

STUDENTS' SPACE ASSOCIATION

THE FACULTY OF POWER AND AERONAUTICAL ENGINEERING

WARSAW UNIVERSITY OF TECHNOLOGY



## CRITICAL DESIGN REVIEW

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# Structural Analyses

Deployment Team Report

November 2016

Issue no. 1

## Changes

| Date       | Changes                     | Pages/Section | Responsible                 |
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|            |                             | -             | Dominik Roszkowski          |

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## Abbreviated terms

|      |  |
|------|--|
| ADCS | Attitude Determination and Control System                    |
| AP   | Argument of Perigee  |
| AR   | Acceptance Review  |
| COMM | Communication subsystem                                      |
| DT   | Deployment Team  |
| EM   | Engineering Model  |
| EPS  | Electrical Power System                                      |
| ESA  | European Space Agency  |
| FM   | Flight Model   |
| FRR  | Flight Readiness Review                                      |
| GS   | Ground Station   |
| IADC | Inter-agency space debris coordination committee             |
| LEO  | Low Earth Orbit  |
| MA   | Mission Analysis   |
| MDR  | Mission Definition Review                                    |
| PDR  | Preliminary Design Review                                    |
| SC   | Spacecraft   |
| SKA  | Studenckie Koło Astronautyczne (Students' Space Association) |
| SW   | Software   |
| TBC  | To Be Continued  |
| TBD  | To Be Defined  |
| TCS  | Thermal Control System                                       |
| WUT  | Warsaw University of Technology                              |

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# 1 INTRODUCTION

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## 1.1 PURPOSE AND SCOPE

Purpose of this document is to share structural analysis of mechanisms on board satellite PW-Sat2. Once the model is finalized it is required to be analyzed by the use of a tool for Finite Element Method (FEM) under given loading and boundary conditions. All analyses were done using data from Sojuz Rocket, which was the only public published for other use.

## 1.2 DOCUMENT STRUCTURE

**Chapter 1** introduces the document, shows the structure of the document, includes reference documents

**Chapter 2** presents preliminary calculations of SADS

**Chapter 3** presents preliminary calculations of SRM

**Chapter 4** presents satellites modal analysis

**Chapter 5** presents preliminary modal analysis of P-Pod

**Chapter 6** summarizes this document

## 1.3 PROJECT DOCUMENTATION STRUCTURE



See section 1.3 in [PW-Sat2-C-00-CDR-Overview].

## 1.4 REFERENCE DOCUMENTS

Internal project documents are referred by its name according to Table 1-1 in [PW-Sat2-C-00.00-Overview-CDR].

[1] CubeSat Design Specifications rev. 13, The CubeSat Programme: Cal Poly SLO, 2014.

[2] Innovative Innovative Solutions In Space, „QuadPack CubeSat deployer,” [Online]. Available: <https://www.isispace.nl/product/quadpack-cubesat-deployer/>. [Data uzyskania dostępu: 2016 11 19].



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## 1.5 APPLICABLE PROJECT DOCUMENTS

- [PW-Sat2-C-00.00-Overview-CDR] – the overview of the PW-Sat2 Phase C
- [PW-Sat2-C-05.01-DT-CDR] – the overview of the PW-Sat2 Deployment Team
- [PW-Sat2-C-05.02-DT-Analytical-Calculations-and-Dynamic-Models]
- [PW-Sat2-C-10.00-CONF-CDR] – Configuration overview of PW-Sat2
- [PW-Sat2-C-10.01-CONF-MICD] – Mechanical Interface Control Document describing DT structures
- [PW-Sat2-C-10.02-CONF-MICD-Drawing] – Mechanical Interface Control Document Technical Drawing which includes a detailed view on the satellite
- [PW-Sat2-C-10.03-CONF-Bill-of-Materials] (spreadsheet) – Bill of Materials (spreadsheet)
- [PW-Sat2-C-11.01-Tests-Plan-Mechanical] – document describing mechanical tests of the satellite systems
- [PW-Sat2-C-11.02-Tests-Plan-Thermal] – document describing thermal tests of the satellite systems
- Assembly plans of the DT structures (see section 1.3 in [PW-Sat2-C-00.00-Overview-CDR])

## 1.6 DOCUMENT CONTRIBUTORS

This document and any results described were prepared solely by PW-Sat2 project team members.

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## 2 SADS – PRELIMINARY FEM ANALYSIS

Author: Kamil Gajc

### 2.1 OVERVIEW

Purpose of this part is to present preliminary calculations of SADS (this subsystem is described in [PW-Sat2-C-05.00-DT-CDR], chapter 2.4.) using Finite Element Method. Calculations include modal analysis and random vibration analysis.

### 2.2 MODEL DESCRIPTION

Figure 2-1 shows model used during analysis. On the bottom of green rail (surface A) is fixed support. End-stops are simulated by two circles which have 2 mm in diameter (point B). Because number of end-stops and exact position is not specified, they might change in further analyses. All materials properties used during analyses are assumed as isotropic, even FR-4 solar array, what decreases accuracy. Also damping is not considered. Anisotropic properties and damping will be probably considered in further analyses.

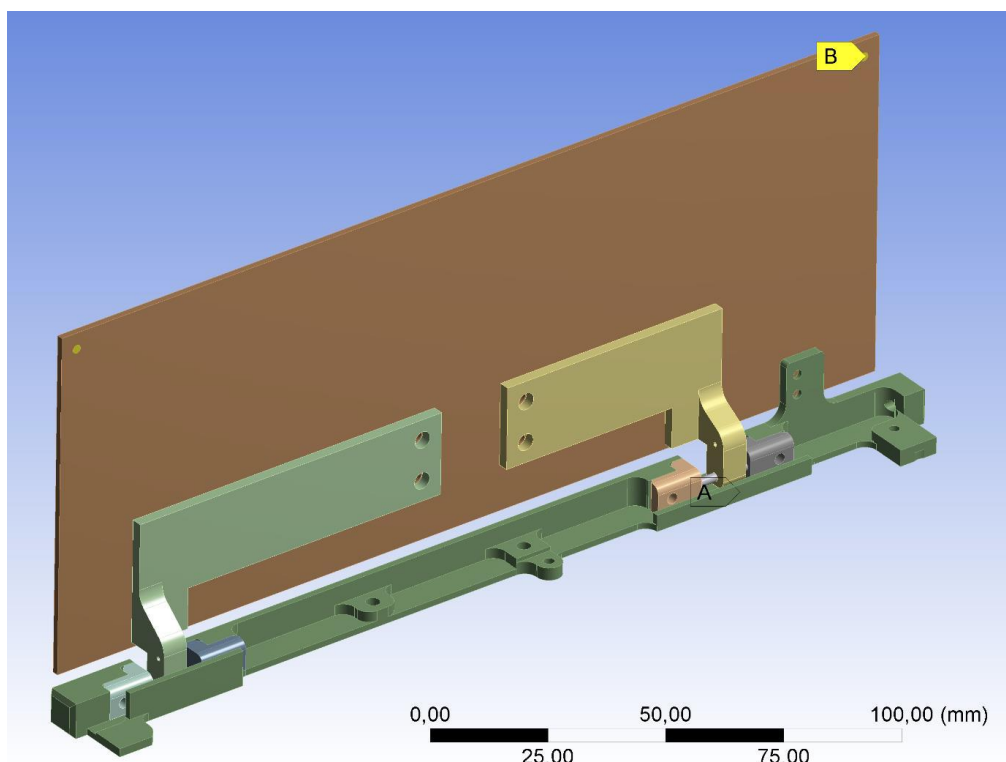




Figure 2-1 Geometry used to analysis

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## 2.3 MODAL ANALYSIS

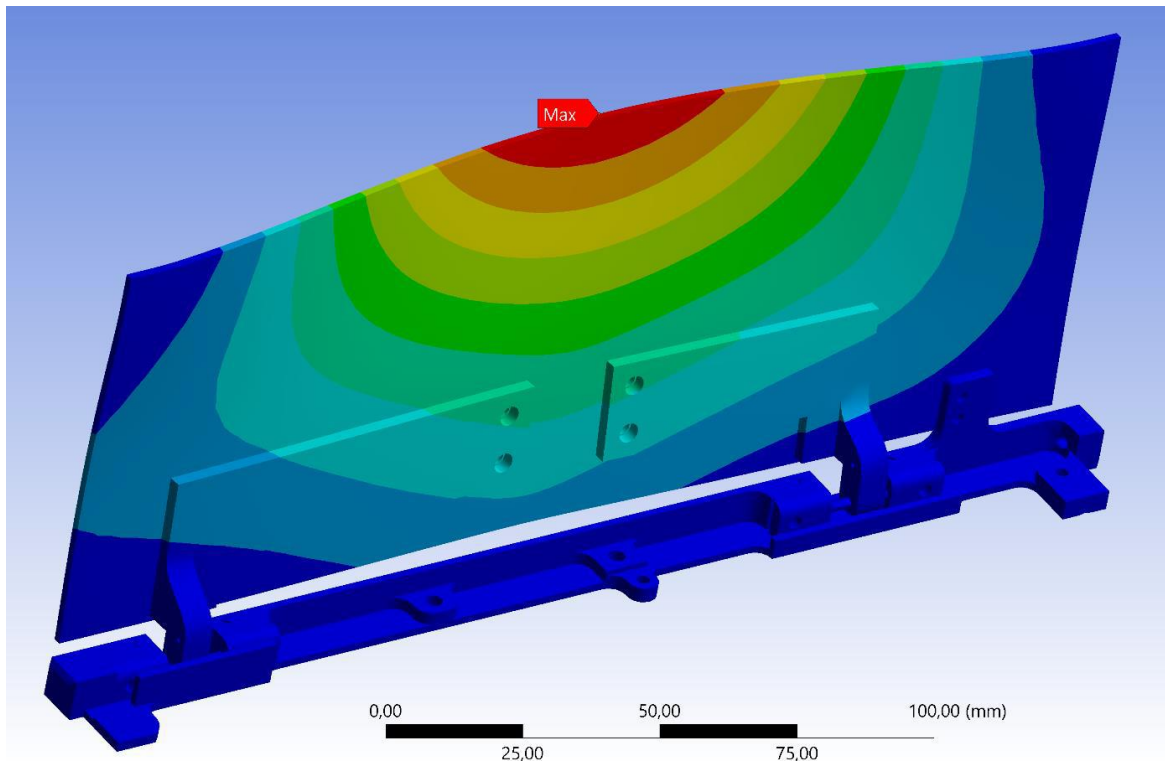
Modal analysis was carried out on range between 0 and 2000 Hz. It was found 12 modes in this range and they are enlisted in Table 2-1.

**Table 2-1 Modes found during FEM analysis.**

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 215,14         |
| 2    | 446,09         |
| 3    | 530,89         |
| 4    | 578,12         |
| 5    | 729,75         |
| 6    | 853,73         |
| 7    | 1073           |
| 8    | 1280,9         |
| 9    | 1494,6         |
| 10   | 1534,1         |
| 11   | 1674,8         |
| 12   | 1939,5         |

First mode (215,14 Hz) is showed in Figure 2-2 First mode (215,14 Hz).

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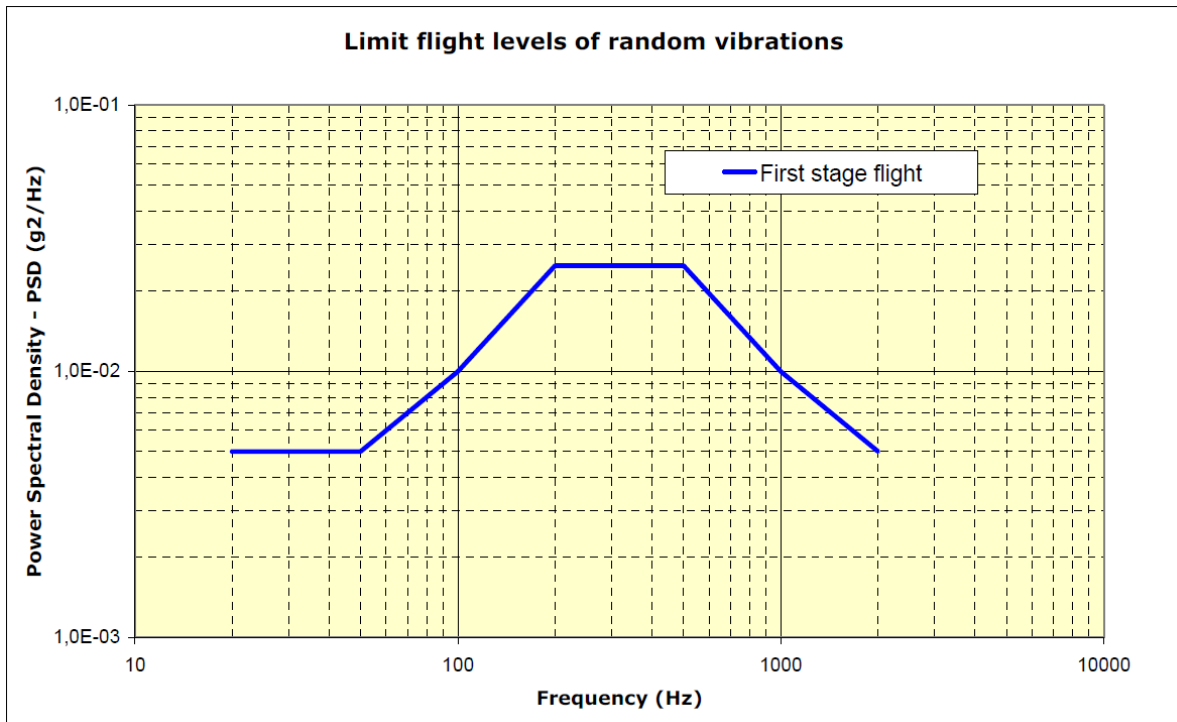


**Figure 2-2 First mode (215,14 Hz)**

According to one of considered Launch Vehicles, Soyuz, first mode should be higher than 35 Hz. Calculated first mode is over 6 times higher than required. But FEM model has many bonded contacts, what causes that model is quite stiff. In addition FR-4 is not anisotropic. Taking into consideration these factors, and also that end-stops might be changed, further analyses may show lower first mode. Ultimately, vibration tests will give the most accurate results.

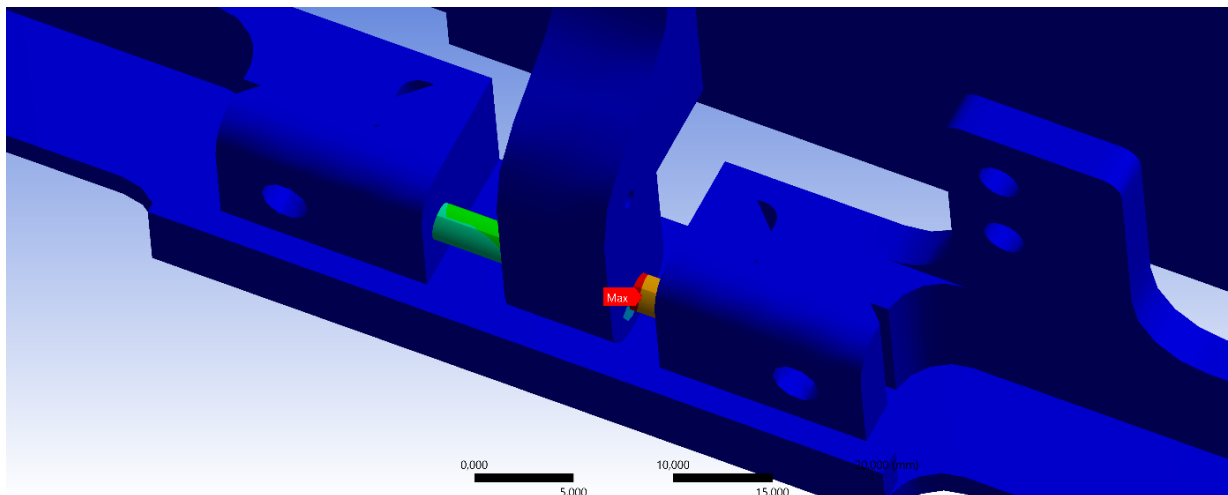
## 2.4 RANDOM VIBRATIONS

Power Spectral Density is assumed for Soyuz rocket and showed in Figure 2-3 Power spectral density.





**Figure 2-3 Power spectral density**



The highest stress is in axis perpendicular to surface of solar arrays. Maximum stress is depicted in Figure 2-4  
Maximum stress during random vibrations (155 MPa, probability 99,73%) (shaft of hinge).



**Figure 2-4 Maximum stress during random vibrations (155 MPa, probability 99,73%)**

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Maximum stress is 155 MPa with probability 99,73%. It was assumed that shaft is made of stainless steel 304. In real satellite it would be probably another steel, with better mechanical properties. This means that in further analyses maximum stress will possibly decrease.

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## 3 SRM PRELIMINARY FEM ANALYSIS

author: Kamil Gajc

### 3.1 OVERVIEW

Purpose of this part is to present preliminary calculations of SRM using Finite Element Method. Calculations include modal analysis and random vibration analysis.

### 3.2 MODEL

Figure 3-1 and Figure 3-2 depict model used during vibration analyses of SRM. (too read more about this subsystem, see [3], chapter 2.2.) In the Figure 2 there is fixed support colored in blue (letter B). Red surface in the same surface (letter C), simulating conical spring force, equals 30 N. In Figure 3-1 there are two yellow circles (letter A) which have blocked displacement in perpendicular to rods axis. It simulates Dyneema® rope.

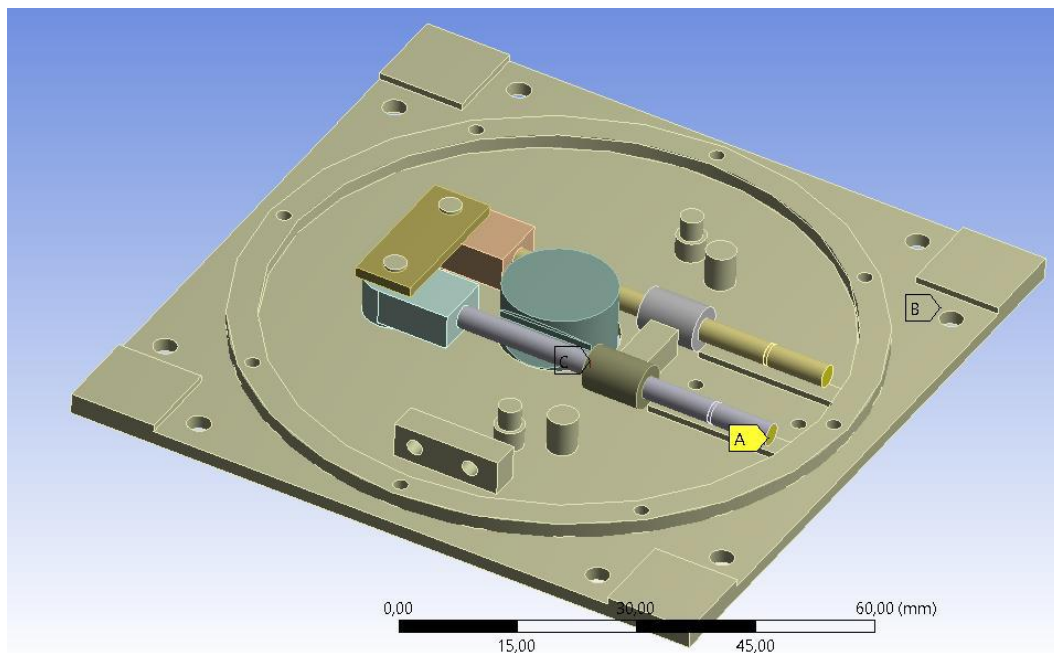


Figure 3-1 Geometry used during SRM analysis.

