# DAAD Workshop – 01/07/2022

General presentation of Adamant Composites

Composites in Space structures

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# Structure of aerospace projects

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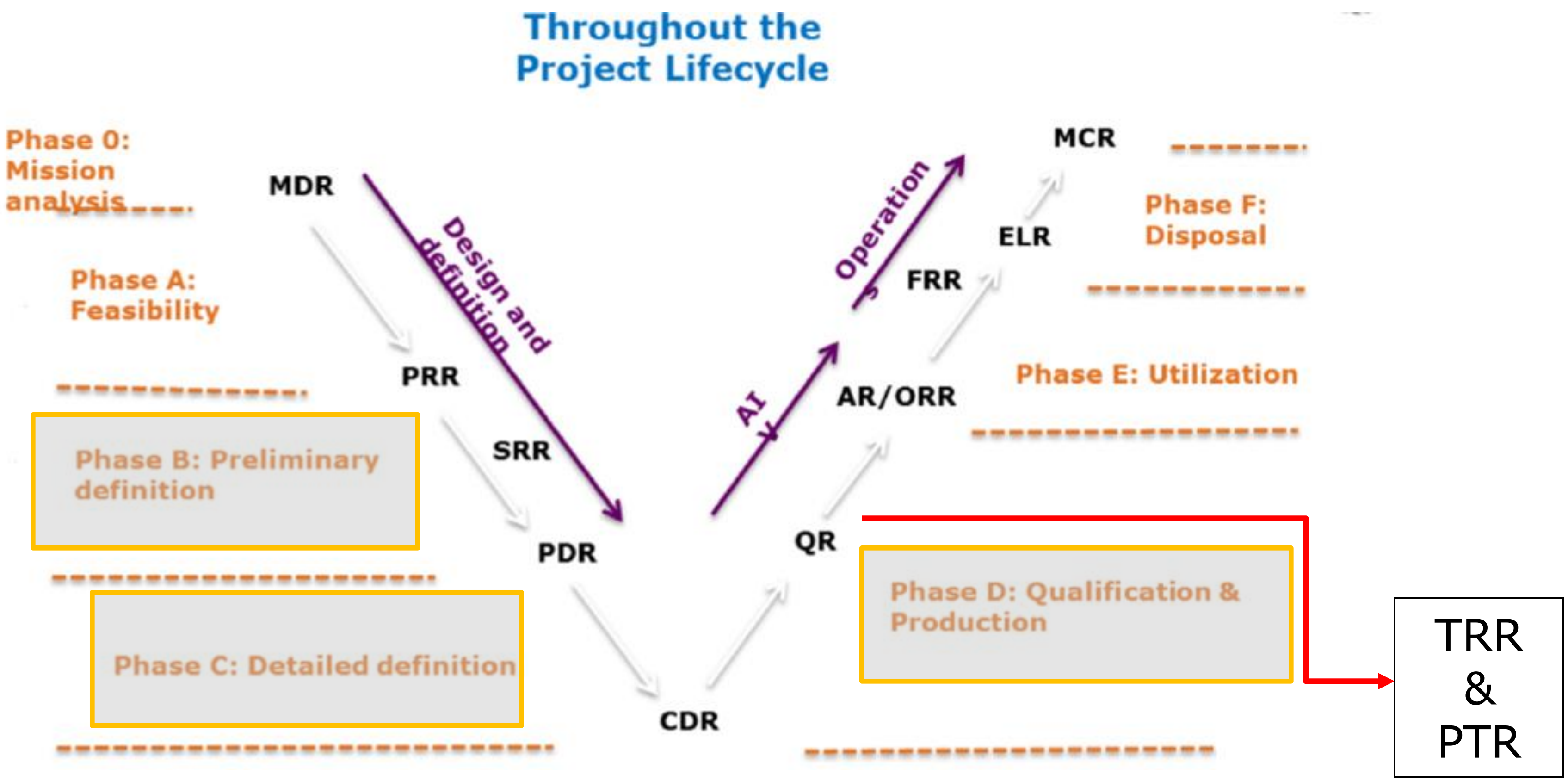
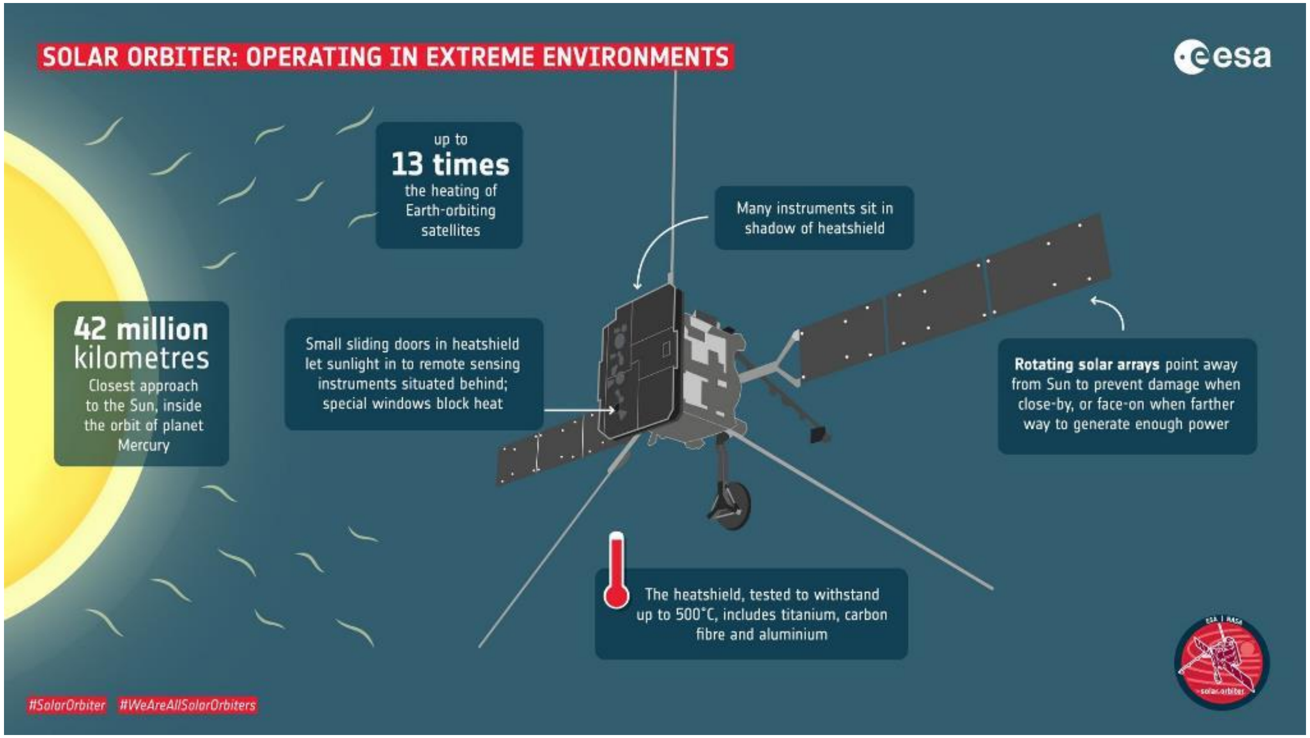



