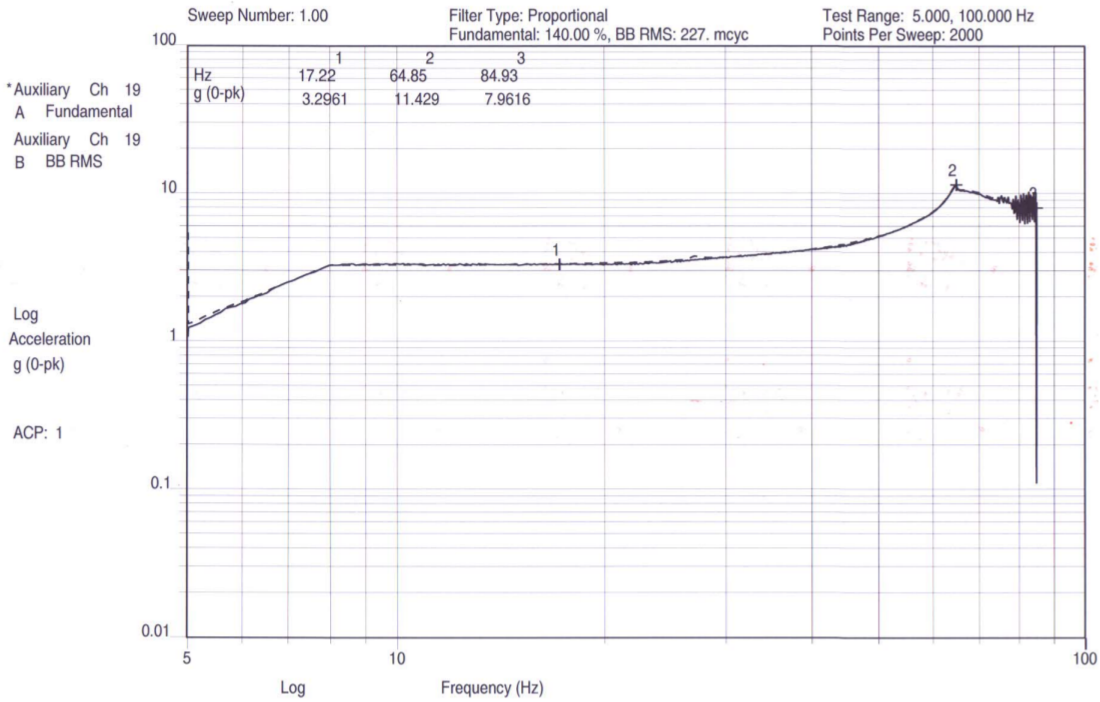



Figure 5.15: Frequency Response on Top of Anti-sunside during YQLS

The above frequency response plot is done in Y direction for qualification level sine. The peak is observed around 70Hz and a sudden break at 75 Hz is due to abortion and it was continued later.