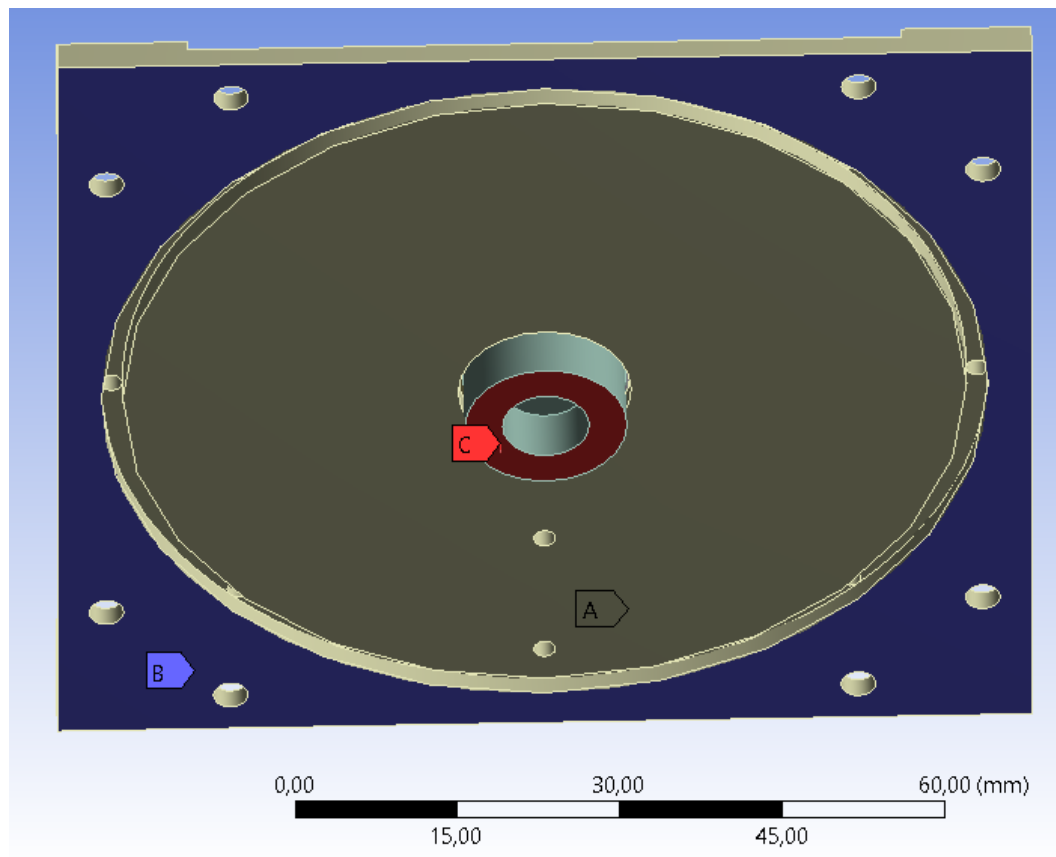


Figure 3-2 Bottom view of geometry used during SRM analysis



### 3.3 MODAL ANALYSIS

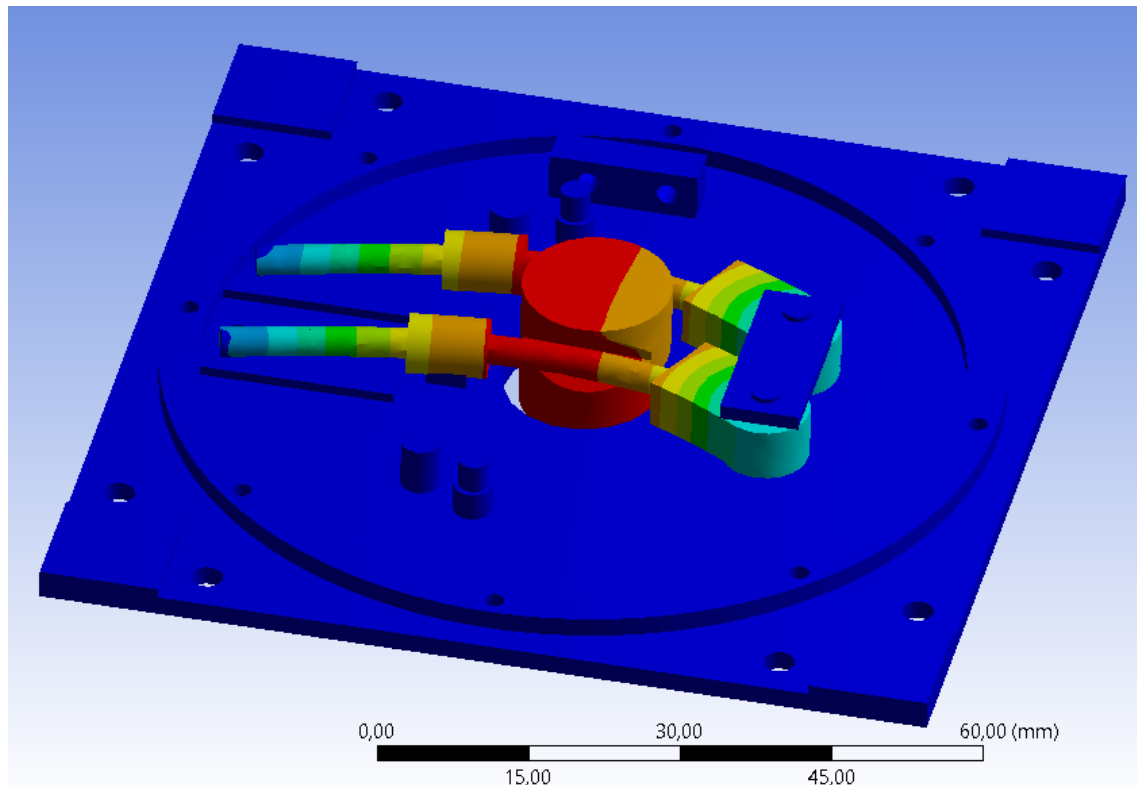
Modal analysis was carried out on range between 0 and 4000 Hz. There were found 3 modes on basic range up to 2000 Hz and 8 modes on range 0-4000 Hz (see Table 2-1).

Table 3-1 SRM modes found during FEM analysis.

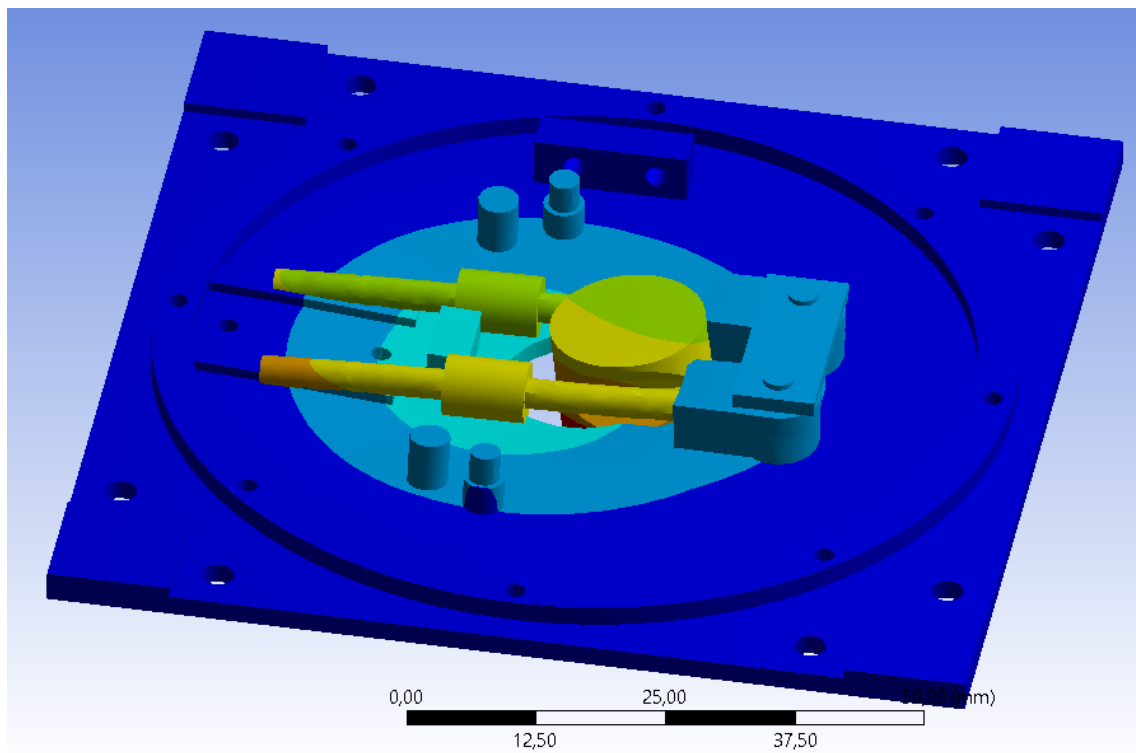
| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 1072,1         |
| 2    | 1678,9         |
| 3    | 1985,4         |
| 4    | 2414           |
| 5    | 2749,3         |
| 6    | 3049,2         |
| 7    | 3790,7         |
| 8    | 3806,9         |

First mode (1072,1 Hz) is showed in Figure 3-3 and third mode (1985,4 Hz) is showed in Figure 3-4.



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**Figure 3-3 First mode (1072,1 Hz)**



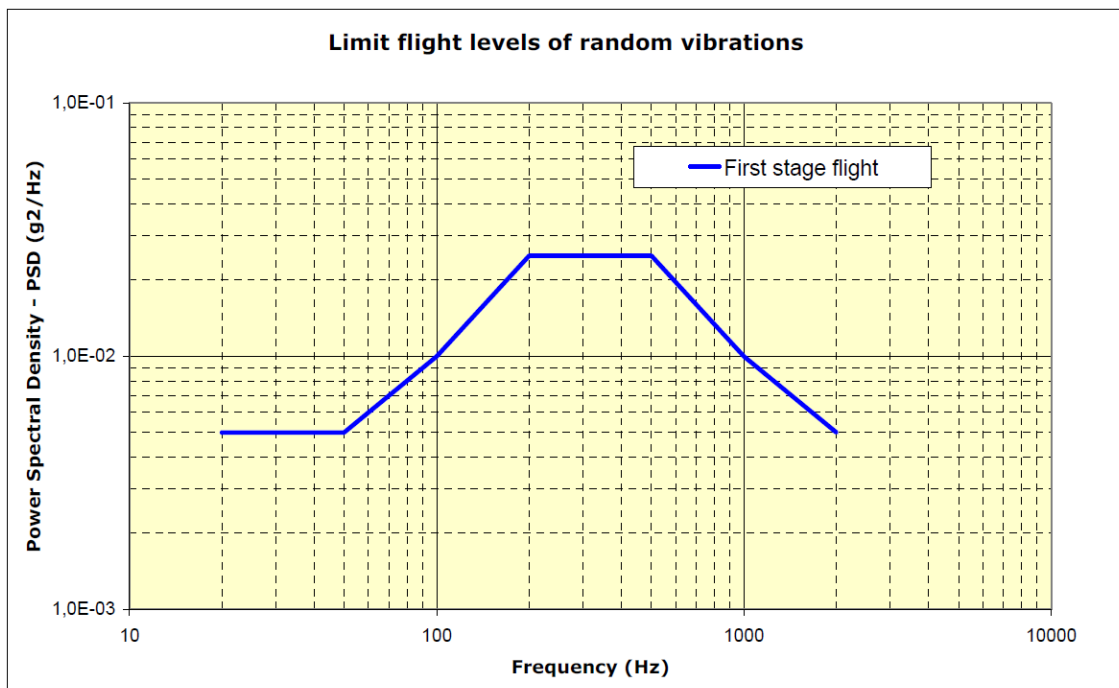
**Figure 3-4 Third mode (1985,4 Hz)**

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According to one of considered Launch Vehicles, Soyuz, first mode should be higher than 35 Hz. Calculated first mode is over 30 times higher than required. But considered model is very stiff compared to real SRM. Firstly, Dyneema® rope is highly susceptible, what causes inaccuracies during analysis. Secondly, it would be many looseness in entire assembly, what is difficult or almost impossible to simulate in FEM analysis, especially that many are difficult to predict. Thirdly, many contacts are nonlinear, and during modal analysis there are allowed only linear contacts, what also decreases accuracy. Moreover, many contacts may be simulated using different ways, each having pros and cons. Taking into account aforementioned reasons there is high possibility that first mode is lower than calculated 1072,1 Hz. In order to verify theoretical models, it will be carried out vibration tests on physical model, what will allow to improve FEM model.



### 3.4 RANDOM VIBRATIONS

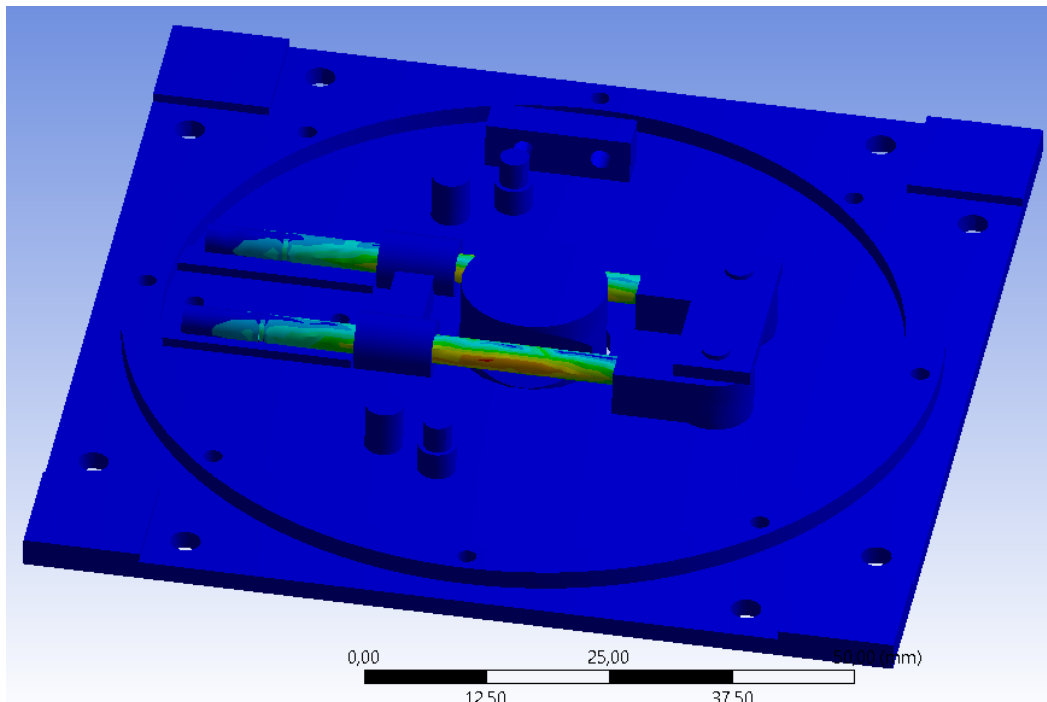
Power Spectral Density is assumed for Soyuz rocket and depicted in Figure 3-5



**Figure 3-5 Power Spectral Density.**



The highest stress is in axis perpendicular to surface of SRM and perpendicular to SRM rods. Maximum stress is showed in Figure 3-6.

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**Figure 3-6 Maximum stress during random vibrations – 11,34 MPa, probability 99,73%.**

Maximum stress is 11,34 MPa with probability 99,73%. It was assumed that shafts are made of steel. This stress is relatively low, so it has not big impact on overall stress performance. Changes in model might vary stress during random vibrations, but these variations still have small impact on entire assembly. Analysis of random vibrations will be also verified with physical tests.

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## 4 SATELLITE MODAL ANALYSIS

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*Authors: Kamil Gajc, Ewelina Ryszawa*

### 4.1 INTRODUCTION

A detailed CAD model of the satellite was simplified for modal analysis:



- Electronic components were removed from PCBs and their mass was added to the PCB's boards
- Deorbit Sail surface was replaced by the mass distribution inside the container

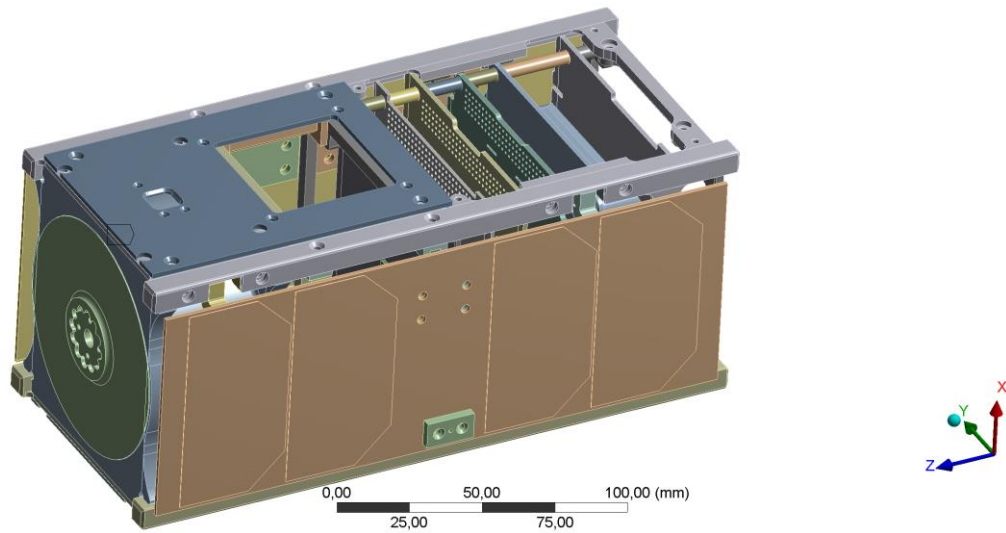
The analysis was prepared in the ANSYS software and includes first 20 resonance frequencies of the satellite (which is up to ~650Hz). In the nearest future a new analysis will be prepared with more detailed model and for the whole frequency range (5-2000Hz).

Due to simplification of the model (simplified parts, contacts) the results are overstated. These results will be compared to the preliminary results from the vibration tests (on a prototype model of PW-Sat2) and then the FEM model will be validated.

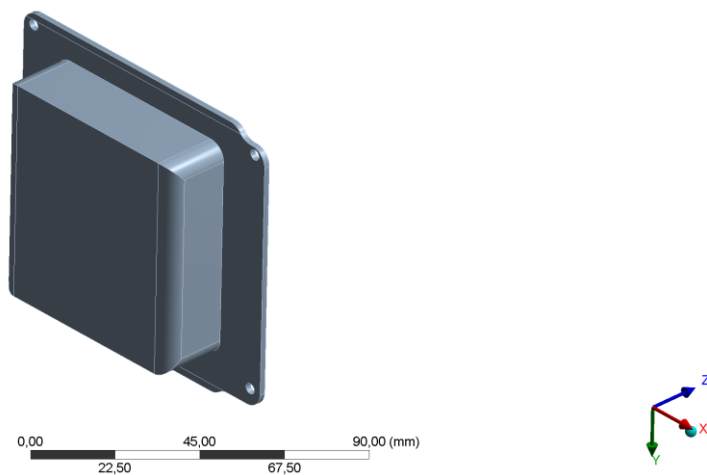
### 4.2 MODEL

In order to carry out FEM analysis it was performed simplified mechanical model. It was depicted in Figure 4-1. PC-104 board were modified so that all electronical elements were removed and board were modelled as a flat surfaces. Material of boards was set as isotropic FR-4 (averaged properties), but density was changed in order to conform to board's masses. Only accumulators board was simplified as board with additional rectangular simulating aforementioned accumulators (see Figure 4-2).

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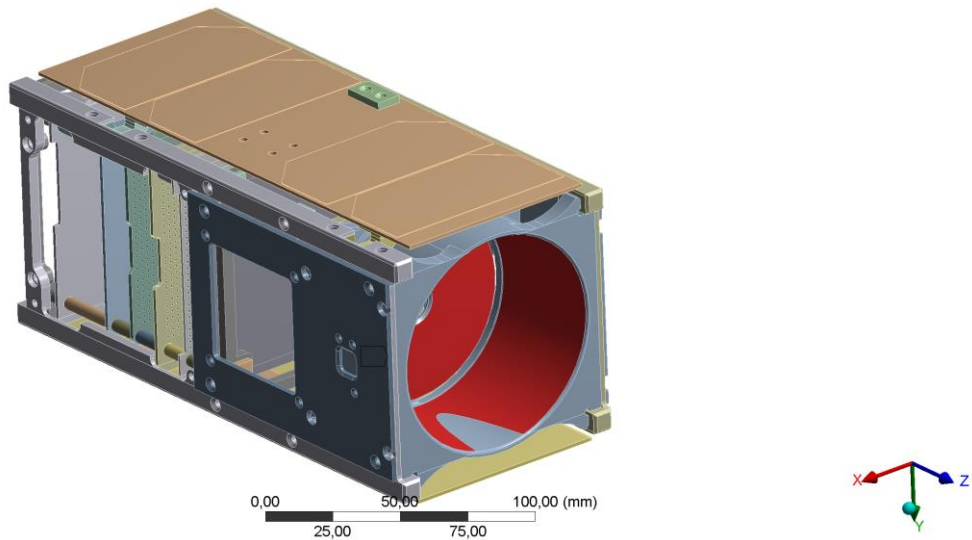
**Figure 4-1 Simplified model of PW-Sat2 satellite**



**Figure 4-2 Simplified accumulator board**

Sail was simulated as a distributed mass on the inner surface of the container. It was showed on Figure 4-3

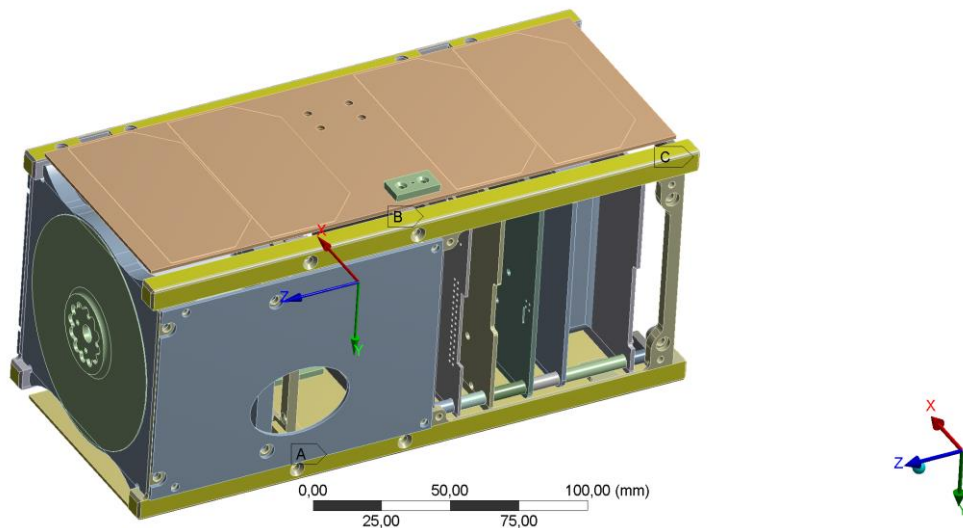
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**Figure 4-3 Distributed mass simulating sail**

FEM modal analysis is a linear analysis. This means that all contacts have to be linear. Because of that all contacts in PW-Sat2 simulation were set as bonded contacts (glued). This stiffens entire model but enables easier convergence of analysis.