SRR : System Requirements Review
PDR : Preliminary Design Review
CDR : Critical Design Review
TRR : Test Readiness Review
PTR : Post Test Review

# Typical Space Structures

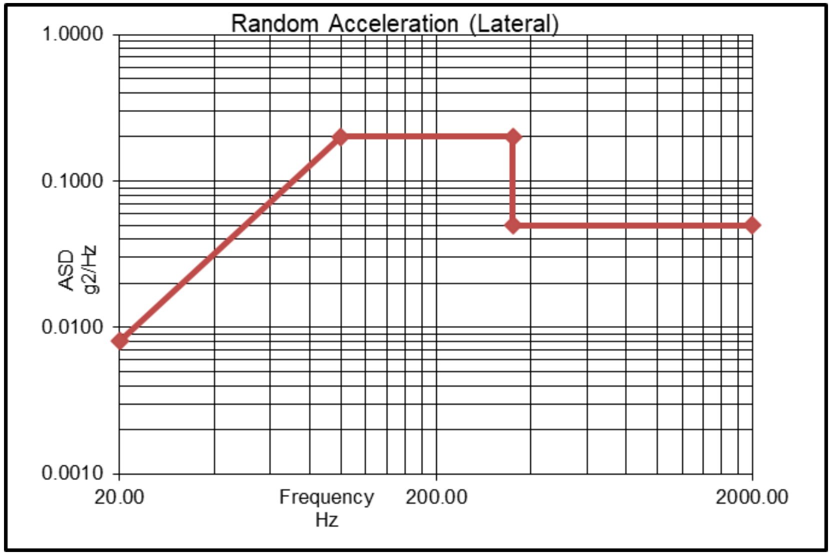

# Mechanical and Space environment

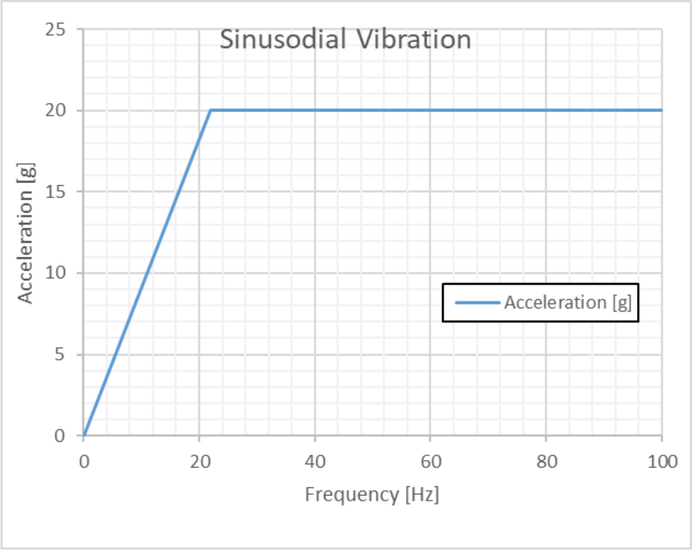
- Mechanical Vibration environment during Launch
- Solar Radiation and large thermal gradients
- Vacuum environment
- High velocity particle impacts



# Space Launch Environment

- Quasistatic acceleration Loading (Engine thrust)
- Sinusoidal Vibration loading (Low frequency - typically from 0 Hz to 100 Hz)
- Random Vibration Loading (High frequency- typically from 20 Hz to 2000 Hz)
- Shock loading (separation of parts, pyrotechnics, etc)



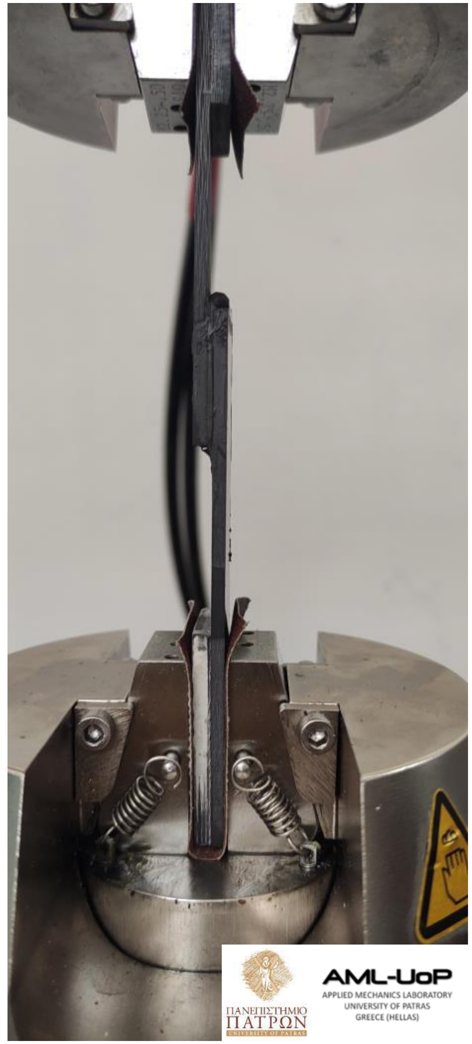
# Failure modes of the system

- Assess and understand the failure modes of the system
    - CFRP ply and interlaminar Failure
    - Aluminum Honeycomb core Shear Failure
    - Insert shear and Pull-out Failure
    - Bolted Joint Slipping, gapping and fracture failure

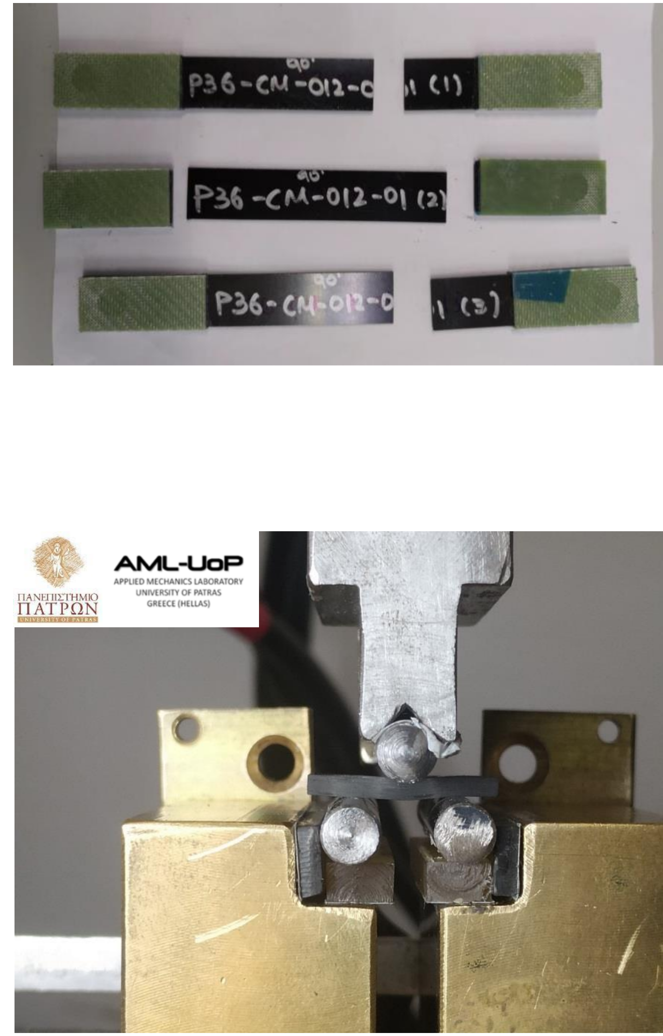
- Know your material properties and strength allowables → Required to build the mathematical model and to calculate the MoS or SF of the subsystems.
    - Use material Datasheet values
    - If a property is not known – assess the criticality of the given property and prepare the component or coupon level testing
    - For process dependent properties like CFRP, adhesive bonding or insert potting coupon level testing is usually required
    - Usually at early stages of a project some properties have to be assumed using good engineering practices or literature data