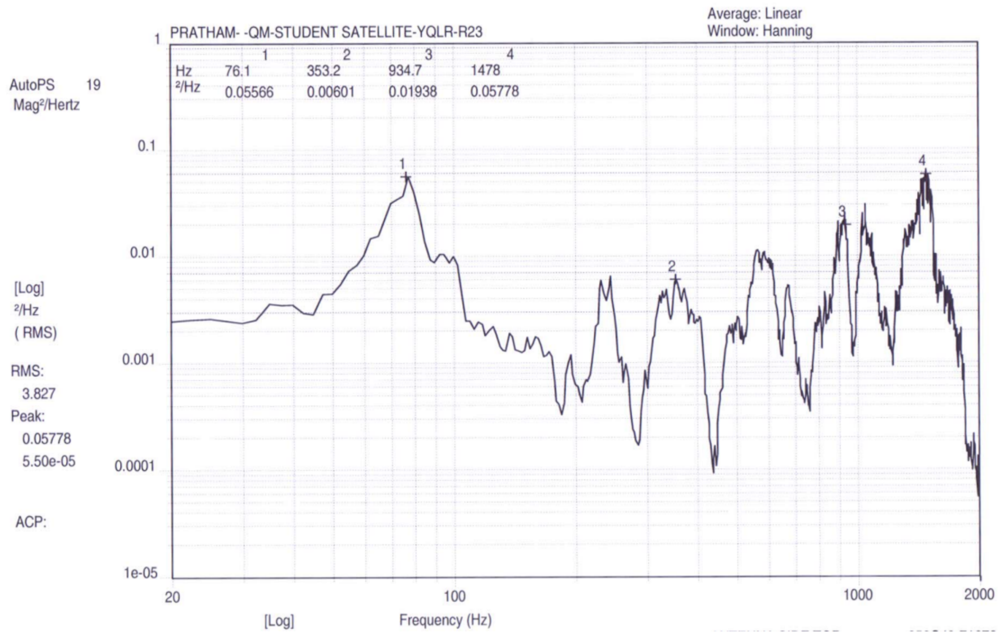



Figure 5.16: Frequency Response on Top of Anti-sunside during YQLR

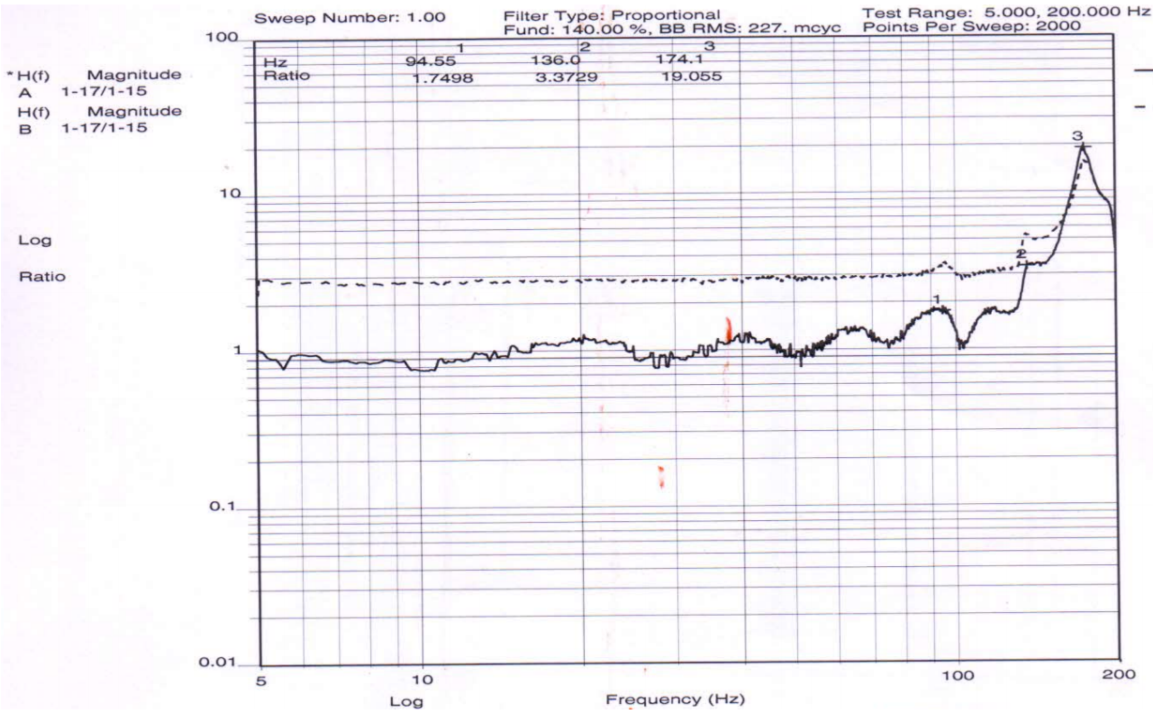



Figure 5.17: Frequency Response on ADC Board during ZLLS

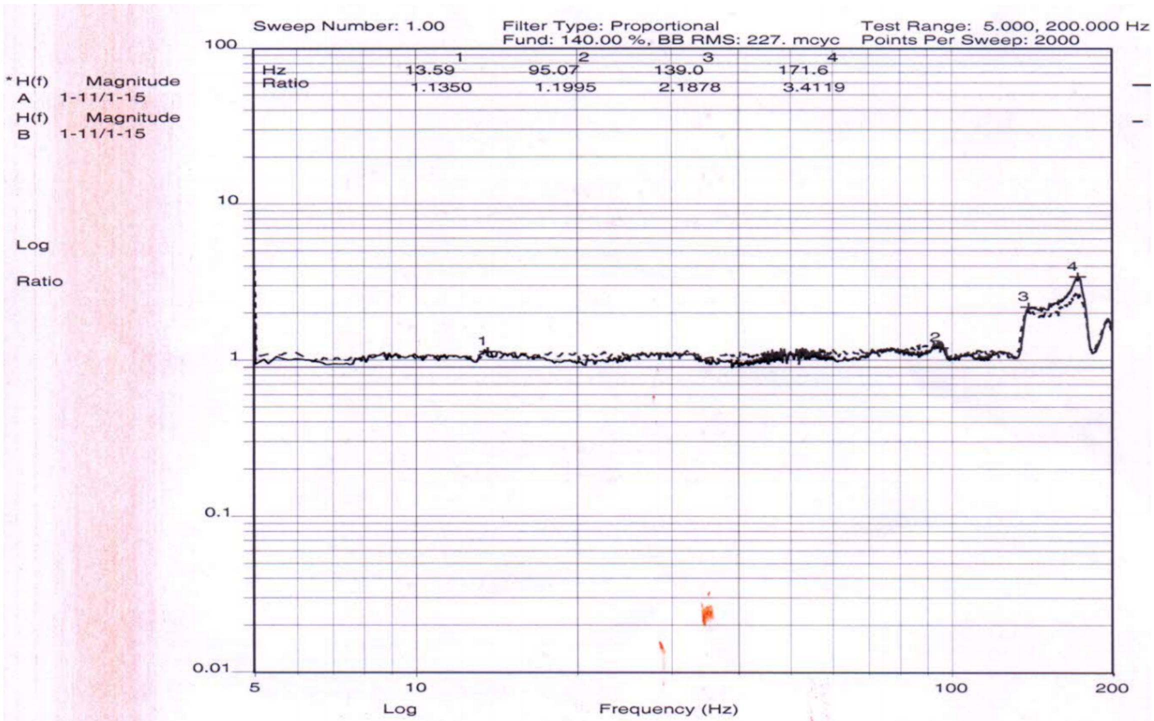



Figure 5.18: Frequency Response on Fixture near Leading Side during ZLLS

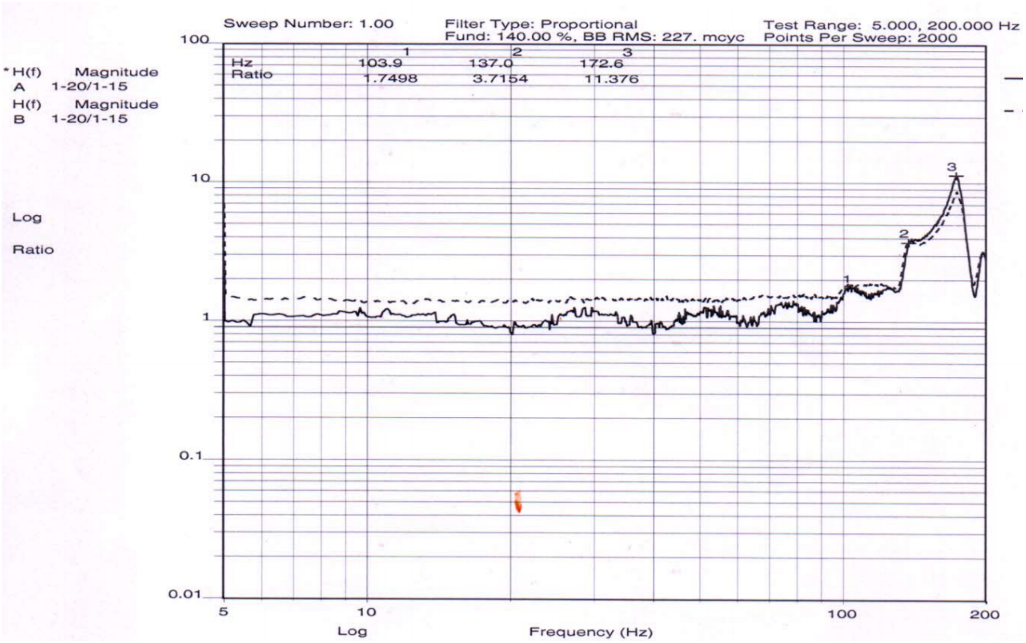



Figure 5.19: Frequency Response on Zenith Side Panel during ZLLS

In all the above three low level sine response plot for Z direction peak is observed around 170 Hz. Which show the 1st global mode at 170 Hz for Z direction. Due to the peak observed at such frequency the amplitude of input given during qualification level test on the same direction is lowered around such frequency range.

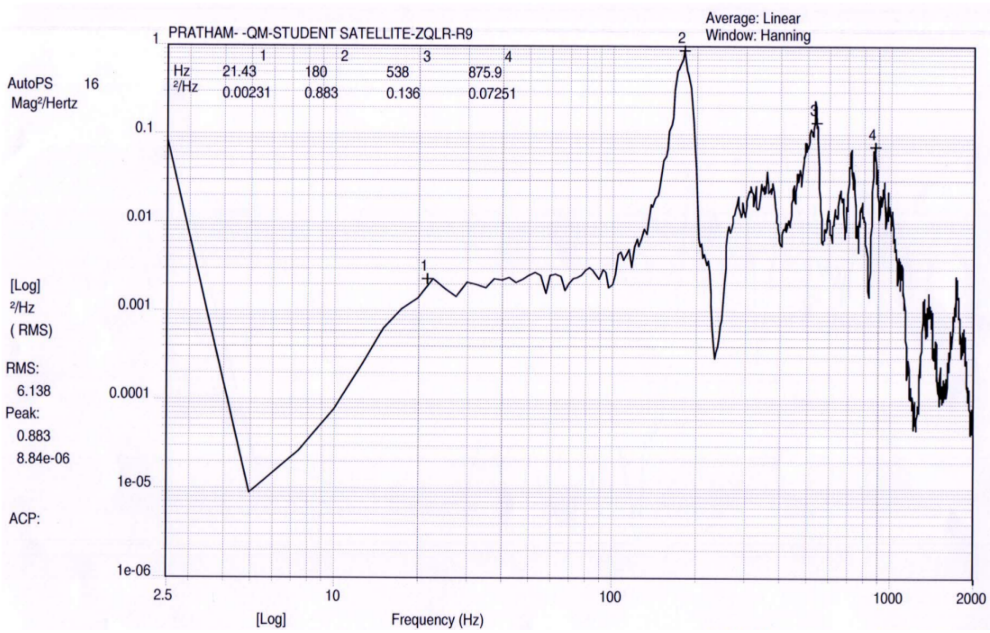



Figure 5.20: Frequency Response on ADC Board during ZQLR

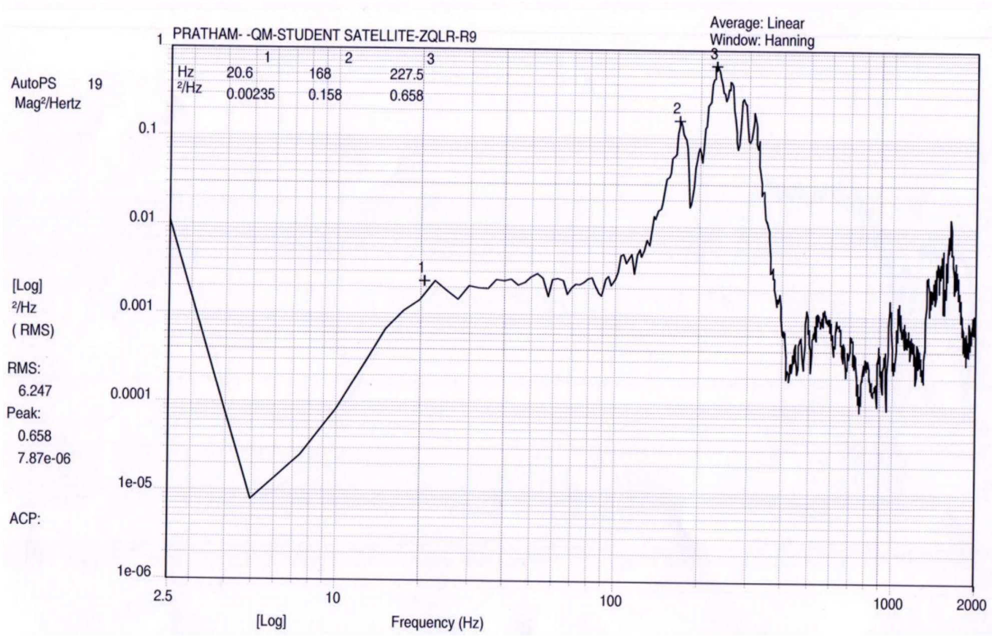



Figure 5.21: Frequency Response on Zenith Side Panel during ZQLR

From the above two Qualification level response plot for Z direction the peak observed at the same frequency of around 170 Hz. A small dip before the 20 Hz is of no use because the results are taken above 20 Hz.