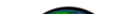

Boundary conditions was set as fixed supports. All fixed support were applied to structure's rails. This simulates structure interface with Quad-Pack. Boundary conditions were presented on Figure 4-4



**Figure 4-4 Boundary conditions during simulation (yellow colour)**

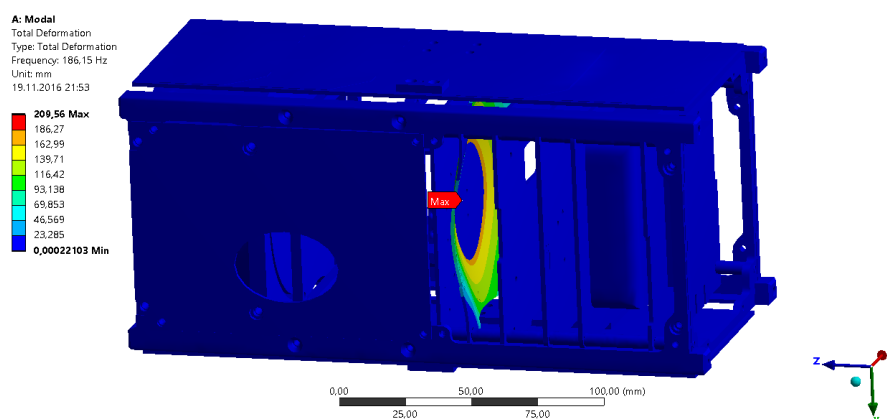
### 4.3 MODAL ANALYSIS

Modal analysis for performed for first 20 resonance frequencies of the satellite which includes the range up to 650Hz. In the next analysis the whole frequency range (up to 2000Hz) will be included in the calculations.

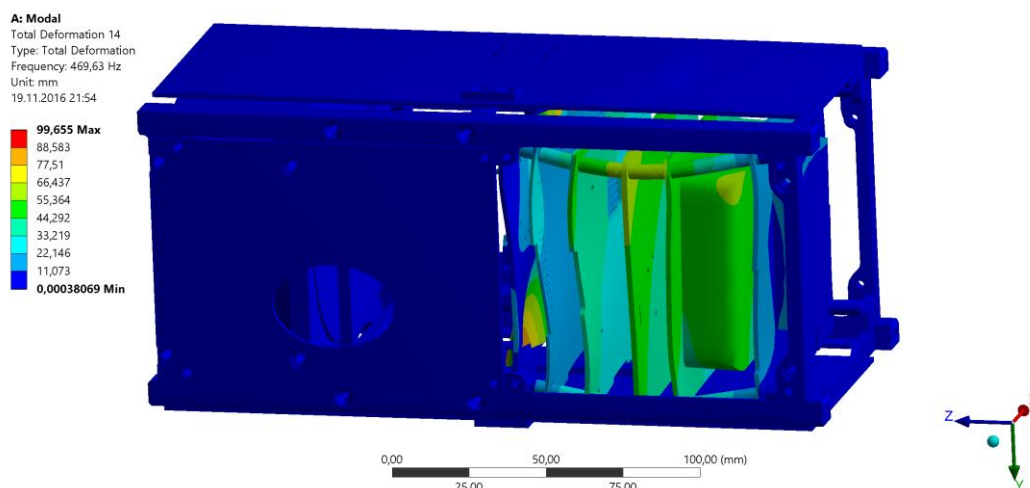
|   |            |                        |   |
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Analysis showed that the first resonance frequency occurred at 186Hz and was identified as the resonance frequency of the On-Board Computer's PCB plate. All first 5 modes are connected to the PCB plates but also all have relatively low effective masses.



The mode with the highest effective mass is the mode no. 14. It occurs at frequency 470Hz and includes the whole PCB Stack. On the figures below some of the modes are shown, including first resonance frequency and mode with the highest effective mass. On the table all information about first 20 modes are collected, including modes frequency and their effective masses in all directions.



**Figure 4-5 First mode at frequency 186Hz**



**Figure 4-6 Mode with the highest effective mass – mode no. 14, f=470Hz**

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|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

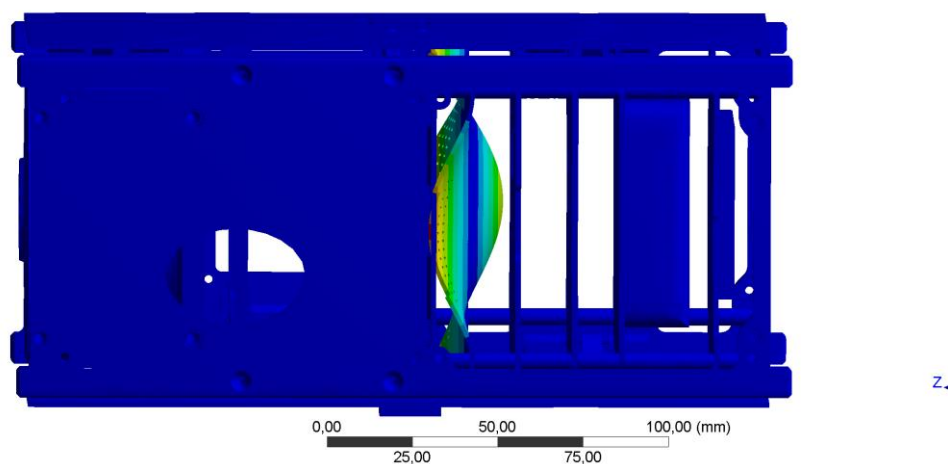






Figure 4-7 20<sup>th</sup> mode at frequency  $f=646\text{Hz}$

Table 4-1 First 20 modes and their effective masses

| MODE | FREQ. | Effective mass |           |           |           |           |           |
|------|-------|----------------|-----------|-----------|-----------|-----------|-----------|
|      |       | X              | Y         | Z         | ROT X     | ROT Y     | ROT Z     |
| 1    | 186   | 1,708E-11      | 1,172E-10 | 4,998E-05 | 2,687E-03 | 1,411E-07 | 9,193E-08 |
| 2    | 190   | 8,720E-12      | 4,159E-10 | 1,607E-04 | 5,729E-03 | 2,818E-06 | 9,665E-08 |
| 3    | 273   | 3,300E-09      | 1,422E-11 | 7,930E-05 | 3,592E-03 | 3,227E-05 | 1,601E-06 |
| 4    | 328   | 1,451E-08      | 3,360E-08 | 4,830E-08 | 2,117E-02 | 6,969E-05 | 8,058E-06 |
| 5    | 329   | 2,669E-08      | 6,852E-08 | 3,341E-08 | 9,224E-02 | 6,654E-07 | 2,666E-05 |
| 6    | 331   | 1,754E-07      | 1,586E-05 | 3,409E-08 | 1,324E-01 | 1,389E-03 | 6,329E-03 |
| 7    | 332   | 1,144E-08      | 2,588E-08 | 7,747E-05 | 6,408E-03 | 3,436E-04 | 2,576E-05 |
| 8    | 354   | 3,637E-07      | 1,720E-05 | 6,768E-08 | 1,359E-01 | 2,535E-03 | 6,135E-03 |
| 9    | 365   | 1,773E-07      | 1,208E-07 | 2,003E-08 | 8,465E-04 | 7,824E-02 | 6,611E-05 |
| 10   | 366   | 2,214E-07      | 4,498E-08 | 7,155E-11 | 7,594E-04 | 1,930E-02 | 4,735E-05 |
| 11   | 401   | 2,182E-07      | 2,641E-07 | 1,719E-08 | 3,193E-04 | 4,712E-03 | 1,175E-04 |
| 12   | 413   | 2,352E-07      | 2,481E-07 | 6,344E-09 | 3,953E-04 | 2,871E-04 | 9,840E-05 |
| 13   | 461   | 2,879E-05      | 4,632E-05 | 7,847E-10 | 2,910E-02 | 8,024E-02 | 1,787E-02 |
| 14   | 470   | 2,172E-04      | 3,323E-04 | 1,474E-08 | 1,174E+00 | 6,519E-01 | 1,333E-01 |
| 15   | 546   | 8,611E-08      | 2,633E-06 | 1,978E-07 | 6,096E-03 | 6,299E-02 | 4,621E-04 |
| 16   | 568   | 1,175E-07      | 2,139E-07 | 3,040E-09 | 5,375E-02 | 1,299E-04 | 9,853E-06 |
| 17   | 589   | 9,013E-08      | 7,321E-09 | 4,168E-07 | 4,618E-05 | 1,433E-04 | 1,999E-05 |

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

|    |     |           |           |           |           |           |           |
|----|-----|-----------|-----------|-----------|-----------|-----------|-----------|
| 18 | 615 | 1,936E-06 | 7,494E-07 | 2,766E-04 | 4,004E-03 | 1,514E-02 | 3,167E-04 |
| 19 | 628 | 2,155E-09 | 3,042E-08 | 1,740E-05 | 9,720E-04 | 2,602E-04 | 6,405E-08 |
| 20 | 646 | 1,693E-07 | 1,377E-07 | 8,551E-06 | 1,416E-03 | 2,378E-04 | 3,371E-05 |

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

## 5 P-POD PRELIMINARY MODAL ANALYSIS

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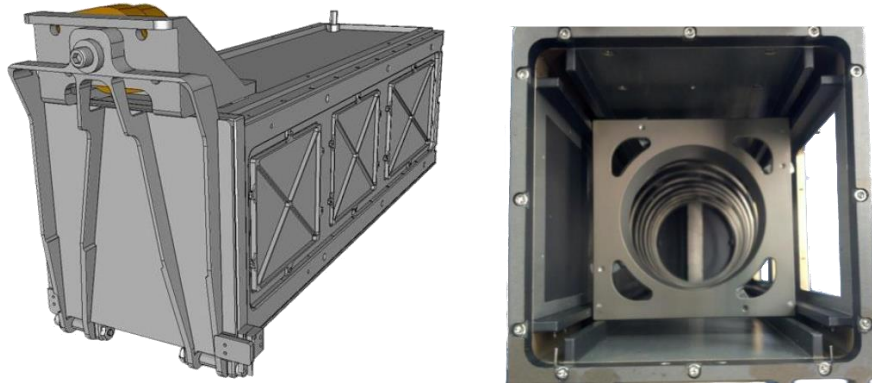
*Author: Krzysztof Pilarski*

### 5.1 OVERVIEW

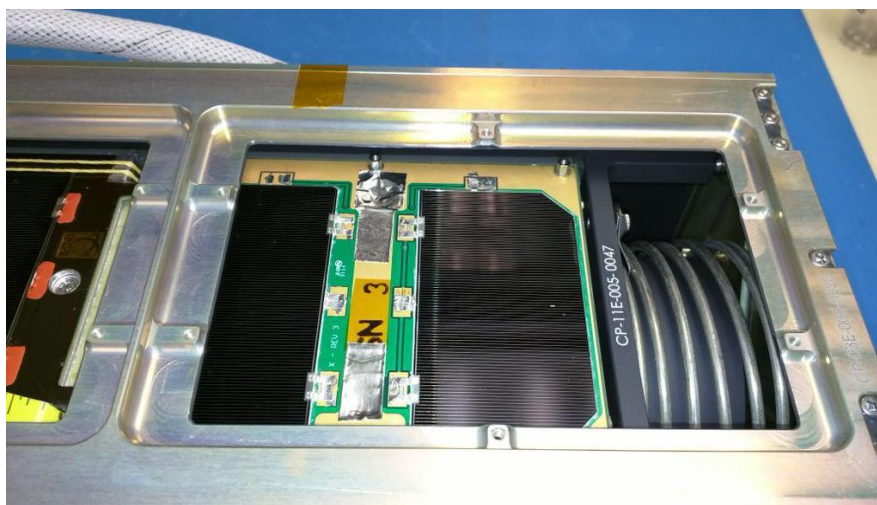
The purpose of this report is to present preliminary modal analysis of P-Pod (poly picosatellite orbital dispenser) using Finite Element Method. Calculations were done in Workbench 16.0.

### 5.2 MODEL DESCRIPTION



Figure 5-1 shows geometry of P-Pod which was used to create cad model and computational mesh.



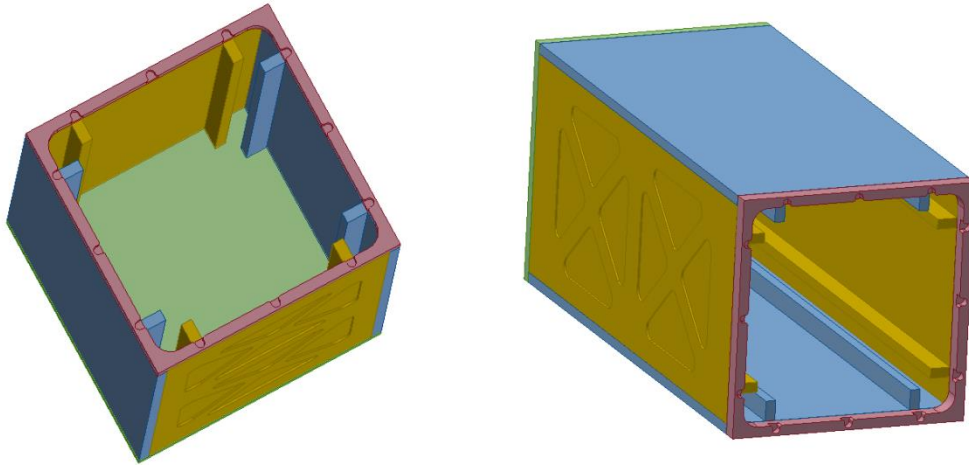
**Figure 5-1 Geometry of P-Pod**



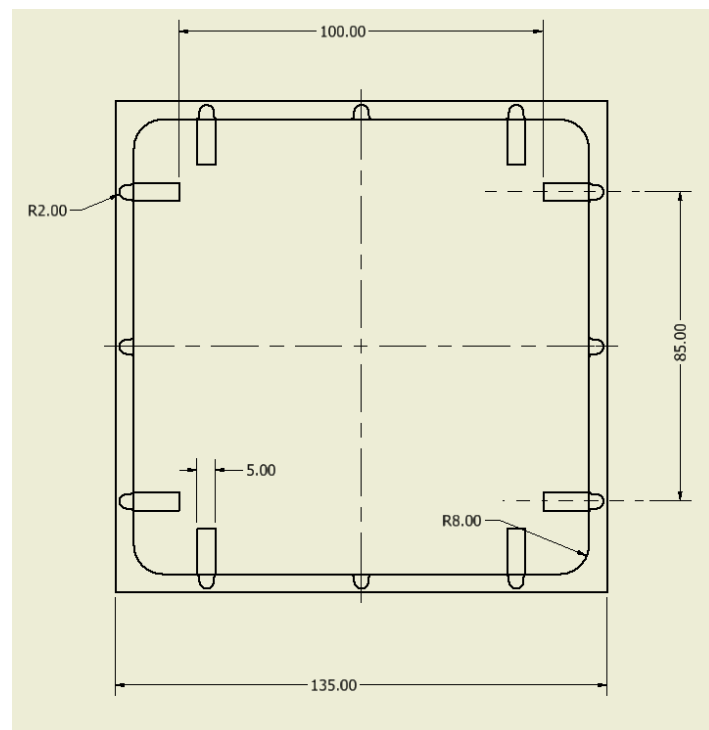
**Figure 5-2 Compressed spring in P-Pod**

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

When Cube Sat is inside a P-Pod its rails are in contact only with 8 rails of the P-Pod and a sliding “table”. Under the “table” there is a spring which push out the Cube Sat when P-Pod is unlocked. When spring is in compressed position it cannot expand since its move is limited by the “table”. The spring can vibrate, but it has little impact on vibration of the whole structure. In further analysis only walls of the P-Pod will be examined, regardless of what is happening with the spring.



**Figure 5-3 P-Pod CAD model**



**Figure 5-4 P-Pod sketch**



|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

Figure 5-3 shows simplified yet sufficient model of P-Pod. Geometry was imported to Workbench and used to create mesh.

### 5.3 MATERIAL DATA

Structure of P-Pod is made of aluminum. Therefore, Young's modulus and Poisson's ratio were assumed as follows.

$E=69 \text{ GPa}$  (Young's Modulus)

$V=0,33$  (Poisson's ratio)

### 5.4 CONTACT POINTS

"Bonded" type of contact was applied to walls and upper frame (Figure 5-5.), the base and walls (Figure 5-6) to perpendicular walls (Figure 5-7).

