# Galileo Galilei satellite

# Design and finite element analysis of the structure

## 1 Introduction

The outer structure of the GG satellite is mainly composed by the parts which are outlined in the mass budget table reported in the next paragraph.

- The perfect axial-symmetric configuration,
- the mass reduction,
- and good strength and rigidity performances

have been the driving factors for the DTM activity so far performed and described in this technical report.
The Prime Contractor TASI, as well as the PI, directed DTM in the selection of the materials, which have to comply with the requirements dictated mainly by science reasons. DTM developed the project of the structure accordingly, and we already envisaged the corresponding manufacturing technologies, which will be deeply developed in the next program phase; nonetheless we can since now guarantee about mass values (approximately), safety margins, dynamic response and technological manufacturing feasibility.

## 2 Mass budget and dynamic response of the structure

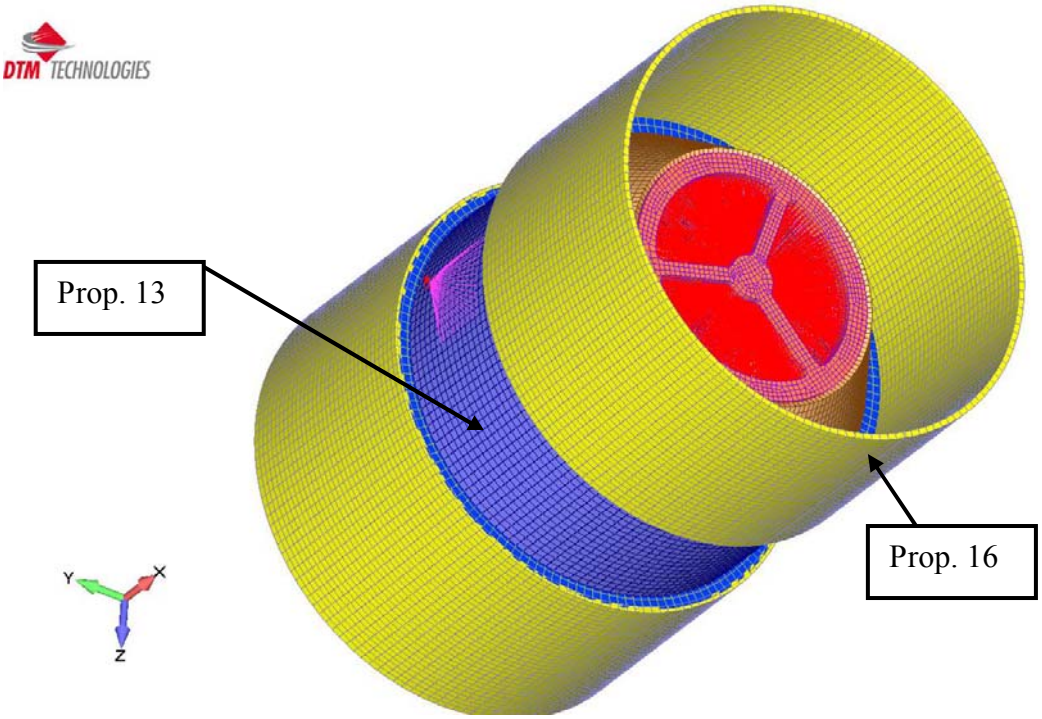
The mass values of the structural components, shown in the following table, are the ones achieved after analytical optimisation via finite element NASTRAN program.
The analysis has been mainly focused on dynamic data tuning. The target values are reported in the VEGA launcher User's Manual.
The first longitudinal frequency has to remain within 20 and 45 Hz, while the first transversal frequency must be above 15 Hz.
These data, as shown in the next paragraphs, are fully met, also without large margins.

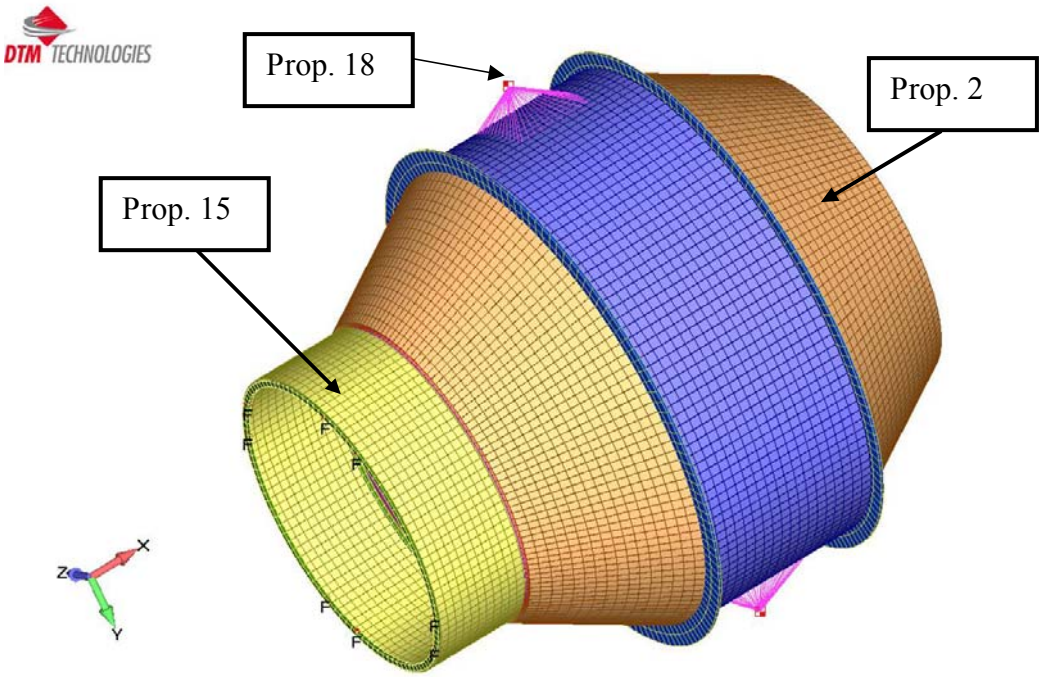
Mass budget table

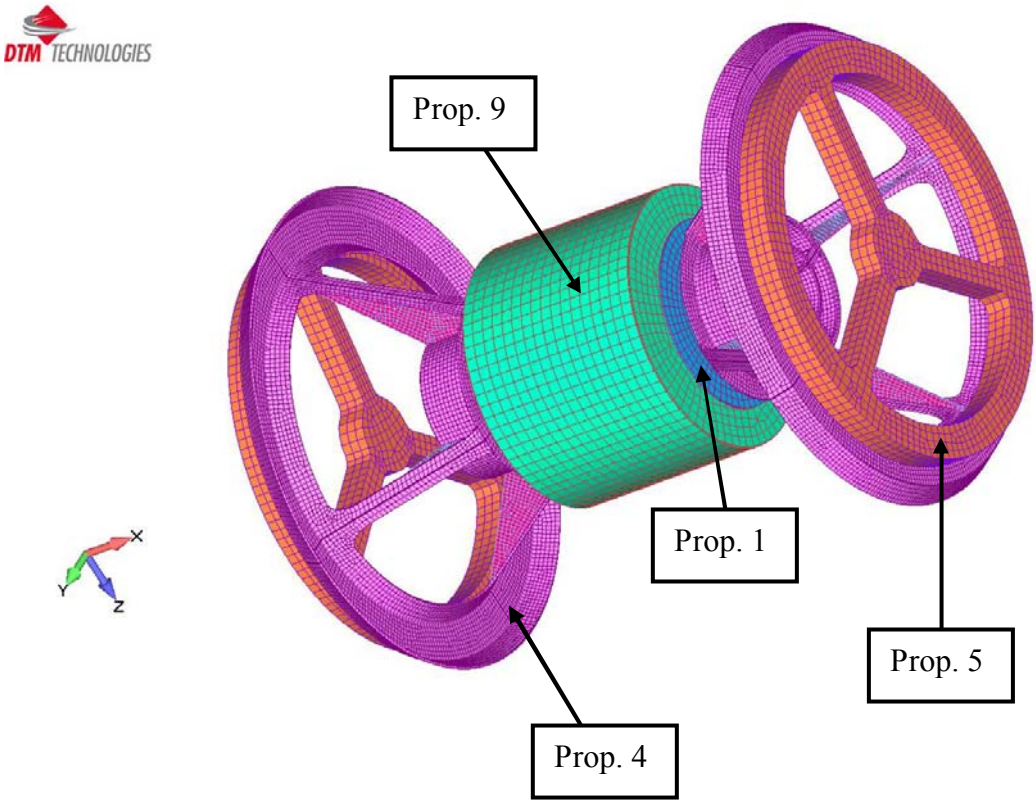
| Layer | Description | Material | Q.ty | Unitary FEM model mass [Kg] | Assembly FEM model [Kg] |
|---|---|---|---|---|---|
| **10** | Closure Platform | Al 7075 T7351 | 2 | 2,960 | 5,920 |
| **20** | Payload Support Cone | Al 7075 T7351 | 2 | 6,800 | 13,600 |
| **30** | PGB Interface | Al 7075 T7351 | 2 | 2,676 | 5,352 |
| **40** | Cone | T300 +Al h/comb | 2 | 11,446 | 22,892 |
| **50** | Cylinder | Al honeycomb | 1 | 21,850 | 21,850 |
| **51** | Cone to Cylinder Interface Flange | Al 7075 T7351 | 2 | 14,910 | 29,820 |
| **60** | PGB | Al7075 T7351 | 1 | 12,250 | 24,569 |
| **100** | Upper load bearing Cylinder | Al7075 T7351 | 2 | 0,085 | 0,170 |
| **101** | Lower load bearing Cylinder | Al7075 T7351 | 2 | 0,085 | 0,170 |
| **110** | Experiment Masses | | 1 | 22,150 | 22,150 |
| **1225** | PCDU | | 1 | 13,500 | 13,500 |
| **1215** | Battery | | 1 | 16,360 | 16,360 |
| **1000** | Cylindrical Solar Array | Al honeycomb | 2 | 14,580 | 29,16 |
| **1205** | N2 tanks | | 2 | 7,160 | 14,320 |
| **1210** | EPS thrusters / electronic | | 2 | 12,000 | 24,000 |
| **1220** | Data handling | | 1 | 16,000 | 16,000 |
| **1230** | Harness | | 1 | 12,600 | 12,600 |
| **1300** | Vega interface spacer | Al 7075 T7351 | 1 | 30,400 | 30,400 |

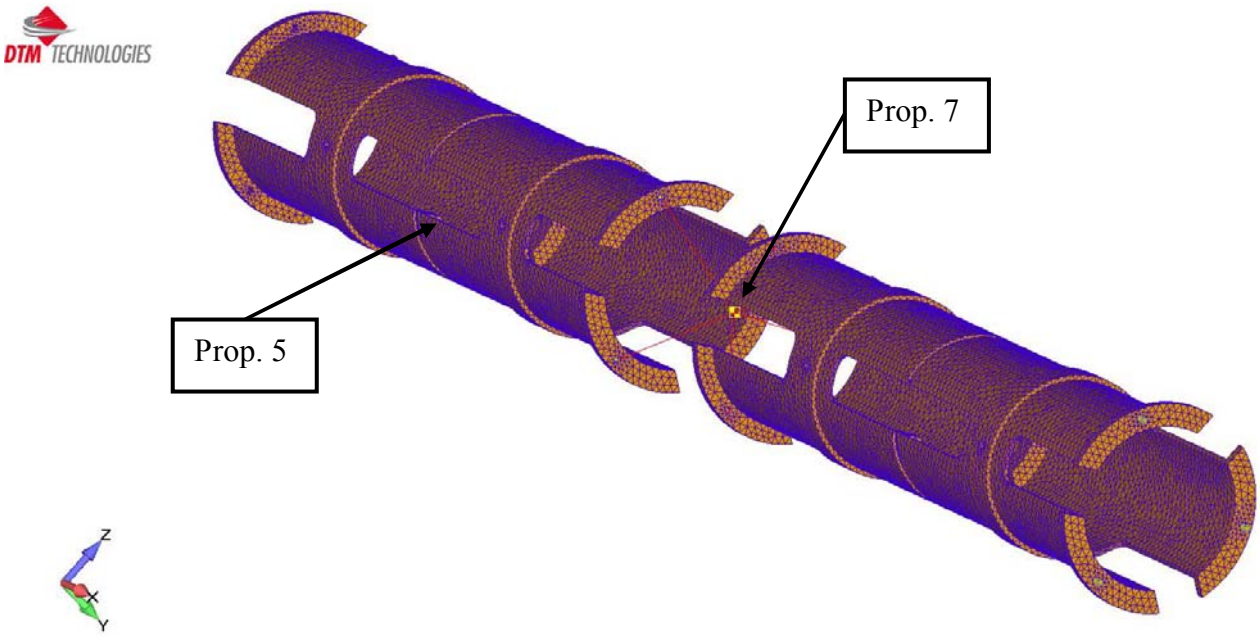
## 3 “Used properties” and “Used materials” data introduced in the finite element model of the GG structure