# Material Level Testing


Insert Pull-out




Adhesive Lap Joint




CFRP Characterization

# Example case study

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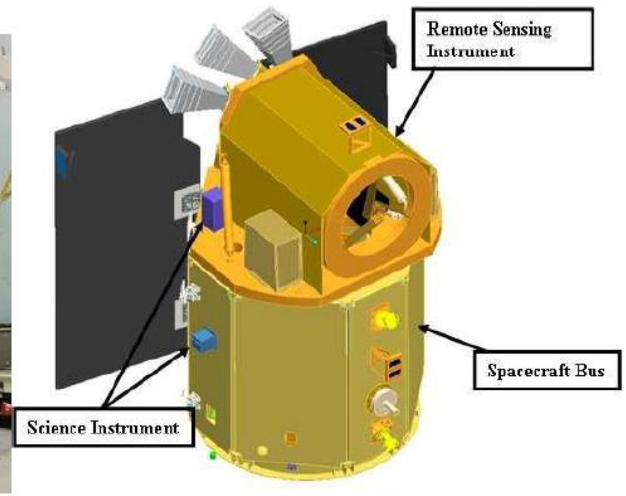
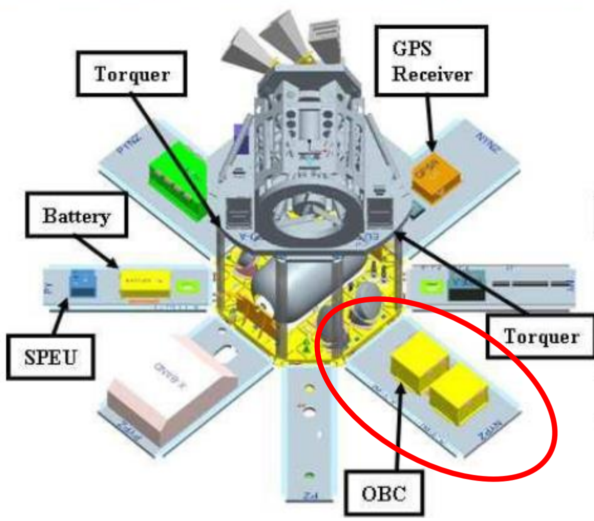
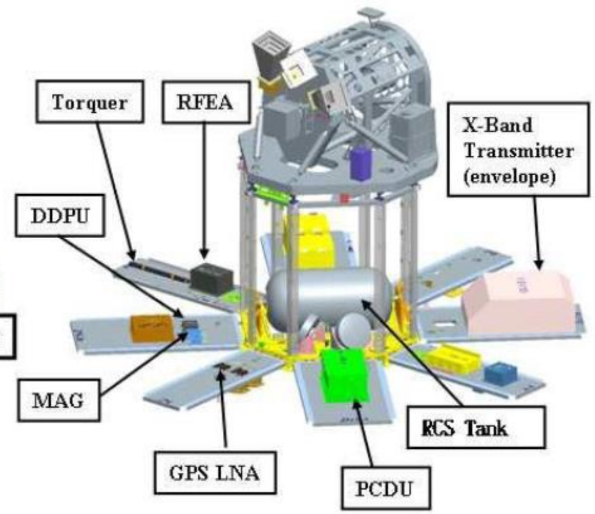
## FORMOSAT5 mission satellite

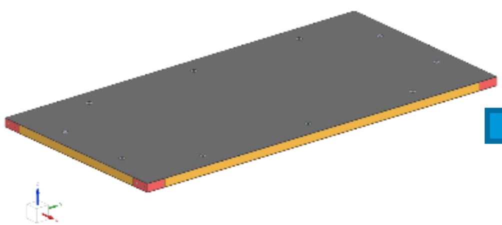


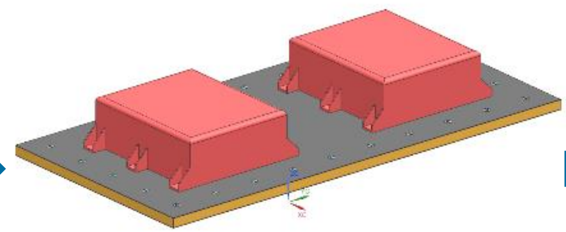



# Progress of Models through phases

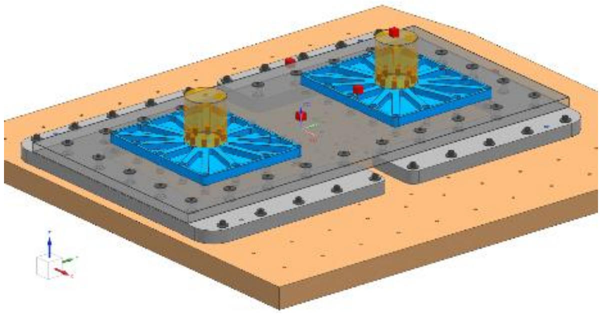
CAD of the Engineering Model



**PDR**



**CDR**



**TRR**

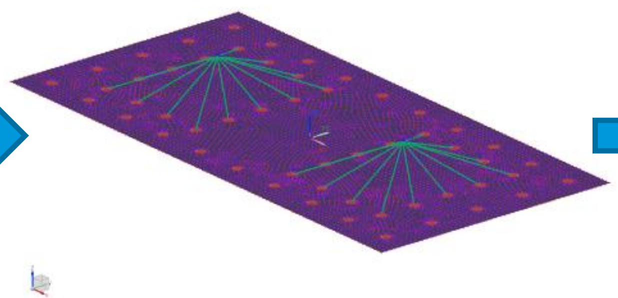
Mathematical Model

**Equation 1: Analytical Modal calculations**

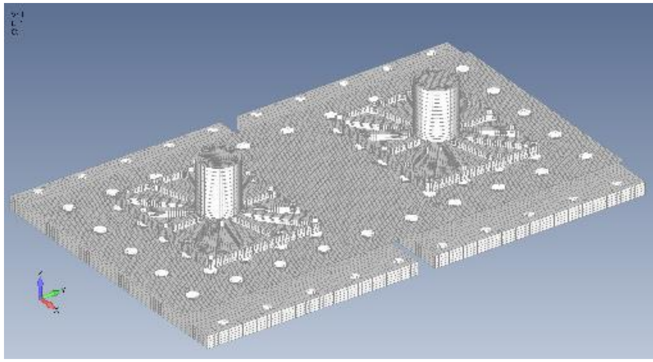
$$f_{ij} = \frac{\lambda_{ij}^2}{2\pi a^2}\left[\frac{Eh^3}{12\gamma(1-\nu^2)}\right]^{\frac{1}{2}} \quad i = 1,2,3..;\ j = 1,2,3..$$

