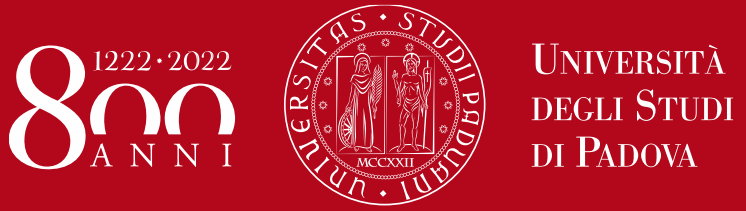


# Development of a Fine Steering Tip/Tilt Mechanism for Space Applications

Armando Grossi - 36th Cycle

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Industrial Supervisor: Eng. Emanuele Piersanti

*PhD Course in Science, Technologies and Measurements for Space*

Admission to third year - 06/09/2021

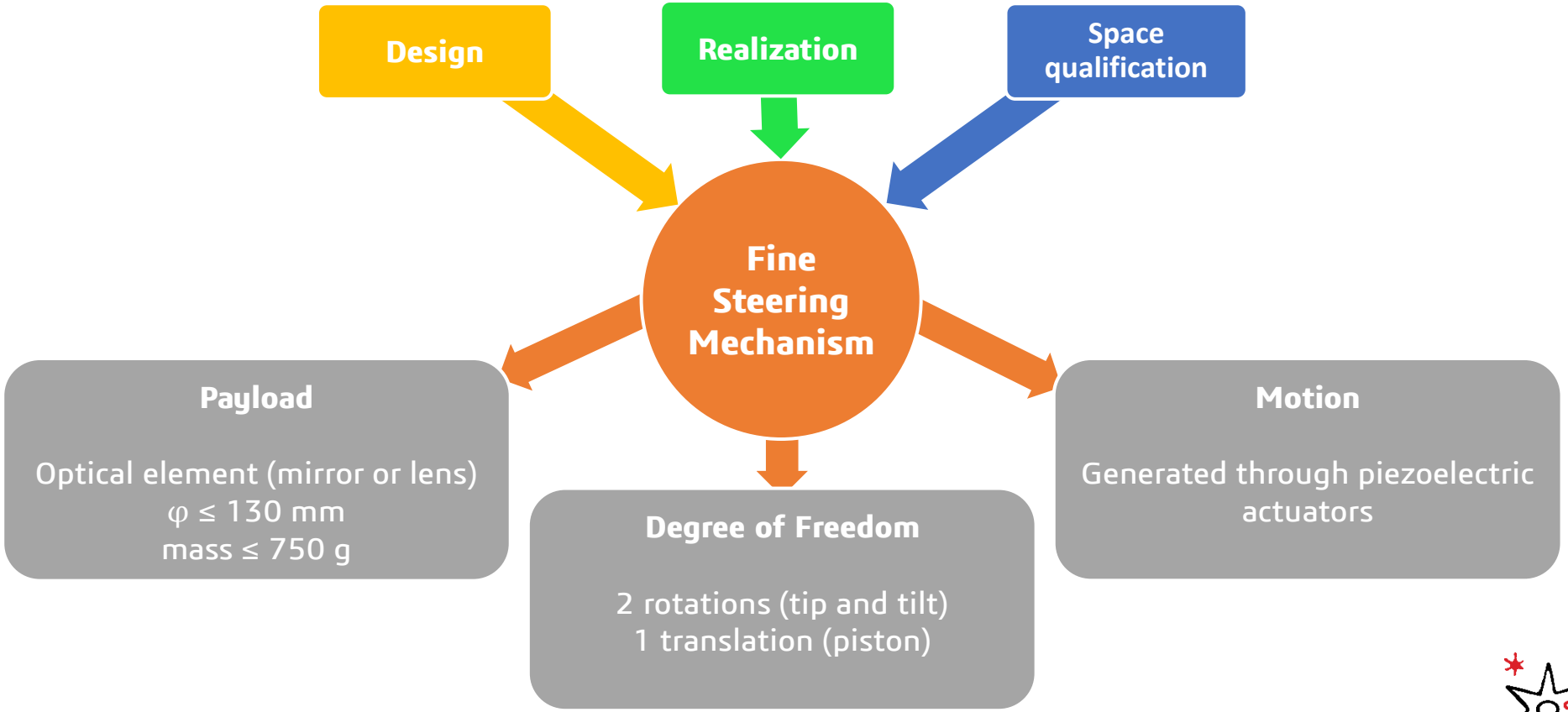
# Summary



- Research Project Objectives
- Actuator Breaboard
  - Piezo actuator tests
  - CoMA tests
  - MAiA tests
- Mechanism critical design
- FEA
- Work activity