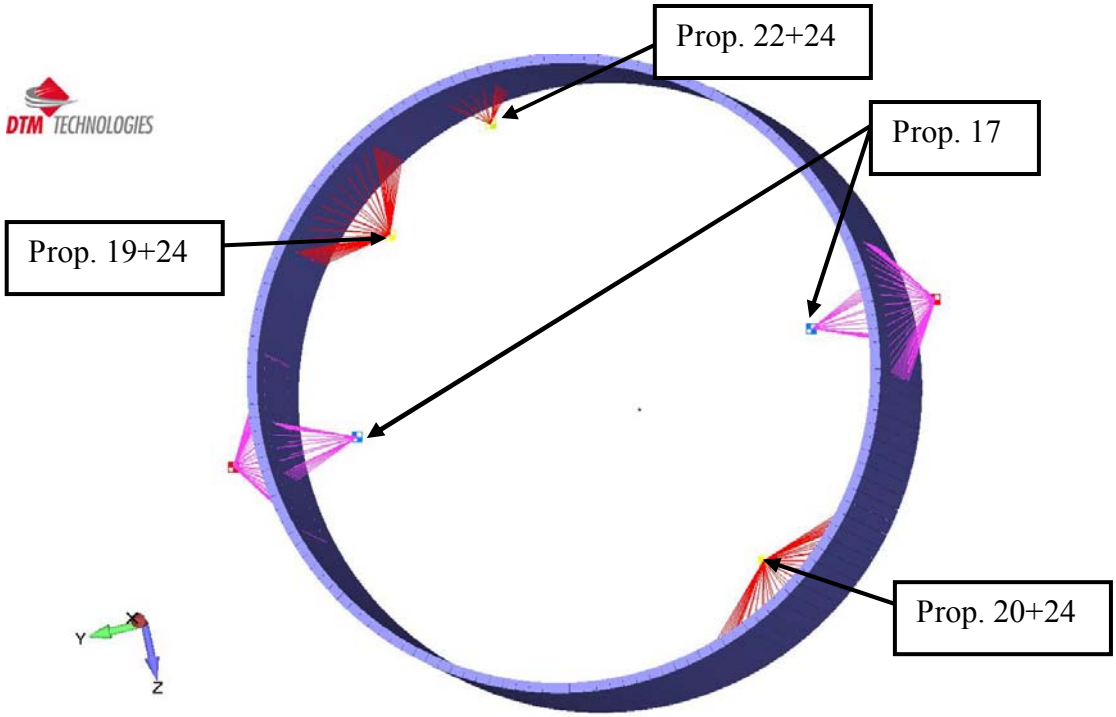
In the next images we identify all the main subsystem of the structure, in order to allow the control of the corresponding properties data. These data, to facilitate the reading of this document, are reported in Annex.




Prop. 18
Prop. 2
Prop. 15
X
Z
Y


Prop. 9
Prop. 1
Prop. 5
Prop. 4
X
Y
Z




In particular, about materials data:

- In Annex 2 we report the mechanical characteristics of the carbon fibre pre-pregs we intend to use for manufacturing, and which are used for the NASTRAN finite element analysis.

- In Annex 3 we report the data of the elements used in the mathematical model, like thickness, dimensions, and elastic properties, as requested by NASTRAN.

## 4 Mass budget of the locking devices

A quite complete description of the locking devices is reported separately with respect to the chapter devoted to the GG Structure.
In synthesis we designed four levels of locking, starting form outside (meaning the PGB) and going towards the inner area of the satellite, the most important and critical one, devoted to science.
The overall mass for the four levels of locking, including thirty linear electric non-magnetic actuators, plus control, is twenty kilograms. The number can be worked out, up to a certain level, when the design will be optimised and defined in the minimum details, including the necessary manufacturing “hints” which always are introduced in the project once the phase B is approached.

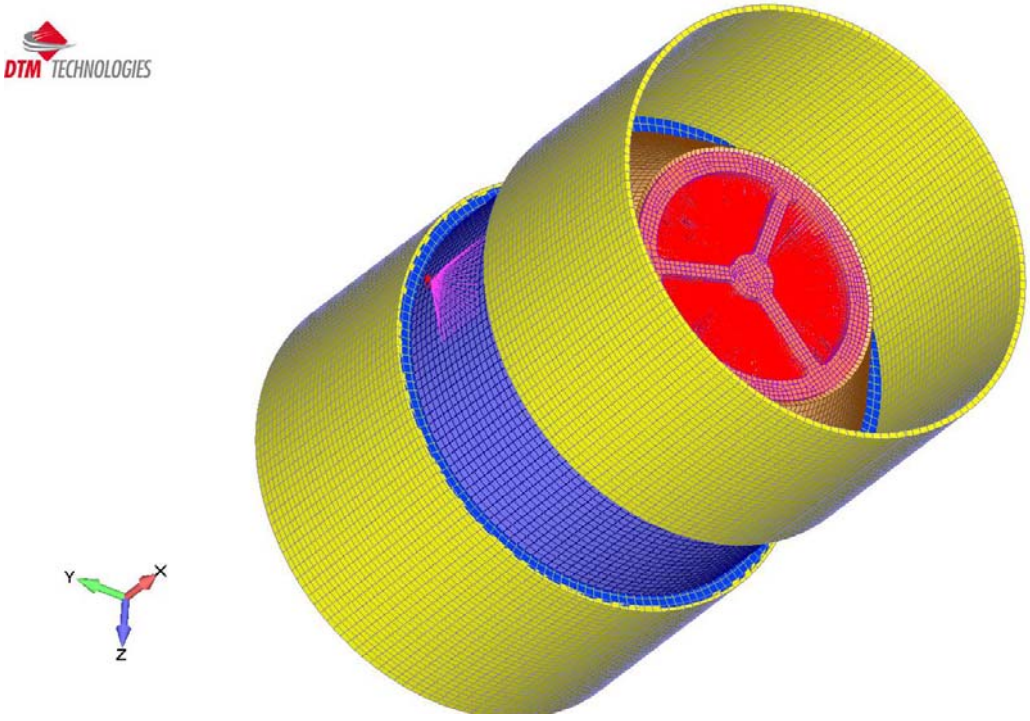
## 5 FEM analysis details and output

First of all we confirm that the requirements dictated by VEGA User Manual:

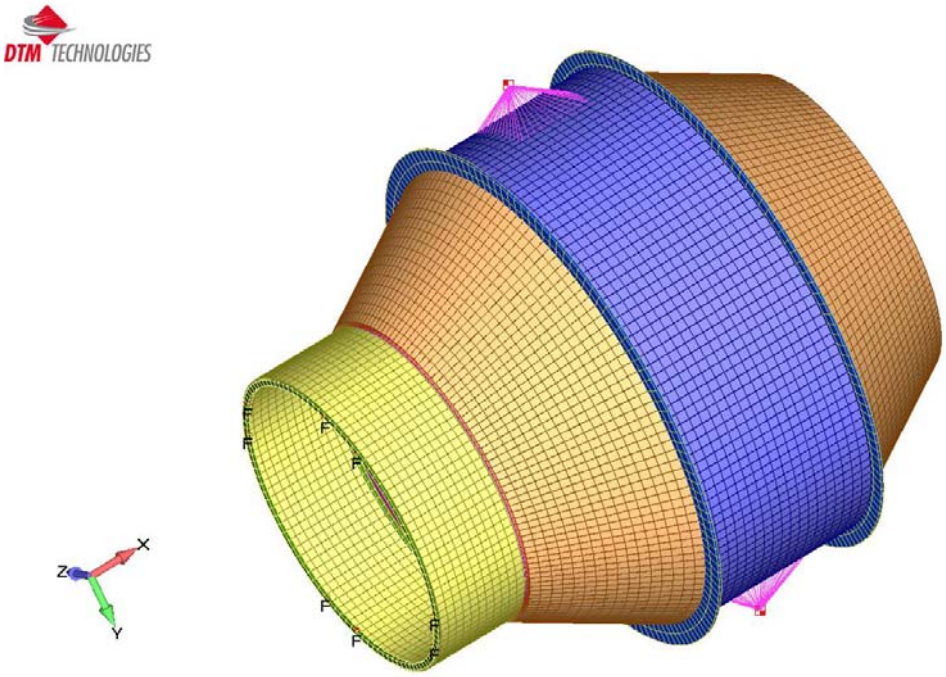
- min. first natural transversal frequency higher than 15 Hz
- first natural longitudinal frequency between 20 and 45 Hz

are met, also after the geometrical modification caused by the increase of the solar panel's dimensions.
In fact it is easy to notice from the following images the increase of the solar panels length which required the introduction of a new spacer to be introduced in between the satellite itself and the interface plate of VEGA.

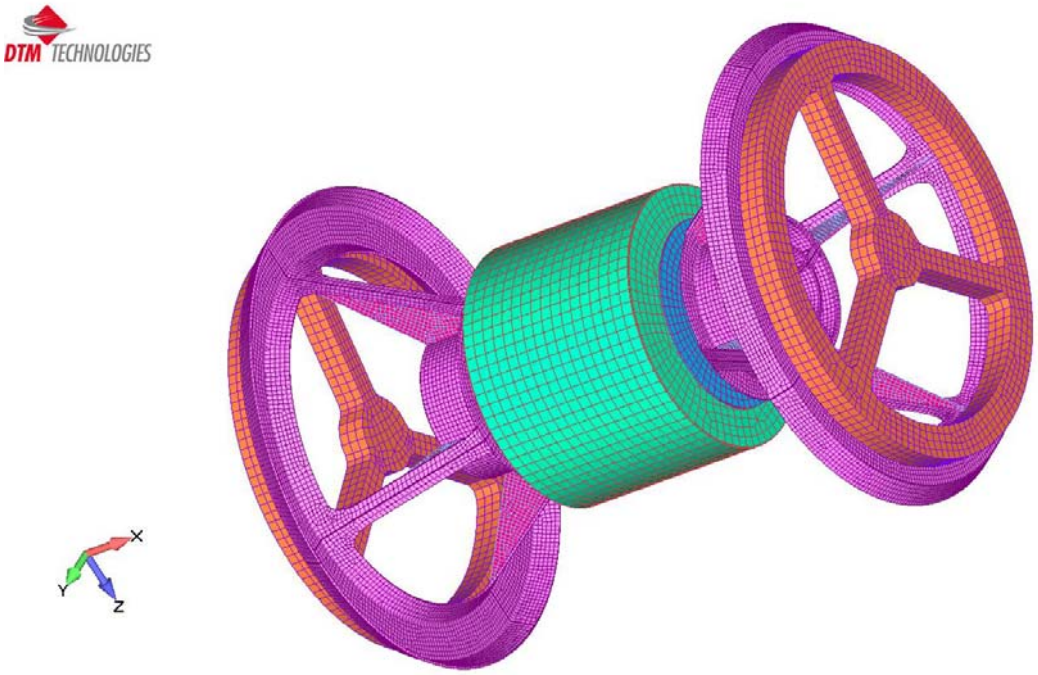
Here below the complete satellite, including solar panels:



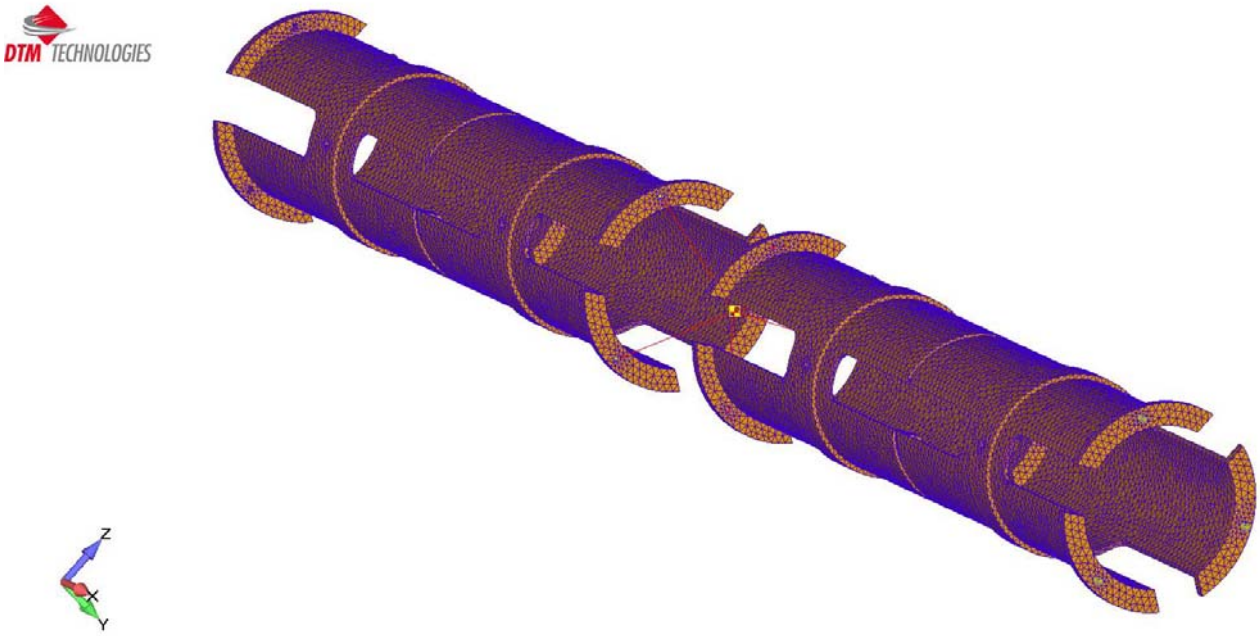
Here below the GG satellite without solar panels:



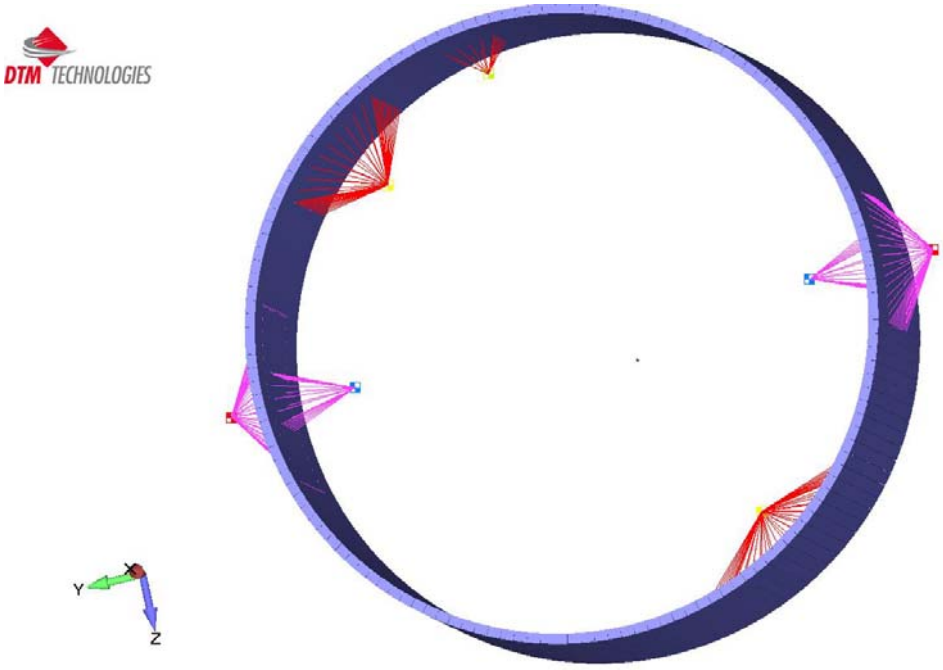
Here below the “science” section of GG, with Cone-to-Cylinder Interface Flange, and PGB:



Here below the upper and lower Cyliners supportino the “science” section:

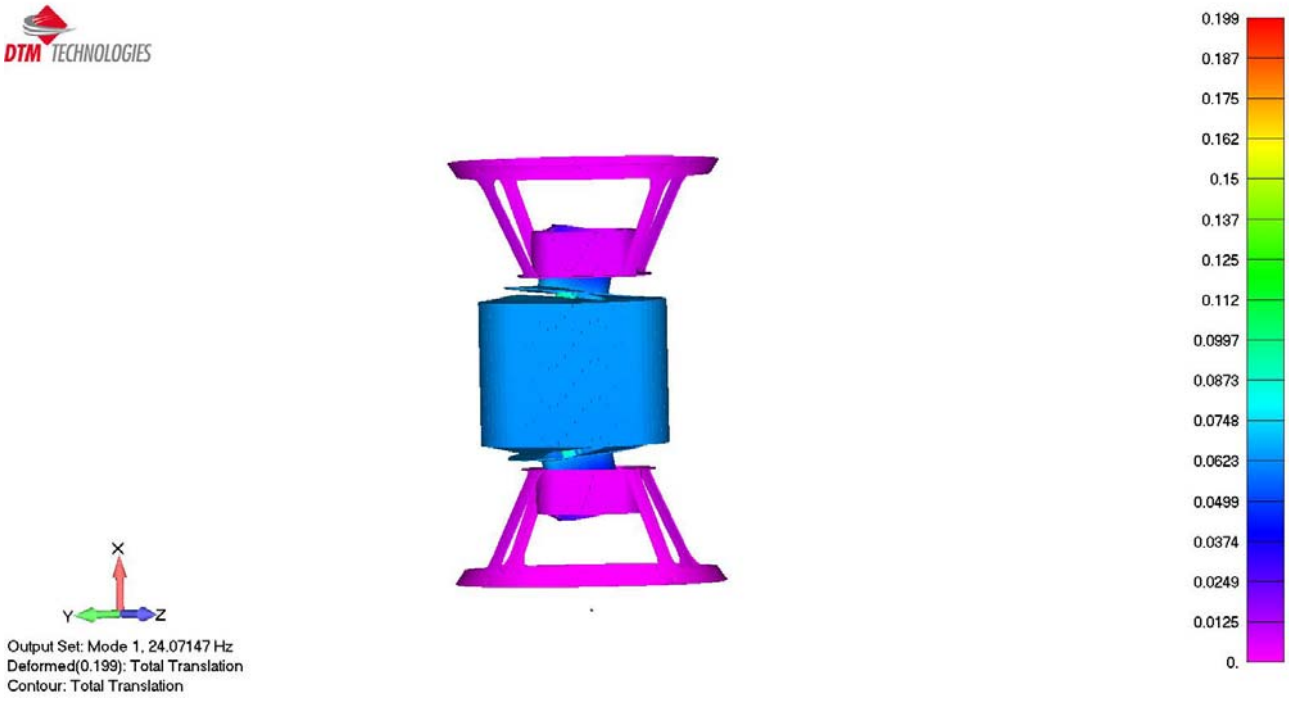


Here below the spacer to correctly position GG within the VEGA fairing:

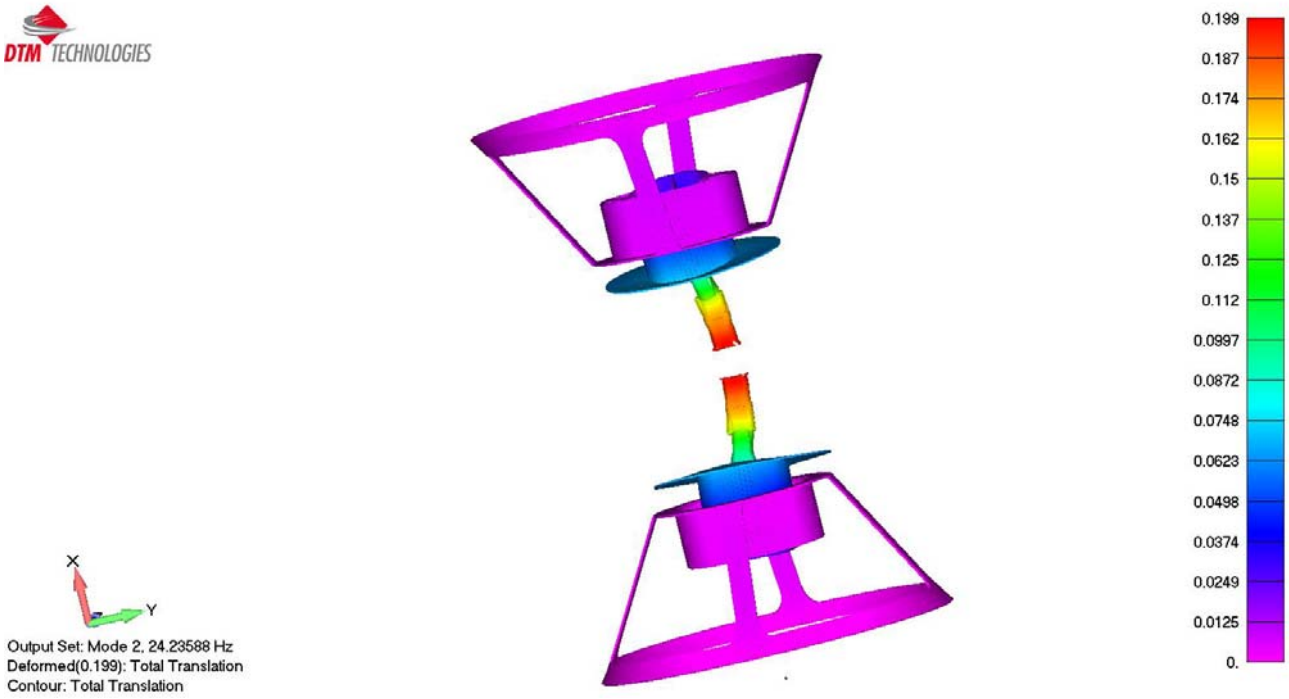


## 6 Natural frequencies of the GG Structure

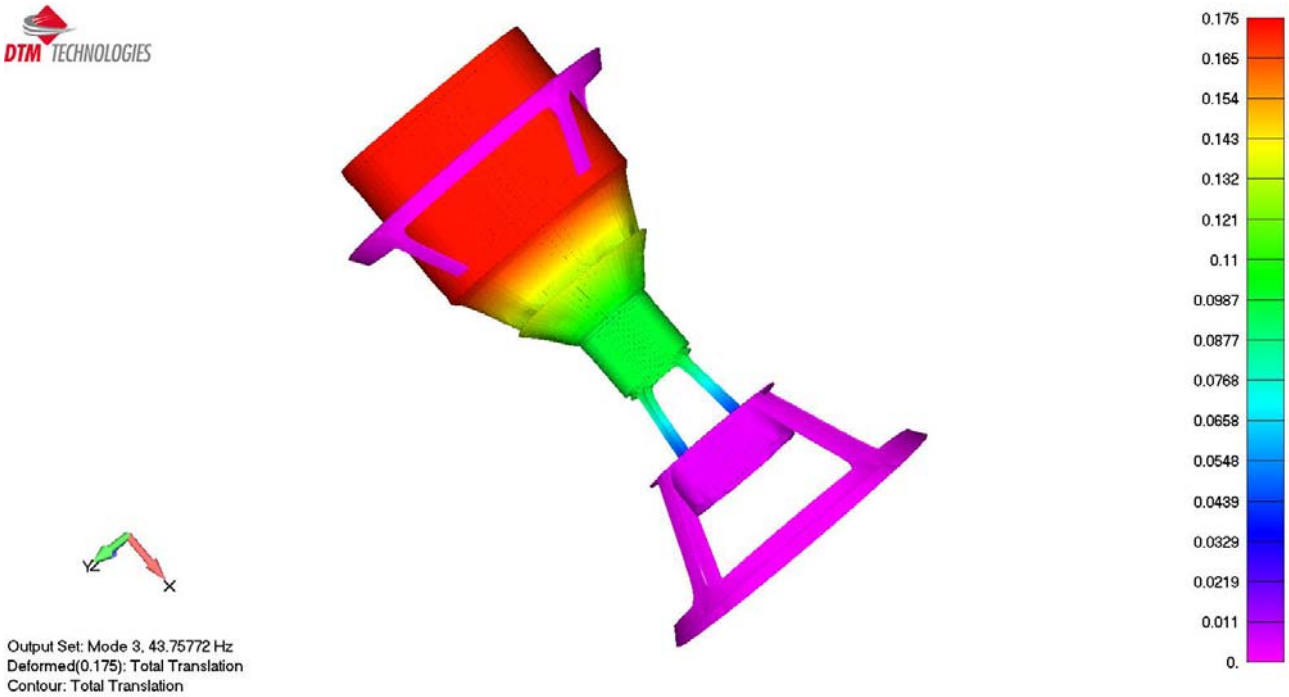
Here below, the representation of the FEM output, showing the first mode (transversal) which is considerably higher that the minimum required (15 Hz).



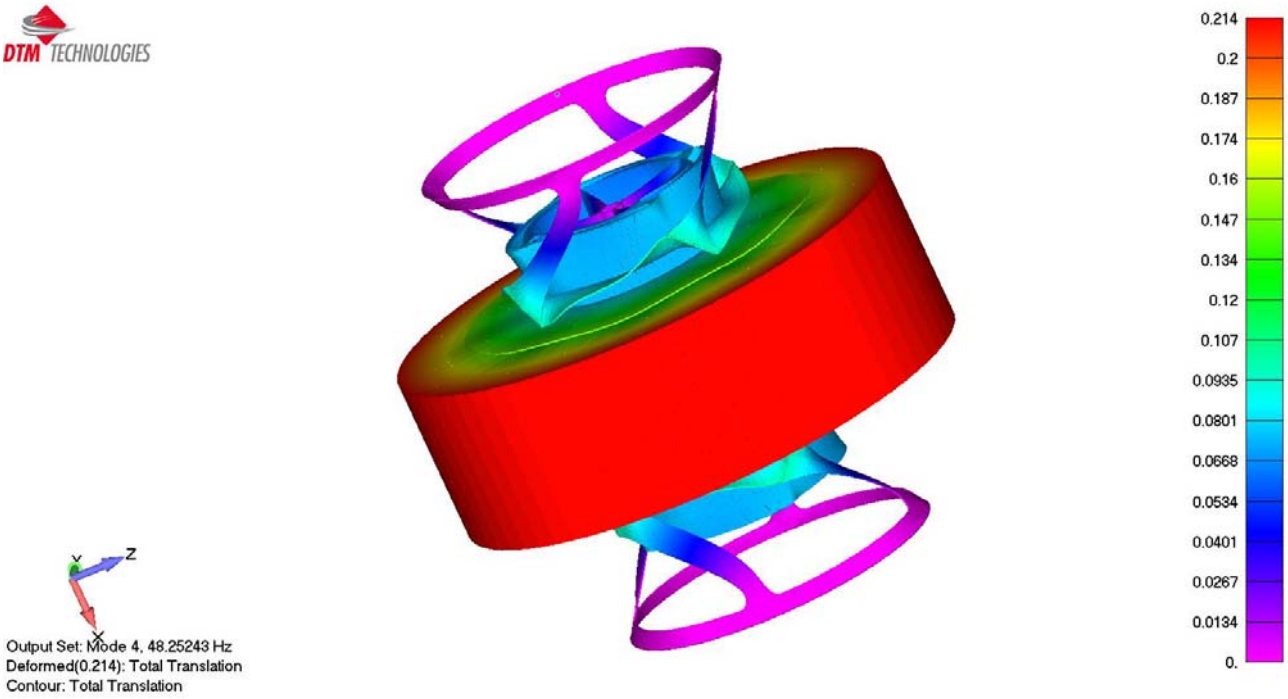
Second mode, still transversal and very closet o the first one.