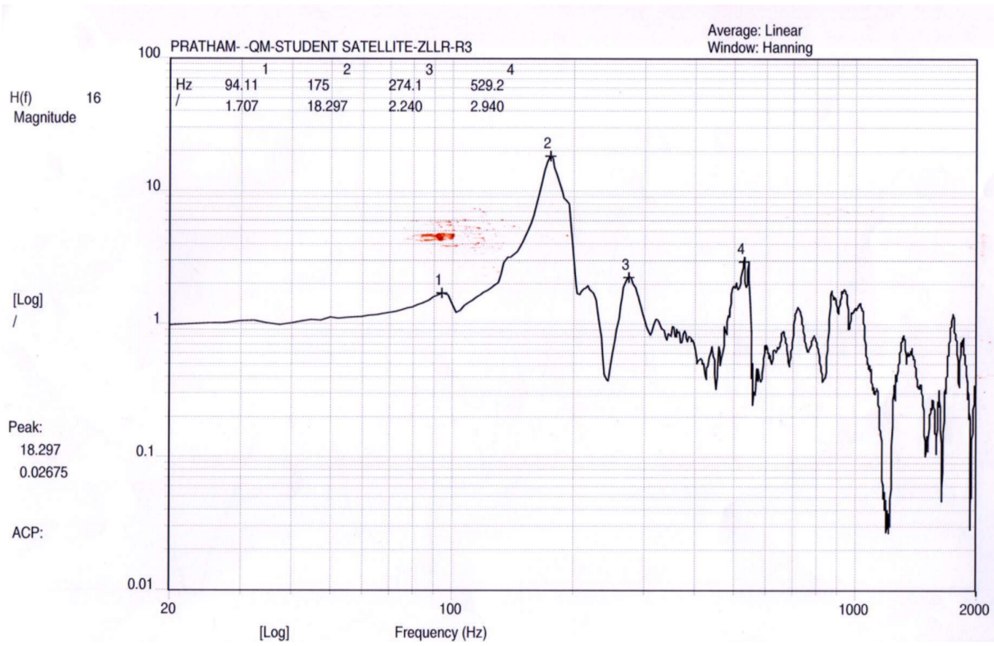



Figure 5.22: Frequency Response on ADC Board during ZLLR

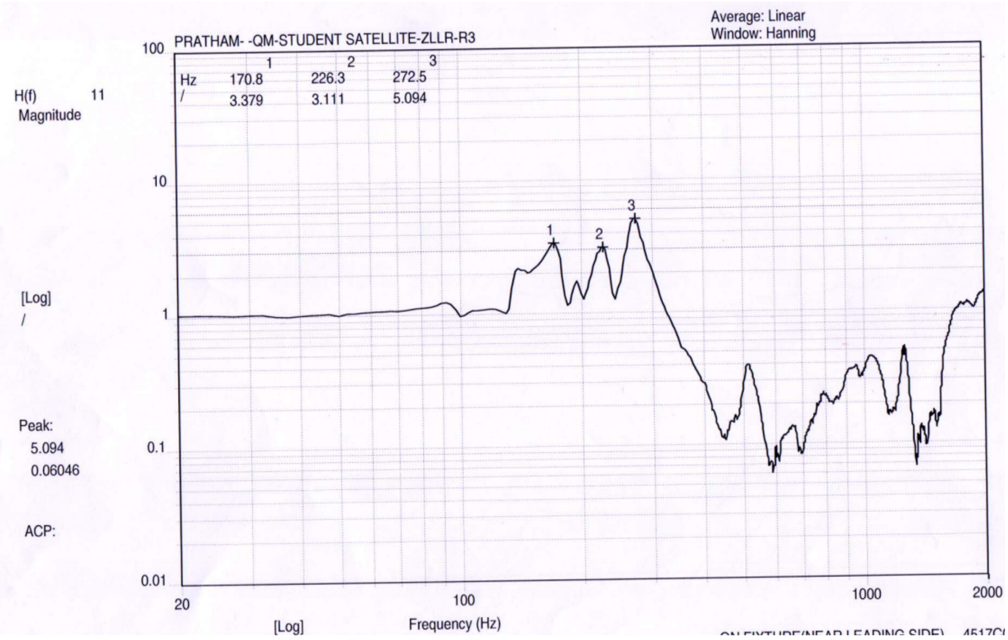



Figure 5.23: Frequency Response on Fixture near Leading Side during ZLLR

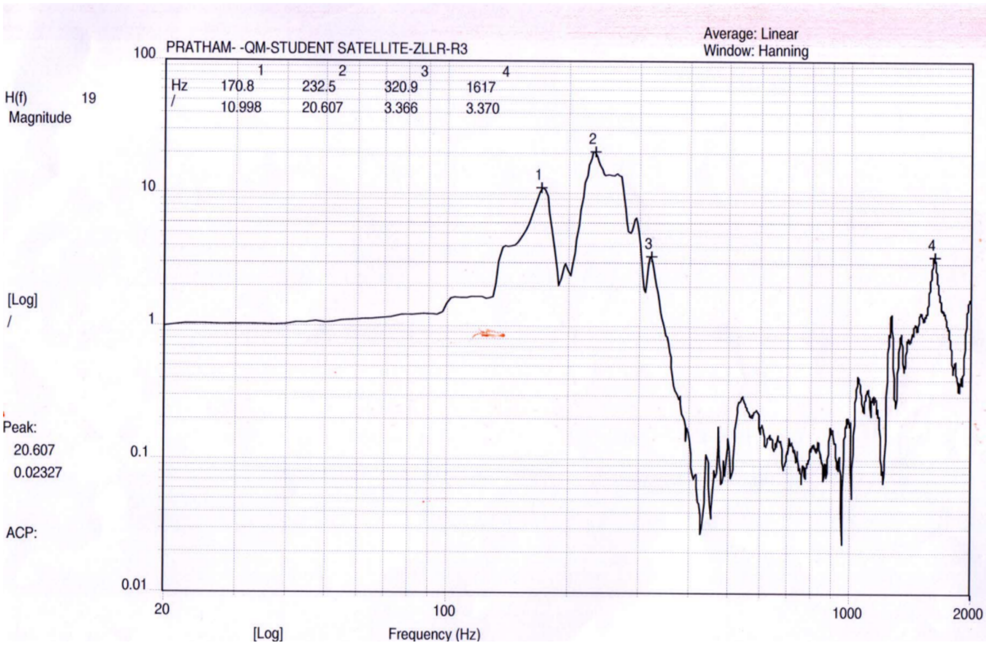



Figure 5.24: Frequency Response on Zenith Side Panel during ZLLR

The above three frequency response plot at different locations of low level random in Z direction is observed. At frequency 170Hz there is peak observed at all locations which confirm the 170 Hz as the global mode. The other peak like at 274 Hz for ADC card might be the PCB mode and at 320 Hz for Zenith side panel might be the side panel mode.

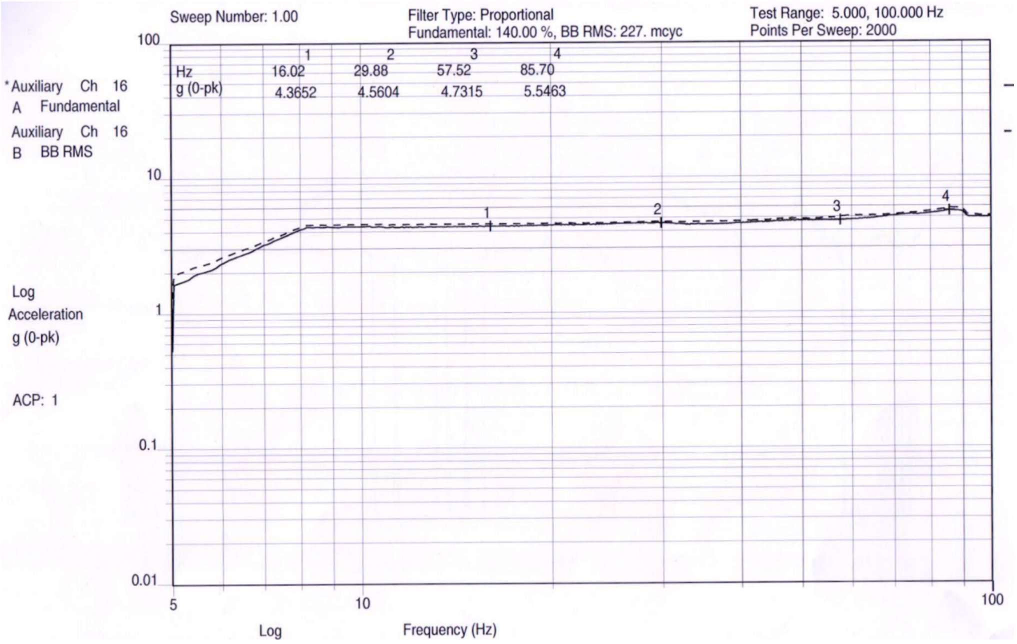



Figure 5.25: Frequency Response on ADC Board during ZQLS

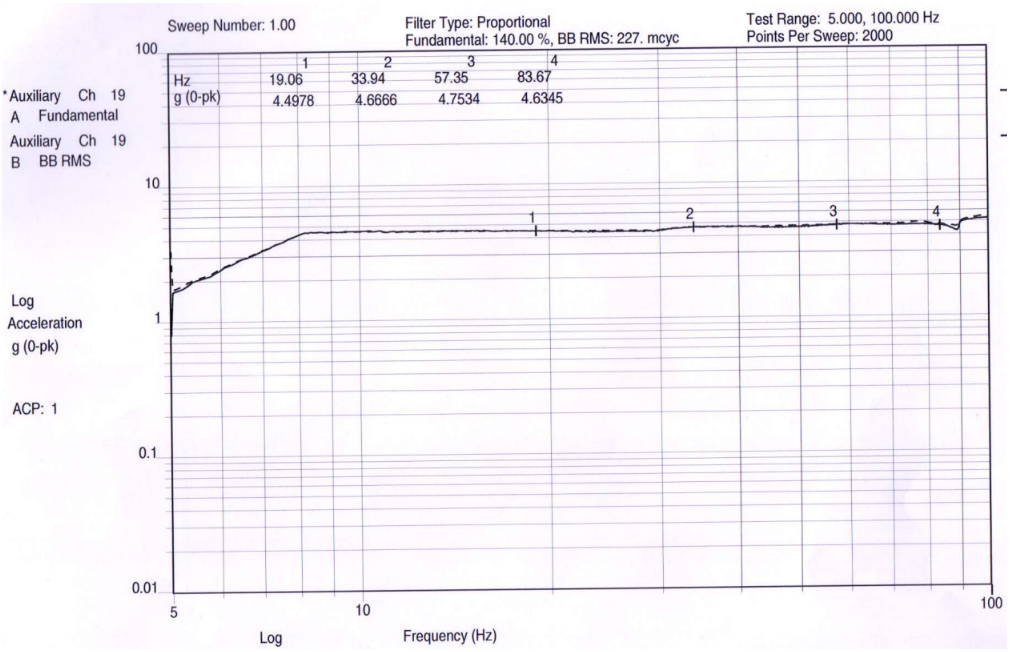



Figure 5.26: Frequency Response on Zenith Side Panel during ZQLS

The above Qualification level sine frequency response plot shows the constant magnitude plot of around 4.5g everywhere, which is the qualification level amplitude.