$$\lambda^2_{ij} = \pi^2\left[i^2 + j^2\left(\frac{a}{b}\right)^2\right]$$

**PDR**



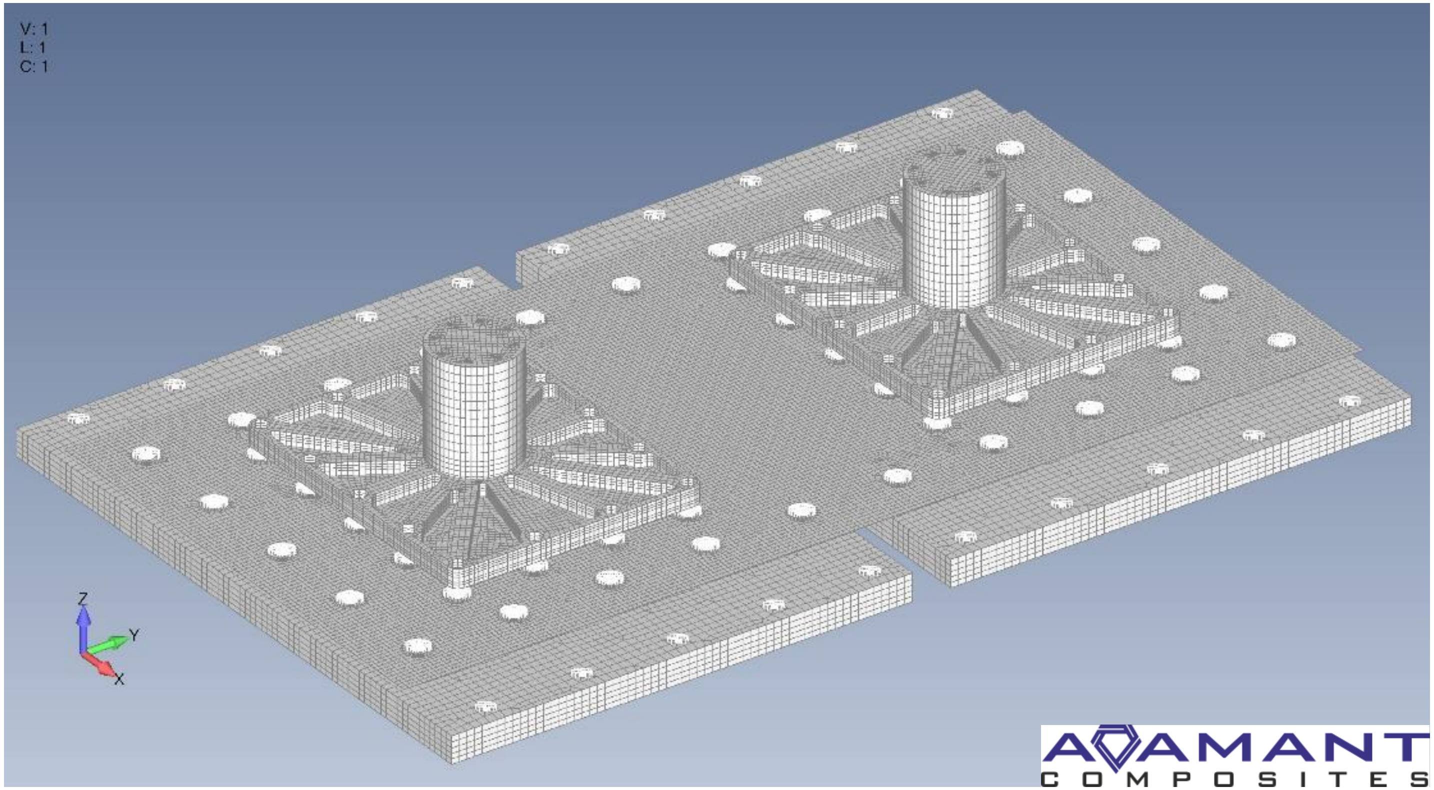
**CDR**



**TRR**

# Development of the Mathematical Models

- Start Simple (simplified models) and build-up as project matures
- Idealization of joints using connection elements (Spring and rigid elements) → develop analytical tools (ie spreadsheet based) to supplement the FE model
- It is good practice to assess the sensitivity of various parameters and properties to the response of the system – understand the important parameters of the system



# Composite Panel Manufacturing

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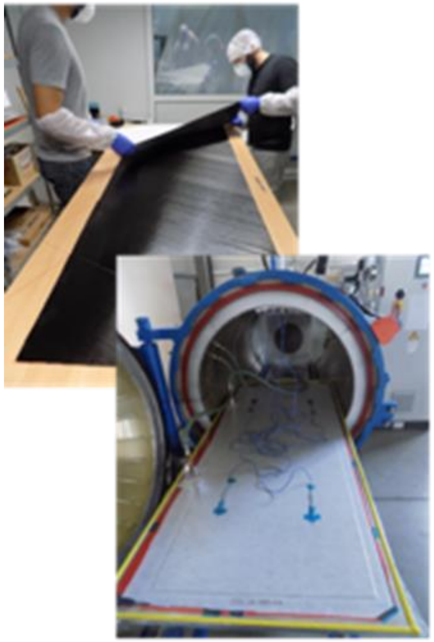
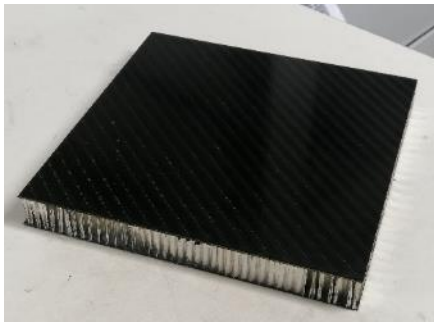
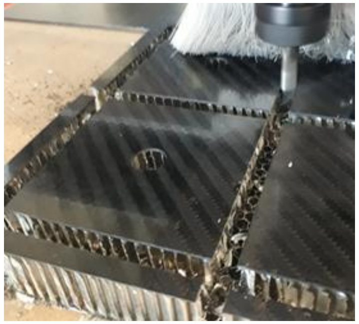
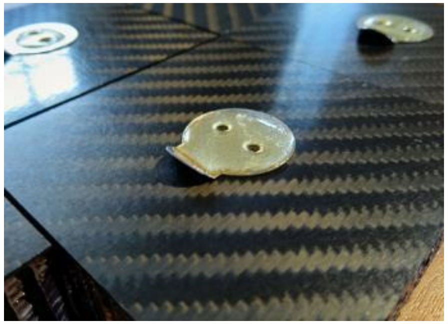
CFRP Facesheet »» Panel assembly »» Machining »» Potting