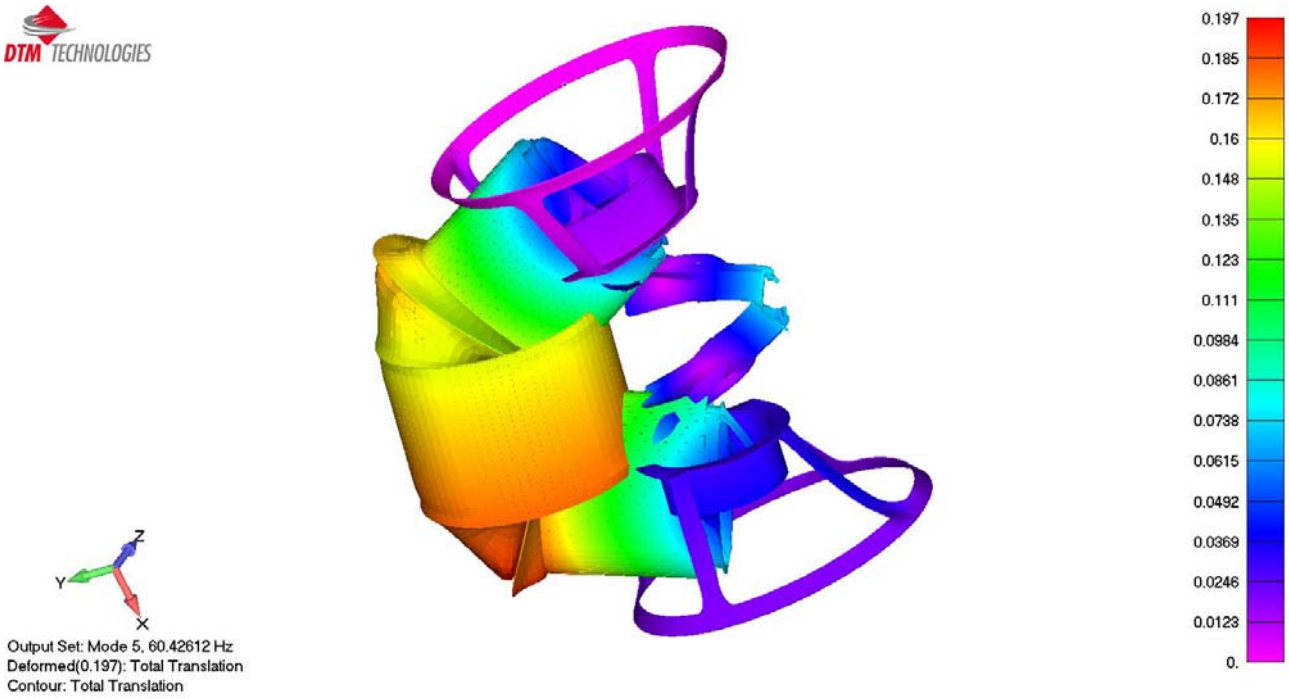
First axial mode, respecting the VEGA requirements.



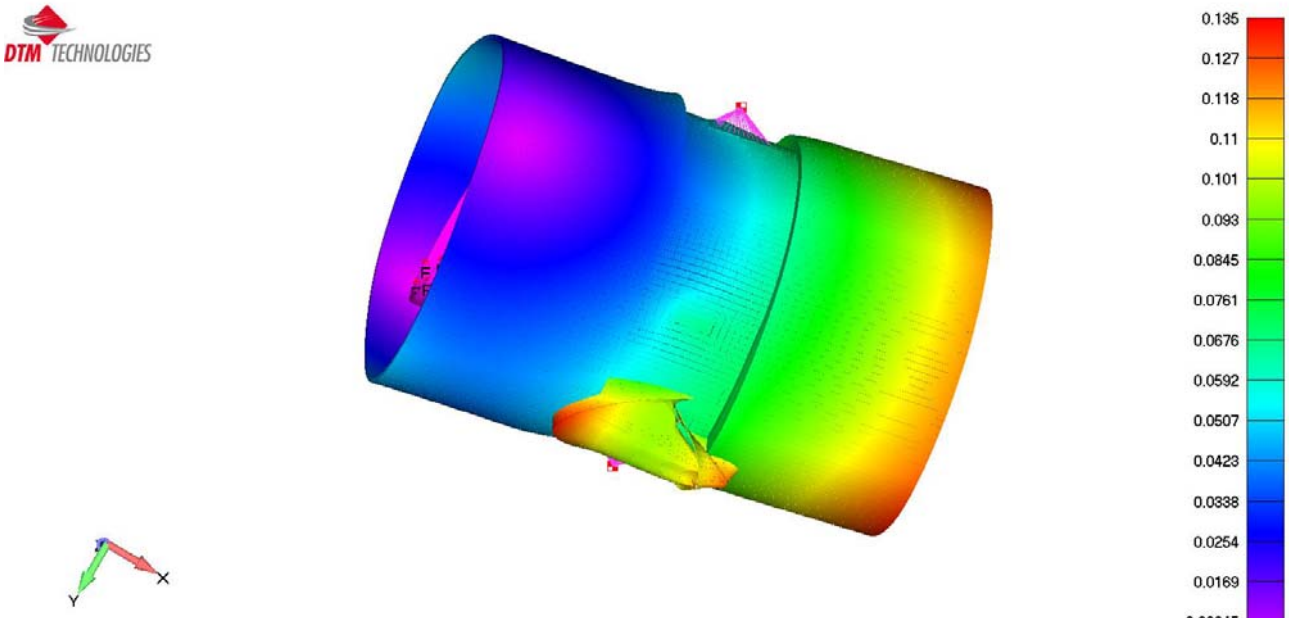
First “torsional” mode at approximately 48 Hz (please see the amplified torsion angle of the Cone-to-Cylinder Interface Flange).



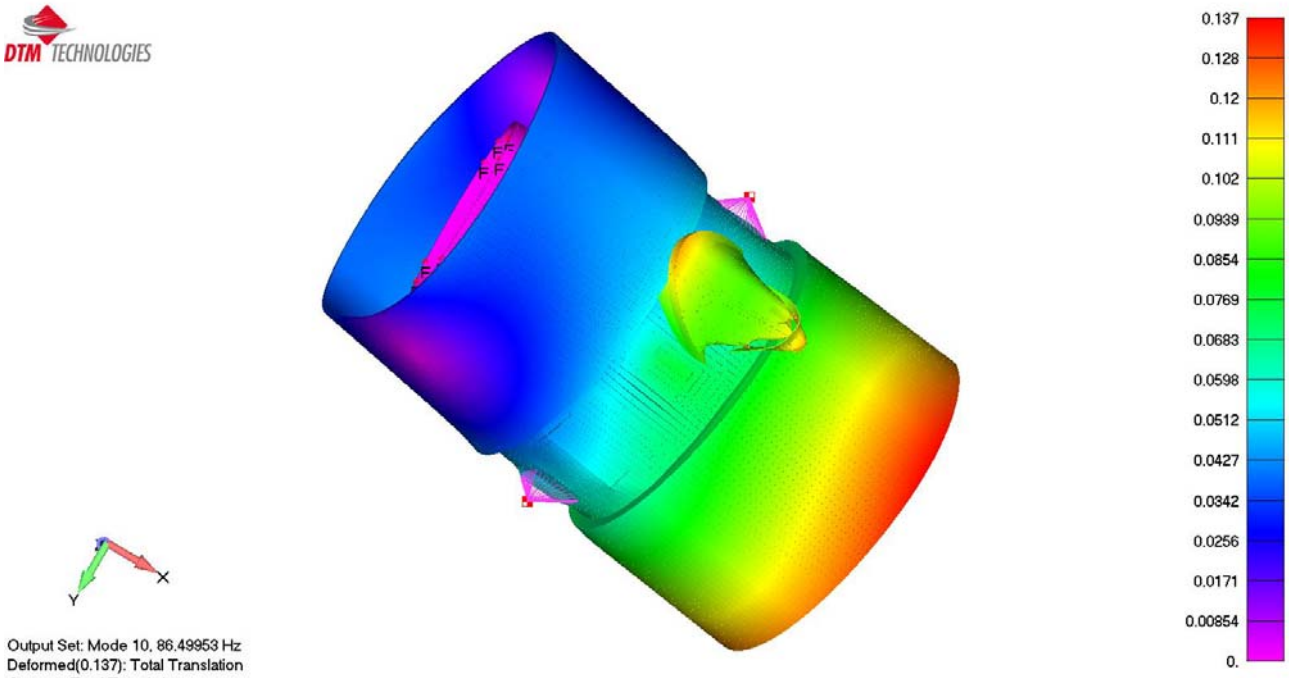
The following mode (at 60 Hz) is here below shown.



The following mode (please see the next two images) is not a local one but involves the whole structure, including solar panels.



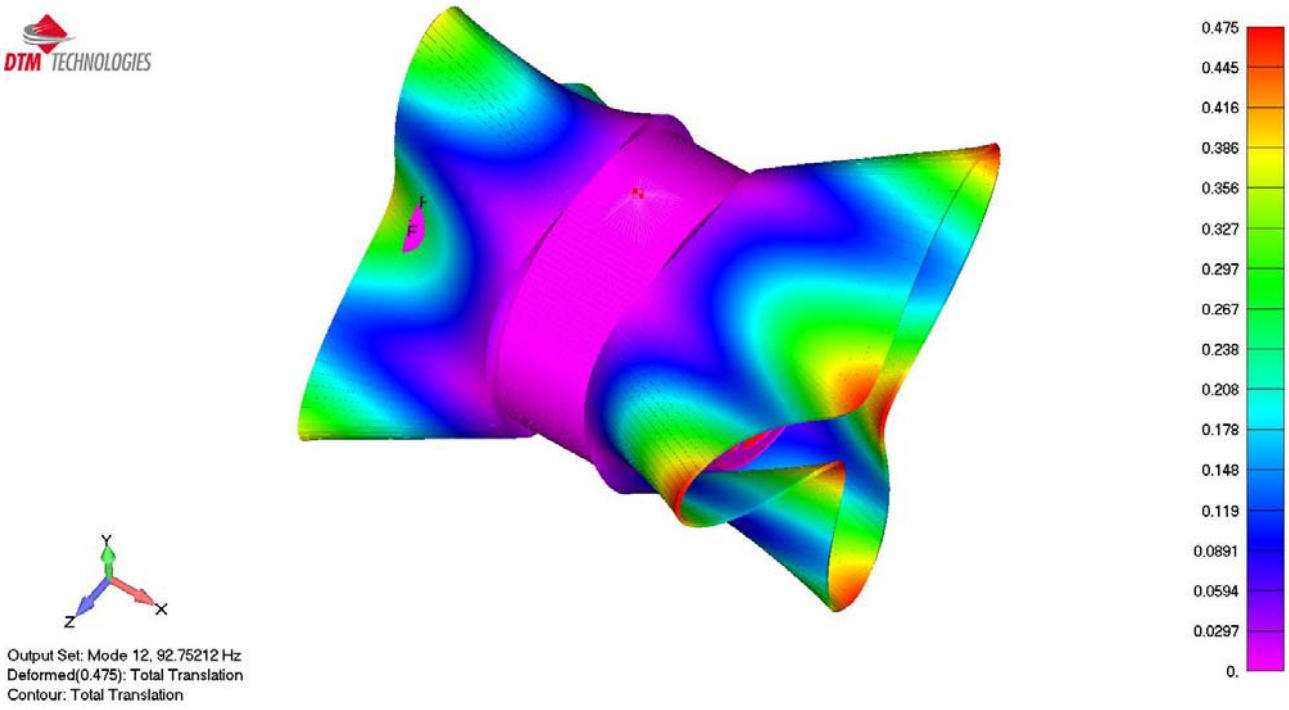

Output Set: Mode 9, 85.22754 Hz
Deformed(0.135): Total Translation
Contour: Total Translation