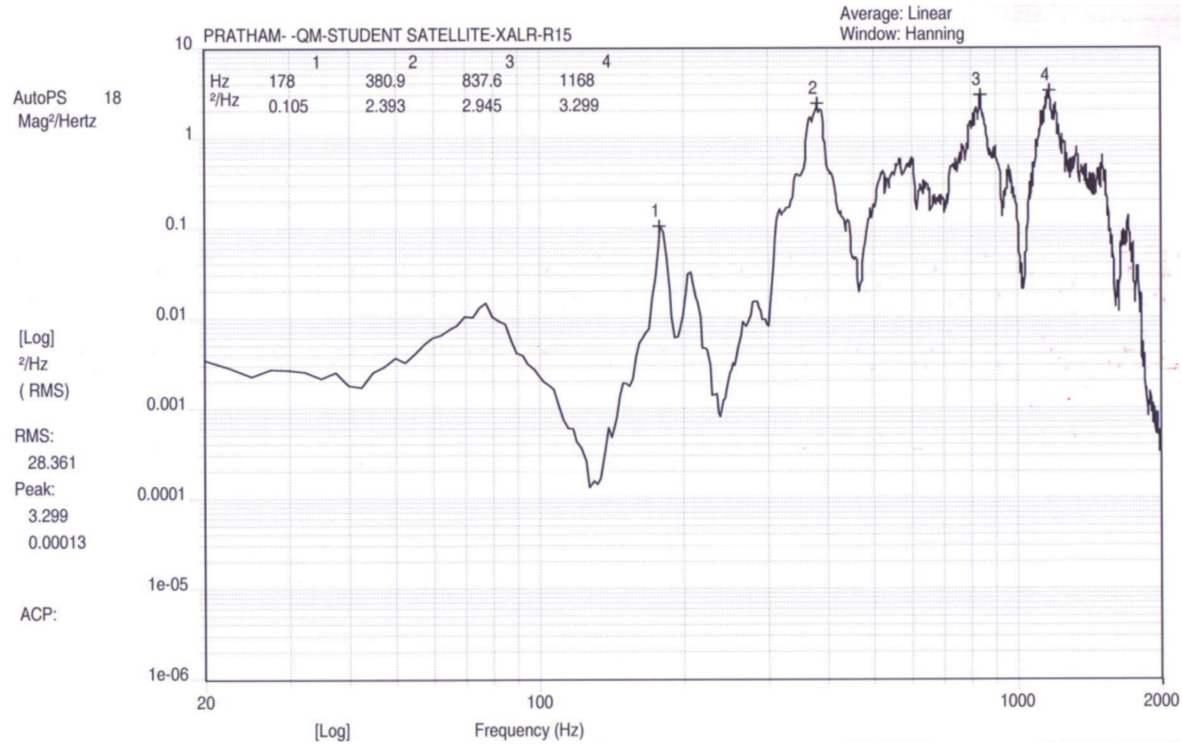



Figure 5.27: Frequency Response on OBC Board during XALR

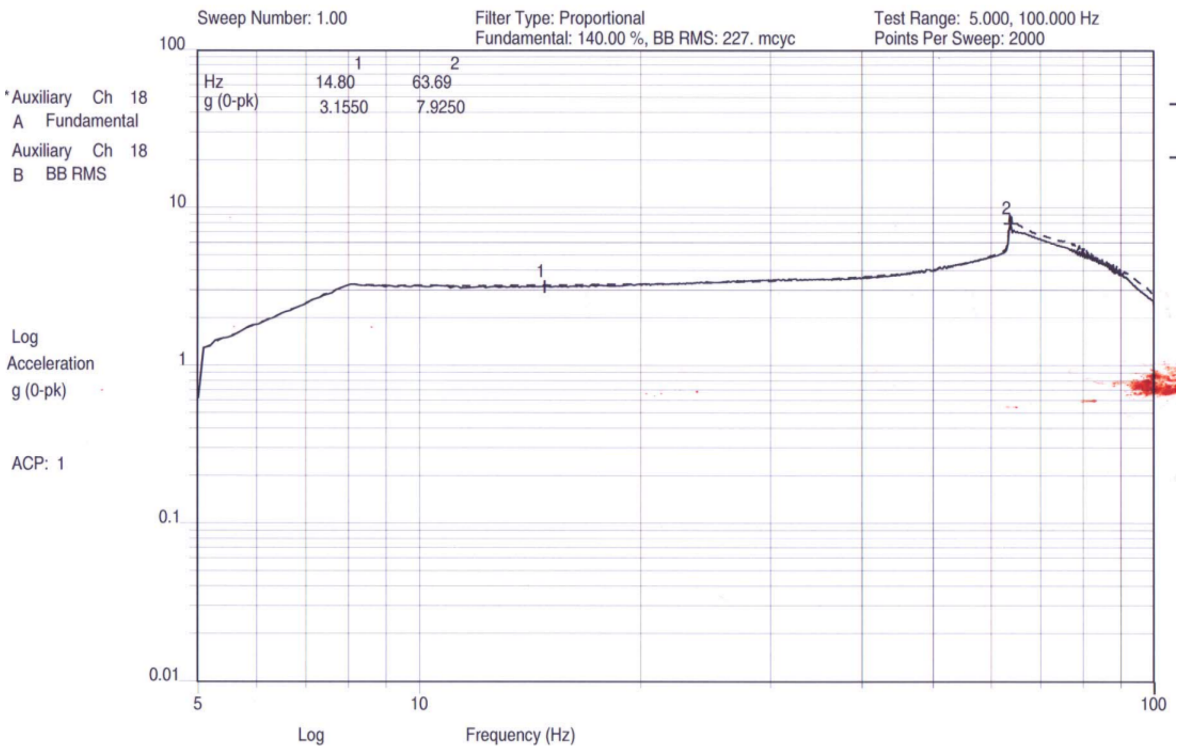



Figure 5.28: Frequency Response on OBC Board during XALS

The above plot of acceptance level sine for X direction shows the constant magnitude plot with peak around 70 Hz and a dip at last possibly due to notching done.