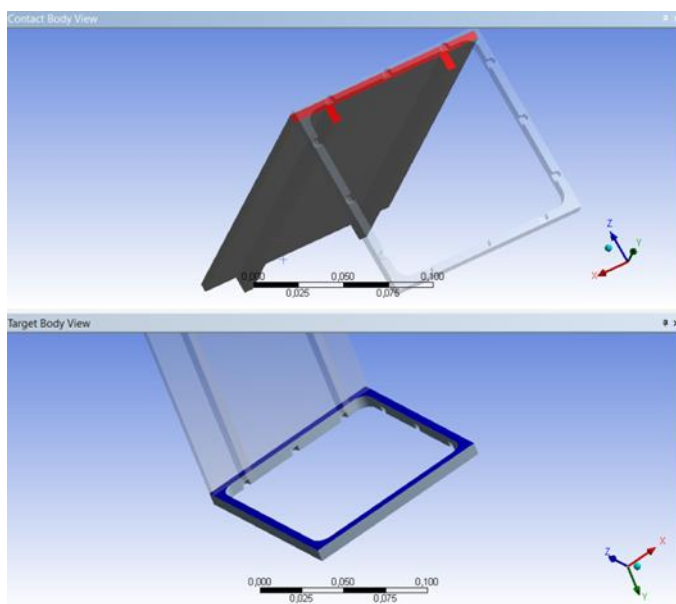


Figure 5-5

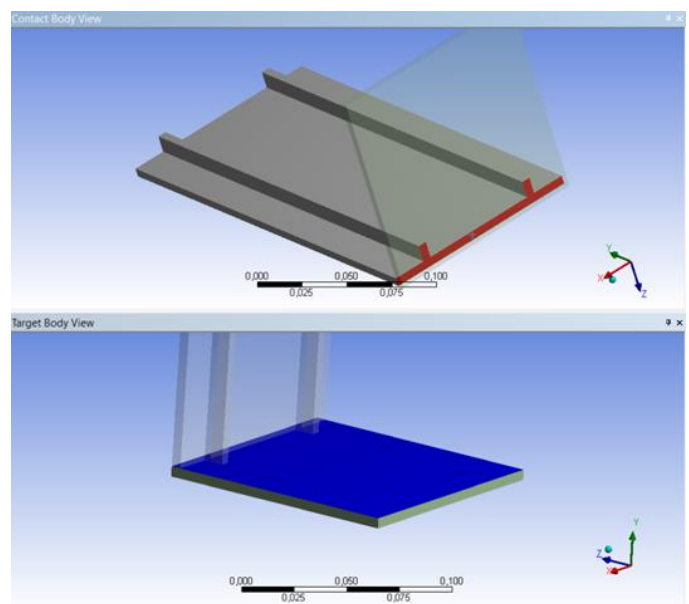


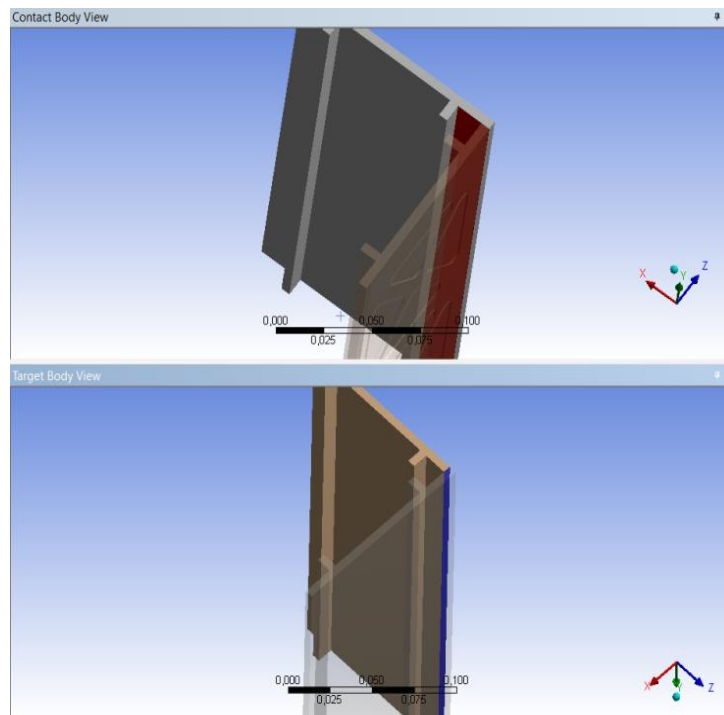


Figure 5-6

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |





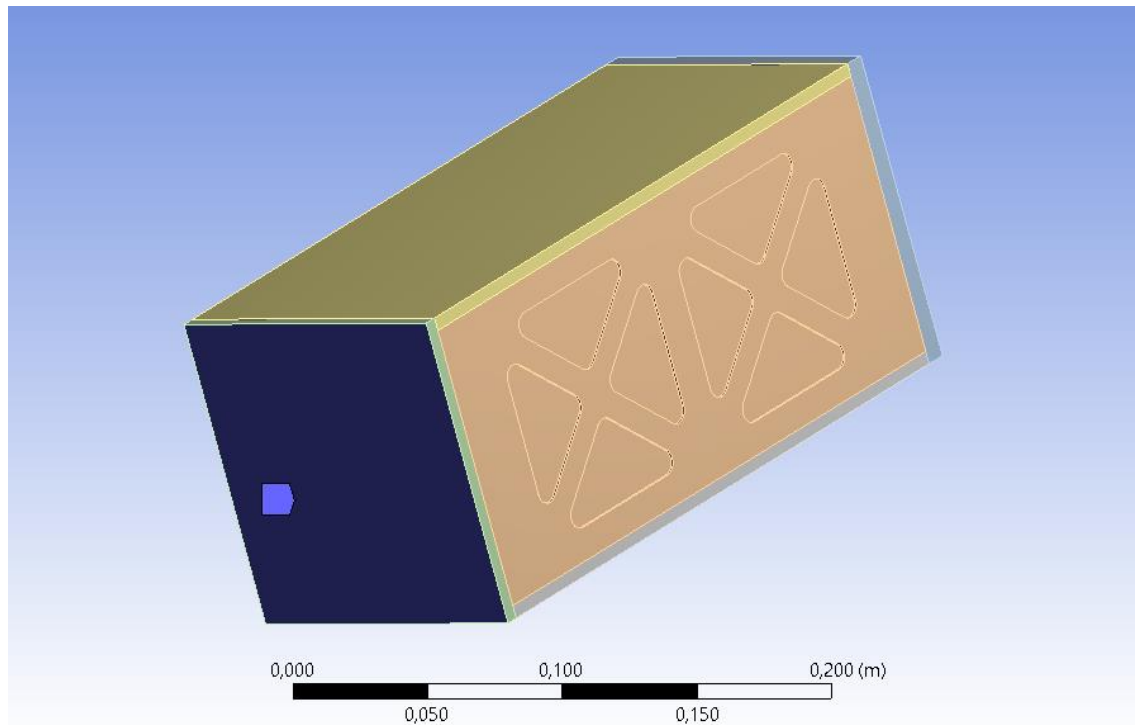
**Figure 5-7**

## 5.5 FIXED SUPPORT

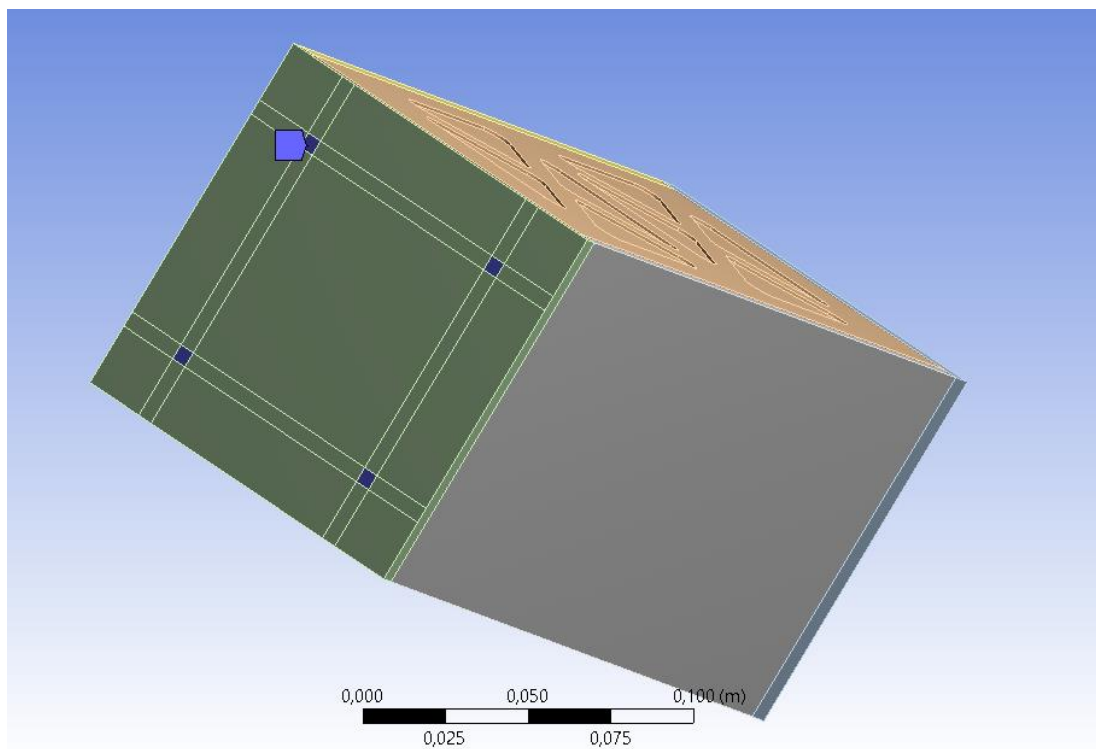
Two types of support were used:

- Whole base is fixed. (Figure 5-8)
- Smaller areas close to corners of base are fixed (Figure 5-9)

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |





**Figure 5-8 First type of support**



**Figure 5-9 Second type of support**

The second one is more realistic because it simulates contact in smaller area as if it was screwed by four bolts.

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

## 5.6 MODEL ANALYSIS



### 5.6.1 WHOLE BASE IS FIXED

Table 5-1 shows 20 lowest frequencies. More detailed information about each mode were shown in figures 10. - 15.

**Table 5-1 20 lowest frequencies in 1. case**

| Mode | Frequency [Hz] | Mode | Frequency [Hz] |
|------|----------------|------|----------------|
| 1    | 913.948        | 11   | 2260.73        |
| 2    | 1089.20        | 12   | 2474.21        |
| 3    | 1093.04        | 13   | 2514.58        |
| 4    | 1105.38        | 14   | 2779.56        |
| 5    | 1452.40        | 15   | 2780.21        |
| 6    | 1822.78        | 16   | 3175.07        |
| 7    | 1831.02        | 17   | 3692.97        |
| 8    | 2140.06        | 18   | 3782.00        |
| 9    | 2155.67        | 19   | 3933.30        |
| 10   | 2175.91        | 20   | 3961.74        |

Figure 5-10 – Figure 5-15 shows raw ANSYS output. Notice that frequency unit is Hz.



|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

| ***** PARTICIPATION FACTOR CALCULATION ***** X DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 913.948   | 0.10942E-02 | 0.51506E-03   | 0.000490 | 0.265282E-06   | 0.153987E-06             | 0.127106E-06                 |
| 2  | 1089.20   | 0.91810E-03 | 0.48601E-02   | 0.004625 | 0.236209E-04   | 0.138651E-04             | 0.113176E-04                 |
| 3  | 1093.04   | 0.91488E-03 | 0.10990E-01   | 0.010459 | 0.120785E-03   | 0.839766E-04             | 0.578723E-04                 |
| 4  | 1105.38   | 0.90466E-03 | 1.0508        | 1.000000 | 1.10413        | 0.640995                 | 0.529028                     |
| 5  | 1452.40   | 0.68851E-03 | -0.12035E-02  | 0.001145 | 0.144831E-05   | 0.640995                 | 0.693935E-06                 |
| 6  | 1822.78   | 0.54861E-03 | -0.27088      | 0.257788 | 0.733748E-01   | 0.683587                 | 0.351564E-01                 |
| 7  | 1831.02   | 0.54614E-03 | 0.75521E-02   | 0.007187 | 0.570347E-04   | 0.683620                 | 0.273273E-04                 |
| 8  | 2140.06   | 0.46728E-03 | -0.47479      | 0.451842 | 0.225421       | 0.814469                 | 0.108007                     |
| 9  | 2155.67   | 0.46389E-03 | -0.25310E-01  | 0.024087 | 0.640602E-03   | 0.814841                 | 0.306935E-03                 |
| 10   | 2175.91   | 0.45958E-03 | 0.33824E-02   | 0.003219 | 0.114409E-04   | 0.814848                 | 0.548175E-05                 |
| 11   | 2260.73   | 0.44234E-03 | -0.12234E-03  | 0.000116 | 0.149666E-07   | 0.814848                 | 0.717104E-08                 |
| 12   | 2474.21   | 0.40417E-03 | -0.78836E-03  | 0.000750 | 0.621519E-06   | 0.814848                 | 0.297792E-06                 |
| 13   | 2514.58   | 0.39768E-03 | 0.23413E-03   | 0.000223 | 0.548188E-07   | 0.814848                 | 0.262656E-07                 |
| 14   | 2779.56   | 0.35977E-03 | 0.94242E-01   | 0.089688 | 0.888152E-02   | 0.820004                 | 0.425545E-02                 |
| 15   | 2780.21   | 0.35968E-03 | 0.14276       | 0.135858 | 0.203794E-01   | 0.831833                 | 0.976446E-02                 |
| 16   | 3175.07   | 0.31495E-03 | -0.62763E-03  | 0.000597 | 0.393921E-06   | 0.831834                 | 0.188741E-06                 |
| 17   | 3692.97   | 0.27078E-03 | -0.75044E-03  | 0.000714 | 0.563163E-06   | 0.831834                 | 0.269831E-06                 |
| 18   | 3782.00   | 0.26441E-03 | -0.42427E-03  | 0.000404 | 0.180003E-06   | 0.831834                 | 0.862460E-07                 |
| 19   | 3933.30   | 0.25424E-03 | -0.16934E-02  | 0.001612 | 0.286759E-05   | 0.831836                 | 0.137396E-05                 |
| 20   | 3961.74   | 0.25241E-03 | 0.12330E-02   | 0.001173 | 0.152031E-05   | 0.831837                 | 0.728434E-06                 |
| 21   | 4073.56   | 0.24549E-03 | -0.15671      | 0.149141 | 0.245594E-01   | 0.846092                 | 0.117673E-01                 |
| 22   | 4101.28   | 0.24383E-03 | -0.33597E-03  | 0.000320 | 0.112878E-06   | 0.846092                 | 0.540837E-07                 |
| 23   | 4275.41   | 0.23390E-03 | -0.33377E-03  | 0.000318 | 0.111400E-06   | 0.846093                 | 0.533759E-07                 |
| 24   | 4286.37   | 0.23330E-03 | 0.62739E-02   | 0.005971 | 0.393619E-04   | 0.846115                 | 0.188597E-04                 |
| 25   | 4294.02   | 0.23288E-03 | 0.37379E-01   | 0.035573 | 0.139722E-02   | 0.846926                 | 0.669457E-03                 |
| 26   | 4672.77   | 0.21401E-03 | -0.12878      | 0.122555 | 0.165836E-01   | 0.856553                 | 0.794580E-02                 |
| 27   | 4685.45   | 0.21343E-03 | -0.72851E-02  | 0.006933 | 0.530725E-04   | 0.856583                 | 0.254289E-04                 |
| 28   | 4862.22   | 0.20567E-03 | 0.13304E-03   | 0.000127 | 0.176989E-07   | 0.856583                 | 0.848015E-08                 |
| 29   | 4865.44   | 0.20553E-03 | 0.27057E-02   | 0.002575 | 0.732105E-05   | 0.856588                 | 0.350777E-05                 |
| 30   | 4992.02   | 0.20032E-03 | 0.43488       | 0.413864 | 0.189120       | 0.966365                 | 0.906138E-01                 |
| 31   | 5000.26   | 0.19999E-03 | 0.11158E-01   | 0.010619 | 0.124510E-03   | 0.966437                 | 0.596572E-04                 |
| 32   | 5580.67   | 0.17919E-03 | 0.64235E-01   | 0.061131 | 0.412608E-02   | 0.968832                 | 0.197695E-02                 |
| 33   | 5584.24   | 0.17908E-03 | 0.16563E-01   | 0.015763 | 0.274332E-03   | 0.968992                 | 0.131442E-03                 |
| 34   | 5627.80   | 0.17769E-03 | 0.80593E-03   | 0.000767 | 0.649525E-06   | 0.968992                 | 0.311210E-06                 |
| 35   | 5687.68   | 0.17582E-03 | 0.10585       | 0.100739 | 0.112051E-01   | 0.975496                 | 0.536876E-02                 |
| 36   | 5694.81   | 0.17560E-03 | 0.20357E-02   | 0.001937 | 0.414418E-05   | 0.975499                 | 0.198562E-05                 |
| 37   | 5757.09   | 0.17370E-03 | 0.61759E-02   | 0.005877 | 0.381411E-04   | 0.975521                 | 0.182748E-04                 |
| 38   | 5849.20   | 0.17096E-03 | -0.20632E-03  | 0.000196 | 0.425684E-07   | 0.975521                 | 0.203960E-07                 |
| 39   | 6097.12   | 0.16401E-03 | 0.21196E-02   | 0.002017 | 0.449268E-05   | 0.975523                 | 0.215260E-05                 |

Figure 5-10

| ***** PARTICIPATION FACTOR CALCULATION ***** Y DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 913.948   | 0.10942E-02 | 0.85805E-03   | 0.000697 | 0.736246E-06   | 0.481755E-06             | 0.352761E-06                 |
| 2  | 1089.20   | 0.91810E-03 | -0.78152E-05  | 0.000006 | 0.610772E-10   | 0.481795E-06             | 0.292642E-10                 |
| 3  | 1093.04   | 0.91488E-03 | 0.22415E-06   | 0.000000 | 0.502448E-13   | 0.481795E-06             | 0.240740E-13                 |
| 4  | 1105.38   | 0.90466E-03 | -0.10601E-06  | 0.000000 | 0.112382E-13   | 0.481795E-06             | 0.538460E-14                 |
| 5  | 1452.40   | 0.68851E-03 | -0.45221E-02  | 0.003675 | 0.204493E-04   | 0.138626E-04             | 0.979799E-05                 |
| 6  | 1822.78   | 0.54861E-03 | 0.45354E-04   | 0.000037 | 0.205703E-08   | 0.138639E-04             | 0.985593E-09                 |
| 7  | 1831.02   | 0.54614E-03 | -0.76203E-05  | 0.000006 | 0.580690E-10   | 0.138640E-04             | 0.278229E-10                 |
| 8  | 2140.06   | 0.46728E-03 | -0.72575E-03  | 0.000590 | 0.526709E-06   | 0.142086E-04             | 0.252365E-06                 |
| 9  | 2155.67   | 0.46389E-03 | 0.13921E-01   | 0.011313 | 0.193805E-03   | 0.141023E-03             | 0.928589E-04                 |
| 10   | 2175.91   | 0.45958E-03 | -0.41797E-03  | 0.000340 | 0.174700E-06   | 0.141137E-03             | 0.837049E-07                 |
| 11   | 2260.73   | 0.44234E-03 | -0.41805E-04  | 0.000034 | 0.174767E-08   | 0.141138E-03             | 0.837372E-09                 |
| 12   | 2474.21   | 0.40417E-03 | -0.15961E-01  | 0.012971 | 0.254745E-03   | 0.307828E-03             | 0.122057E-03                 |
| 13   | 2514.58   | 0.39768E-03 | 0.44656E-02   | 0.003629 | 0.199420E-04   | 0.320877E-03             | 0.955491E-05                 |
| 14   | 2779.56   | 0.35977E-03 | -0.38243E-04  | 0.000031 | 0.146252E-08   | 0.320878E-03             | 0.700744E-09                 |
| 15   | 2780.21   | 0.35968E-03 | -0.13458E-03  | 0.000109 | 0.181106E-07   | 0.320890E-03             | 0.867743E-08                 |
| 16   | 3175.07   | 0.31495E-03 | -0.14372E-01  | 0.011679 | 0.206545E-03   | 0.456040E-03             | 0.989629E-04                 |
| 17   | 3692.97   | 0.27078E-03 | 0.11271E-03   | 0.000092 | 0.127036E-07   | 0.456049E-03             | 0.608672E-08                 |
| 18   | 3782.00   | 0.26441E-03 | 0.24727E-04   | 0.000020 | 0.611441E-09   | 0.456049E-03             | 0.292963E-09                 |
| 19   | 3933.30   | 0.25424E-03 | -0.33649E-01  | 0.027345 | 0.113225E-02   | 0.119692E-02             | 0.542499E-03                 |
| 20   | 3961.74   | 0.25241E-03 | -0.66164E-03  | 0.000538 | 0.437772E-06   | 0.119721E-02             | 0.209752E-06                 |
| 21   | 4073.56   | 0.24549E-03 | 0.85880E-03   | 0.000698 | 0.737536E-06   | 0.119769E-02             | 0.353380E-06                 |
| 22   | 4101.28   | 0.24383E-03 | -0.65986E-04  | 0.000054 | 0.435412E-08   | 0.119769E-02             | 0.208621E-08                 |
| 23   | 4275.41   | 0.23390E-03 | 0.66378E-03   | 0.000539 | 0.440604E-06   | 0.119798E-02             | 0.111109E-06                 |
| 24   | 4286.37   | 0.23330E-03 | 0.15236E-01   | 0.012382 | 0.232136E-03   | 0.134988E-02             | 0.111225E-03                 |
| 25   | 4294.02   | 0.23288E-03 | -0.20138E-02  | 0.001637 | 0.405535E-05   | 0.135253E-02             | 0.194306E-05                 |
| 26   | 4672.77   | 0.21401E-03 | 0.31511E-03   | 0.000256 | 0.992933E-07   | 0.135260E-02             | 0.475749E-07                 |
| 27   | 4685.45   | 0.21343E-03 | 0.13201E-02   | 0.001073 | 0.174259E-05   | 0.135374E-02             | 0.834938E-06                 |
| 28   | 4862.22   | 0.20567E-03 | 1.2305        | 1.000000 | 1.51419        | 0.992149                 | 0.725503                     |
| 29   | 4865.44   | 0.20553E-03 | 0.23765E-01   | 0.019313 | 0.564755E-03   | 0.992519                 | 0.270594E-03                 |
| 30   | 4992.02   | 0.20032E-03 | -0.68706E-03  | 0.000558 | 0.472055E-06   | 0.992519                 | 0.226178E-06                 |
| 31   | 5000.26   | 0.19999E-03 | 0.10442E-02   | 0.000849 | 0.109028E-05   | 0.992520                 | 0.522392E-06                 |
| 32   | 5580.67   | 0.17919E-03 | -0.52751E-03  | 0.000429 | 0.278264E-06   | 0.992520                 | 0.133326E-06                 |
| 33   | 5584.24   | 0.17908E-03 | 0.57800E-02   | 0.004697 | 0.334087E-04   | 0.992542                 | 0.160073E-04                 |
| 34   | 5627.80   | 0.17769E-03 | 0.18624E-02   | 0.001514 | 0.346862E-05   | 0.992544                 | 0.166194E-05                 |
| 35   | 5687.68   | 0.17582E-03 | 0.28069E-02   | 0.002281 | 0.787894E-05   | 0.992549                 | 0.377507E-05                 |
| 36   | 5694.81   | 0.17560E-03 | -0.70719E-04  | 0.000057 | 0.500112E-08   | 0.992550                 | 0.239621E-08                 |
| 37   | 5757.09   | 0.17370E-03 | -0.26493E-01  | 0.021530 | 0.701890E-03   | 0.993009                 | 0.336300E-03                 |
| 38   | 5849.20   | 0.17096E-03 | 0.29531E-03   | 0.000240 | 0.872107E-07   | 0.993009                 | 0.417857E-07                 |
| 39   | 6097.12   | 0.16401E-03 | -0.29238E-04  | 0.000024 | 0.854873E-09   | 0.993009                 | 0.409600E-09                 |