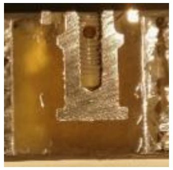


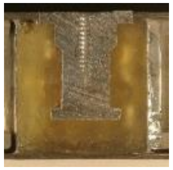






»» Testing

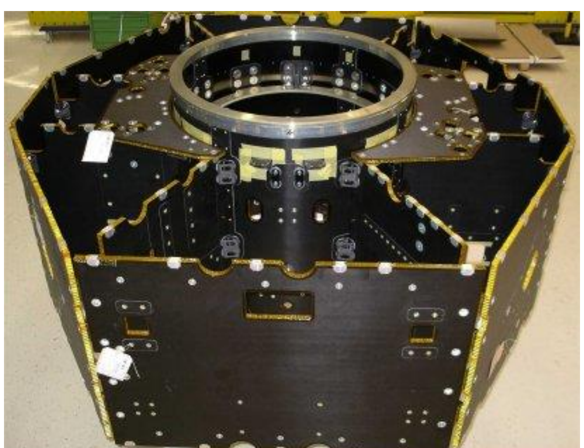


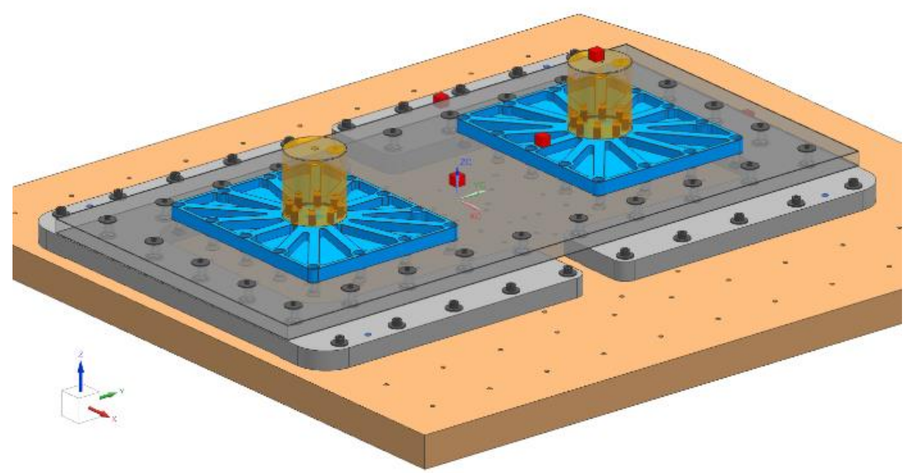


# Qualification of CFRP Sandwich Structure

An Engineering Model which:

- is representative of the main building block of a satellite structure, (sandwich structure),
- was implemented to go through the qualification process according to the aerospace standards.
- (Present Case) consists of
    - a CFRP sandwich panel with Aluminum honeycomb core
    - with attached Mass dummies which introduces the main loads during vibration.
- Vibrational Testing to prove survival under Qualification launch loads
- TVAC (Thermal vacuum chamber) survivability test under Temperature loading





# Preliminary test – Modal testing

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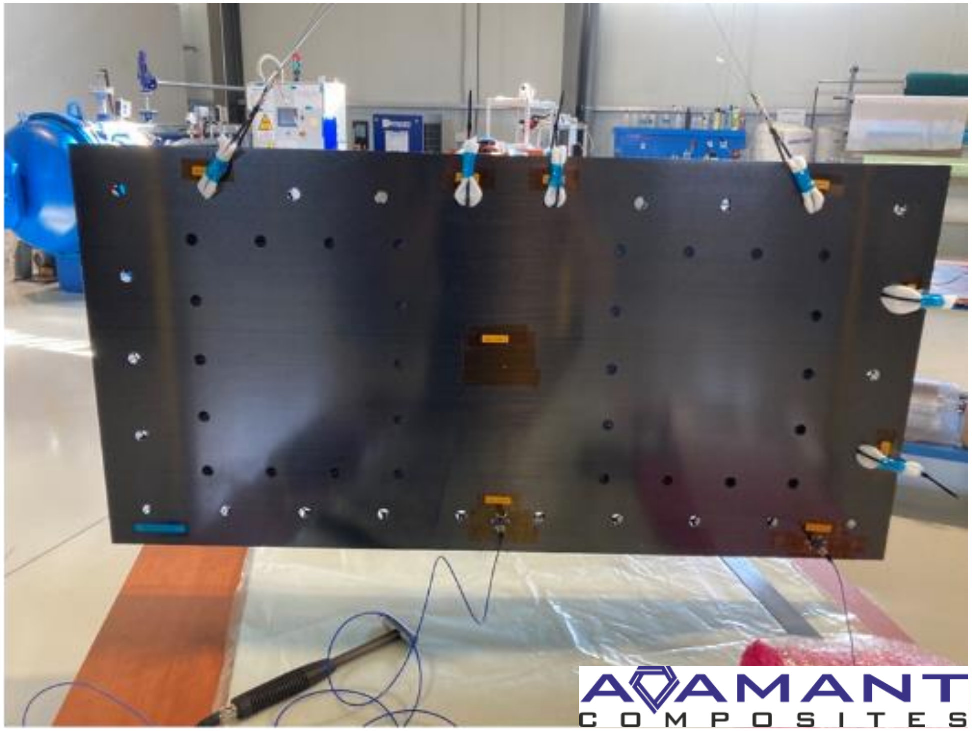
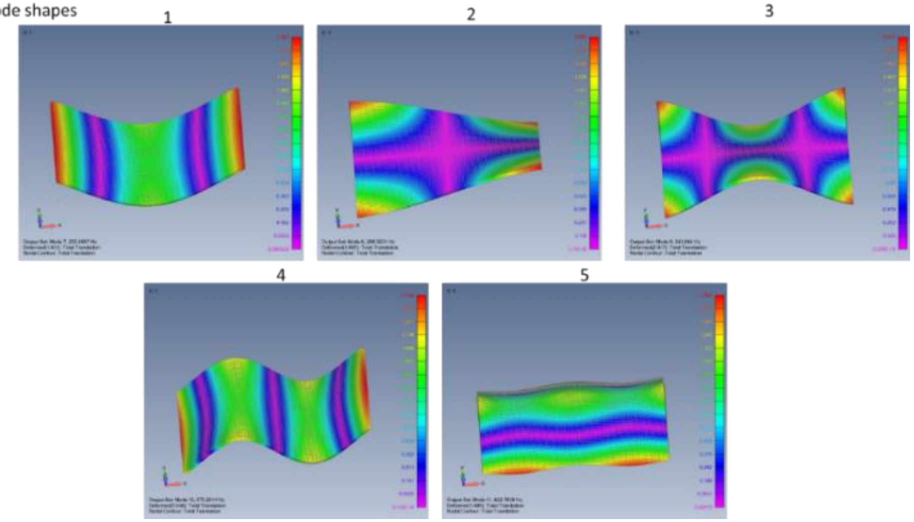
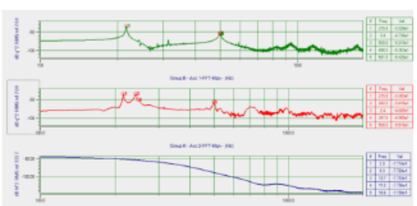
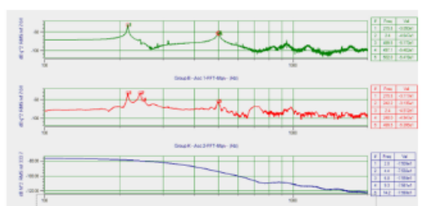