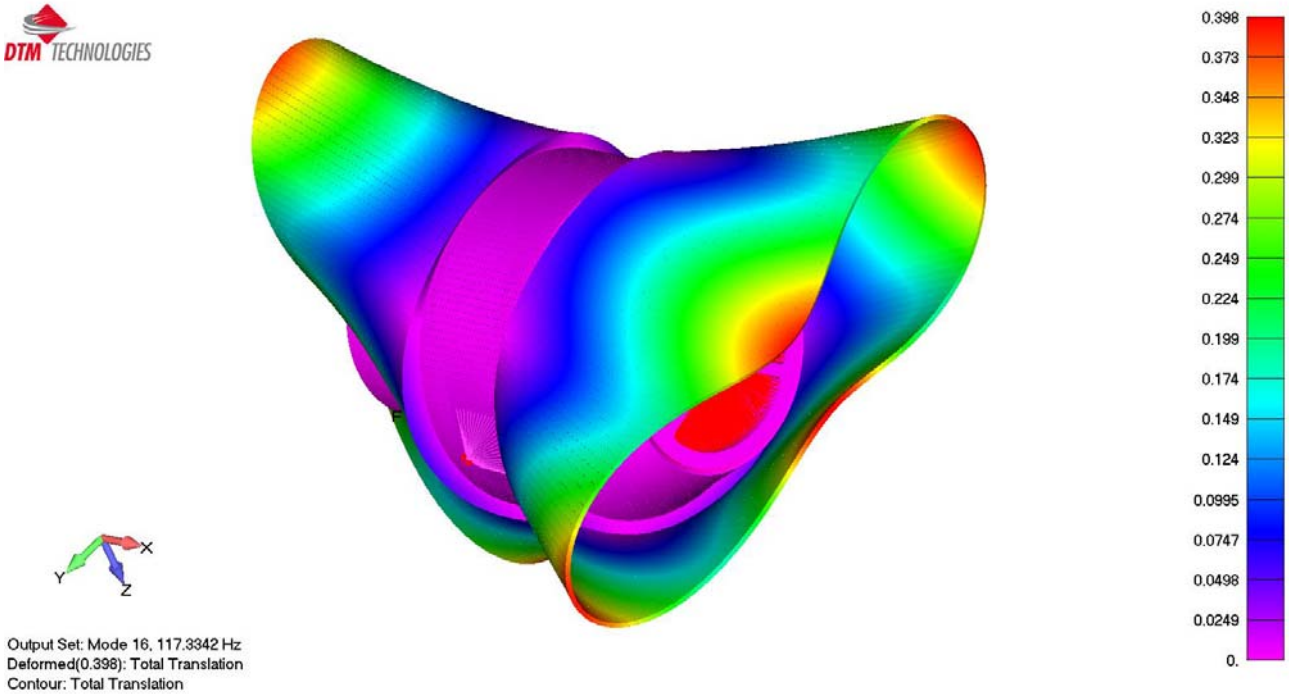

Output Set: Mode 10, 86.49953 Hz
Deformed(0.137): Total Translation
Contour: Total Translation

## 7 Solar panels

In the following three last images of this chapter the shape of the deformed solar panels are shown. The natural frequency correspond respectively to 92, 117 e 133 Hz.




Output Set: Mode 12, 92.75212 Hz
Deformed(0.475): Total Translation
Contour: Total Translation




Output Set: Mode 16, 117.3342 Hz
Deformed(0.398): Total Translation
Contour: Total Translation

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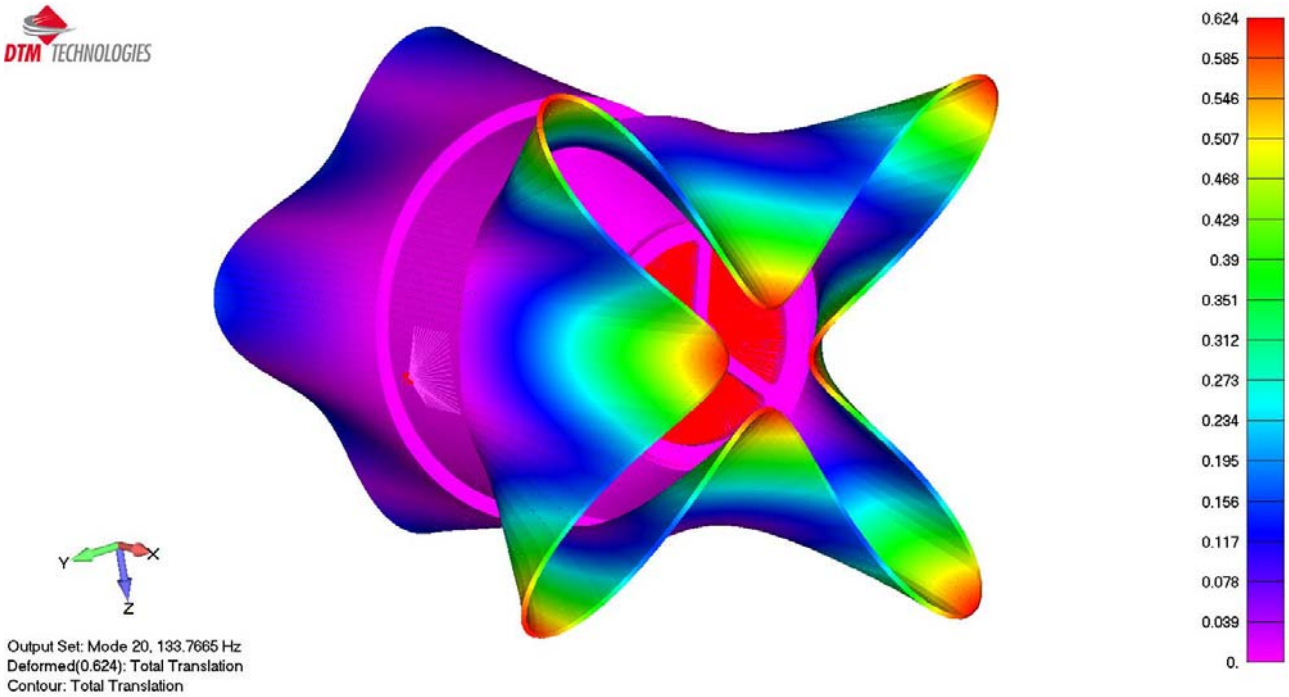


DTM TECHNOLOGIES

## Annex 1

The following table reports the first 100 natural modes of the GG satellite structure.