Figure 5-11



|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

| ***** PARTICIPATION FACTOR CALCULATION ***** Z DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 913.948   | 0.10942E-02 | -0.32700E-03  | 0.000307 | 0.106928E-06   | 0.615979E-07             | 0.512328E-07                 |
| 2  | 1089.20   | 0.91810E-03 | 1.0652        | 1.000000 | 1.13462        | 0.653623                 | 0.543638                     |
| 3  | 1093.04   | 0.91488E-03 | 0.35497E-01   | 0.033325 | 0.126003E-02   | 0.654349                 | 0.603723E-03                 |
| 4  | 1105.38   | 0.90466E-03 | -0.54842E-02  | 0.005149 | 0.300767E-04   | 0.654366                 | 0.144108E-04                 |
| 5  | 1452.40   | 0.68851E-03 | -0.73934E-03  | 0.000694 | 0.546619E-06   | 0.654367                 | 0.261904E-06                 |
| 6  | 1822.78   | 0.54861E-03 | -0.83864E-02  | 0.007873 | 0.703324E-04   | 0.654407                 | 0.336987E-04                 |
| 7  | 1831.02   | 0.54614E-03 | -0.29436      | 0.276346 | 0.866482E-01   | 0.704323                 | 0.415162E-01                 |
| 8  | 2140.06   | 0.46728E-03 | -0.27707E-02  | 0.002601 | 0.767659E-05   | 0.704327                 | 0.367812E-05                 |
| 9  | 2155.67   | 0.46389E-03 | -0.14929E-01  | 0.014016 | 0.222885E-03   | 0.704456                 | 0.106792E-03                 |
| 10   | 2175.91   | 0.45958E-03 | -0.45091      | 0.423317 | 0.203322       | 0.821583                 | 0.974185E-01                 |
| 11   | 2260.73   | 0.44234E-03 | -0.16166E-02  | 0.001518 | 0.261326E-05   | 0.821585                 | 0.125210E-05                 |
| 12   | 2474.21   | 0.40417E-03 | 0.78323E-03   | 0.000735 | 0.613441E-06   | 0.821585                 | 0.293921E-06                 |
| 13   | 2514.58   | 0.39768E-03 | 0.32373E-03   | 0.000304 | 0.104801E-06   | 0.821585                 | 0.502137E-07                 |
| 14   | 2779.56   | 0.35977E-03 | 0.14180       | 0.133119 | 0.201063E-01   | 0.833168                 | 0.963362E-02                 |
| 15   | 2780.21   | 0.35968E-03 | -0.93776E-01  | 0.088037 | 0.879399E-02   | 0.838234                 | 0.421351E-02                 |
| 16   | 3175.07   | 0.31495E-03 | 0.27768E-03   | 0.000261 | 0.771049E-07   | 0.838234                 | 0.369437E-07                 |
| 17   | 3692.97   | 0.27078E-03 | -0.26946E-03  | 0.000253 | 0.726094E-07   | 0.838234                 | 0.347897E-07                 |
| 18   | 3782.00   | 0.26441E-03 | -0.62229E-04  | 0.000058 | 0.387247E-08   | 0.838234                 | 0.185543E-08                 |
| 19   | 3933.30   | 0.25424E-03 | -0.31431E-04  | 0.000030 | 0.987918E-09   | 0.838234                 | 0.473346E-09                 |
| 20   | 3961.74   | 0.25241E-03 | 0.22316E-03   | 0.000210 | 0.498018E-07   | 0.838234                 | 0.238618E-07                 |
| 21   | 4073.56   | 0.24549E-03 | 0.26524E-03   | 0.000249 | 0.703504E-07   | 0.838234                 | 0.337074E-07                 |
| 22   | 4101.28   | 0.24383E-03 | -0.13382      | 0.125627 | 0.179067E-01   | 0.848550                 | 0.857974E-02                 |
| 23   | 4275.41   | 0.23390E-03 | 0.12204E-02   | 0.001146 | 0.148945E-05   | 0.848550                 | 0.713647E-06                 |
| 24   | 4286.37   | 0.23330E-03 | -0.14846E-02  | 0.001394 | 0.220414E-05   | 0.848552                 | 0.105608E-05                 |
| 25   | 4294.02   | 0.23288E-03 | 0.63248E-03   | 0.000594 | 0.400026E-06   | 0.848552                 | 0.191666E-06                 |
| 26   | 4672.77   | 0.21401E-03 | -0.72119E-02  | 0.006771 | 0.520121E-04   | 0.848552                 | 0.249208E-04                 |
| 27   | 4685.45   | 0.21343E-03 | 0.12777       | 0.119949 | 0.163248E-01   | 0.857986                 | 0.782180E-02                 |
| 28   | 4862.22   | 0.20567E-03 | -0.43398E-03  | 0.000407 | 0.188336E-06   | 0.857986                 | 0.902386E-07                 |
| 29   | 4865.44   | 0.20553E-03 | -0.94401E-03  | 0.000886 | 0.891162E-06   | 0.857987                 | 0.426987E-06                 |
| 30   | 4992.02   | 0.20032E-03 | -0.10643E-01  | 0.009992 | 0.113283E-03   | 0.858052                 | 0.542777E-04                 |
| 31   | 5000.26   | 0.19999E-03 | 0.41851       | 0.392899 | 0.175151       | 0.958952                 | 0.839212E-01                 |
| 32   | 5580.67   | 0.17919E-03 | 0.22227E-03   | 0.000209 | 0.494050E-07   | 0.958952                 | 0.236717E-07                 |
| 33   | 5584.24   | 0.17908E-03 | -0.15094E-02  | 0.001417 | 0.227824E-05   | 0.958953                 | 0.109158E-05                 |
| 34   | 5627.80   | 0.17769E-03 | 0.36015E-02   | 0.003381 | 0.129712E-04   | 0.958960                 | 0.621494E-05                 |
| 35   | 5687.68   | 0.17582E-03 | -0.28341E-02  | 0.002661 | 0.803216E-05   | 0.958965                 | 0.384849E-05                 |
| 36   | 5694.81   | 0.17560E-03 | 0.12427       | 0.116665 | 0.154432E-01   | 0.967861                 | 0.739936E-02                 |
| 37   | 5757.09   | 0.17370E-03 | -0.44673E-03  | 0.000419 | 0.199564E-06   | 0.967861                 | 0.956182E-07                 |
| 38   | 5849.20   | 0.17096E-03 | 0.37803E-03   | 0.000355 | 0.142906E-06   | 0.967862                 | 0.684715E-07                 |
| 39   | 6097.12   | 0.16401E-03 | 0.19178E-04   | 0.000018 | 0.367779E-09   | 0.967862                 | 0.176216E-09                 |

Figure 5-12

| ***** PARTICIPATION FACTOR CALCULATION ***** ROTX DIRECTION |           |             |               |          |                |                          |                              |
|---|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE  | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1   | 913.948   | 0.10942E-02 | -0.10489E-04  | 0.000097 | 0.110014E-09   | 0.629397E-08             | 0.527886E-08                 |
| 2   | 1089.20   | 0.91810E-03 | 0.10813       | 1.000000 | 0.116915E-01   | 0.668877                 | 0.560999                     |
| 3   | 1093.04   | 0.91488E-03 | 0.36030E-02   | 0.033322 | 0.129816E-04   | 0.669620                 | 0.622900E-03                 |
| 4   | 1105.38   | 0.90466E-03 | -0.55212E-03  | 0.005106 | 0.304841E-06   | 0.669637                 | 0.146273E-04                 |
| 5   | 1452.40   | 0.68851E-03 | -0.11739E-03  | 0.001086 | 0.137810E-07   | 0.669638                 | 0.661259E-06                 |
| 6   | 1822.78   | 0.54861E-03 | 0.87509E-03   | 0.008093 | 0.765779E-06   | 0.669682                 | 0.367446E-04                 |
| 7   | 1831.02   | 0.54614E-03 | 0.29774E-01   | 0.275356 | 0.886462E-03   | 0.720397                 | 0.425354E-01                 |
| 8   | 2140.06   | 0.46728E-03 | -0.33219E-03  | 0.003072 | 0.110349E-06   | 0.720403                 | 0.529489E-05                 |
| 9   | 2155.67   | 0.46389E-03 | -0.14498E-02  | 0.013408 | 0.210190E-05   | 0.720524                 | 0.100856E-03                 |
| 10  | 2175.91   | 0.45958E-03 | -0.49536E-01  | 0.458127 | 0.245382E-02   | 0.860908                 | 0.117742                     |
| 11  | 2260.73   | 0.44234E-03 | -0.13573E-03  | 0.001255 | 0.184234E-07   | 0.860909                 | 0.884017E-06                 |
| 12  | 2474.21   | 0.40417E-03 | -0.17838E-03  | 0.001650 | 0.318185E-07   | 0.860910                 | 0.152676E-05                 |
| 13  | 2514.58   | 0.39768E-03 | 0.76871E-05   | 0.000071 | 0.590922E-10   | 0.860910                 | 0.283544E-08                 |
| 14  | 2779.56   | 0.35977E-03 | -0.81441E-02  | 0.075319 | 0.663259E-04   | 0.864705                 | 0.318254E-02                 |
| 15  | 2780.21   | 0.35968E-03 | 0.53773E-02   | 0.049731 | 0.289155E-04   | 0.866359                 | 0.138746E-02                 |
| 16  | 3175.07   | 0.31495E-03 | -0.11736E-03  | 0.001085 | 0.137738E-07   | 0.866360                 | 0.660912E-06                 |
| 17  | 3692.97   | 0.27078E-03 | -0.33912E-04  | 0.000314 | 0.115000E-08   | 0.866360                 | 0.551810E-07                 |
| 18  | 3782.00   | 0.26441E-03 | -0.22927E-05  | 0.000021 | 0.525667E-11   | 0.866360                 | 0.252233E-09                 |
| 19  | 3933.30   | 0.25424E-03 | -0.22482E-03  | 0.002079 | 0.505434E-07   | 0.866363                 | 0.242524E-05                 |
| 20  | 3961.74   | 0.25241E-03 | 0.99614E-05   | 0.000092 | 0.992289E-10   | 0.866363                 | 0.476134E-08                 |
| 21  | 4073.56   | 0.24549E-03 | -0.33809E-04  | 0.000313 | 0.114304E-08   | 0.866363                 | 0.548467E-07                 |
| 22  | 4101.28   | 0.24383E-03 | 0.92525E-02   | 0.085571 | 0.856091E-04   | 0.871261                 | 0.410781E-02                 |
| 23  | 4275.41   | 0.23390E-03 | 0.37868E-02   | 0.035022 | 0.143400E-04   | 0.872081                 | 0.688080E-03                 |
| 24  | 4286.37   | 0.23330E-03 | 0.36573E-04   | 0.000338 | 0.133758E-08   | 0.872081                 | 0.641817E-07                 |
| 25  | 4294.02   | 0.23288E-03 | -0.78783E-04  | 0.000729 | 0.620671E-08   | 0.872082                 | 0.297819E-06                 |
| 26  | 4672.77   | 0.21401E-03 | 0.66081E-03   | 0.006111 | 0.436669E-06   | 0.872107                 | 0.209528E-04                 |
| 27  | 4685.45   | 0.21343E-03 | -0.11690E-01  | 0.108111 | 0.136650E-03   | 0.879924                 | 0.655693E-02                 |
| 28  | 4862.22   | 0.20567E-03 | 0.84792E-02   | 0.078418 | 0.718966E-04   | 0.884038                 | 0.344984E-02                 |
| 29  | 4865.44   | 0.20553E-03 | 0.24183E-03   | 0.002237 | 0.584827E-07   | 0.884041                 | 0.280619E-05                 |
| 30  | 4992.02   | 0.20032E-03 | 0.10163E-02   | 0.009399 | 0.103285E-05   | 0.884100                 | 0.495596E-04                 |
| 31  | 5000.26   | 0.19999E-03 | -0.40019E-01  | 0.370110 | 0.160152E-02   | 0.975724                 | 0.768463E-01                 |
| 32  | 5580.67   | 0.17919E-03 | -0.61636E-04  | 0.000570 | 0.379900E-08   | 0.975724                 | 0.182289E-06                 |
| 33  | 5584.24   | 0.17908E-03 | 0.29734E-03   | 0.002750 | 0.884121E-07   | 0.975729                 | 0.424231E-05                 |
| 34  | 5627.80   | 0.17769E-03 | -0.10546E-02  | 0.009753 | 0.111210E-05   | 0.975793                 | 0.533625E-04                 |
| 35  | 5687.68   | 0.17582E-03 | 0.21976E-03   | 0.002032 | 0.482931E-07   | 0.975795                 | 0.231726E-05                 |
| 36  | 5694.81   | 0.17560E-03 | -0.86331E-02  | 0.079842 | 0.745297E-04   | 0.980059                 | 0.357619E-02                 |
| 37  | 5757.09   | 0.17370E-03 | -0.18977E-03  | 0.001755 | 0.360123E-07   | 0.980061                 | 0.172799E-05                 |
| 38  | 5849.20   | 0.17096E-03 | -0.28861E-04  | 0.000267 | 0.832983E-09   | 0.980061                 | 0.399693E-07                 |

Figure 5-13



|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

| ***** PARTICIPATION FACTOR CALCULATION *****ROTY DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 913.948   | 0.10942E-02 | 0.53230E-04   | 0.000290 | 0.283341E-08   | 0.480906E-07             | 0.401727E-07                 |
| 2  | 1089.20   | 0.91810E-03 | -0.18329      | 1.000000 | 0.335965E-01   | 0.570223                 | 0.476338                     |
| 3  | 1093.04   | 0.91488E-03 | -0.52125E-02  | 0.028438 | 0.271703E-04   | 0.570684                 | 0.385227E-03                 |
| 4  | 1105.38   | 0.90466E-03 | -0.62678E-02  | 0.034196 | 0.392855E-04   | 0.571351                 | 0.556997E-03                 |
| 5  | 1452.40   | 0.68851E-03 | 0.13127E-03   | 0.000716 | 0.172309E-07   | 0.571351                 | 0.244303E-06                 |
| 6  | 1822.78   | 0.54861E-03 | 0.32283E-02   | 0.017612 | 0.104216E-04   | 0.571528                 | 0.147760E-03                 |
| 7  | 1831.02   | 0.54614E-03 | 0.50565E-01   | 0.275872 | 0.255687E-02   | 0.614925                 | 0.362518E-01                 |
| 8  | 2140.06   | 0.46728E-03 | 0.37577E-02   | 0.020501 | 0.141205E-04   | 0.615164                 | 0.200203E-03                 |
| 9  | 2155.67   | 0.46389E-03 | 0.28030E-02   | 0.015292 | 0.785667E-05   | 0.615298                 | 0.111393E-03                 |
| 10   | 2175.91   | 0.45958E-03 | 0.77265E-01   | 0.421535 | 0.596982E-02   | 0.716622                 | 0.846413E-01                 |
| 11   | 2260.73   | 0.44234E-03 | 0.78128E-01   | 0.426243 | 0.610391E-02   | 0.820221                 | 0.865425E-01                 |
| 12   | 2474.21   | 0.40417E-03 | -0.16696E-03  | 0.000911 | 0.278743E-07   | 0.820222                 | 0.395208E-06                 |
| 13   | 2514.58   | 0.39768E-03 | -0.75739E-04  | 0.000413 | 0.573638E-08   | 0.820222                 | 0.813316E-07                 |
| 14   | 2779.56   | 0.35977E-03 | -0.25018E-01  | 0.136489 | 0.625878E-03   | 0.830845                 | 0.887383E-02                 |
| 15   | 2780.21   | 0.35968E-03 | 0.15100E-01   | 0.082383 | 0.228016E-03   | 0.834715                 | 0.323286E-02                 |
| 16   | 3175.07   | 0.31495E-03 | -0.56230E-04  | 0.000307 | 0.316186E-08   | 0.834715                 | 0.448295E-07                 |
| 17   | 3692.97   | 0.27078E-03 | -0.14259E-01  | 0.077793 | 0.203320E-03   | 0.838166                 | 0.288271E-02                 |
| 18   | 3782.00   | 0.26441E-03 | 0.95684E-03   | 0.005220 | 0.915538E-06   | 0.838181                 | 0.129807E-04                 |
| 19   | 3933.30   | 0.25424E-03 | -0.50575E-03  | 0.002759 | 0.255787E-06   | 0.838186                 | 0.362659E-05                 |
| 20   | 3961.74   | 0.25241E-03 | 0.22961E-01   | 0.125271 | 0.527224E-03   | 0.847134                 | 0.747509E-02                 |
| 21   | 4073.56   | 0.24549E-03 | 0.12543E-02   | 0.006843 | 0.157332E-05   | 0.847161                 | 0.223069E-04                 |
| 22   | 4101.28   | 0.24383E-03 | 0.22943E-01   | 0.125169 | 0.526365E-03   | 0.856094                 | 0.746291E-02                 |
| 23   | 4275.41   | 0.23390E-03 | -0.44029E-03  | 0.002402 | 0.193857E-06   | 0.856098                 | 0.274854E-05                 |
| 24   | 4286.37   | 0.23330E-03 | 0.27869E-03   | 0.001520 | 0.776665E-07   | 0.856099                 | 0.110117E-05                 |
| 25   | 4294.02   | 0.23288E-03 | -0.30669E-03  | 0.001684 | 0.952909E-07   | 0.856101                 | 0.135105E-05                 |
| 26   | 4672.77   | 0.21401E-03 | 0.21099E-02   | 0.011511 | 0.445171E-05   | 0.856176                 | 0.631172E-04                 |
| 27   | 4685.45   | 0.21343E-03 | -0.22152E-01  | 0.120857 | 0.490723E-03   | 0.864505                 | 0.695757E-02                 |
| 28   | 4862.22   | 0.20567E-03 | 0.24781E-03   | 0.001352 | 0.614099E-07   | 0.864506                 | 0.870683E-06                 |
| 29   | 4865.44   | 0.20553E-03 | -0.88906E-02  | 0.048504 | 0.790419E-04   | 0.865848                 | 0.112067E-02                 |
| 30   | 4992.02   | 0.20032E-03 | -0.10809E-02  | 0.005897 | 0.116829E-05   | 0.865868                 | 0.165642E-04                 |
| 31   | 5000.26   | 0.19999E-03 | -0.72040E-01  | 0.393031 | 0.518976E-02   | 0.953952                 | 0.735814E-01                 |
| 32   | 5580.67   | 0.17919E-03 | -0.48975E-03  | 0.002672 | 0.239855E-06   | 0.953956                 | 0.340071E-05                 |
| 33   | 5584.24   | 0.17908E-03 | 0.12292E-03   | 0.000671 | 0.151105E-07   | 0.953956                 | 0.214240E-06                 |
| 34   | 5627.80   | 0.17769E-03 | -0.58179E-03  | 0.003174 | 0.338482E-06   | 0.953962                 | 0.479907E-05                 |
| 35   | 5687.68   | 0.17582E-03 | -0.36249E-03  | 0.001978 | 0.131398E-06   | 0.953964                 | 0.186298E-05                 |
| 36   | 5694.81   | 0.17560E-03 | -0.21391E-01  | 0.116706 | 0.457594E-03   | 0.961731                 | 0.648786E-02                 |
| 37   | 5757.09   | 0.17370E-03 | 0.19142E-04   | 0.000104 | 0.366405E-09   | 0.961731                 | 0.519497E-08                 |
| 38   | 5849.20   | 0.17096E-03 | 0.13542E-03   | 0.000739 | 0.183391E-07   | 0.961731                 | 0.260016E-06                 |
| 39   | 6097.12   | 0.16401E-03 | 0.10096E-02   | 0.005508 | 0.101932E-05   | 0.961748                 | 0.144521E-04                 |