Mode shapes



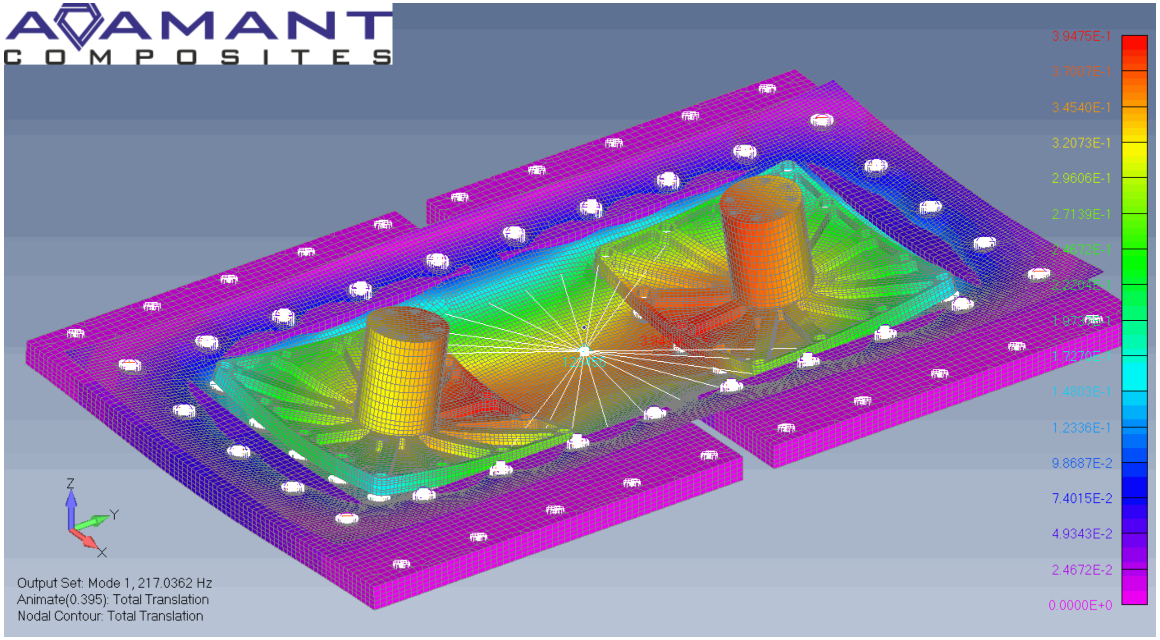

| EM1.1 | RUN 1 | RUN 2 |
| --- | --- | --- |
| SETUP A |  |  |

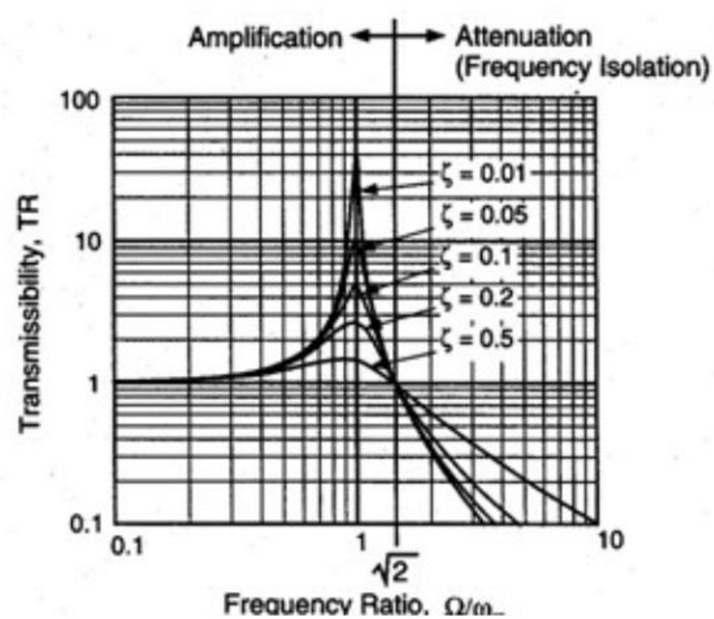
**EM1.1 Panel – Eigenfrequency [Hz]**

| Mode | Simulation | Experimental | Difference |
| --- | --- | --- | --- |
| 1 | 235.9 | 216 | 8.4% |
| 2 | 266.5 | 242 | 9.2% |
| 3 | 540.9 | 500 | 7.6% |
| 4 | 575.3 | n/a | n/a |

# Design for Vibration Loading

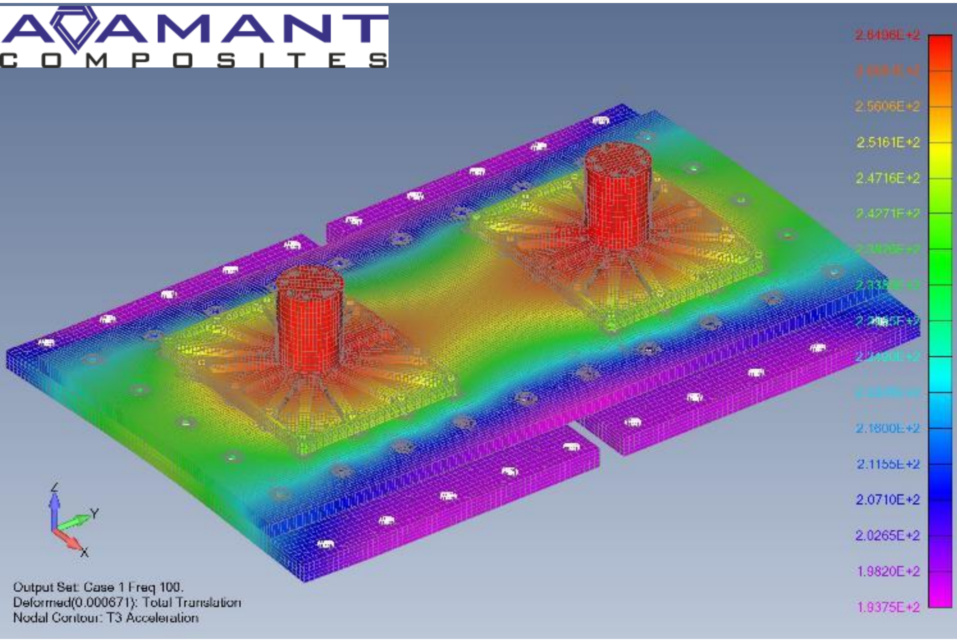
- During the vibration loading to avoid overloading, the structure is designed to have eigenfrequencies that are outside of the sinusoidal spectrum (in our case 0 – 100 Hz).
    - The effect of resonance is usually detrimental to the structure.
    - As an example, during resonance a single DoF system with damping ratio of 2% has an amplification of the response levels of 25 ($Q = 1 / 2\zeta$)
    - As a rule of thumb to increase the eigenfrequency of a structure, the structure has to stiffen up and the mass has to be reduced ($\omega = \sqrt{k/m}$)