| N. | Freq. [Hz] | T1 | T2 | T3 | R1 | R2 | R3 |
|---|---|---|---|---|---|---|---|
| 1 | 2,41E+01 | 1,58E-05 | 4,34E+01 | 1,01E+00 | 1,76E-04 | 5,46E-01 | 2,30E+01 |
| 2 | 2,42E+01 | 1,35E-04 | 1,03E+00 | 4,39E+01 | 1,84E-05 | 2,32E+01 | 5,33E-01 |
| 3 | 4,38E+01 | 5,52E+01 | 1,08E-08 | 1,45E-05 | 5,17E-08 | 8,37E-05 | 6,57E-07 |
| 4 | 4,83E+01 | 2,30E-07 | 6,88E-04 | 7,90E-05 | 2,03E+00 | 5,00E-05 | 4,42E-04 |
| 5 | 6,04E+01 | 2,83E-03 | 3,27E+01 | 2,23E+00 | 1,31E-02 | 1,88E+00 | 2,59E+01 |
| 6 | 6,12E+01 | 1,11E-02 | 1,96E+00 | 3,18E+01 | 3,84E-03 | 2,39E+01 | 1,35E+00 |
| 7 | 7,18E+01 | 2,74E-02 | 1,33E+01 | 2,11E+00 | 5,39E-02 | 5,02E+00 | 3,09E+01 |
| 8 | 7,19E+01 | 6,36E-02 | 1,62E+00 | 1,11E+01 | 2,33E-02 | 2,44E+01 | 3,45E+00 |
| 9 | 8,52E+01 | 1,12E-01 | 8,54E+01 | 2,37E+01 | 3,49E-01 | 2,79E+01 | 1,01E+02 |
| 10 | 8,65E+01 | 1,38E-01 | 2,65E+01 | 9,51E+01 | 3,48E-01 | 9,58E+01 | 2,67E+01 |
| 11 | 9,10E+01 | 3,39E+00 | 2,17E-03 | 1,11E-01 | 1,26E-04 | 9,74E-02 | 1,33E-03 |
| 12 | 9,28E+01 | 2,63E-06 | 4,47E-02 | 2,64E-03 | 2,31E-04 | 1,86E-03 | 3,23E-02 |
| 13 | 9,28E+01 | 8,42E-04 | 1,96E-02 | 2,71E-03 | 1,31E-04 | 6,61E-03 | 2,82E-02 |
| 14 | 9,35E+01 | 2,40E-05 | 2,63E-02 | 1,99E-04 | 4,26E-04 | 9,74E-05 | 3,39E-02 |
| 15 | 9,37E+01 | 5,31E-04 | 1,45E-02 | 5,14E-02 | 5,35E-04 | 5,66E-02 | 1,10E-02 |
| 16 | 1,17E+02 | 4,42E-03 | 1,74E-04 | 6,01E-03 | 4,78E-03 | 4,78E-04 | 3,23E-04 |
| 17 | 1,17E+02 | 3,16E-02 | 1,88E-04 | 1,10E-05 | 4,16E-04 | 3,16E-05 | 1,06E-04 |
| 18 | 1,22E+02 | 1,16E-03 | 1,51E-03 | 3,75E-04 | 1,39E-02 | 4,25E-03 | 5,21E-03 |
| 19 | 1,22E+02 | 3,10E-04 | 8,47E-06 | 2,03E-03 | 1,51E-02 | 7,45E-03 | 2,56E-04 |
| 20 | 1,34E+02 | 5,27E-04 | 1,37E-05 | 3,06E-06 | 9,16E-08 | 1,30E-06 | 2,48E-05 |
| 21 | 1,34E+02 | 6,62E-04 | 4,39E-05 | 3,15E-05 | 1,03E-04 | 9,76E-05 | 1,07E-05 |
| 22 | 1,34E+02 | 5,87E-05 | 8,16E-07 | 1,16E-06 | 3,04E-05 | 1,33E-04 | 2,04E-05 |
| 23 | 1,34E+02 | 6,77E-04 | 3,77E-05 | 1,03E-04 | 2,31E-03 | 2,45E-04 | 2,73E-05 |
| 24 | 1,52E+02 | 3,85E-01 | 4,00E-02 | 1,80E-01 | 2,17E+01 | 5,86E-01 | 4,69E-01 |
| 25 | 1,57E+02 | 2,61E-01 | 4,04E-02 | 1,51E-01 | 1,91E+01 | 1,83E-01 | 2,63E-02 |
| 26 | 1,66E+02 | 8,27E-02 | 4,21E-07 | 3,02E-03 | 1,20E-04 | 3,60E-04 | 3,54E-05 |
| 27 | 1,66E+02 | 2,66E-01 | 6,04E-02 | 3,70E-01 | 8,54E-01 | 4,91E-01 | 1,42E-01 |
| 28 | 1,71E+02 | 1,86E+00 | 8,63E-01 | 1,93E+00 | 4,83E+00 | 1,46E+00 | 3,66E-01 |
| 29 | 1,82E+02 | 1,44E-01 | 1,35E-04 | 1,94E-02 | 8,59E+00 | 1,52E-02 | 3,39E-06 |
| 30 | 1,82E+02 | 2,22E-04 | 2,62E-04 | 2,17E-02 | 1,82E+01 | 5,54E-02 | 6,67E-05 |
| 31 | 2,00E+02 | 7,31E+01 | 5,36E-01 | 3,03E+00 | 2,02E-02 | 1,63E-01 | 6,66E-02 |
| 32 | 2,02E+02 | 3,18E-02 | 1,30E-02 | 5,04E-05 | 6,93E-04 | 1,06E-05 | 2,59E-04 |
| 33 | 2,02E+02 | 9,38E-03 | 6,03E-03 | 2,20E-06 | 3,35E-04 | 1,75E-05 | 1,28E-04 |
| 34 | 2,02E+02 | 1,25E+00 | 1,05E+00 | 2,84E-03 | 4,20E-02 | 8,19E-04 | 1,97E-02 |
| 35 | 2,02E+02 | 3,75E-02 | 3,70E-02 | 6,64E-05 | 5,50E-05 | 5,81E-05 | 7,64E-04 |
| 36 | 2,02E+02 | 3,94E-01 | 2,69E-01 | 2,09E-04 | 8,14E-03 | 8,75E-05 | 5,04E-03 |
| 37 | 2,04E+02 | 9,53E+00 | 4,57E-01 | 2,87E+00 | 2,73E-02 | 5,69E-02 | 1,20E-02 |
| 38 | 2,04E+02 | 4,01E-01 | 4,18E+00 | 6,19E-01 | 3,17E-02 | 2,71E-03 | 2,04E-01 |
| 39 | 2,05E+02 | 1,38E+01 | 1,11E-01 | 8,44E-01 | 7,95E-02 | 3,40E-01 | 5,06E-02 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 40 | 2,15E+02 | 6,82E-01 | 8,11E+00 | 4,52E-01 | 1,17E+00 | 2,69E-02 | 3,28E-01 |
| 41 | 2,18E+02 | 1,43E+01 | 2,63E+00 | 1,29E+01 | 5,04E-02 | 6,71E-01 | 2,32E-01 |
| 42 | 2,22E+02 | 3,20E+00 | 2,18E+01 | 6,93E-02 | 3,67E-01 | 2,27E-02 | 1,80E+00 |
| 43 | 2,31E+02 | 2,12E+01 | 9,60E-01 | 1,36E+01 | 6,71E-02 | 6,27E-01 | 5,59E-02 |
| 44 | 2,40E+02 | 1,90E+00 | 8,75E-01 | 1,11E+00 | 3,67E-01 | 1,99E-02 | 4,43E-03 |
| 45 | 2,45E+02 | 5,18E-01 | 1,43E-02 | 4,09E-02 | 6,15E-01 | 1,12E-02 | 1,49E-03 |
| 46 | 2,54E+02 | 1,06E-01 | 1,55E-01 | 5,42E-02 | 2,18E-01 | 9,36E-03 | 5,40E-03 |
| 47 | 2,66E+02 | 6,30E-01 | 2,57E-01 | 3,41E-01 | 8,43E-01 | 1,66E-03 | 1,96E-02 |
| 48 | 2,69E+02 | 4,72E-01 | 6,51E-02 | 1,29E-01 | 1,68E+00 | 3,34E-03 | 1,01E-04 |
| 49 | 2,71E+02 | 2,82E-02 | 1,36E-01 | 4,23E-01 | 2,57E-01 | 9,66E-03 | 2,26E-05 |
| 50 | 2,71E+02 | 6,93E-03 | 5,82E-01 | 1,32E-01 | 6,96E-01 | 2,33E-03 | 1,24E-02 |
| 51 | 2,73E+02 | 1,21E+00 | 5,03E-01 | 3,69E-02 | 5,94E-01 | 3,76E-03 | 1,70E-03 |
| 52 | 2,74E+02 | 1,27E-01 | 2,88E-02 | 2,91E-01 | 1,32E-01 | 1,06E-02 | 1,75E-02 |
| 53 | 2,78E+02 | 3,94E+01 | 4,62E-02 | 3,19E-01 | 2,67E-01 | 4,49E-02 | 1,49E-04 |
| 54 | 2,87E+02 | 1,43E-05 | 1,82E-06 | 3,61E-07 | 1,58E-04 | 3,03E-07 | 1,74E-07 |
| 55 | 2,87E+02 | 9,09E-04 | 2,78E-06 | 1,36E-08 | 2,79E-05 | 2,49E-06 | 2,45E-08 |
| 56 | 2,87E+02 | 1,18E-03 | 2,36E-08 | 1,39E-05 | 9,10E-05 | 1,37E-06 | 1,40E-07 |
| 57 | 2,87E+02 | 4,32E-03 | 3,88E-06 | 4,12E-05 | 5,29E-05 | 9,64E-06 | 4,33E-07 |
| 58 | 2,89E+02 | 2,36E-02 | 7,82E-04 | 3,70E-04 | 1,15E-02 | 1,63E-04 | 8,34E-05 |
| 59 | 2,97E+02 | 3,65E-02 | 3,63E-05 | 4,77E-03 | 1,35E-01 | 4,64E-04 | 1,05E-03 |
| 60 | 3,05E+02 | 6,73E-01 | 1,50E-02 | 1,10E-01 | 3,85E+00 | 1,11E-02 | 2,22E-02 |
| 61 | 3,09E+02 | 2,46E-01 | 3,65E-05 | 2,96E-03 | 2,80E-02 | 3,24E-05 | 2,96E-05 |
| 62 | 3,22E+02 | 1,16E-04 | 2,26E-03 | 1,74E-04 | 5,24E-04 | 5,36E-04 | 1,40E-04 |
| 63 | 3,26E+02 | 2,36E-02 | 2,69E-01 | 7,37E-01 | 3,41E-02 | 3,33E-01 | 1,75E-01 |
| 64 | 3,32E+02 | 1,34E+00 | 2,17E+00 | 7,87E-01 | 5,36E-02 | 3,29E-01 | 1,05E+00 |
| 65 | 3,74E+02 | 7,51E-06 | 1,02E-05 | 4,92E-06 | 1,37E-05 | 8,02E-07 | 1,39E-06 |
| 66 | 3,74E+02 | 5,38E-05 | 3,02E-06 | 2,37E-07 | 1,89E-07 | 1,64E-07 | 4,42E-07 |
| 67 | 3,81E+02 | 8,89E-06 | 2,25E-06 | 1,52E-07 | 6,78E-06 | 1,05E-06 | 3,47E-07 |
| 68 | 3,81E+02 | 8,68E-05 | 4,59E-06 | 6,22E-06 | 2,37E-08 | 2,18E-09 | 2,27E-08 |
| 69 | 3,83E+02 | 1,38E-07 | 1,14E-03 | 5,15E-04 | 1,30E-04 | 1,71E-04 | 1,00E-04 |
| 70 | 3,83E+02 | 1,02E-02 | 4,41E-03 | 1,82E-04 | 3,79E-05 | 8,56E-05 | 1,15E-03 |
| 71 | 3,83E+02 | 5,91E-04 | 6,08E-05 | 2,26E-04 | 1,27E-04 | 3,64E-05 | 3,87E-05 |
| 72 | 3,83E+02 | 8,42E-04 | 2,61E-04 | 1,25E-05 | 2,38E-04 | 5,43E-05 | 3,08E-05 |
| 73 | 3,85E+02 | 4,73E-08 | 8,33E-07 | 1,14E-07 | 1,43E-07 | 3,49E-07 | 3,07E-11 |
| 74 | 3,85E+02 | 2,71E-06 | 2,92E-05 | 4,61E-07 | 6,29E-07 | 1,10E-07 | 2,84E-06 |
| 75 | 3,85E+02 | 2,77E-05 | 2,26E-05 | 9,63E-06 | 6,85E-09 | 5,89E-07 | 7,63E-06 |
| 76 | 3,85E+02 | 6,83E-06 | 2,84E-05 | 8,28E-06 | 6,20E-08 | 1,44E-10 | 6,98E-06 |
| 77 | 3,87E+02 | 1,33E-03 | 5,09E-04 | 2,41E-03 | 1,53E-05 | 6,92E-06 | 5,22E-05 |
| 78 | 3,87E+02 | 2,23E-04 | 2,43E-03 | 7,33E-04 | 2,46E-05 | 2,28E-07 | 6,05E-04 |
| 79 | 3,87E+02 | 4,39E-06 | 1,31E-04 | 4,88E-05 | 6,44E-05 | 4,57E-05 | 1,58E-05 |
| 80 | 3,88E+02 | 1,14E-04 | 1,21E-03 | 3,31E-04 | 9,69E-06 | 1,22E-04 | 3,65E-04 |
| 81 | 4,02E+02 | 2,34E-02 | 5,99E-04 | 5,44E-05 | 2,13E-05 | 1,83E-05 | 1,59E-04 |
| 82 | 4,12E+02 | 1,64E-01 | 2,20E-01 | 3,61E-01 | 4,67E-03 | 2,44E-03 | 8,09E-02 |
| 83 | 4,12E+02 | 4,16E-02 | 1,90E-01 | 3,53E-01 | 3,90E-03 | 2,86E-03 | 7,05E-02 |
| 84 | 4,22E+02 | 4,96E-08 | 1,90E-09 | 5,17E-10 | 5,58E-11 | 3,77E-10 | 6,92E-10 |
| 85 | 4,22E+02 | 9,94E-08 | 2,98E-08 | 8,03E-11 | 4,67E-10 | 7,27E-11 | 1,90E-10 |

DTM TECHNOLOGIES

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 86 | 4,26E+02 | 1,31E-02 | 5,94E-05 | 2,69E-04 | 7,72E-06 | 3,38E-05 | 1,97E-05 |
| 87 | 4,28E+02 | 5,64E-05 | 3,64E-01 | 3,67E-03 | 2,09E-03 | 3,17E-04 | 3,45E-02 |
| 88 | 4,29E+02 | 6,13E-04 | 7,56E-05 | 2,35E-02 | 1,48E-04 | 2,79E-03 | 4,62E-04 |
| 89 | 4,30E+02 | 1,21E-05 | 7,45E-04 | 9,01E-03 | 6,93E-08 | 3,14E-03 | 2,37E-05 |
| 90 | 4,31E+02 | 2,48E-03 | 7,67E-02 | 5,32E-02 | 1,44E-03 | 1,79E-02 | 9,44E-03 |
| 91 | 4,35E+02 | 2,90E-05 | 1,86E-04 | 4,56E-04 | 1,49E-05 | 2,47E-05 | 3,53E-05 |
| 92 | 4,35E+02 | 2,35E-04 | 8,01E-06 | 6,08E-03 | 1,17E-05 | 4,95E-04 | 3,22E-05 |
| 93 | 4,36E+02 | 1,72E-04 | 4,22E-05 | 4,60E-03 | 2,79E-06 | 3,56E-04 | 7,31E-06 |
| 94 | 4,36E+02 | 1,00E-04 | 3,69E-04 | 6,07E-04 | 9,28E-06 | 5,69E-06 | 9,11E-05 |
| 95 | 4,38E+02 | 1,19E-01 | 3,52E-03 | 1,29E+00 | 1,64E-03 | 9,90E-02 | 2,01E-03 |
| 96 | 4,51E+02 | 3,05E-08 | 8,37E-10 | 1,23E-08 | 6,72E-10 | 2,05E-09 | 3,86E-10 |
| 97 | 4,51E+02 | 1,48E-09 | 6,80E-09 | 1,28E-10 | 1,33E-13 | 1,06E-13 | 3,22E-11 |
| 98 | 4,62E+02 | 1,65E-08 | 2,73E-07 | 9,64E-08 | 3,23E-10 | 3,48E-09 | 5,25E-09 |
| 99 | 4,62E+02 | 3,02E-08 | 1,81E-07 | 6,46E-08 | 1,12E-09 | 1,57E-08 | 4,42E-09 |
| 100 | 4,69E+02 | 5,34E-02 | 5,46E+00 | 9,07E-01 | 2,73E-04 | 1,14E-01 | 3,12E-01 |
| | | | | | | | |
| | **TOTAL** | **2,47E+02** | **2,59E+02** | **2,56E+02** | **8,78E+01** | **2,09E+02** | **2,18E+02** |

DTM TECHNOLOGIES

# Annex 2

## (Material properties used for FEM analysis)

DTM TECHNOLOGIES

# 5052
## High strength aluminium honeycomb

*Product Data*

## Description

5052 is a hexagonal cell honeycomb material used principally as a shear carrying core in light weight adhesively bonded sandwich structures.

The 5052 aluminium alloy used is a fully hard H191 temper 2.5% magnesium alloy conforming to MIL-A-81596. Except where indicated, the 5052 foil is treated against corrosion using a chromate conversion coating process.

5052 is available in a wide range of cell sizes and densities allowing versatility in design of sandwich structures and other applications.

## Key Features

- High strength and stiffness to weight ratio.
- High fatigue resistance.
- Good vibration damping characteristics.
- Non-combustible.
- Good retention of properties at elevated temperatures.
- Can be machined to complex profiles.
- Exhibits uniform crushing characteristics.
- Compatible with a wide range of materials providing a good bonding surface for Redux® adhesives.

## Typical Applications

- Helicopter blades
- Aircraft engine structures and nacelles
- Aircraft doors and hatches
- Aircraft floor panels
- Racing car structures and aerofoils
- Energy absorbers

DTM TECHNOLOGIES

# 5052

## Typical Mechanical Properties

| Honeycomb Designation | Stabilised Compression | | Plate Shear | | | | |
|---|---|---|---|---|---|---|---|
| | Strength (MPa) | Modulus (MPa) | Strength "L Direction" (MPa) | Modulus "L Direction" (MPa) | Strength "W Direction" (MPa) | Modulus "W Direction" (MPa) | Maximum Thickness mm |
| 1.8-3/4-25 | 0.95 | 215 | 0.74 | 182 | 0.46 | 96 | 150 |
| 2.3-1/4-10 | 1.35 | 310 | 0.96 | 220 | 0.58 | 112 | 150 |
| 3.0-3/8-20 | 2.10 | 485 | 1.35 | 295 | 0.85 | 145 | 150 |
| 3.1-3/16-10 | 2.30 | 517 | 1.45 | 310 | 0.90 | 152 | 150 |
| 3.4-1/4-15 | 2.60 | 620 | 1.60 | 345 | 1.10 | 166 | 150 |
| 3.7-3/8-25 | 2.95 | 725 | 1.80 | 380 | 1.17 | 180 | 150 |
| 3.9-1/2-40 | 3.30 | 820 | 1.94 | 405 | 1.25 | 190 | 150 |
| 4.3-1/4-20 | 3.75 | 965 | 2.20 | 455 | 1.45 | 205 | 150 |
| 4.4-3/16-15 | 4.10 | 1000 | 2.25 | 470 | 1.48 | 210 | 150 |
| 4.5-1/8-10 | 4.20 | 1034 | 2.30 | 483 | 1.50 | 214 | 150 |
| 5.2-1/4-25 | 5.20 | 1310 | 2.80 | 565 | 1.80 | 245 | 150 |
| 5.4-3/8-40 | 5.35 | 1380 | 2.90 | 590 | 1.95 | 250 | 150 |
| 5.7-3/16-20 | 5.80 | 1520 | 3.15 | 620 | 2.05 | 265 | 150 |
| 6.9-3/16-25 | 8.00 | 1965 | 4.04 | 785 | 2.50 | 320 | 75 |
| 7.9-1/4-40 | 10.00 | 2345 | 4.80 | 896 | 2.90 | 364 | 75 |
| 8.1-1/8-20 | 11.00 | 2414 | 5.00 | 930 | 3.00 | 372 | 50 |

† See Typical dimensions and tolerances section opposite

## Material Properties

Fire Properties

Classified as non-combustible when tested to IMO resolution A.472(XII).