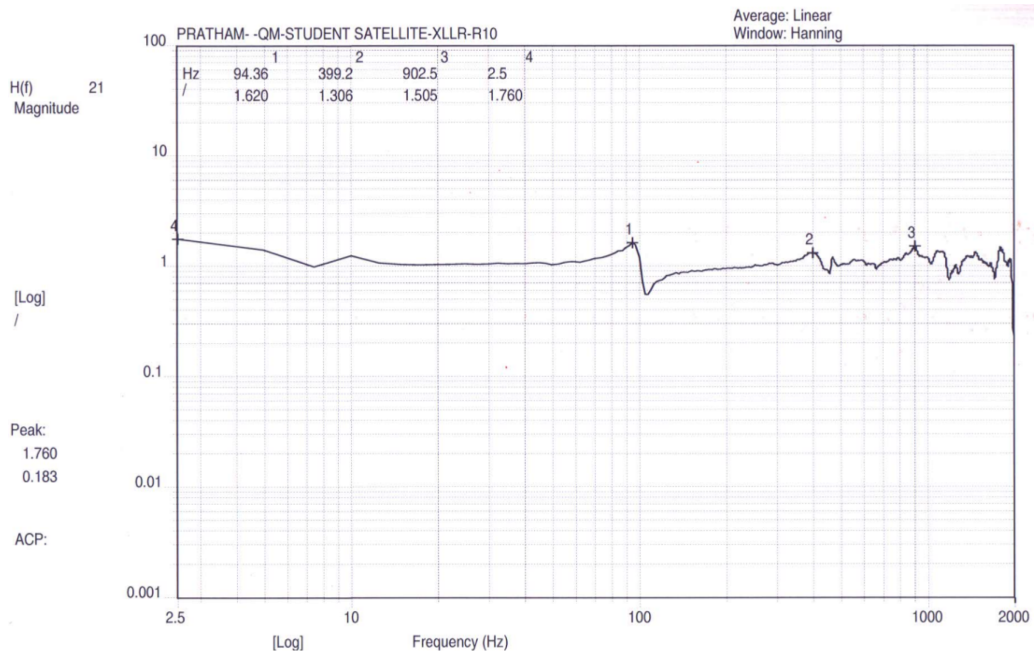



Figure 5.29: Frequency Response on Bottom of Leading Side Panel during XLLR

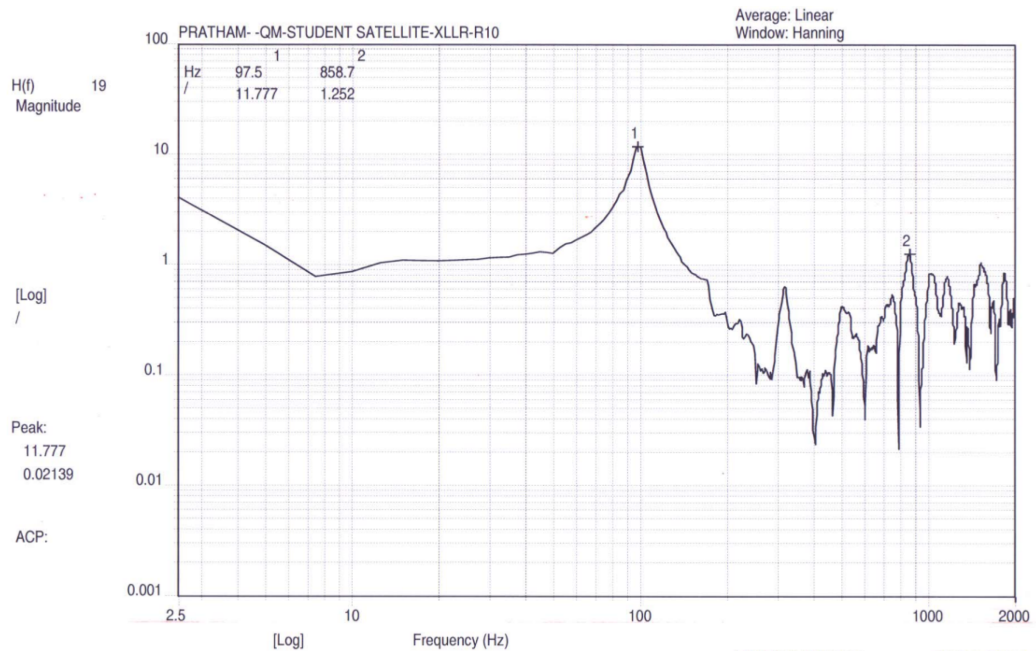



Figure 5.30: Frequency Response on top of Leading Side Panel during XLLR

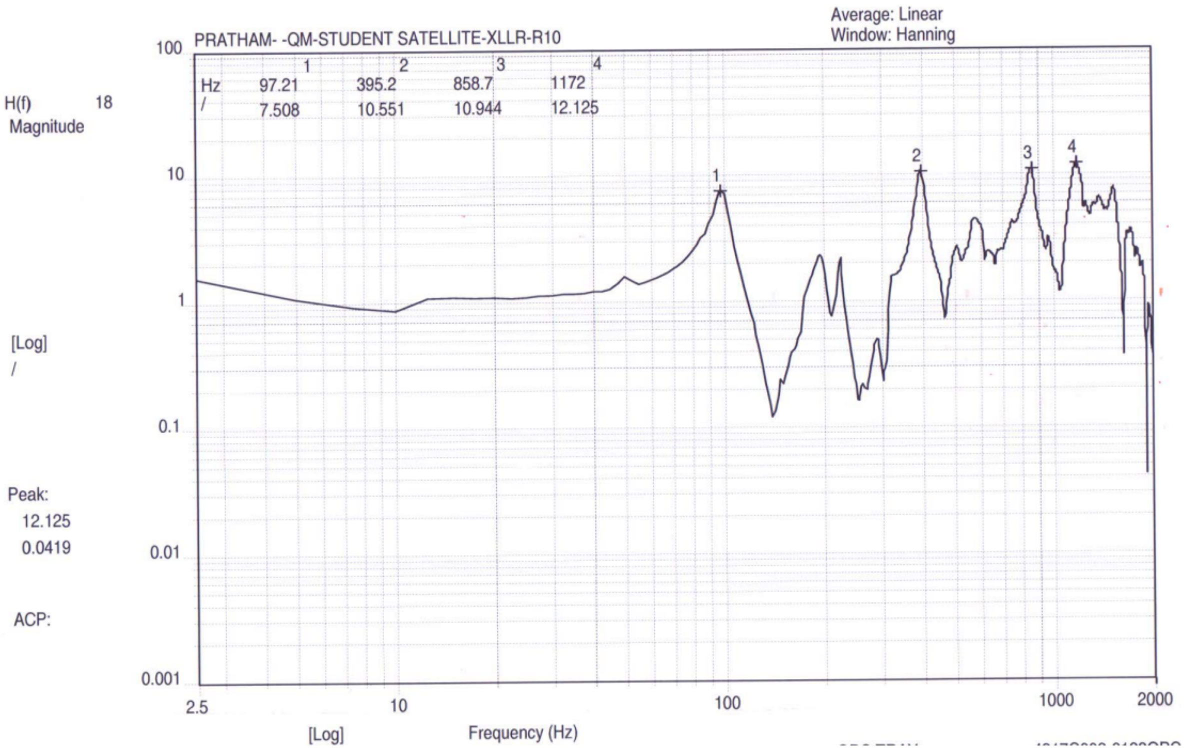



Figure 5.31: Frequency Response on OBC Board during XLLR

The above three plot shows the frequency response plot for low level random testing in X direction. 1st peak for all the three plot is at 95 Hz which confirm the 1st global mode in X direction.

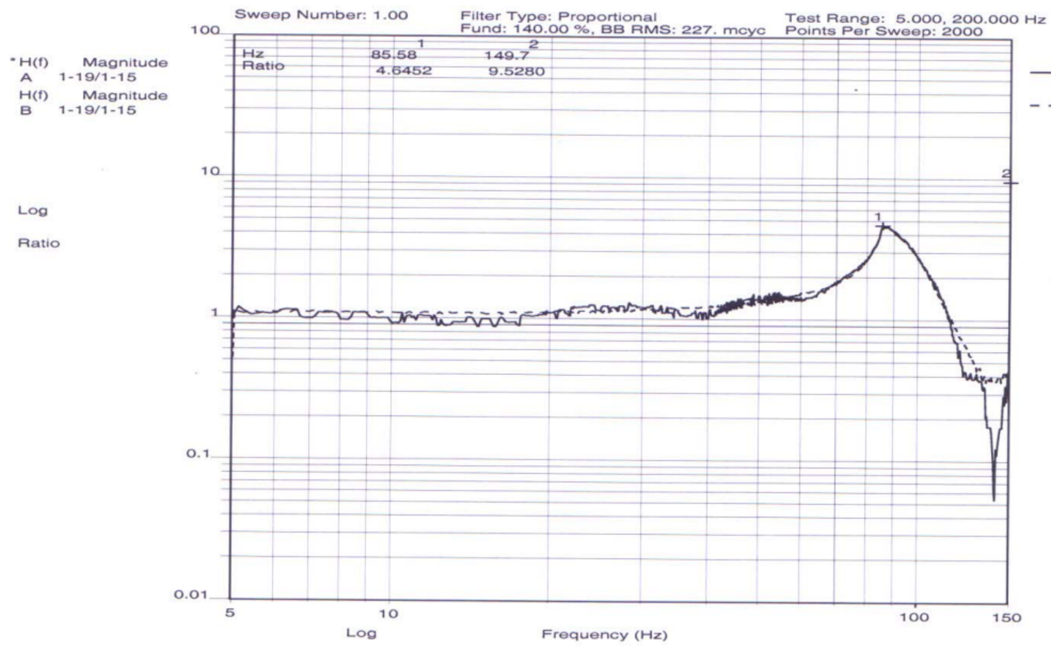



Figure 5.32: Frequency Response on OBC Board during XLLS

The frequency response is plotted for low level sine in X direction. Above plot only shows the response of OBC card. The peak observed in all the other low level sine plots along with the above OBC card plot is at 85 Hz. Which shows the 85 Hz as the 1st global frequency in X direction.

| **Direction of Testing** | **Modal Frequency from Testing** | **Modal Frequency from Simulation** |
|---|---|---|
| X (leading to Lagging) | 84 | 122 |
| Y (Antisun to Sunside) | 95 | 150 |
| Z (Nadir to Zenith) | 172 | 187 |

Table 5.4: Frequency Comparison between Testing and Simulation

# Chapter 6

# Validation

## 6.1 Validation of Static Results

### 6.1.1 Only Longitudinal Load of -7g applied

1. Assuming satellite to be symmetric the longitudinal load will be uniformly distributed on all M6 screws of FE ring.
2. Force on each screw due to load of -7g $= -7 * m * g/8 = -84.89N$
3. Area of Cross section of screw $28.27mm^2$
4. Stress on each screw = -3 MPa

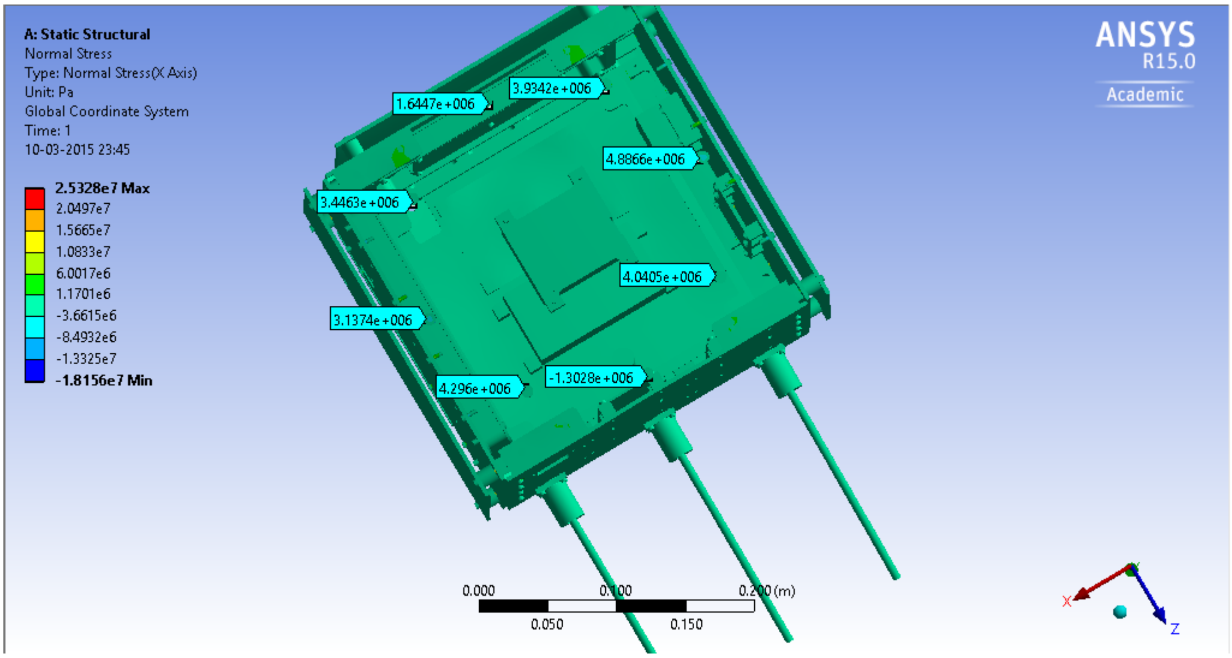



Figure 6.1: Validation of Static Load

### 6.1.2 Only Lateral Load Applied

#### Shear stress

1. Assuming satellite to be symmetric the shear force due to lateral load will be uniformly distributed on all M6 screws of FE ring.
2. Since the satellite is more symmetric about the Y-Z plane the lateral load used for validation is applied in X direction(i.e from Lagging to Leading side)

3. Shear force on each screw due to load of 6g in X direction $= 6 * m * g/8 = 72.77N$
4. Stress in each screw = 2.57MPa

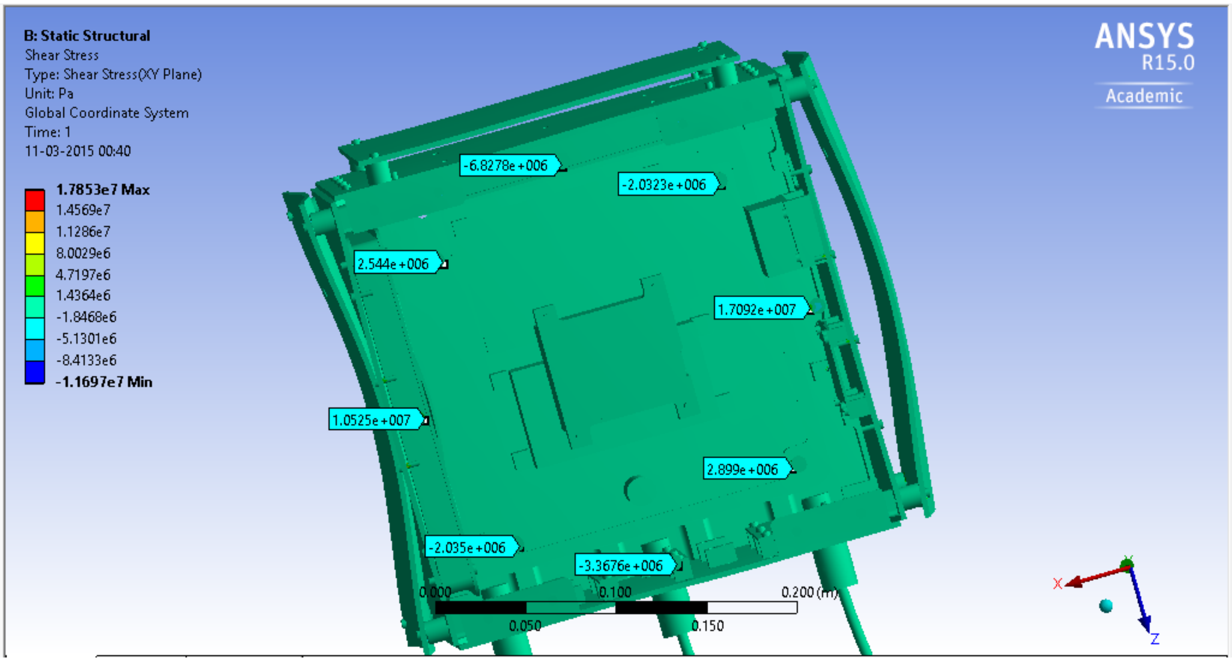



Figure 6.2: Validation of Lateral Load

### Normal stress

1. Due to application of the Lateral load there is a moment generated at the base of the FE ring. This leads to development of normal force on the screws of the FE ring.
2. Due to symmetry and the fact that there is no longitudinal load screws along the Z axis will have 0 normal stress
3. The normal forces on the screws is directly proportional to their X coordinate (sign included)
4. Equating the torque due to each screw to the total moment generated, Max Normal force $= 3 * m * g * l/2 * D = 166.87N$
5. Max Normal stress(on screws 3 and 7) = 5.9MPa