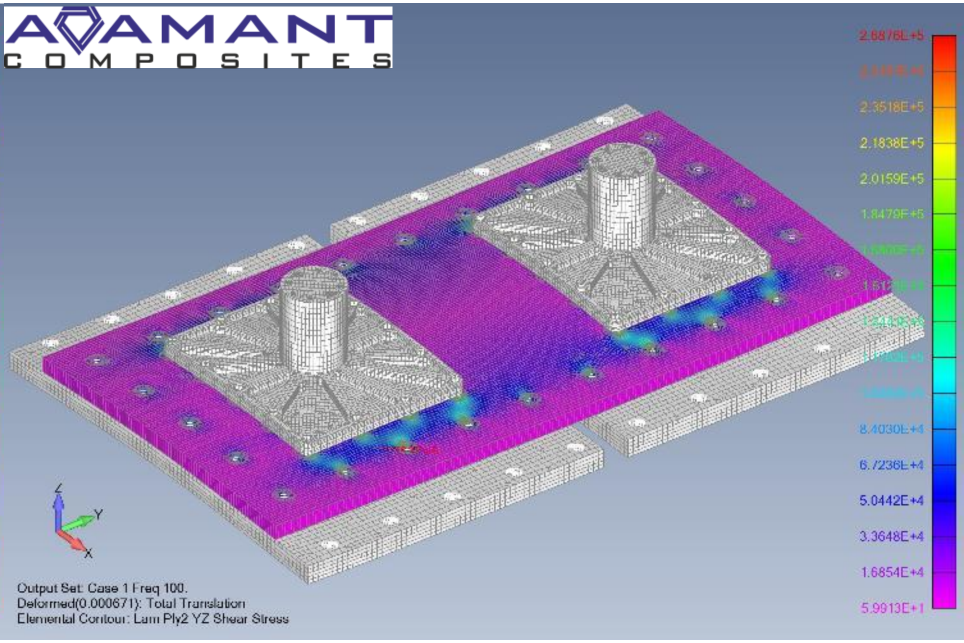



# Simulation of Vibration loading

- Quantitative assessment of the structural integrity of the structure
  - Calculation of MoS for all failure modes
  - Identification of highly stressed areas and critical elements
  - Identification of stiffness of the structure and resulting displacement levels
- Iteration of the structure design in case of overloading or noncompliance to the requirements