Figure 5-14

| ***** PARTICIPATION FACTOR CALCULATION *****ROTY DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 913.948   | 0.10942E-02 | 0.84176E-04   | 0.000398 | 0.708565E-08   | 0.113475E-06             | 0.860700E-07                 |
| 2  | 1089.20   | 0.91810E-03 | -0.50344E-03  | 0.002379 | 0.253456E-06   | 0.417251E-05             | 0.307875E-05                 |
| 3  | 1093.04   | 0.91488E-03 | -0.11227E-02  | 0.005304 | 0.126049E-05   | 0.243590E-04             | 0.153113E-04                 |
| 4  | 1105.38   | 0.90466E-03 | -0.10832      | 0.511745 | 0.117325E-01   | 0.187917                 | 0.142515                     |
| 5  | 1452.40   | 0.68851E-03 | -0.72095E-03  | 0.003406 | 0.519770E-06   | 0.187925                 | 0.631369E-05                 |
| 6  | 1822.78   | 0.54861E-03 | -0.29375E-01  | 0.138784 | 0.862907E-03   | 0.201744                 | 0.104818E-01                 |
| 7  | 1831.02   | 0.54614E-03 | 0.86550E-03   | 0.004089 | 0.749086E-06   | 0.201756                 | 0.909920E-05                 |
| 8  | 2140.06   | 0.46728E-03 | 0.49210E-01   | 0.232492 | 0.242159E-02   | 0.240538                 | 0.294153E-01                 |
| 9  | 2155.67   | 0.46389E-03 | 0.50797E-02   | 0.023999 | 0.258034E-04   | 0.240951                 | 0.313437E-03                 |
| 10   | 2175.91   | 0.45958E-03 | -0.44720E-03  | 0.002113 | 0.199985E-06   | 0.240954                 | 0.242924E-05                 |
| 11   | 2260.73   | 0.44234E-03 | -0.50348E-04  | 0.000238 | 0.253492E-08   | 0.240954                 | 0.307918E-07                 |
| 12   | 2474.21   | 0.40417E-03 | -0.27321E-02  | 0.012908 | 0.746451E-05   | 0.241074                 | 0.906721E-04                 |
| 13   | 2514.58   | 0.39768E-03 | 0.76241E-03   | 0.003602 | 0.581273E-06   | 0.241083                 | 0.706077E-05                 |
| 14   | 2779.56   | 0.35977E-03 | 0.47065E-02   | 0.022236 | 0.221513E-04   | 0.241438                 | 0.269074E-03                 |
| 15   | 2780.21   | 0.35968E-03 | 0.71216E-02   | 0.033646 | 0.507167E-04   | 0.242250                 | 0.616059E-03                 |
| 16   | 3175.07   | 0.31495E-03 | -0.25001E-02  | 0.011812 | 0.625064E-05   | 0.242350                 | 0.759271E-04                 |
| 17   | 3692.97   | 0.27078E-03 | -0.81844E-05  | 0.000039 | 0.669840E-10   | 0.242350                 | 0.813661E-09                 |
| 18   | 3782.00   | 0.26441E-03 | -0.19064E-04  | 0.000090 | 0.363442E-09   | 0.242350                 | 0.441476E-08                 |
| 19   | 3933.30   | 0.25424E-03 | -0.58969E-02  | 0.027860 | 0.347734E-04   | 0.242907                 | 0.422396E-03                 |
| 20   | 3961.74   | 0.25241E-03 | -0.31625E-04  | 0.000149 | 0.100013E-08   | 0.242907                 | 0.121487E-07                 |
| 21   | 4073.56   | 0.24549E-03 | -0.99370E-02  | 0.046948 | 0.987442E-04   | 0.244488                 | 0.119945E-02                 |
| 22   | 4101.28   | 0.24383E-03 | -0.34410E-04  | 0.000163 | 0.118406E-08   | 0.244488                 | 0.143829E-07                 |
| 23   | 4275.41   | 0.23390E-03 | 0.43391E-04   | 0.000205 | 0.188282E-08   | 0.244488                 | 0.228708E-07                 |
| 24   | 4286.37   | 0.23330E-03 | 0.26682E-02   | 0.012606 | 0.711948E-05   | 0.244602                 | 0.864809E-04                 |
| 25   | 4294.02   | 0.23288E-03 | -0.10030E-02  | 0.004739 | 0.100609E-05   | 0.244618                 | 0.122211E-04                 |
| 26   | 4672.77   | 0.21401E-03 | -0.11122E-01  | 0.052544 | 0.123690E-03   | 0.246599                 | 0.150248E-02                 |
| 27   | 4685.45   | 0.21343E-03 | -0.40531E-03  | 0.001915 | 0.164276E-06   | 0.246602                 | 0.199547E-05                 |
| 28   | 4862.22   | 0.20567E-03 | 0.21166       | 1.000000 | 0.448006E-01   | 0.964071                 | 0.544196                     |
| 29   | 4865.44   | 0.20553E-03 | 0.43417E-02   | 0.020512 | 0.188499E-04   | 0.964373                 | 0.228972E-03                 |
| 30   | 4992.02   | 0.20032E-03 | 0.38901E-01   | 0.183790 | 0.151331E-02   | 0.988608                 | 0.183823E-01                 |
| 31   | 5000.26   | 0.19999E-03 | 0.11798E-02   | 0.005574 | 0.139185E-05   | 0.988630                 | 0.169069E-04                 |
| 32   | 5580.67   | 0.17919E-03 | 0.34265E-02   | 0.016188 | 0.117406E-04   | 0.988818                 | 0.142615E-03                 |
| 33   | 5584.24   | 0.17908E-03 | 0.18187E-02   | 0.008593 | 0.330778E-05   | 0.988871                 | 0.401799E-04                 |
| 34   | 5627.80   | 0.17769E-03 | 0.34068E-03   | 0.001610 | 0.116063E-06   | 0.988873                 | 0.140983E-05                 |
| 35   | 5687.68   | 0.17582E-03 | 0.84571E-02   | 0.039956 | 0.715228E-04   | 0.990018                 | 0.868794E-03                 |
| 36   | 5694.81   | 0.17560E-03 | 0.14031E-03   | 0.000663 | 0.196869E-07   | 0.990019                 | 0.239139E-06                 |
| 37   | 5757.09   | 0.17370E-03 | -0.41045E-02  | 0.019392 | 0.168467E-04   | 0.990288                 | 0.204638E-03                 |
| 38   | 5849.20   | 0.17096E-03 | 0.52689E-04   | 0.000249 | 0.277611E-08   | 0.990289                 | 0.337216E-07                 |
| 39   | 6097.12   | 0.16401E-03 | 0.13790E-03   | 0.000652 | 0.190177E-07   | 0.990289                 | 0.231009E-06                 |

Figure 5-15

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |



### 5.6.2 SMALLER AREAS CLOSE TO CORNERS OF BASE ARE FIXED (FIGURE 8.)

Table 5-2 shows 20 lowest frequencies. More detailed information about each mode were shown in figures 10. - 15.

**Table 5-2 20 lowest frequencies in 2. case**

| Mode | Frequency [Hz] | Mode | Frequency [Hz] |
|------|----------------|------|----------------|
| 1    | 490,30         | 11   | 1969,35        |
| 2    | 491,61         | 12   | 2143,55        |
| 3    | 586,99         | 13   | 2413,88        |
| 4    | 899,72         | 14   | 2460,35        |
| 5    | 1407,70        | 15   | 2681,01        |
| 6    | 1770,06        | 16   | 2685,98        |
| 7    | 1781,71        | 17   | 3098,56        |
| 8    | 1782,79        | 18   | 3356,09        |
| 9    | 1797,37        | 19   | 3536,04        |
| 10   | 1929,52        | 20   | 3592,80        |

Figures 16. – 20. shows raw ANSYS output. Notice that frequency unit is Hz.



|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

| ***** PARTICIPATION FACTOR CALCULATION ***** X DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 490.297   | 0.20396E-02 | 0.70869E-01   | 0.035902 | 0.502242E-02   | 0.930873E-03             | 0.858339E-03                 |
| 2  | 491.614   | 0.20341E-02 | 1.9739        | 1.000000 | 3.89640        | 0.723104                 | 0.665902                     |
| 3  | 586.993   | 0.17036E-02 | 0.69113E-03   | 0.000350 | 0.477661E-06   | 0.723104                 | 0.816331E-07                 |
| 4  | 899.716   | 0.11115E-02 | -0.38119E-03  | 0.000193 | 0.145306E-06   | 0.723104                 | 0.248330E-07                 |
| 5  | 1407.70   | 0.71038E-03 | -0.41534E-03  | 0.000210 | 0.172505E-06   | 0.723105                 | 0.294814E-07                 |
| 6  | 1770.06   | 0.56495E-03 | 0.21829       | 0.110584 | 0.476487E-01   | 0.731936                 | 0.814324E-02                 |
| 7  | 1781.71   | 0.56126E-03 | -0.45230      | 0.229139 | 0.204579       | 0.769853                 | 0.349629E-01                 |
| 8  | 1782.79   | 0.56092E-03 | -0.84363E-01  | 0.042739 | 0.711710E-02   | 0.771172                 | 0.121632E-02                 |
| 9  | 1797.37   | 0.55637E-03 | 0.66541E-02   | 0.003371 | 0.442769E-04   | 0.771181                 | 0.756700E-05                 |
| 10   | 1929.52   | 0.51826E-03 | 0.10418E-02   | 0.000528 | 0.108540E-05   | 0.771181                 | 0.185496E-06                 |
| 11   | 1969.35   | 0.50778E-03 | -0.32219E-03  | 0.000163 | 0.103807E-06   | 0.771181                 | 0.177408E-07                 |
| 12   | 2143.55   | 0.46652E-03 | -0.34866E-03  | 0.000177 | 0.121566E-06   | 0.771181                 | 0.207758E-07                 |
| 13   | 2413.88   | 0.41427E-03 | 0.10625E-03   | 0.000054 | 0.112900E-07   | 0.771181                 | 0.192948E-08                 |
| 14   | 2460.35   | 0.40645E-03 | -0.10412E-02  | 0.000527 | 0.108416E-05   | 0.771181                 | 0.185285E-06                 |
| 15   | 2681.01   | 0.37299E-03 | 0.20007       | 0.101355 | 0.400272E-01   | 0.778600                 | 0.684071E-02                 |
| 16   | 2685.98   | 0.37230E-03 | -0.14230E-01  | 0.007209 | 0.202482E-03   | 0.778637                 | 0.346046E-04                 |
| 17   | 3098.56   | 0.32273E-03 | -0.69257E-03  | 0.000351 | 0.479652E-06   | 0.778637                 | 0.819733E-07                 |
| 18   | 3356.09   | 0.29797E-03 | -0.34016E-04  | 0.000017 | 0.115709E-08   | 0.778637                 | 0.197749E-09                 |
| 19   | 3536.04   | 0.28280E-03 | 0.85478E-03   | 0.000433 | 0.730654E-06   | 0.778638                 | 0.124870E-06                 |
| 20   | 3592.80   | 0.27833E-03 | -0.79654E-03  | 0.000404 | 0.634481E-06   | 0.778638                 | 0.108434E-06                 |
| 21   | 3772.44   | 0.26508E-03 | -0.30583E-02  | 0.001549 | 0.935322E-05   | 0.778639                 | 0.159846E-05                 |
| 22   | 3774.33   | 0.26495E-03 | -0.17615E-02  | 0.000892 | 0.310285E-05   | 0.778640                 | 0.530282E-06                 |
| 23   | 3903.86   | 0.25616E-03 | -0.24716      | 0.125214 | 0.610899E-01   | 0.789963                 | 0.104404E-01                 |
| 24   | 3943.56   | 0.25358E-03 | 0.75942E-04   | 0.000038 | 0.576722E-08   | 0.789963                 | 0.985628E-09                 |
| 25   | 4192.02   | 0.23855E-03 | 0.30482E-03   | 0.000154 | 0.929172E-07   | 0.789963                 | 0.158797E-07                 |
| 26   | 4193.01   | 0.23849E-03 | 0.33903E-02   | 0.001718 | 0.114941E-04   | 0.789965                 | 0.196435E-05                 |
| 27   | 4226.68   | 0.23659E-03 | 0.25952E-01   | 0.013147 | 0.673481E-03   | 0.790090                 | 0.115099E-03                 |
| 28   | 4291.20   | 0.23303E-03 | 0.87862       | 0.445113 | 0.771978       | 0.933171                 | 0.131932                     |
| 29   | 4315.66   | 0.23171E-03 | 0.10315E-02   | 0.000523 | 0.106403E-05   | 0.933171                 | 0.181844E-06                 |
| 30   | 4637.54   | 0.21563E-03 | 0.25038       | 0.126843 | 0.626902E-01   | 0.944790                 | 0.107139E-01                 |
| 31   | 4649.75   | 0.21507E-03 | 0.77068E-02   | 0.003904 | 0.593945E-04   | 0.944801                 | 0.101506E-04                 |
| 32   | 4735.74   | 0.21116E-03 | 0.40916E-02   | 0.002073 | 0.167411E-04   | 0.944804                 | 0.286109E-05                 |
| 33   | 5356.66   | 0.18668E-03 | 0.74263E-01   | 0.037622 | 0.551492E-02   | 0.945826                 | 0.942509E-03                 |
| 34   | 5365.39   | 0.18638E-03 | 0.15768       | 0.079883 | 0.248643E-01   | 0.950435                 | 0.424935E-02                 |
| 35   | 5437.72   | 0.18390E-03 | -0.14282E-03  | 0.000072 | 0.203967E-07   | 0.950435                 | 0.348583E-08                 |
| 36   | 5492.49   | 0.18207E-03 | 0.21103E-02   | 0.001069 | 0.445346E-05   | 0.950436                 | 0.761103E-06                 |
| 37   | 5508.10   | 0.18155E-03 | 0.47832E-01   | 0.024232 | 0.228791E-02   | 0.950860                 | 0.391008E-03                 |
| 38   | 5578.87   | 0.17925E-03 | 0.45682E-02   | 0.002314 | 0.208685E-04   | 0.950864                 | 0.356646E-05                 |
| 39   | 5675.85   | 0.17619E-03 | -0.31132E-04  | 0.000016 | 0.969232E-09   | 0.950864                 | 0.165643E-09                 |

Figure 5-16

| ***** PARTICIPATION FACTOR CALCULATION ***** Y DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 490.297   | 0.20396E-02 | 0.40974E-04   | 0.000020 | 0.167890E-08   | 0.291003E-09             | 0.286926E-09                 |
| 2  | 491.614   | 0.20341E-02 | 0.82977E-03   | 0.000411 | 0.688522E-06   | 0.119632E-06             | 0.117670E-06                 |
| 3  | 586.993   | 0.17036E-02 | 0.42769E-05   | 0.000002 | 0.182918E-10   | 0.119636E-06             | 0.312610E-11                 |
| 4  | 899.716   | 0.11115E-02 | 0.25819E-02   | 0.001278 | 0.666637E-05   | 0.127512E-05             | 0.113929E-05                 |
| 5  | 1407.70   | 0.71038E-03 | -0.16817E-01  | 0.008325 | 0.282811E-03   | 0.502948E-04             | 0.483329E-04                 |
| 6  | 1770.06   | 0.56495E-03 | -0.61369E-02  | 0.003038 | 0.376618E-04   | 0.568227E-04             | 0.643646E-05                 |
| 7  | 1781.71   | 0.56126E-03 | 0.91003E-03   | 0.000451 | 0.828148E-06   | 0.569662E-04             | 0.141532E-06                 |
| 8  | 1782.79   | 0.56092E-03 | 0.30643E-02   | 0.001517 | 0.938971E-05   | 0.585937E-04             | 0.160472E-05                 |
| 9  | 1797.37   | 0.55637E-03 | 0.97268E-03   | 0.000482 | 0.946103E-06   | 0.587577E-04             | 0.161691E-06                 |
| 10   | 1929.52   | 0.51826E-03 | 0.14119E-02   | 0.000699 | 0.199337E-05   | 0.591032E-04             | 0.340670E-06                 |
| 11   | 1969.35   | 0.50778E-03 | 2.0200        | 1.000000 | 4.08028        | 0.707293                 | 0.697326                     |
| 12   | 2143.55   | 0.46652E-03 | 0.74179       | 0.367228 | 0.550252       | 0.802668                 | 0.940390E-01                 |
| 13   | 2413.88   | 0.41427E-03 | -0.84710E-01  | 0.041936 | 0.717576E-02   | 0.803912                 | 0.122635E-02                 |
| 14   | 2460.35   | 0.40645E-03 | 0.64974       | 0.321660 | 0.422166       | 0.877086                 | 0.721489E-01                 |
| 15   | 2681.01   | 0.37299E-03 | 0.34178E-02   | 0.001692 | 0.116816E-04   | 0.877088                 | 0.199641E-05                 |
| 16   | 2685.98   | 0.37230E-03 | -0.31830E-02  | 0.001576 | 0.101314E-04   | 0.877090                 | 0.173147E-05                 |
| 17   | 3098.56   | 0.32273E-03 | 0.54539       | 0.269998 | 0.297449       | 0.928647                 | 0.508345E-01                 |
| 18   | 3356.09   | 0.29797E-03 | -0.23029E-03  | 0.000114 | 0.530318E-07   | 0.928647                 | 0.906322E-08                 |
| 19   | 3536.04   | 0.28280E-03 | 0.58062       | 0.287441 | 0.337123       | 0.987080                 | 0.576148E-01                 |
| 20   | 3592.80   | 0.27833E-03 | -0.11645E-02  | 0.000576 | 0.135609E-05   | 0.987080                 | 0.231757E-06                 |
| 21   | 3772.44   | 0.26508E-03 | 0.58162E-02   | 0.002879 | 0.338286E-04   | 0.987086                 | 0.578137E-05                 |
| 22   | 3774.33   | 0.26495E-03 | 0.11221E-01   | 0.005555 | 0.125914E-03   | 0.987108                 | 0.215188E-04                 |
| 23   | 3903.86   | 0.25616E-03 | -0.49840E-03  | 0.000247 | 0.248403E-06   | 0.987108                 | 0.424525E-07                 |
| 24   | 3943.56   | 0.25358E-03 | 0.45448E-03   | 0.000225 | 0.206550E-06   | 0.987108                 | 0.352997E-07                 |
| 25   | 4192.02   | 0.23855E-03 | 0.50202E-01   | 0.024853 | 0.252019E-02   | 0.987545                 | 0.430705E-03                 |
| 26   | 4193.01   | 0.23849E-03 | -0.10166      | 0.050327 | 0.103345E-01   | 0.989336                 | 0.176619E-02                 |
| 27   | 4226.68   | 0.23659E-03 | -0.30484E-02  | 0.001509 | 0.929305E-05   | 0.989338                 | 0.158820E-05                 |
| 28   | 4291.20   | 0.23303E-03 | 0.10455E-02   | 0.000518 | 0.109313E-05   | 0.989338                 | 0.186819E-06                 |
| 29   | 4315.66   | 0.23171E-03 | -0.76793E-03  | 0.000380 | 0.589712E-06   | 0.989338                 | 0.100783E-06                 |
| 30   | 4637.54   | 0.21563E-03 | 0.34932E-04   | 0.000017 | 0.122023E-08   | 0.989338                 | 0.208540E-09                 |
| 31   | 4649.75   | 0.21507E-03 | -0.57007E-03  | 0.000282 | 0.324981E-06   | 0.989338                 | 0.555398E-07                 |
| 32   | 4735.74   | 0.21116E-03 | 0.36612E-03   | 0.000181 | 0.134044E-06   | 0.989338                 | 0.229083E-07                 |
| 33   | 5356.66   | 0.18668E-03 | 0.17926E-01   | 0.008874 | 0.321339E-03   | 0.989394                 | 0.549174E-04                 |
| 34   | 5365.39   | 0.18638E-03 | -0.60769E-02  | 0.003008 | 0.369284E-04   | 0.989400                 | 0.631113E-05                 |
| 35   | 5437.72   | 0.18390E-03 | -0.44525E-03  | 0.000220 | 0.198245E-06   | 0.989400                 | 0.338804E-07                 |
| 36   | 5492.49   | 0.18207E-03 | 0.57487E-02   | 0.002846 | 0.330470E-04   | 0.989406                 | 0.564778E-05                 |
| 37   | 5508.10   | 0.18155E-03 | 0.33099E-02   | 0.001639 | 0.109557E-04   | 0.989408                 | 0.187234E-05                 |
| 38   | 5578.87   | 0.17925E-03 | -0.10145      | 0.050222 | 0.102915E-01   | 0.991192                 | 0.175884E-02                 |
| 39   | 5675.85   | 0.17619E-03 | -0.23205E-03  | 0.000115 | 0.538474E-07   | 0.991192                 | 0.920260E-08                 |