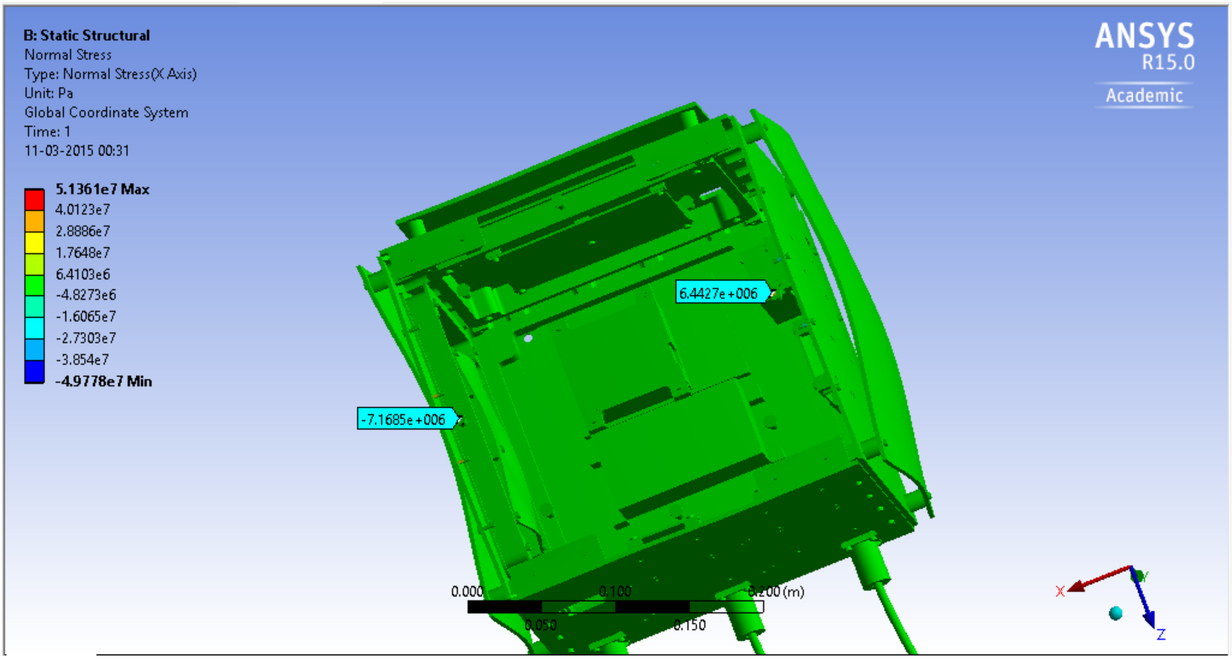



Figure 6.3: Validation of Lateral load

## 6.2 Validation of Modal Results

### 6.2.1 Validation of elements used in Ansys

ANSYS Workbench automatically selects which elements to use for meshing. It is important to first validate the element. For validation, results obtained from modal analysis of aluminium plate are compared to the theoretical results for first natural frequency. The formula used for the theoretical calculation of natural frequency is the formula used in Roark's formulae for stress and strain. The natural frequency of the plate with all sides fixed is given by:

$$f = \frac{k_1}{2\pi}\sqrt{\frac{Dg}{wa^4}}$$

Where f is the natural frequency of the plate, k1 =36 if length = breadth, w/g is mass per unit area, and D is given by:

$$D = \frac{Et^3}{12(1-\gamma^2)}$$

Here E is the modulus of elasticity, t is the thickness and ? is the Poisson's ratio. The result obtained using this formula was used to validate the element for the case of modal analysis. Geometry considered is a plate of sides 230x230x230 mm and of thickness 6mm with material properties of Al6061T6. The results obtained for first natural frequency are tabulated below.

| **Theoretical** | **By simulation** |
|---|---|
| 1001.32 Hz | 999.6 Hz |

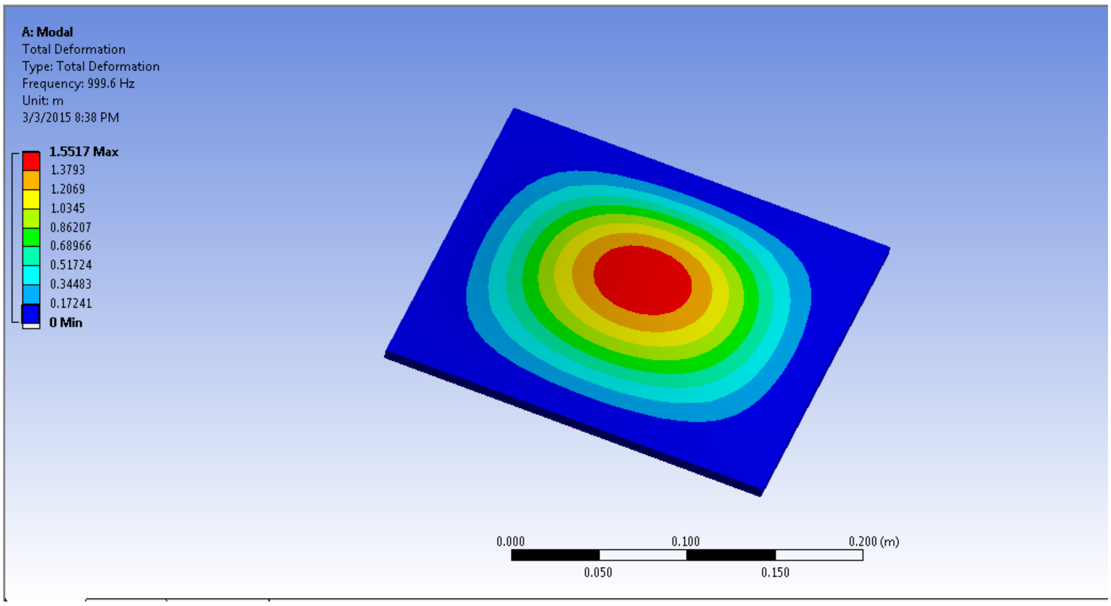



Figure 6.4: Thin plate validation

### 6.2.2 Validation of Satellite Model

#### Only antennas modeled

In this geometry, only the antenna was modeled. The base of the outer cover (monopole holder) was fixed. The first 2 resonant frequencies were obtained. Since the first 6 modes of the structure are antenna modes, the 2 modes extracted from this model serve as a good representative of the first 2 QM modes.

| **Mode** | **Satellite Model frequency [Hz]** | **Antenna Model Frequency [Hz]** |
|---|---|---|
| 1 | 127.23 | 157.65 |

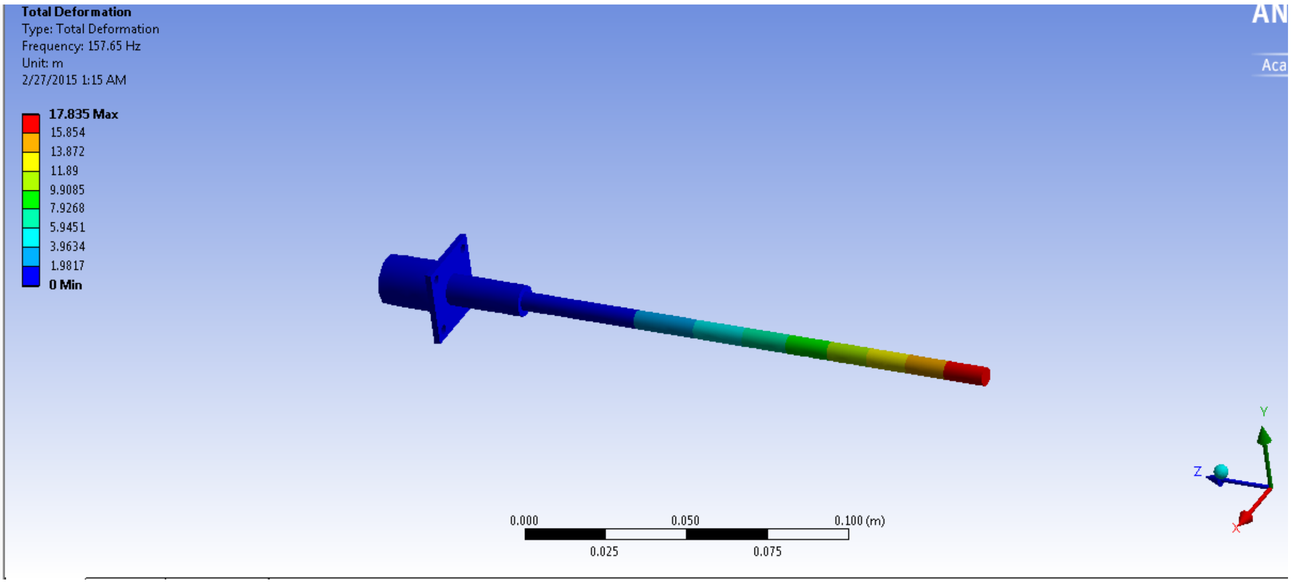



Figure 6.5: Antenna validation

# Chapter 7

# Handle Design and Simulations

According to the rules of ISRO any satellite must have a mechanism of transportation inbuilt in them. For this purpose we have modeled a handle of two 'C' shape connected to each other. Model is so well placed on Sun-side and Anti sun-side such that it does not interfere with solar panels. It is designed to sustain the whole satellite in longitudinal and lateral direction too so that it can be carried easily.