Elevated Temperature Performance

5052 honeycomb employs a node bond adhesive which retains a high proportion of its strength at temperatures up to 200°C.

Machining

5052 honeycomb can be machined to form complex surfaces with the use of high speed routers. Some single curvature contours can be machined on to an un-expanded slice before expansion.

Bonding

Non-volatile adhesives should be used for bonding skins to the honeycomb to prevent possible build up of volatiles during cure. This may be alleviated by using perforated honeycomb.

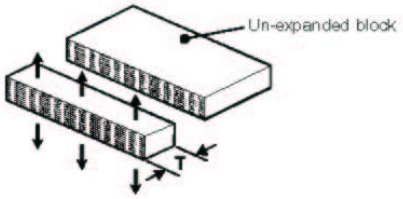
DTM TECHNOLOGIES

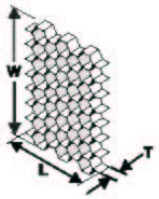
*High strength aluminium honeycomb*

## Material Form

5052 honeycomb is supplied in flat sheets as shown where the length and width are determined by the block dimensions and the slice thickness "T" is cut to customer order.

The material can be supplied expanded or in the un-expanded form for expansion by the customer. In this case, the L and W dimensions given are those in the expanded condition.




W = direction of expansion

L = ribbon direction

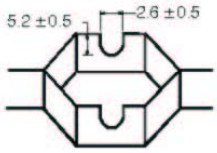
### Perforation

Perforated foil can be used for the production of Aeroweb aluminium honeycomb. Pin holes in the honeycomb allow gasses to be vented from the cells. Perforated honeycomb is only available to special order.

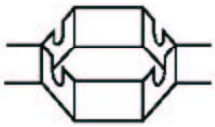
### Slotting

Slotting is available on 3/4" and 1/2" cell materials. Two slotting styles are available as follows:

Single slotting




Double slotting



The centre line of the slot is within 2mm of the centre line of the node wall

| | | |
|---|---|---|
| Maximum slice thickness for slotted honeycomb | 51mm | for all cell sizes |
| Minimum slice thickness for slotted honeycomb | 11mm | for 1/2" cell |
| | 16mm | for 3/4" cell |

### Typical dimensions and tolerances

| | Length | | Width |
|---|---|---|---|
| | 1250mm | x | 2500mm |
| | 1400mm | x | 3000mm |
| Standard tolerance | -0/+50mm | | -0/+75mm |

Thicknesses are available between 3mm and 150mm depending on material density (please refer to 'Typical Mechanical Properties' table).

| Slice thickness | Tolerance |
|---|---|
| 3mm to 75mm | ±0.125mm |
| 75mm + | -0/+2.5mm |

Density ±10% of nominal

Other dimensions and tolerances may be available subject to minimum order limitations or stock availability.
Please refer to Hexcel Composites for any non standard requirement.

DTM TECHNOLOGIES

# 5052 *Product Data*

## Ordering

To specify the material you require, the material type and dimensions must be defined, e.g.

Material type: AEROWEB 5.2-1/4-25P(5052)T-UNX

| 5.2 | 1/4 | 25 | P | (5052) | T | UNX |
|---|---|---|---|---|---|---|
| density ($lb/ft^3$) | cell size (inches) | nominal foil thickness (inches x $10^{-6}$) | specifies perforated foil (optional) | specifies alloy type | corrosion protected foil | un-expanded slice |

Dimensions: 1220 x 2440 x 12.7

| 1220 | 2440 | 12.7 |
|---|---|---|
| L or ribbon dimension | W or direction of expansion | Customer specified thickness |

Material is tested to DTD900/4764 unless otherwise specified.

## Handling and Safety Precautions

The usual precautions when handling metallic materials should be observed. The use of clean disposable inert gloves provides protection for the operator and avoids contamination of material and components. Product safety data sheets have been prepared for all Hexcel Composites products and are available to company Safety Officers on request.

### Important



### For More Information

Hexcel Composites is a leading worldwide supplier of composite materials to aerospace and other demanding industries. Our comprehensive product range includes:

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- Structural film adhesives
- Honeycomb sandwich panels
- Special process honeycombs
- RTM materials

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DTM TECHNOLOGIES

# M74 350°F (177°C) curing epoxy matrix

**Licensed 934 technology from Cytec Fiberite**

*Product Data*

## Features

- 350°F (177°C) cure
- Available in a broad range of fibers and forms including tape, fabric, and tow
- Large industry database
- Laminate and sandwich panel usage
- Material widely used in space, aerospace, and military structural applications
- Autoclave or press-mold processing
- Shelf life: 6 months at 0°F (-18°C); 10 days at 72°F (22°C)

## Description

M74 is a high flow, 350°F (177°C) curing epoxy resin with extensive space structural heritage. M74 is formulated for autoclave processing, but it has been successfully processed by press molding. Unidirectional tape and woven fabric impregnated with M74 resin will retain good tack and drape for at least 10 days at 70°F (21°C). Standard cure is for two hours at 350°F (177°C). Hexcel recommended lay-up procedure is HSP-L1 or HSP-L2. Recommended cure procedure is HSP-C1 or HSP-C2.

Typical applications for M74 include structural aircraft components and critical space structures. M74 meets all NASA outgassing requirements.

## Typical Neat Resin Properties

| Properties | | RT | 200°F (93°C) | 200°F (93°C) Wet |
|---|---|---|---|---|
| **Tensile Strength,** | **ksi** | 12 | | |
| | ***MPa*** | *83* | | |
| **Tensile Modulus,** | **Msi** | 0.6 | | |
| | ***GPa*** | *4.1* | | |
| **Flexural Strength,** | **ksi** | 10.0 | 17 | 10.0 |
| | ***MPa*** | *69* | *117* | *69* |
| **Flexural Modulus,** | **Msi** | 0.6 | 0.5 | 0.4 |
| | ***GPa*** | *4.1* | *3.4* | *2.8* |
| **Tg** | **Dry** | 381°F (194°C) | | |
| | ***Wet*** | *320°F (160°C)* | | |
| **Density,** | **g/cc** | 1.30 | | |

## M74 Laminate Outgassing

| | T300/934 | ASTM LIMITS |
|---|---|---|
| **Total Mass Loss, %** | 0.4 | 1.0 |
| Volatile Condensable Mat'l | <0.01 | 0.1 |
| Water Vapor Recovered | 0.13 | |

Notes: Tested per ASTM E 595

DTM TECHNOLOGIES

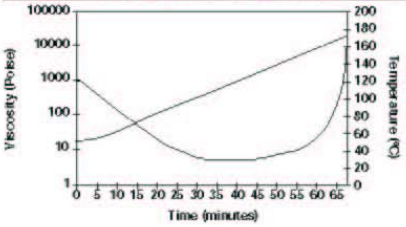
# M74 Product Data

## Typical Mechanical Properties (Various Fibers)

| Property | | Fibers (Average Values) | | | | | |
|---|---|---|---|---|---|---|---|
| | | M40J | M46J | M55J | K1392U | XN70A | P120 |
| 0 Tensile Strength, | ksi | 304 | 288 | 319 | 272 | 193 | 188 |
| | *MPa* | *2096* | *1985* | *2199* | *1875* | *1331* | *1296* |
| 0 Tensile Modulus, | Msi | 29.7 | 39.0 | 52.8 | 64.6 | 59.9 | 70.1 |
| | *GPa* | *205* | *269* | *364* | *445* | *413* | *483* |
| 90 Tensile Strength, | ksi | 4.5 | 7.4 | 4.4 | — | — | — |
| | *MPa* | *31* | *51* | *30* | | | |
| 90 Tensile Modulus, | Msi | 1.12 | 1.04 | 0.99 | — | — | — |
| | *GPa* | *7.7* | *7.2* | *6.8* | | | |
| 0 Comp. Strength, | ksi | 171 | 190 | 135 | 60.9 | 55.8 | 48.8 |
| | *MPa* | *1179* | *1310* | *931* | *420* | *385* | *336* |
| 0 Comp. Modulus, | Msi | 25.7 | 32.0 | 46.6 | 59.9 | 58.7 | 69.1 |
| | *GPa* | *177* | *221* | *321* | *413* | *415* | *476* |
| 0 Flexural Strength, | ksi | 171 | 179 | 146 | 96.8 | 103 | — |
| | *MPa* | *1179* | *1234* | *1007* | *667* | *710* | |
| 0 Flexural Modulus, | Msi | 23.5 | 30.0 | 41.5 | 50.3 | 49.7 | — |
| | *GPa* | *162* | *207* | *286* | *347* | *343* | |
| 0 IL Shear Strength, | ksi | 12.9 | 12.3 | 10.3 | 9.3 | 11.5 | 5.0 |
| | *MPa* | *89* | *85* | *71* | *64* | *79* | *34* |

Notes: 0 tensile, compression, and flex values are normalized to 60% fiber volume. All testing performed at RT.

## M74 Viscosity Profile [Ramp to 350°F (177°C)]

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## Annex 3

**Geometrical and elastic properties, as they have been introduced in the NASTRAN finite element program in order to run the analysis.**
**The property table makes reference to the 3-D drawings shown in the first page of this report.**

**Property 1 - Plate Al 7075 s = 4 mm**

```
  Type PLATE           Color 115   Layer 30       Material 1        #Elem 4276
 Bending Matl 0           TrShear Matl 0           CouplingMatl 0
    Thickness 0.004          Top Fiber 0.004          Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.              Tshear/T 0.
```

**Property 2 - Struttura cono esterno**

```
  Type LAMINATE        Color 69    Layer 40       Material 0        #Elem 4672
  Laminate Option    As Specified
  Failure Theory  HILL     Bond Shear Allowable 37000000.
  Ref Temp    293.15       Damping Coef 0.
  Bottom Surf 0.           NS Mass/Area 0.
  Layup 1 - Cono esterno
    Ply  1  Material 2        Thickness 0.0003             Angle 0.
    Ply  2  Material 2        Thickness 0.0003             Angle 60.
    Ply  3  Material 2        Thickness 0.0003             Angle -60.
    Ply  4  Material 2        Thickness 0.0003             Angle 60.
    Ply  5  Material 2        Thickness 0.0003             Angle -60.
    Ply  6  Material 2        Thickness 0.0003             Angle 0.
    Ply  7  Material 3        Thickness 0.02               Angle 0.
    Ply  8  Material 2        Thickness 0.0003             Angle 0.
    Ply  9  Material 2        Thickness 0.0003             Angle -60.
    Ply 10  Material 2        Thickness 0.0003             Angle 60.
    Ply 11  Material 2        Thickness 0.0003             Angle -60.
    Ply 12  Material 2        Thickness 0.0003             Angle 60.
    Ply 13  Material 2        Thickness 0.0003             Angle 0.
```

**Property 3 - Plate Al 7075 s = 15 mm**

```
  Type PLATE           Color 112   Layer 50       Material 1        #Elem 0
 Bending Matl 0           TrShear Matl 0           CouplingMatl 0
    Thickness 0.015          Top Fiber -0.015         Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.              Tshear/T 0.
```

**Property 4 - Plate Al 7075 s = 5 mm**

```
  Type PLATE           Color 114   Layer 25       Material 1        #Elem 21944
 Bending Matl 0           TrShear Matl 0           CouplingMatl 0
    Thickness 0.005          Top Fiber 0.             Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.              Tshear/T 0.
```

**Property 5 - Solid Al 7075**

```
  Type SOLID           Color 14    Layer 20       CoordSys 0        #Elem 84044
 Material 1        Integration Net 0     Material Aligned to Coordinate System
```

**Property 7 - Mass esperimento**

```
  Type MASS            Color 24    Layer 110      CoordSys 0        #Elem 1
      Mass, X 22.15             Mass, Y 22.15             Mass, Z 22.15
```

```
  Inertia,I11 0.                  I22 0.                  I33 0.
          I21 0.                  I31 0.                  I32 0.
  Offset,   X 0.                    Y 0.                    Z 0.
     Diameter 0.
```