Figure 5-17

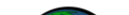

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

| ***** PARTICIPATION FACTOR CALCULATION ***** Z DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 490.297   | 0.20396E-02 | 1.9733        | 1.000000 | 3.89380        | 0.724152                 | 0.665456                     |
| 2  | 491.614   | 0.20341E-02 | -0.70807E-01  | 0.035883 | 0.501362E-02   | 0.725084                 | 0.856835E-03                 |
| 3  | 586.993   | 0.17036E-02 | -0.40809E-02  | 0.002068 | 0.166538E-04   | 0.725088                 | 0.284616E-05                 |
| 4  | 899.716   | 0.11115E-02 | -0.80083E-04  | 0.000041 | 0.641325E-08   | 0.725088                 | 0.109604E-08                 |
| 5  | 1407.70   | 0.71038E-03 | -0.13717E-03  | 0.000070 | 0.188147E-07   | 0.725088                 | 0.321546E-08                 |
| 6  | 1770.06   | 0.56495E-03 | 0.32756E-02   | 0.001660 | 0.107297E-04   | 0.725090                 | 0.183373E-05                 |
| 7  | 1781.71   | 0.56126E-03 | -0.88569E-01  | 0.044884 | 0.784451E-02   | 0.726548                 | 0.134064E-02                 |
| 8  | 1782.79   | 0.56092E-03 | 0.46497       | 0.235633 | 0.216195       | 0.766756                 | 0.369481E-01                 |
| 9  | 1797.37   | 0.55637E-03 | -0.23070      | 0.116912 | 0.532220E-01   | 0.776654                 | 0.909573E-02                 |
| 10   | 1929.52   | 0.51826E-03 | 0.68662E-03   | 0.000348 | 0.471447E-06   | 0.776654                 | 0.805710E-07                 |
| 11   | 1969.35   | 0.50778E-03 | -0.85355E-03  | 0.000433 | 0.728551E-06   | 0.776654                 | 0.124511E-06                 |
| 12   | 2143.55   | 0.46652E-03 | 0.37588E-03   | 0.000190 | 0.141284E-06   | 0.776654                 | 0.241456E-07                 |
| 13   | 2413.88   | 0.41427E-03 | 0.64887E-04   | 0.000033 | 0.421032E-08   | 0.776654                 | 0.719551E-09                 |
| 14   | 2460.35   | 0.40645E-03 | 0.14187E-02   | 0.000719 | 0.201282E-05   | 0.776654                 | 0.343994E-06                 |
| 15   | 2681.01   | 0.37299E-03 | 0.14215E-01   | 0.007204 | 0.202062E-03   | 0.776692                 | 0.345328E-04                 |
| 16   | 2685.98   | 0.37230E-03 | 0.20457       | 0.103669 | 0.418480E-01   | 0.784474                 | 0.715189E-02                 |
| 17   | 3098.56   | 0.32273E-03 | 0.50629E-04   | 0.000026 | 0.256327E-08   | 0.784474                 | 0.438067E-09                 |
| 18   | 3356.09   | 0.29797E-03 | -0.16100E-03  | 0.000082 | 0.259196E-07   | 0.784474                 | 0.442969E-08                 |
| 19   | 3536.04   | 0.28280E-03 | -0.11871E-03  | 0.000060 | 0.140917E-07   | 0.784474                 | 0.240829E-08                 |
| 20   | 3592.80   | 0.27833E-03 | -0.34038E-04  | 0.000017 | 0.115857E-08   | 0.784474                 | 0.198001E-09                 |
| 21   | 3772.44   | 0.26508E-03 | -0.88555E-03  | 0.000449 | 0.784202E-06   | 0.784475                 | 0.134021E-06                 |
| 22   | 3774.33   | 0.26495E-03 | 0.64353E-03   | 0.000326 | 0.414132E-06   | 0.784475                 | 0.707758E-07                 |
| 23   | 3903.86   | 0.25616E-03 | 0.39970E-03   | 0.000203 | 0.159758E-06   | 0.784475                 | 0.273029E-07                 |
| 24   | 3943.56   | 0.25358E-03 | -0.17984      | 0.091139 | 0.323435E-01   | 0.790490                 | 0.552755E-02                 |
| 25   | 4192.02   | 0.23855E-03 | 0.28371       | 0.143776 | 0.804912E-01   | 0.805459                 | 0.137561E-01                 |
| 26   | 4193.01   | 0.23849E-03 | 0.13509       | 0.068458 | 0.182484E-01   | 0.808853                 | 0.311869E-02                 |
| 27   | 4226.68   | 0.23659E-03 | -0.31437E-02  | 0.001593 | 0.988301E-05   | 0.808855                 | 0.168902E-05                 |
| 28   | 4291.20   | 0.23303E-03 | -0.18807E-02  | 0.000953 | 0.353694E-05   | 0.808855                 | 0.604468E-06                 |
| 29   | 4315.66   | 0.23171E-03 | 0.81894       | 0.415016 | 0.670661       | 0.933582                 | 0.114617                     |
| 30   | 4637.54   | 0.21563E-03 | 0.10072E-01   | 0.005104 | 0.101447E-03   | 0.933601                 | 0.173375E-04                 |
| 31   | 4649.75   | 0.21507E-03 | -0.26752      | 0.135571 | 0.715655E-01   | 0.946910                 | 0.122307E-01                 |
| 32   | 4735.74   | 0.21116E-03 | -0.29836E-02  | 0.001512 | 0.890201E-05   | 0.946912                 | 0.152137E-05                 |
| 33   | 5356.66   | 0.18668E-03 | -0.10554E-02  | 0.000535 | 0.111387E-05   | 0.946912                 | 0.190363E-06                 |
| 34   | 5365.39   | 0.18638E-03 | 0.38799E-03   | 0.000197 | 0.150533E-06   | 0.946912                 | 0.257263E-07                 |
| 35   | 5437.72   | 0.18390E-03 | 0.18451       | 0.093505 | 0.340441E-01   | 0.953244                 | 0.581819E-02                 |
| 36   | 5492.49   | 0.18207E-03 | -0.19165E-01  | 0.009712 | 0.367300E-03   | 0.953312                 | 0.627722E-04                 |
| 37   | 5508.10   | 0.18155E-03 | 0.75045E-03   | 0.000380 | 0.563177E-06   | 0.953312                 | 0.962479E-07                 |
| 38   | 5578.87   | 0.17925E-03 | -0.27924E-02  | 0.001415 | 0.779759E-05   | 0.953314                 | 0.133262E-05                 |
| 39   | 5675.85   | 0.17619E-03 | -0.67339E-03  | 0.000341 | 0.453448E-06   | 0.953314                 | 0.774950E-07                 |

Figure 5-18

| ***** PARTICIPATION FACTOR CALCULATION *****ROTX DIRECTION |           |             |               |          |                |                          |                              |
|--|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE   | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1  | 490.297   | 0.20396E-02 | 0.19946       | 1.000000 | 0.397832E-01   | 0.727522                 | 0.680893                     |
| 2  | 491.614   | 0.20341E-02 | -0.71519E-02  | 0.035857 | 0.511494E-04   | 0.728457                 | 0.875426E-03                 |
| 3  | 586.993   | 0.17036E-02 | -0.41745E-03  | 0.002093 | 0.174264E-06   | 0.728460                 | 0.298254E-05                 |
| 4  | 899.716   | 0.11115E-02 | 0.39681E-04   | 0.000199 | 0.157455E-08   | 0.728461                 | 0.269486E-07                 |
| 5  | 1407.70   | 0.71038E-03 | -0.15281E-03  | 0.000766 | 0.233500E-07   | 0.728461                 | 0.399637E-06                 |
| 6  | 1770.06   | 0.56495E-03 | -0.73996E-03  | 0.003710 | 0.547542E-06   | 0.728471                 | 0.937123E-05                 |
| 7  | 1781.71   | 0.56126E-03 | 0.10237E-01   | 0.051324 | 0.104796E-03   | 0.730387                 | 0.179359E-02                 |
| 8  | 1782.79   | 0.56092E-03 | -0.56695E-01  | 0.284245 | 0.321429E-02   | 0.789168                 | 0.550128E-01                 |
| 9  | 1797.37   | 0.55637E-03 | -0.20861E-02  | 0.010459 | 0.435161E-05   | 0.789247                 | 0.744782E-04                 |
| 10   | 1929.52   | 0.51826E-03 | 0.15134E-04   | 0.000076 | 0.229043E-09   | 0.789247                 | 0.392009E-08                 |
| 11   | 1969.35   | 0.50778E-03 | 0.13957E-01   | 0.069976 | 0.194806E-03   | 0.792810                 | 0.333412E-02                 |
| 12   | 2143.55   | 0.46652E-03 | 0.50020E-02   | 0.025078 | 0.250199E-04   | 0.793267                 | 0.428218E-03                 |
| 13   | 2413.88   | 0.41427E-03 | -0.56751E-03  | 0.002845 | 0.322062E-06   | 0.793273                 | 0.551213E-05                 |
| 14   | 2460.35   | 0.40645E-03 | 0.43073E-02   | 0.021595 | 0.185525E-04   | 0.793612                 | 0.317527E-03                 |
| 15   | 2681.01   | 0.37299E-03 | -0.16931E-02  | 0.008489 | 0.286657E-05   | 0.793665                 | 0.490616E-04                 |
| 16   | 2685.98   | 0.37230E-03 | -0.24411E-01  | 0.122387 | 0.595895E-03   | 0.804562                 | 0.101988E-01                 |
| 17   | 3098.56   | 0.32273E-03 | 0.37474E-02   | 0.018788 | 0.140427E-04   | 0.804819                 | 0.240342E-03                 |
| 18   | 3356.09   | 0.29797E-03 | 0.11780E-04   | 0.000059 | 0.138758E-09   | 0.804819                 | 0.237485E-08                 |
| 19   | 3536.04   | 0.28280E-03 | 0.40121E-02   | 0.020115 | 0.160968E-04   | 0.805113                 | 0.275498E-03                 |
| 20   | 3592.80   | 0.27833E-03 | -0.17503E-04  | 0.000088 | 0.306342E-09   | 0.805113                 | 0.524307E-08                 |
| 21   | 3772.44   | 0.26508E-03 | 0.10807E-03   | 0.000542 | 0.116783E-07   | 0.805113                 | 0.199875E-06                 |
| 22   | 3774.33   | 0.26495E-03 | -0.94054E-05  | 0.000047 | 0.884613E-10   | 0.805113                 | 0.151402E-08                 |
| 23   | 3903.86   | 0.25616E-03 | -0.46776E-04  | 0.000235 | 0.218799E-08   | 0.805113                 | 0.374476E-07                 |
| 24   | 3943.56   | 0.25358E-03 | 0.20440E-01   | 0.102479 | 0.417804E-03   | 0.812754                 | 0.715075E-02                 |
| 25   | 4192.02   | 0.23855E-03 | -0.28953E-01  | 0.145160 | 0.838288E-03   | 0.828084                 | 0.143474E-01                 |
| 26   | 4193.01   | 0.23849E-03 | -0.14694E-01  | 0.073670 | 0.215914E-03   | 0.832032                 | 0.369539E-02                 |
| 27   | 4226.68   | 0.23659E-03 | 0.27764E-03   | 0.001392 | 0.770839E-07   | 0.832034                 | 0.131930E-05                 |
| 28   | 4291.20   | 0.23303E-03 | 0.18618E-03   | 0.000933 | 0.346647E-07   | 0.832034                 | 0.593290E-06                 |
| 29   | 4315.66   | 0.23171E-03 | -0.77422E-01  | 0.388165 | 0.599423E-02   | 0.941652                 | 0.102592                     |
| 30   | 4637.54   | 0.21563E-03 | -0.86951E-03  | 0.004359 | 0.756055E-06   | 0.941665                 | 0.129399E-04                 |
| 31   | 4649.75   | 0.21507E-03 | 0.22758E-01   | 0.114102 | 0.517949E-03   | 0.951137                 | 0.886474E-02                 |
| 32   | 4735.74   | 0.21116E-03 | 0.23916E-03   | 0.001199 | 0.571979E-07   | 0.951138                 | 0.978947E-06                 |
| 33   | 5356.66   | 0.18668E-03 | 0.14978E-03   | 0.000751 | 0.224347E-07   | 0.951139                 | 0.383972E-06                 |
| 34   | 5365.39   | 0.18638E-03 | -0.35081E-04  | 0.000176 | 0.123069E-08   | 0.951139                 | 0.210634E-07                 |
| 35   | 5437.72   | 0.18390E-03 | -0.19902E-01  | 0.099782 | 0.396098E-03   | 0.958382                 | 0.677926E-02                 |
| 36   | 5492.49   | 0.18207E-03 | -0.14571E-02  | 0.007306 | 0.212327E-05   | 0.958421                 | 0.363399E-04                 |
| 37   | 5508.10   | 0.18155E-03 | 0.58108E-04   | 0.000291 | 0.337656E-08   | 0.958421                 | 0.577901E-07                 |
| 38   | 5578.87   | 0.17925E-03 | -0.66358E-03  | 0.003327 | 0.440335E-06   | 0.958429                 | 0.753637E-05                 |
| 39   | 5675.85   | 0.17619E-03 | 0.21384E-04   | 0.000107 | 0.457296E-09   | 0.958429                 | 0.782666E-08                 |

Figure 5-19

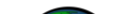

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

| ***** PARTICIPATION FACTOR CALCULATION ***** ROTY DIRECTION |           |             |               |          |                |                          |                              |
|---|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE  | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1   | 490.297   | 0.20396E-02 | -0.33989      | 1.000000 | 0.115524       | 0.631376                 | 0.584225                     |
| 2   | 491.614   | 0.20341E-02 | -0.13487E-02  | 0.003968 | 0.181907E-05   | 0.631386                 | 0.919939E-05                 |
| 3   | 586.993   | 0.17036E-02 | -0.22340E-02  | 0.006573 | 0.499073E-05   | 0.631414                 | 0.252391E-04                 |
| 4   | 899.716   | 0.11115E-02 | 0.17414E-04   | 0.000051 | 0.303241E-09   | 0.631414                 | 0.153355E-08                 |
| 5   | 1407.70   | 0.71038E-03 | 0.21843E-04   | 0.000064 | 0.477134E-09   | 0.631414                 | 0.241296E-08                 |
| 6   | 1770.06   | 0.56495E-03 | -0.18575E-02  | 0.005465 | 0.345038E-05   | 0.631432                 | 0.174492E-04                 |
| 7   | 1781.71   | 0.56126E-03 | 0.18134E-01   | 0.053353 | 0.328841E-03   | 0.633230                 | 0.166301E-02                 |
| 8   | 1782.79   | 0.56092E-03 | -0.79460E-01  | 0.233783 | 0.631388E-02   | 0.667737                 | 0.319305E-01                 |
| 9   | 1797.37   | 0.55637E-03 | 0.39279E-01   | 0.115565 | 0.154284E-02   | 0.676169                 | 0.780245E-02                 |
| 10  | 1929.52   | 0.51826E-03 | -0.14372      | 0.422840 | 0.206549E-01   | 0.789055                 | 0.104456                     |
| 11  | 1969.35   | 0.50778E-03 | 0.23468E-03   | 0.000690 | 0.550765E-07   | 0.789056                 | 0.278533E-06                 |
| 12  | 2143.55   | 0.46652E-03 | -0.58311E-05  | 0.000017 | 0.340016E-10   | 0.789056                 | 0.171953E-09                 |
| 13  | 2413.88   | 0.41427E-03 | -0.12410E-04  | 0.000037 | 0.153997E-09   | 0.789056                 | 0.778794E-09                 |
| 14  | 2460.35   | 0.40645E-03 | -0.27040E-03  | 0.000796 | 0.731139E-07   | 0.789056                 | 0.369751E-06                 |
| 15  | 2681.01   | 0.37299E-03 | -0.38678E-02  | 0.011380 | 0.149599E-04   | 0.789138                 | 0.756549E-04                 |
| 16  | 2685.98   | 0.37230E-03 | -0.35034E-01  | 0.103076 | 0.122740E-02   | 0.795846                 | 0.620719E-02                 |
| 17  | 3098.56   | 0.32273E-03 | -0.15191E-04  | 0.000045 | 0.230779E-09   | 0.795846                 | 0.116710E-08                 |
| 18  | 3356.09   | 0.29797E-03 | -0.59609E-03  | 0.001754 | 0.355318E-06   | 0.795846                 | 0.179691E-05                 |
| 19  | 3536.04   | 0.28280E-03 | 0.20248E-04   | 0.000060 | 0.409992E-09   | 0.795848                 | 0.207341E-08                 |
| 20  | 3592.80   | 0.27833E-03 | -0.27281E-01  | 0.080265 | 0.744266E-03   | 0.799916                 | 0.376390E-02                 |
| 21  | 3772.44   | 0.26508E-03 | -0.22581E-01  | 0.066436 | 0.509899E-03   | 0.802702                 | 0.257866E-02                 |
| 22  | 3774.33   | 0.26495E-03 | 0.10085E-01   | 0.029672 | 0.101713E-03   | 0.803258                 | 0.514383E-03                 |
| 23  | 3903.86   | 0.25616E-03 | 0.19020E-02   | 0.005596 | 0.361772E-05   | 0.803278                 | 0.182955E-04                 |
| 24  | 3943.56   | 0.25358E-03 | 0.30869E-01   | 0.090821 | 0.952882E-03   | 0.808486                 | 0.481891E-02                 |
| 25  | 4192.02   | 0.23855E-03 | -0.48652E-01  | 0.143141 | 0.236701E-02   | 0.821422                 | 0.119704E-01                 |
| 26  | 4193.01   | 0.23849E-03 | -0.23133E-01  | 0.068061 | 0.535134E-03   | 0.824347                 | 0.270628E-02                 |
| 27  | 4226.68   | 0.23659E-03 | 0.29452E-03   | 0.000867 | 0.867426E-07   | 0.824348                 | 0.438674E-06                 |
| 28  | 4291.20   | 0.23303E-03 | -0.56984E-02  | 0.016765 | 0.324713E-04   | 0.824525                 | 0.164214E-03                 |
| 29  | 4315.66   | 0.23171E-03 | -0.14107      | 0.415052 | 0.199010E-01   | 0.933291                 | 0.100643                     |
| 30  | 4637.54   | 0.21563E-03 | -0.35476E-02  | 0.010438 | 0.125856E-04   | 0.933360                 | 0.636479E-04                 |
| 31  | 4649.75   | 0.21507E-03 | 0.45510E-01   | 0.133896 | 0.207114E-02   | 0.944679                 | 0.104741E-01                 |
| 32  | 4735.74   | 0.21116E-03 | 0.13673E-01   | 0.040228 | 0.186955E-03   | 0.945701                 | 0.945468E-03                 |
| 33  | 5356.66   | 0.18668E-03 | -0.35313E-03  | 0.001039 | 0.124701E-06   | 0.945702                 | 0.630639E-06                 |
| 34  | 5365.39   | 0.18638E-03 | -0.12732E-02  | 0.003746 | 0.162104E-05   | 0.945710                 | 0.819790E-05                 |
| 35  | 5437.72   | 0.18390E-03 | -0.31740E-01  | 0.093384 | 0.100744E-02   | 0.951216                 | 0.509483E-02                 |
| 36  | 5492.49   | 0.18207E-03 | 0.33811E-02   | 0.009948 | 0.114316E-04   | 0.951279                 | 0.578116E-04                 |
| 37  | 5508.10   | 0.18155E-03 | -0.62319E-03  | 0.001834 | 0.388360E-06   | 0.951281                 | 0.196401E-05                 |
| 38  | 5578.87   | 0.17925E-03 | 0.42405E-03   | 0.001248 | 0.179818E-06   | 0.951282                 | 0.909373E-06                 |
| 39  | 5675.85   | 0.17619E-03 | -0.88907E-03  | 0.002616 | 0.790439E-06   | 0.951286                 | 0.399740E-05                 |