## 7.1 Modeling

The four rectangular plates of handle are attached to Anti Sun-side and Sun-side by using M3 screws, two in each plates..

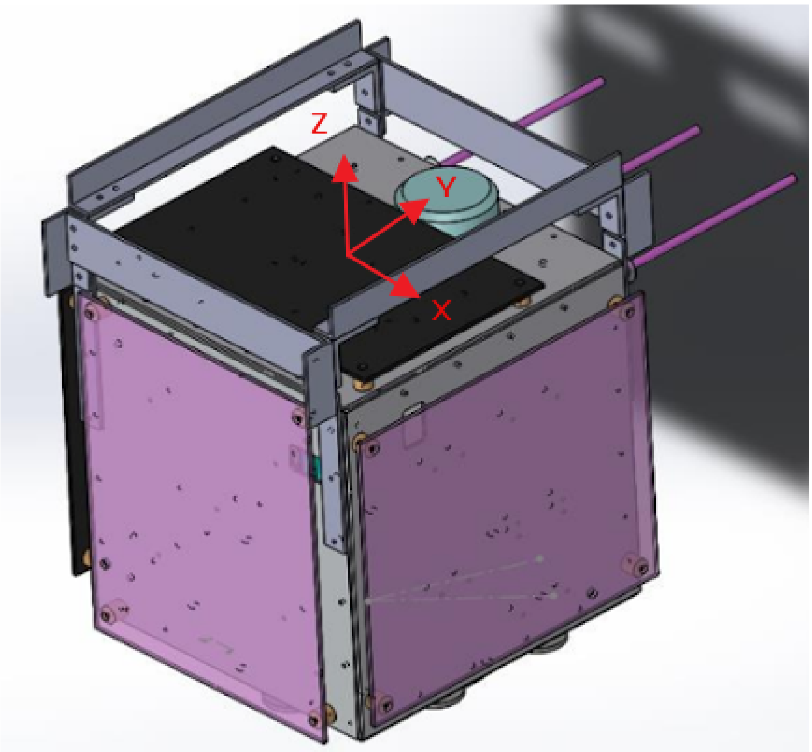



Figure 7.1: Satellite Handling Design

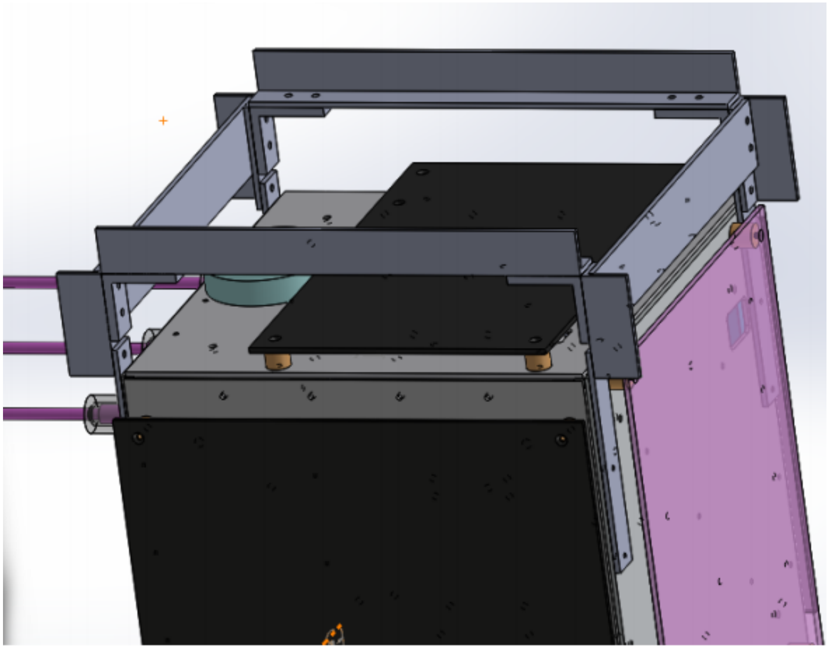


Figure 7.2: Satellite Handling Design

## 7.2 Analysis

Since the Handle is to be removed at the time of testing, only static analysis has been done on the model and the load applied is equal to the weight of the satellite. This is because Weight is the only load that the satellite prominently encounters at the time of transportation

### 7.2.1 Static Analysis

1. Aim of Analysis: To determine the stress developed due to its own weight
2. **Type of Analysis:** Static
3. **Material Properties:** As given in section 8.1
4. **Constraints:** Aiming at real scenario the middle part (100mm length) of the uppermost two parts of handle was constrained for movement in all directions as shown in figure 7.3. All the screw joints are rigidly linked.

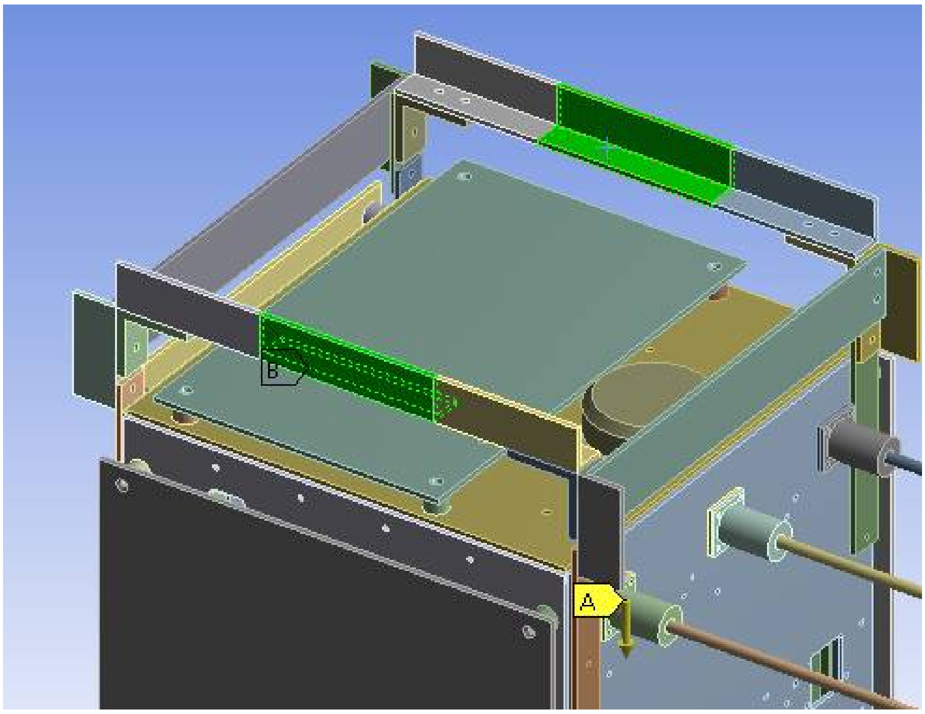



Figure 7.3: Handle Fixed Support

5. **Loads applied and results:** The loads as specified in table 7.1 were applied in different combinations on the model. The results are presented in the same table.

| Sl no. | Acceleration Direction | Value | Max Stress (MPa) | Location |
|---|---|---|---|---|
| 1 | Longitudinal (zenith to nadir) | -9.81 | 9.645 | Top most handle part, M4 screw |
| 2 | Longitudinal (zenith to nadir) and Lateral(lagging to leading) | -9.81, 9.81 | 22.001 | M3 screw SS |
| 3 | Longitudinal (zenith to nadir) and two Lateral(lagging to leading & SS to ASS) | -9.81, 9.81, 9.81 | 81.632 | M3 screw ASS |