**Property 8 - M2.5*0.45**

```
  Type BAR            Color 24    Layer 106      Material 5        #Elem 21
  SHAPE - Circular Bar               Poisson Ratio 0.3
         Radius 0.00104
         Area 0.0000033979  ShearAr, K1 0.0000030111  ShearAr, K2 0.0000030111
           I1 9.188E-13              I2 9.188E-13              I12 0.
  NS Mass/Len 0.              Perimeter 0.0065345               J 1.8361E-12
  Recover Stresses At:  Y 0.            Z -0.00104
  Recover Stresses At:  Y 0.00104       Z 0.
  Recover Stresses At:  Y 0.            Z 0.00104
  Recover Stresses At:  Y -0.00104      Z 0.
```

**Property 9 - Plate Al 7075 s = 2.5 mm (camera vuoto)**

```
  Type PLATE          Color 95    Layer 60       Material 5        #Elem 2454
 Bending Matl 0           TrShear Matl 0           CouplingMatl 0
    Thickness 0.0025         Top Fiber 0.0025         Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.              Tshear/T 0.
```

**Property 10 - Bar M6*1**

```
  Type BAR            Color 74    Layer 62       Material 5        #Elem 16
  SHAPE - Circular Bar               Poisson Ratio 0.3
         Radius 0.00253
         Area 0.000020109   ShearAr, K1 0.00001782    ShearAr, K2 0.00001782
           I1 3.2179E-11             I2 3.2179E-11             I12 0.
  NS Mass/Len 0.              Perimeter 0.015897                J 6.4304E-11
  Recover Stresses At:  Y 0.            Z -0.00253
  Recover Stresses At:  Y 0.00253       Z 0.
  Recover Stresses At:  Y 0.            Z 0.00253
  Recover Stresses At:  Y -0.00253      Z 0.
```

**Property 11 - Plate Al 7075 s = 5 mm nerva**

```
  Type PLATE          Color 54    Layer 25       Material 1        #Elem 2544
 Bending Matl 0           TrShear Matl 0           CouplingMatl 0
    Thickness 0.005          Top Fiber 0.005          Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.              Tshear/T 0.
```

**Property 12 - Plate pannelli solari**

```
  Type PLATE          Color 23    Layer 1000     Material 1        #Elem 0
 Bending Matl 0           TrShear Matl 0           CouplingMatl 0
    Thickness 0.008          Top Fiber -0.015         Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.              Tshear/T 0.
```

**Property 13 - Laminate cilindro centrale**

```
  Type LAMINATE       Color 112   Layer 50       Material 0        #Elem 2628
  Laminate Option    As Specified
  Failure Theory  HILL     Bond Shear Allowable 36000000.
  Ref Temp    0.           Damping Coef 0.
  Bottom Surf 0.002        NS Mass/Area 0.
  Layup 2 - Cilindro centrale
    Ply  1  Material 1        Thickness 0.0015             Angle 0.
    Ply  2  Material 3        Thickness 0.02               Angle 0.
    Ply  3  Material 1        Thickness 0.0015             Angle 0.
```

**Property 14 - Plate Al 7075 s = 10 mm**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | PLATE | Color | 11 | Layer | 1300 | Material | 1 | #Elem | 216 |
| Bending Matl | 0 | TrShear Matl | 0 | CouplingMatl | 0 | | | | |
| Thickness | 0.01 | Top Fiber | 0. | Bot Fiber | 0. | | | | |
| NS Mass/Area | 0. | 12I/T**3 | 0. | Tshear/T | 0. | | | | |

**Property 15 - Plate Al 7075 adattatore Vega**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | PLATE | Color | 74 | Layer | 1300 | Material | 1 | #Elem | 1188 |
| Bending Matl | 0 | TrShear Matl | 0 | CouplingMatl | 0 | | | | |
| Thickness | 0.0125 | Top Fiber | 0. | Bot Fiber | 0. | | | | |
| NS Mass/Area | 0. | 12I/T**3 | 0. | Tshear/T | 0. | | | | |

**Property 16 - Pannelli solari**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | LAMINATE | Color | 24 | Layer | 1000 | Material | 0 | #Elem | 9996 |
| Laminate Option | As Specified | | | | | | | | |
| Failure Theory | HILL | Bond Shear Allowable | 3400000000. | | | | | | |
| Ref Temp | 0. | Damping Coef | 0. | | | | | | |
| Bottom Surf | 0. | NS Mass/Area | 1.404 | | | | | | |

Layup 3 - Laminate pannello solare

| | | | | | |
|---|---|---|---|---|---|
| Ply 1 | Material 1 | Thickness | 0.0002 | Angle | 0. |
| Ply 2 | Material 3 | Thickness | 0.02 | Angle | 0. |
| Ply 3 | Material 1 | Thickness | 0.0002 | Angle | 0. |

**Property 17 - Mass N2 tanks**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | MASS | Color | 110 | Layer | 1205 | CoordSys | 0 | #Elem | 2 |
| Mass, X | 7.16 | Mass, Y | 7.16 | Mass, Z | 7.16 | | | | |
| Inertia,I11 | 0. | I22 | 0. | I33 | 0. | | | | |
| I21 | 0. | I31 | 0. | I32 | 0. | | | | |
| Offset, X | 0. | Y | 0. | Z | 0. | | | | |
| Diameter | 0. | | | | | | | | |

**Property 18 - Mass FEEP propulsion**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | MASS | Color | 4 | Layer | 1210 | CoordSys | 0 | #Elem | 2 |
| Mass, X | 12. | Mass, Y | 12. | Mass, Z | 12. | | | | |
| Inertia,I11 | 0. | I22 | 0. | I33 | 0. | | | | |
| I21 | 0. | I31 | 0. | I32 | 0. | | | | |
| Offset, X | 0. | Y | 0. | Z | 0. | | | | |
| Diameter | 0. | | | | | | | | |

**Property 19 - Mass battery**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | MASS | Color | 120 | Layer | 1215 | CoordSys | 0 | #Elem | 1 |
| Mass, X | 16.36 | Mass, Y | 16.36 | Mass, Z | 16.36 | | | | |
| Inertia,I11 | 0. | I22 | 0. | I33 | 0. | | | | |
| I21 | 0. | I31 | 0. | I32 | 0. | | | | |
| Offset, X | 0. | Y | 0. | Z | 0. | | | | |
| Diameter | 0. | | | | | | | | |

**Property 20 - Mass data handling**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | MASS | Color | 15 | Layer | 1220 | CoordSys | 0 | #Elem | 1 |
| Mass, X | 16. | Mass, Y | 16. | Mass, Z | 16. | | | | |
| Inertia,I11 | 0. | I22 | 0. | I33 | 0. | | | | |
| I21 | 0. | I31 | 0. | I32 | 0. | | | | |
| Offset, X | 0. | Y | 0. | Z | 0. | | | | |
| Diameter | 0. | | | | | | | | |

**Property 22 - Mass PCDU**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | MASS | Color | 23 | Layer | 1225 | CoordSys | 0 | #Elem | 1 |
| Mass, X | 13.5 | Mass, Y | 13.5 | Mass, Z | 13.5 | | | | |

```
  Inertia,I11 0.                  I22 0.                  I33 0.
          I21 0.                  I31 0.                  I32 0.
  Offset,   X 0.                    Y 0.                    Z 0.
     Diameter 0.
```

**Property 23 - Plate Al 7075 s = 8 mm**

```
  Type PLATE          Color 105   Layer 30       Material 1        #Elem 584
 Bending Matl 0           TrShear Matl 0          CouplingMatl 0
    Thickness 0.008          Top Fiber 0.008         Bot Fiber 0.
 NS Mass/Area 0.              12I/T**3 0.             Tshear/T 0.
```

**Property 24 - Mass harness**

```
  Type MASS           Color 24    Layer 30       CoordSys 0        #Elem 3
      Mass, X 4.2               Mass, Y 4.2               Mass, Z 4.2
  Inertia,I11 0.                  I22 0.                  I33 0.
          I21 0.                  I31 0.                  I32 0.
  Offset,   X 0.                    Y 0.                    Z 0.
     Diameter 0.
```

# Materials list

**Material 1 - Al 7075 T7351**

```
  Type ISOTROPIC       Color 115   Layer 25          #Prop/Ply 13
          Density 2788.          Damping 0.           Ref Temp 0.
STIFFNESS       E 71000000000.          G 0.               Nu 0.33
STRENGTH  Tension 0.            Compress 0.            Shear 0.
THERMAL     Alpha 0.                   K 0.          SpecHeat 0.
            HtGen 0.
OPTICAL   Front   Off           Reverse  Off
```

**Material 2 - T300 1k/PW-934 Hexcel**

```
  Type 2D ORTHOTROPIC  Color 65    Layer 40          #Prop/Ply 12
          Density 1560.          Damping 0.           Ref Temp 293.15
          Tsai-Wu 0.
STIFFNESS      E1 62052000000.       G12 4800000000.      Nu12 0.04
               E2 62742000000.       G1z 4800000000.
                                     G2z 4800000000.
STRENGTH Tension1 535000000.   Compress1 524000000.      Shear 68296000.
         Tension2 483000000.   Compress2 547000000.
THERMAL   Alpha11 0.                 K11 0.               K12 0.
          Alpha22 0.                 K22 0.               K13 0.
                                     K33 0.               K23 0.
        Spec Heat 0.
OPTICAL   Front   Off           Reverse  Off
```

**Material 3 - Honeycomb 3/16 5052**

```
  Type 2D ORTHOTROPIC  Color 109   Layer 40          #Prop/Ply 3
          Density 49.69          Damping 0.           Ref Temp 0.
          Tsai-Wu 293.15
STIFFNESS      E1 310000000.         G12 128280000.       Nu12 0.45
               E2 152000000.         G1z 128280000.
                                     G2z 128280000.
STRENGTH Tension1 1450000.     Compress1 100000.         Shear 1700000.
         Tension2 900000.      Compress2 100000.
THERMAL   Alpha11 0.                 K11 0.               K12 0.
          Alpha22 0.                 K22 0.               K13 0.
                                     K33 0.               K23 0.
```

Spec Heat 0.

**Material 5 - AISI 316**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Type | ISOTROPIC | Color | 143 | Layer | 106 | #Prop/Ply | 3 |
| | Density | 8027. | | Damping | 0. | Ref Temp | 293.15 |
| STIFFNESS | E | 2.01E+11 | | G | 0. | Nu | 0.3 |
| STRENGTH | Tension | 0. | | Compress | 0. | Shear | 0. |
| THERMAL | Alpha | 0. | | K | 0. | SpecHeat | 0. |
| | HtGen | 0. | | | | | |
| OPTICAL | Front | Off | | Reverse | Off | | |

## Mass properties

**O U T P U T  F R O M  G R I D  P O I N T  W E I G H T  G E N E R A T O R**

0 REFERENCE POINT = 0

M O

| | | | | | |
|---|---|---|---|---|---|
| * 3.020289E+02 | 0.000000E+00 | 0.000000E+00 | 0.000000E+00 | -9.933019E+00 | -2.571445E+00 * |
| * 0.000000E+00 | 3.020289E+02 | 0.000000E+00 | 9.933019E+00 | 0.000000E+00 | 1.889010E+02 * |
| * 0.000000E+00 | 0.000000E+00 | 3.020289E+02 | 2.571445E+00 | -1.889010E+02 | 0.000000E+00 * |
| * 0.000000E+00 | 9.933019E+00 | 2.571445E+00 | 9.549988E+01 | -1.828880E+00 | 7.054592E+00 * |
| * -9.933019E+00 | 0.000000E+00 | -1.889010E+02 | -1.828880E+00 | 2.145369E+02 | 7.063282E+00 * |
| * -2.571445E+00 | 1.889010E+02 | 0.000000E+00 | 7.054592E+00 | 7.063282E+00 | 2.239695E+02 * |

S

| | | | |
|---|---|---|---|
| * | 1.000000E+00 | 0.000000E+00 | 0.000000E+00 * |
| * | 0.000000E+00 | 1.000000E+00 | 0.000000E+00 * |
| * | 0.000000E+00 | 0.000000E+00 | 1.000000E+00 * |

DIRECTION

| MASS AXIS SYSTEM (S) | MASS | X-C.G. | Y-C.G. | Z-C.G. |
|---|---|---|---|---|
| X | 3.020289E+02 | 0.000000E+00 | 8.513903E-03 | -3.288764E-02 |
| Y | 3.020289E+02 | 6.254401E-01 | 0.000000E+00 | -3.288764E-02 |
| Z | 3.020289E+02 | 6.254401E-01 | 8.513903E-03 | 0.000000E+00 |

I(S)

| | | | |
|---|---|---|---|
| * | 9.515131E+01 | 2.205951E-01 | -8.420849E-01 * |
| * | 2.205951E-01 | 9.606398E+01 | -6.978713E+00 * |
| * | -8.420849E-01 | -6.978713E+00 | 1.058014E+02 * |

I(Q)

| | | | |
|---|---|---|---|
| * | 1.094709E+02 | | * |
| * | | 9.524343E+01 | * |
| * | | | 9.230229E+01 * |

Q

| | | | |
|---|---|---|---|
| * | 4.503095E-02 | 9.781826E-01 | 2.028078E-01 * |
| * | 4.606710E-01 | -2.004728E-01 | 8.646345E-01 * |
| * | 8.864279E-01 | 5.449234E-02 | -4.596478E-01 * |