Figure 5-20

| ***** PARTICIPATION FACTOR CALCULATION ***** ROTZ DIRECTION |           |             |               |          |                |                          |                              |
|---|-----------|-------------|---------------|----------|----------------|--------------------------|------------------------------|
| MODE  | FREQUENCY | PERIOD      | PARTIC.FACTOR | RATIO    | EFFECTIVE MASS | CUMULATIVE MASS FRACTION | RATIO EFF.MASS TO TOTAL MASS |
| 1   | 490.297   | 0.20396E-02 | -0.71242E-02  | 0.020496 | 0.507540E-04   | 0.225802E-03             | 0.219903E-03                 |
| 2   | 491.614   | 0.20341E-02 | -0.19872      | 0.571710 | 0.394902E-01   | 0.175916                 | 0.171100                     |
| 3   | 586.993   | 0.17036E-02 | -0.70964E-04  | 0.000204 | 0.503592E-08   | 0.175916                 | 0.218192E-07                 |
| 4   | 899.716   | 0.11115E-02 | 0.46230E-03   | 0.001330 | 0.213718E-06   | 0.175917                 | 0.925980E-06                 |
| 5   | 1407.70   | 0.71038E-03 | -0.29355E-02  | 0.008445 | 0.861694E-05   | 0.175955                 | 0.373348E-04                 |
| 6   | 1770.06   | 0.56495E-03 | 0.43373E-01   | 0.124781 | 0.188121E-02   | 0.184324                 | 0.815074E-02                 |
| 7   | 1781.71   | 0.56126E-03 | -0.31276E-01  | 0.089980 | 0.978203E-03   | 0.188676                 | 0.423828E-02                 |
| 8   | 1782.79   | 0.56092E-03 | -0.56799E-02  | 0.016341 | 0.322613E-04   | 0.188820                 | 0.139779E-03                 |
| 9   | 1797.37   | 0.55637E-03 | 0.36362E-03   | 0.001046 | 0.132219E-06   | 0.188820                 | 0.572867E-06                 |
| 10  | 1929.52   | 0.51826E-03 | 0.34787E-03   | 0.001001 | 0.121011E-06   | 0.188821                 | 0.524304E-06                 |
| 11  | 1969.35   | 0.50778E-03 | 0.34759       | 1.000000 | 0.120820       | 0.726341                 | 0.523478                     |
| 12  | 2143.55   | 0.46652E-03 | 0.12755       | 0.366944 | 0.162682E-01   | 0.798718                 | 0.704853E-01                 |
| 13  | 2413.88   | 0.41427E-03 | -0.14528E-01  | 0.041796 | 0.211056E-03   | 0.799656                 | 0.914447E-03                 |
| 14  | 2460.35   | 0.40645E-03 | 0.11169       | 0.321335 | 0.124754E-01   | 0.855159                 | 0.540525E-01                 |
| 15  | 2681.01   | 0.37299E-03 | 0.24635E-01   | 0.070875 | 0.606908E-03   | 0.857859                 | 0.262956E-02                 |
| 16  | 2685.98   | 0.37230E-03 | -0.22526E-02  | 0.006481 | 0.507440E-05   | 0.857882                 | 0.219860E-04                 |
| 17  | 3098.56   | 0.32273E-03 | 0.93754E-01   | 0.269726 | 0.878987E-02   | 0.896987                 | 0.380840E-01                 |
| 18  | 3356.09   | 0.29797E-03 | -0.42953E-04  | 0.000124 | 0.184492E-08   | 0.896987                 | 0.799352E-08                 |
| 19  | 3536.04   | 0.28280E-03 | 0.99983E-01   | 0.287646 | 0.999667E-02   | 0.941462                 | 0.433128E-01                 |
| 20  | 3592.80   | 0.27833E-03 | -0.31164E-03  | 0.000897 | 0.971165E-07   | 0.941462                 | 0.420778E-06                 |
| 21  | 3772.44   | 0.26508E-03 | 0.69025E-03   | 0.001986 | 0.476440E-06   | 0.941464                 | 0.206428E-05                 |
| 22  | 3774.33   | 0.26495E-03 | 0.16973E-02   | 0.004883 | 0.288070E-05   | 0.941477                 | 0.124813E-04                 |
| 23  | 3903.86   | 0.25616E-03 | -0.26845E-01  | 0.077232 | 0.720668E-03   | 0.944684                 | 0.312245E-02                 |
| 24  | 3943.56   | 0.25358E-03 | 0.82142E-04   | 0.000236 | 0.674734E-08   | 0.944684                 | 0.292343E-07                 |
| 25  | 4192.02   | 0.23855E-03 | 0.86986E-02   | 0.025026 | 0.756665E-04   | 0.945020                 | 0.327842E-03                 |
| 26  | 4193.01   | 0.23849E-03 | -0.17186E-01  | 0.049444 | 0.295367E-03   | 0.946334                 | 0.127974E-02                 |
| 27  | 4226.68   | 0.23659E-03 | 0.42174E-02   | 0.012133 | 0.177866E-04   | 0.946413                 | 0.770644E-04                 |
| 28  | 4291.20   | 0.23303E-03 | 0.83115E-01   | 0.239118 | 0.690817E-02   | 0.977147                 | 0.299311E-01                 |
| 29  | 4315.66   | 0.23171E-03 | -0.26671E-04  | 0.000077 | 0.711367E-09   | 0.977147                 | 0.308215E-08                 |
| 30  | 4637.54   | 0.21563E-03 | 0.20853E-01   | 0.059993 | 0.434857E-03   | 0.979082                 | 0.188411E-02                 |
| 31  | 4649.75   | 0.21507E-03 | 0.54279E-03   | 0.001562 | 0.294625E-06   | 0.979083                 | 0.127653E-05                 |
| 32  | 4735.74   | 0.21116E-03 | 0.46484E-03   | 0.001337 | 0.216079E-06   | 0.979084                 | 0.936209E-06                 |
| 33  | 5356.66   | 0.18668E-03 | 0.10856E-01   | 0.031231 | 0.117848E-03   | 0.979609                 | 0.510601E-03                 |
| 34  | 5365.39   | 0.18638E-03 | 0.15203E-01   | 0.043737 | 0.231121E-03   | 0.980637                 | 0.100138E-02                 |
| 35  | 5437.72   | 0.18390E-03 | -0.92168E-04  | 0.000265 | 0.849499E-08   | 0.980637                 | 0.368064E-07                 |
| 36  | 5492.49   | 0.18207E-03 | 0.13349E-02   | 0.003841 | 0.178209E-05   | 0.980645                 | 0.772128E-05                 |
| 37  | 5508.10   | 0.18155E-03 | 0.94063E-02   | 0.027062 | 0.884794E-04   | 0.981039                 | 0.383356E-03                 |
| 38  | 5578.87   | 0.17925E-03 | -0.16854E-01  | 0.048489 | 0.284066E-03   | 0.982302                 | 0.123078E-02                 |
| 39  | 5675.85   | 0.17619E-03 | -0.71366E-04  | 0.000205 | 0.509312E-08   | 0.982302                 | 0.220670E-07                 |

Figure 5-21

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

According to first case model mode is 914 Hz and according to second model it is 490 Hz. The difference is significant yet both are higher than the lowest required frequency (35 Hz for considered Launch Vehicle – Soyuz). Despite the fact that computational model is very simplified, it certainly gives information about modes and approximate magnitude of modal frequencies.

Pictures below shows first six modes for both models.

Model a) (whole base is fixed) – Figure 5-22 - Figure 5-25.

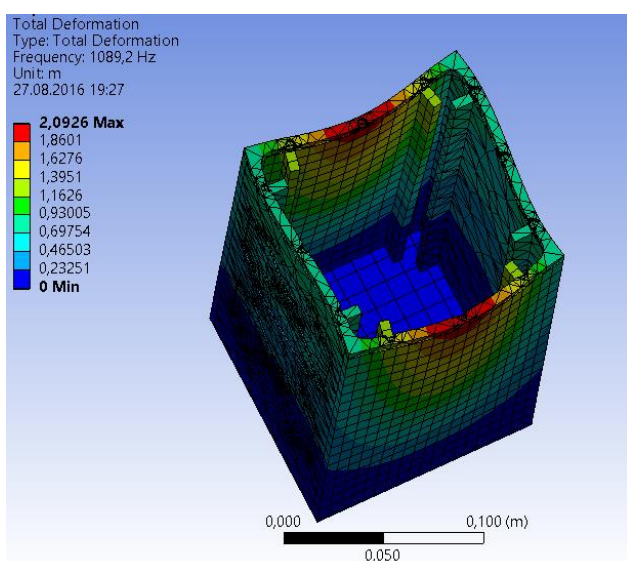


Figure 5-22 Mode (1089,2 Hz)

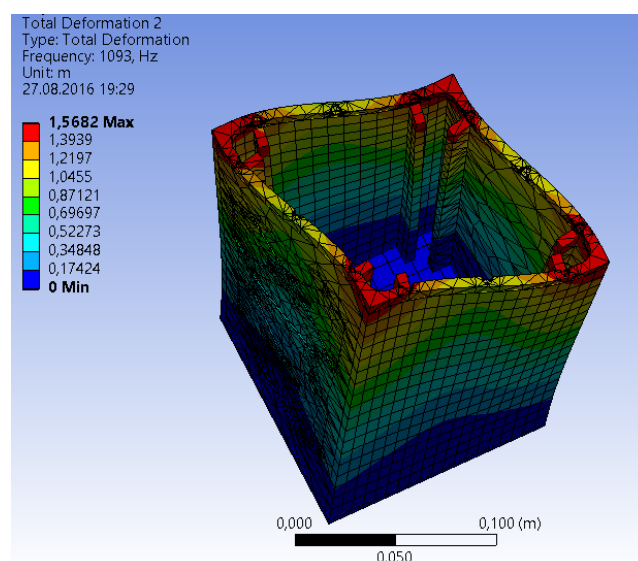


Figure 5-23 2. Mode (1093 Hz)

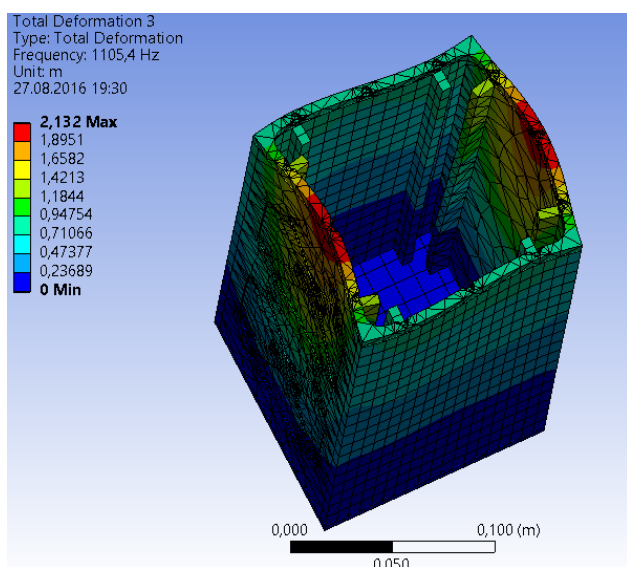


Figure 5-24 3. Mode (1105,4 Hz)

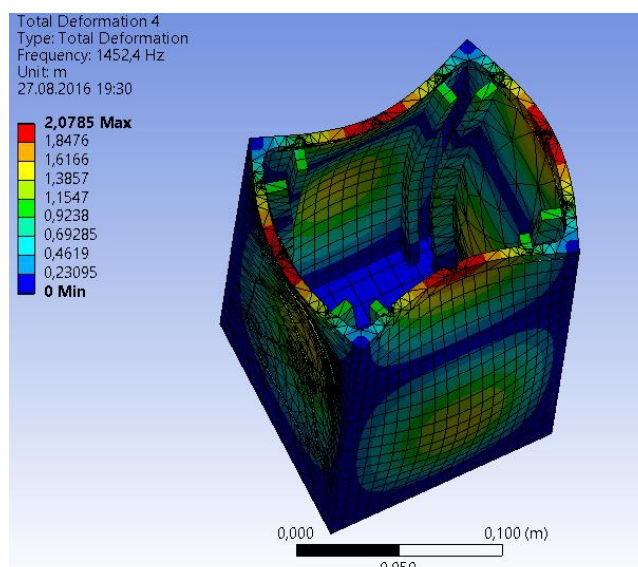




Figure 5-25 4. Mode (1452,4 Hz)

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

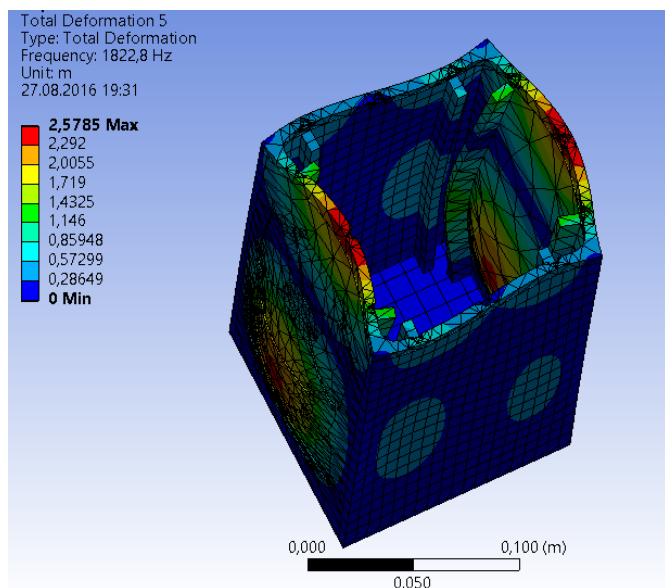


Figure 5-26 5. Mode (1822,8 Hz)

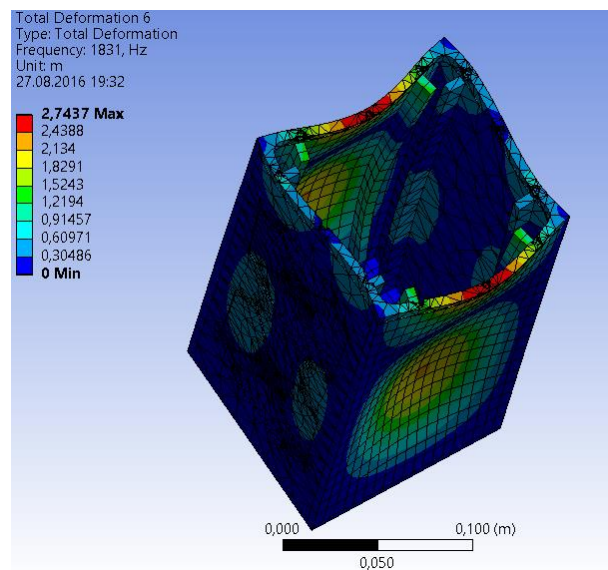


Figure 5-27 6. Mode (1831 Hz)

Model b) (base is fixed in points) – Figure 5-28 - Figure 5-33.

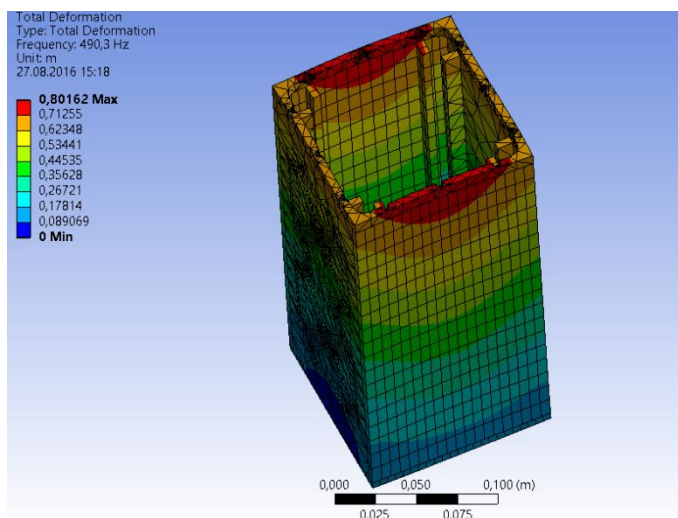


Figure 5-28 1. Mode (490,3 Hz)

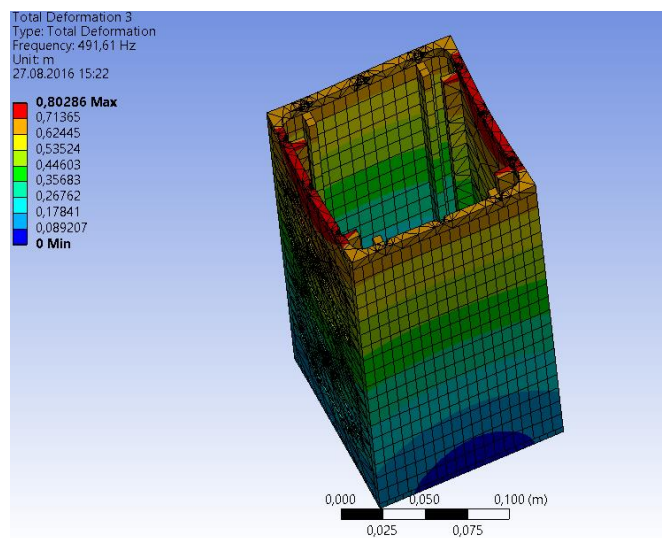




Figure 5-29 2. Mode (491,61 Hz)

|   |            |                        |   |
|---|------------|------------------------|---|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |   |
|   | Phase C    |                        |   |

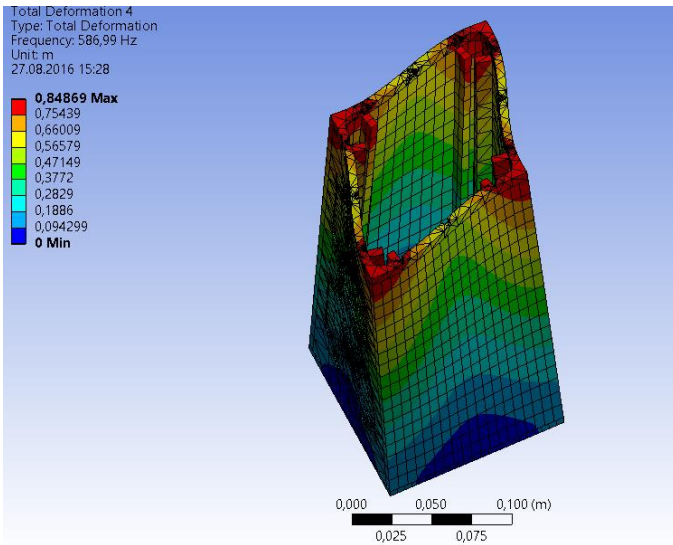


Figure 5-30 3. Mode (586,99 Hz)

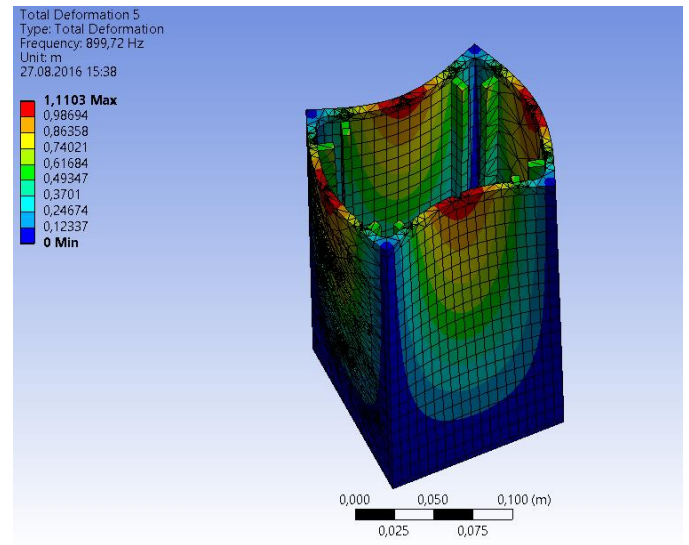


Figure 5-31 4. Mode (899,72 Hz)

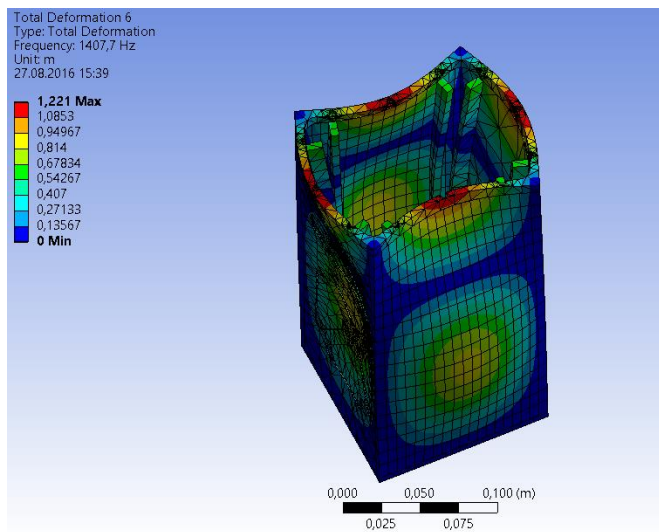


Figure 5-32 5. Mode (1407,7 Hz)

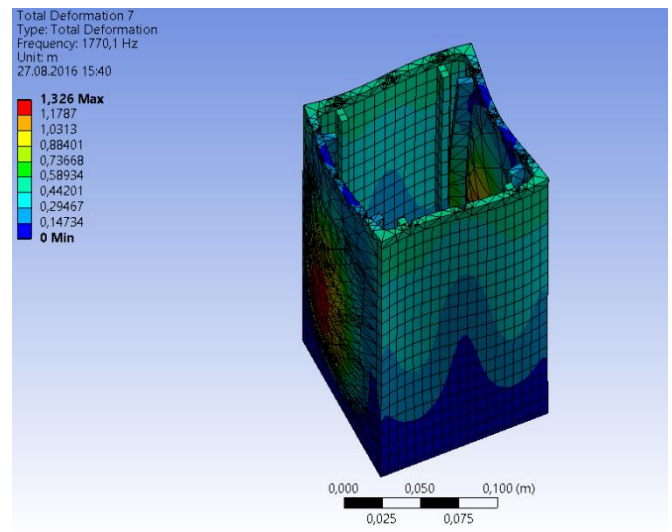




Figure 5-33 6. Mode (1770,1 Hz)

|   |            |                        |  |
|---|------------|------------------------|--|
|  | PW-Sat2    | Critical Design Review |  |
|   | 2016-11-30 | Structural Analyses    |  |
|   | Phase C    |                        |  |

## 6 SUMMARY

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In summary, the satellite structure is modeled and analyzed to ensure that the structure sustains in the harsh launch loads. Thanks these analyses a detailed study is carried out for the design of the PW-Sat2 satellite structure focusing on the factors such as the selection of material, optimization of shape and geometry, and accommodation of different subsystems and payload. These analyses are very useful and clearly indicate that the satellite's structure does not fail and retains its structural integrity during launch environment.

The document about environmental requirements of the rocket Falcon 9 has been delivered and new analyses will be done using extortions expected on the booster rocket. The finite element analysis results will be also validated and compared with the theoretical predictions. Analysis of random vibrations of the hole satellite's structure must done in the nearest future and then verified with real physical tests. Of the engineering model of PW-Sat2. Until now the data for Soyuz rocket was taken into account as it was the easiest to acquire.

Owing to the fact there are no requirements to do shock test on the engineering model of the whole satellite, only extensive shock analyses will be done. This will help to verify if the construction of PW-Sat2 will withstand g-forces.