Table 7.1: Static Loads and Results

6. **Simulation Figures**

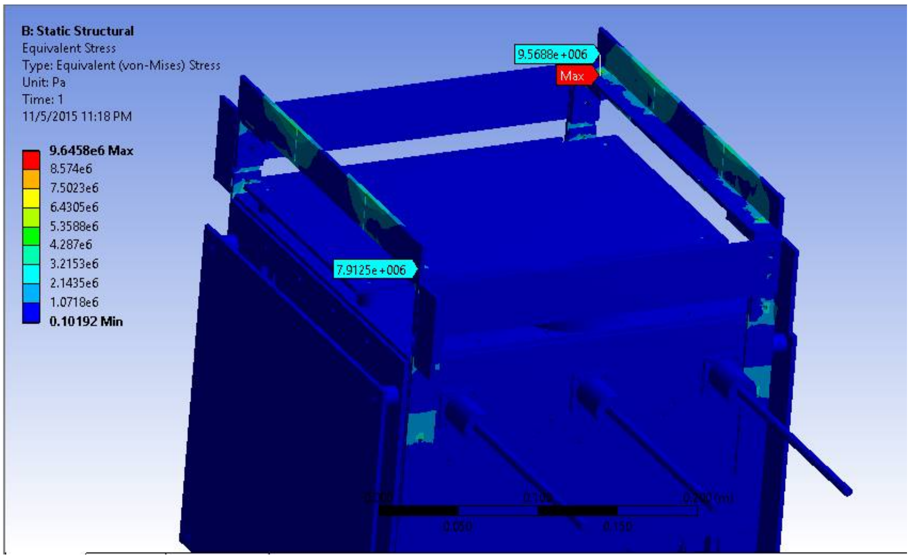



Figure 7.4: Longitudinal Loading

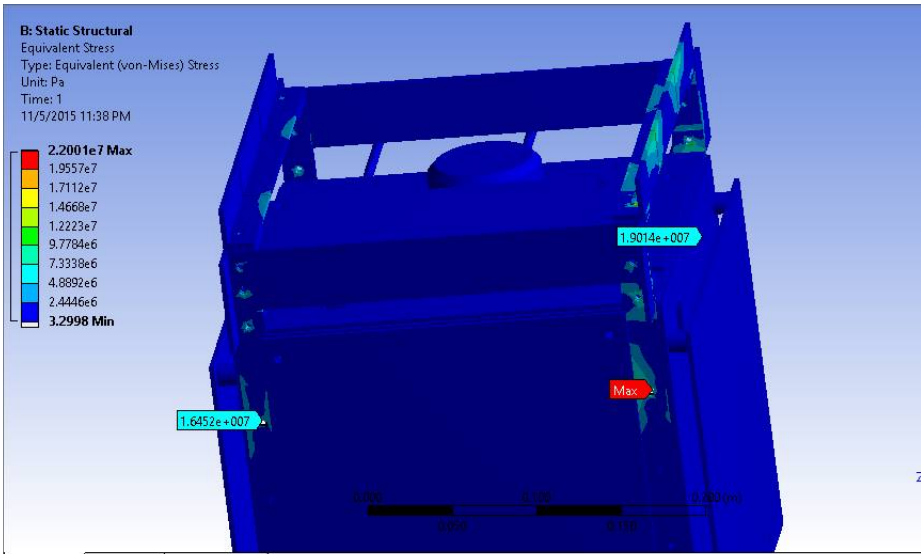



Figure 7.5: Longitudinal and Lateral Loading

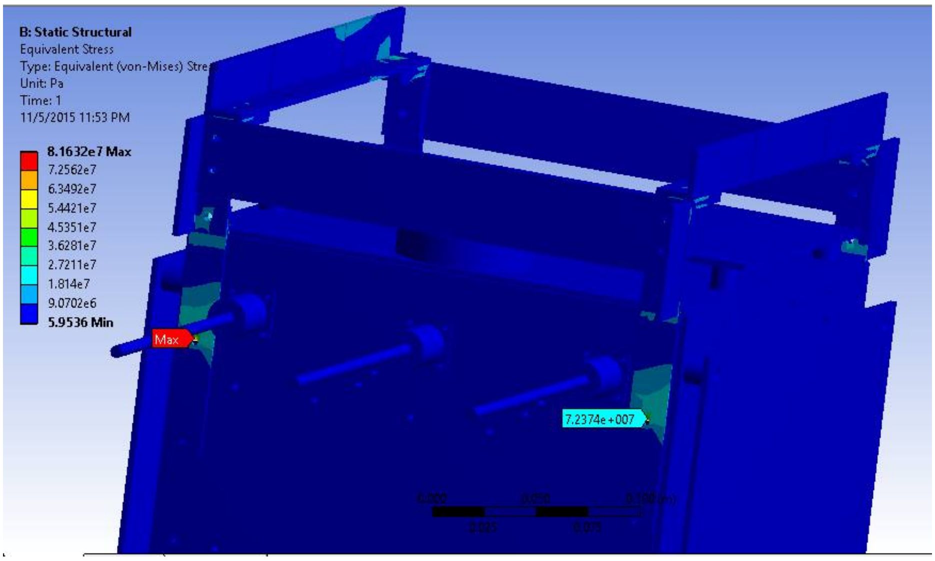



Figure 7.6: Longitudinal and Lateral loading in both directions

7. **Interpretation of results:** These results show that design is quite good enough to sustain its own weight. For simply gravity equivalent stress is 9.645 MPa. In worst case for the combination of three directional load results in 81.632 MPa which is appeared in a very small region. Its value decreases to around 40 MPa at points around 2-3mm distance

8. **Conclusion:** The satellite handle can withstand the complete load of the satellite without yielding

### 7.2.2 Modal Analysis

1. **Aim of Analysis:** To determine the resonance frequencies of the structure

2. **Type of Analysis:** Modal

3. **Material Properties:** As given in section 8.1

4. **Constraints Applied:** The FE ring, attached to the base of the Nadir was constrained for movement in all directions. All the screw joints are rigidly linked.

5. **Loads applied:** NIL

6. **No. of modes extracted:** 10

7. **Screenshot of Simulation:**

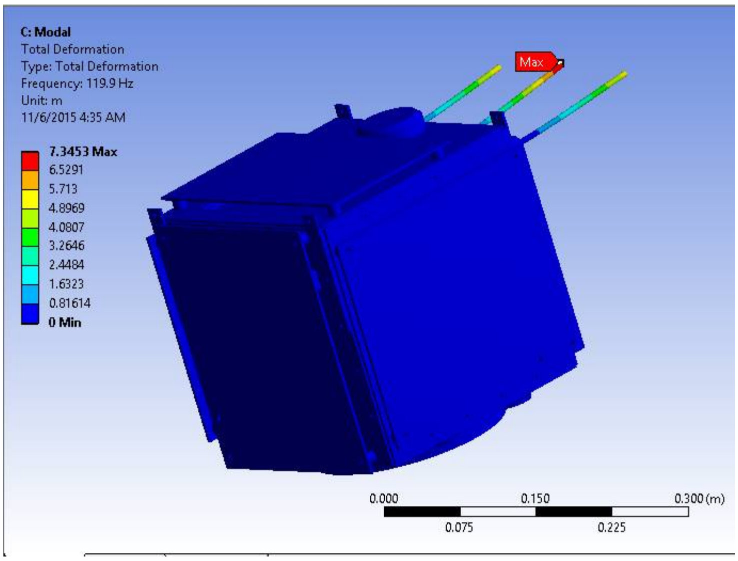



Figure 7.7: Longitudinal and Lateral Loading

| Mode | Frequency [Hz] | Mode | Frequency [Hz] |
|---|---|---|---|
| 1 | 119.9 | 6 | 127.5 |
| 2 | 123.78 | 7 | 129.71 |
| 3 | 124.11 | 8 | 154.23 |
| 4 | 126.51 | 9 | 162.79 |
| 5 | 126.73 | 10 | 166.0 |

Table 7.2: Modal Results

8. **Interpretation of Results:** The fundamental frequency is coming around 119.9 Hz. This frequency and subsequent frequencies are very close to results obtained previously. So the results and interpretation remains same.

# Chapter 8

# Appendix1:Material properties

## 8.1 Material Properties

| Property | Al 6016-T6 | SS 304 | FR04 | GFRP |
|---|---|---|---|---|
| **Density(kg/m^3)** | 2700 | 8000 | 1800 | 1800 |
| Ultimate Tensile strength (MPa) | 310 | 505 | 310 | 530 |
| Tensile Yield Strength (MPa) | 276 | 215 | 125 | 125 |
| Modulus of elasticity(GPa) | 68.9 | 193 | 24 | 26 |
| Poisson's Ratio | 0.33 | 0.29 | 0.136 | 0.28 |

Table 8.1: Material properties

| Material | Used in | Reason |
|---|---|---|
| Al 6061-T6 | Satellite body,<br>Solar panel backing plates<br>Monopole antennae | Ductile,<br>Lightweight,<br>Easily machinable,<br>Easily procurable,Cheap,<br>Sufficiently stiff,<br>Characterized for space applications |
| SS 304 | Screws, Helocoils | Easy Availability<br>Sufficiently stiff |
| FR 04 | Base of Circuit Boards | |
| GFRP | Washers | |

Table 8.2: Materials Used

| **Sl. No.** | **Material** | **Component Type** | **Components** | **X= 3g, Y= 4.5g, Z= 0** | **X= 0, Y= 4.5g, Z= 6g** | **X= 6g, Y= 0, Z= 6g** |
|---|---|---|---|---|---|---|
| | | | | **Max MPa** | **Max (Mpa)** | Max (Mpa) |
| 1 | | | Whole body | 25.172 | 22.582 | 12.994 |
| 2 | FR 04 | PCBs | Downlink | 1.0405 | 1.0963 | 1.1717 |
| 3 | | | Beacon | 0.8815 | 1.2734 | 0.96868 |
| 4 | | | Uplink | 1.4435 | 0.70176 | 0.8123 |
| 5 | | | Power | 0.7107 | 2.8262 | 2.3543 |
| 6 | | | OBC | 2.0287 | 0.6831 | 2.2364 |
| 7 | | | Sunsensor Board | 2.6216 | 1.9792 | 0.9101 |
| 8 | Al 6061-T6 | Solar Panel | Solar-panel Sunside | 6.6566 | 12.514 | 12.994 |
| 9 | | | Solar panel Lagging | 12.427 | 1.7736 | 12.732 |
| 10 | | | Solar panel Leading | 12.233 | 1.7914 | 11.556 |
| 11 | | | Solar panel Zenith | 25.172 | 21.65 | 2.8944 |
| 12 | | Side Panels | Sunside | 5.6798 | 5.2296 | 1.4706 |
| 13 | | | Leading | 7.8696 | 6.7755 | 1.3009 |
| 14 | | | Nadir | 21.982 | 22.582 | 1.5014 |
| 15 | | | Lagging | 5.5557 | 5.828 | 1.5244 |
| 16 | | | Anti-sunside | 6.7995 | 7.0914 | 2.2489 |
| 17 | | | Zenith | 5.2965 | 4.6218 | 3.3601 |
| 18 | | Monopole +Holder | Outercover+ Antenna(leading 1st) | 10.438 | 13.793 | 7.3645 |
| 19 | | | Outercover+ Antenna(lagging 1st) | 7.1026 | 13.759 | 3.4863 |
| 20 | | | Outercover+ Antennna( middle) | 8.8469 | 14.716 | 6.2667 |
| 21 | | Battery | Battery box | 0.2347 | 0.2509 | 0.4288 |
| 22 | | Torquer | Torquer Sunside | 0.48088 | 0.42616 | 0.1165 |
| 23 | | | Torquer Leading | 0.49526 | 0.4934 | 0.0827 |
| 24 | | | Torquer Zenith | 0.25249 | 0.27659 | 0.06888 |
| 25 | | FE Ring | FE Ring | 9.5109 | 9.2332 | 0.2949 |
| 26 | GFRP | Washer | All washers | 0.0029 | 0.002705 | 0.00068 |

Table 8.3: Harmonic Simulation Results for Combined loads