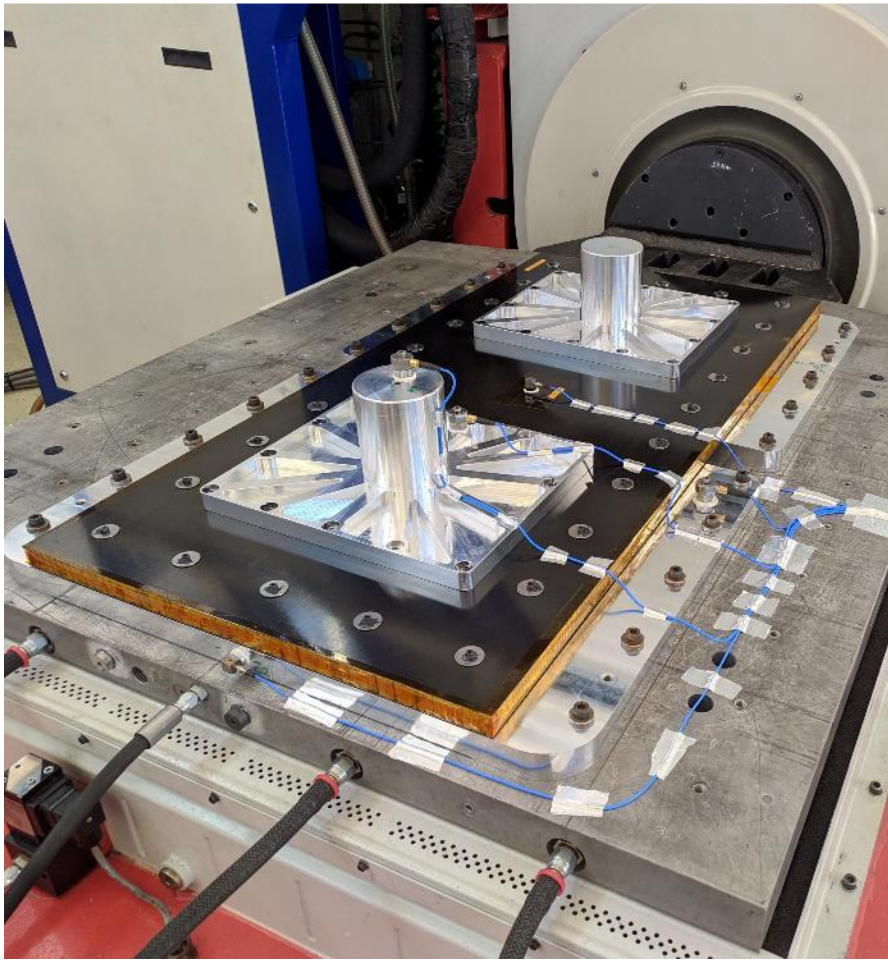



Acceleration Contour Z-direction – Sine Z excitation @100Hz




Shear Stress YZ Contour (Core) – Sine Z excitation @100Hz

# Vibration Test Campaign

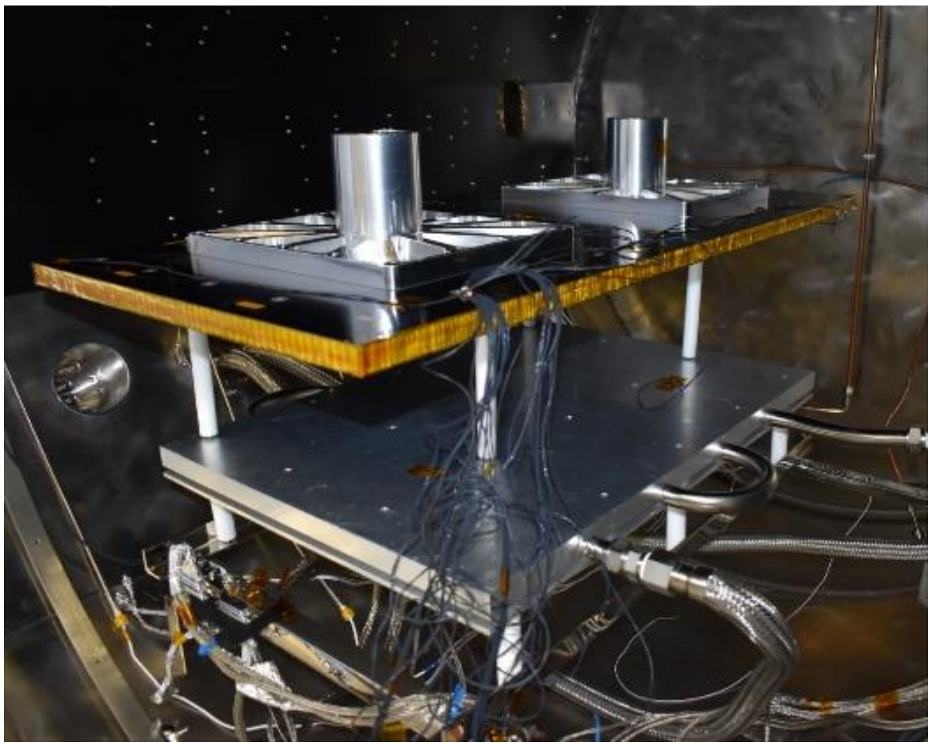


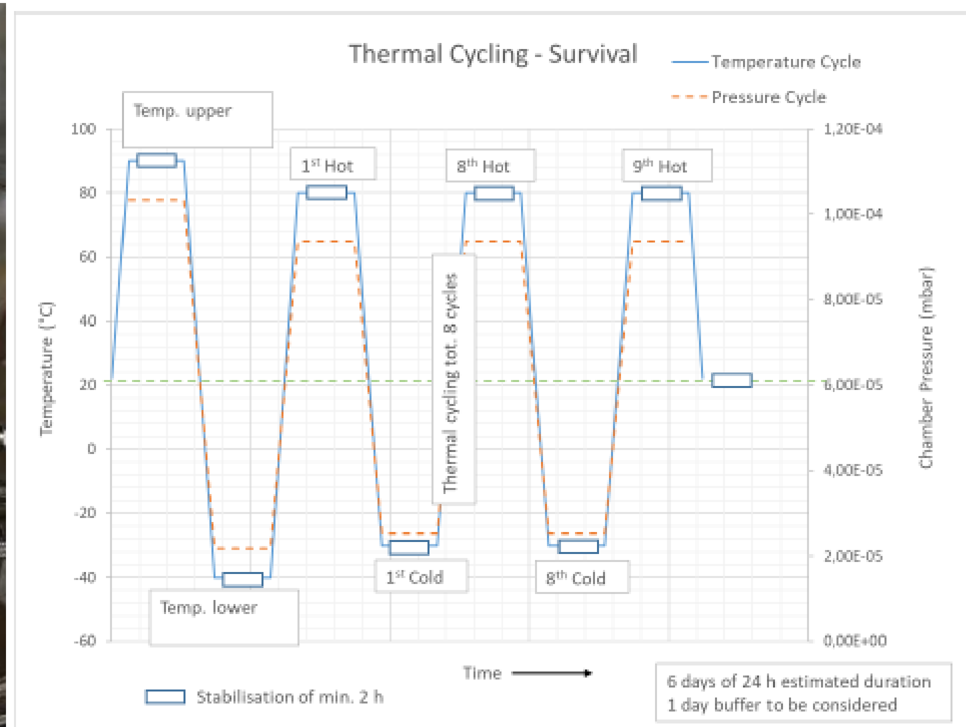
Lateral Axis (in-Plane)

Perpendicular Axis (out-of-Plane)

# Thermal Vacuum Test Campaign

- Thermal Cycling of the Engineering Model
- Temperature Range from – 40°C to 100 °C
- Prove the survival of the structure under Thermal-Vacuum environment

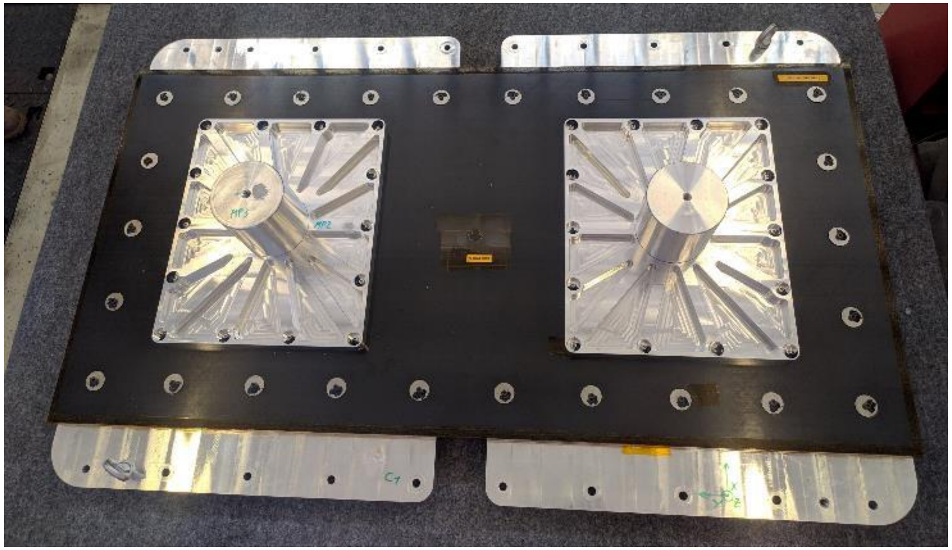




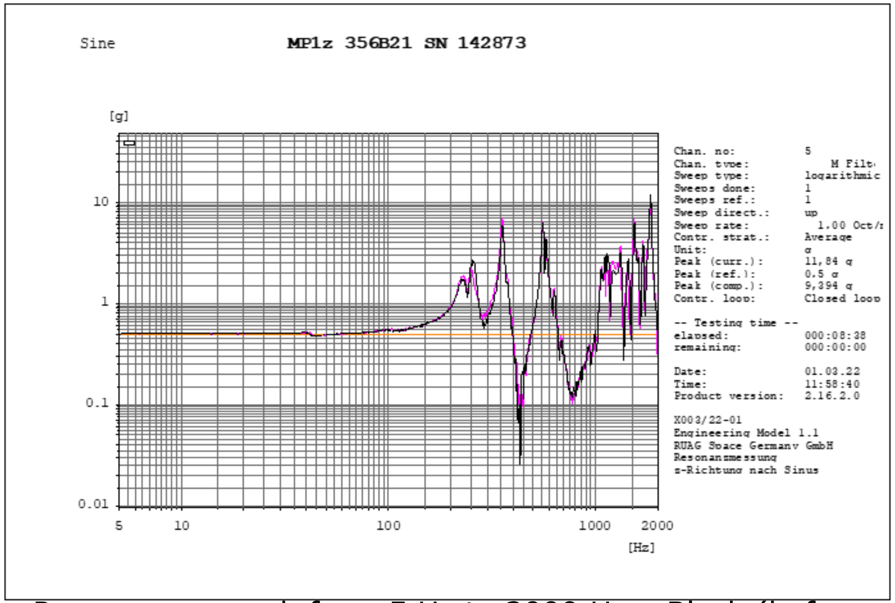
# Post test inspections

After the execution of the qualification testing:

- Visual inspection
  - Check for local damages or loose bolts and inserts
  - In case of damage root cause investigation shall be performed
- Post processing of the vibration test data
  - Check for frequency or amplitude shift before and after vibration testing
  - Correlation of the FEM model to the test hardware



Test Article after execution of Vibration testing




Resonance search from 5 Hz to 2000 Hz – Black (before Random Testing) / Magenta (After Random Testing)

# Conclusions

- Space structures are designed to function in a demanding environment without any inspection or maintenance for a long period of time (from 3-15 years)
- Strict product assurance and quality control protocols are applied throughout the development of spacecrafts up to launch and during operations.
    - Extensive testing on different levels (material, component, sub-system, etc)
    - Control points throughout the production process
    - Heritage is extremely important and valuable
    - Detailing of test campaigns is critical
- Structural performance is only one of the disciplines that must be taken in consideration, often contradictory to others.

Thank you for your attention!

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