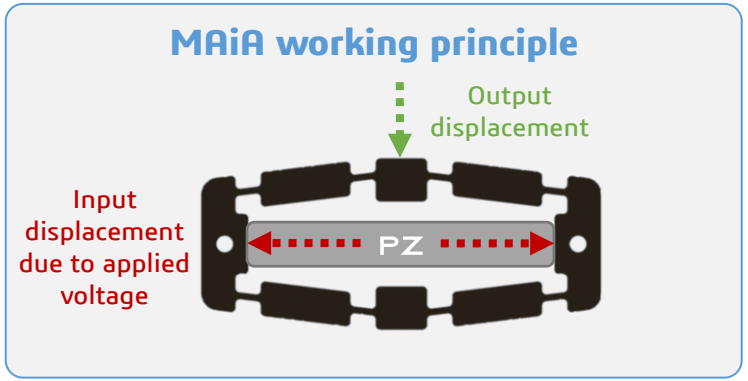
# Research Project Objectives

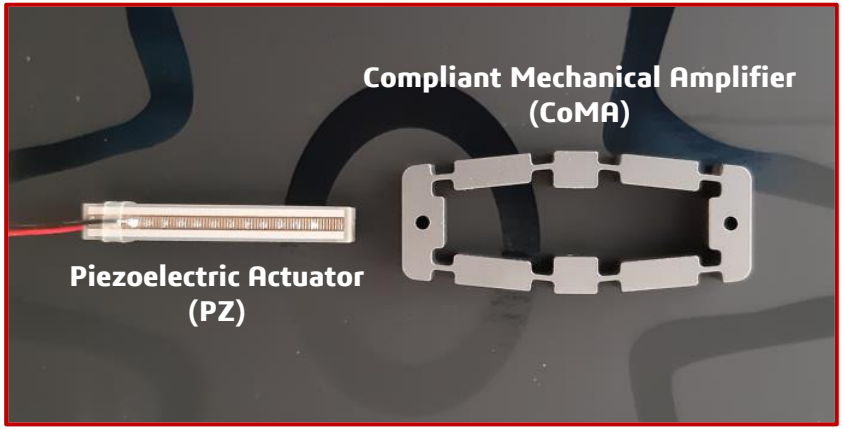


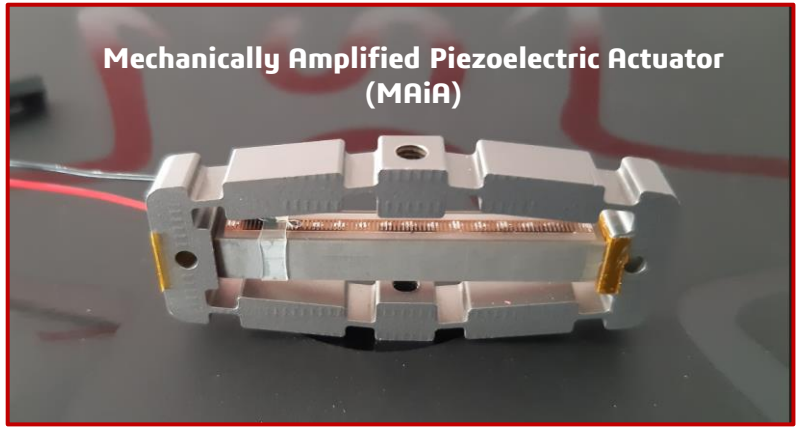


# Actuator Breadboard

- During PhD first year, a preliminary design of the mechanism actuators has been done.
- Designed actuator consists of:
  - a piezoelectric actuator: PI PICMA Stack Multilayer P-885.91;
  - a compliant mechanical amplifier, necessary to increase piezo displacement.
- A breadboard of the actuator has been realized to perform several tests during PhD second year.

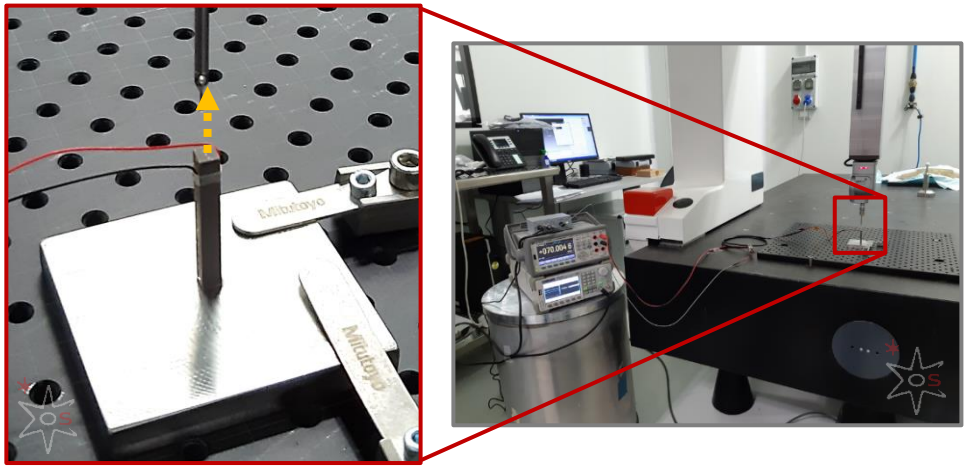


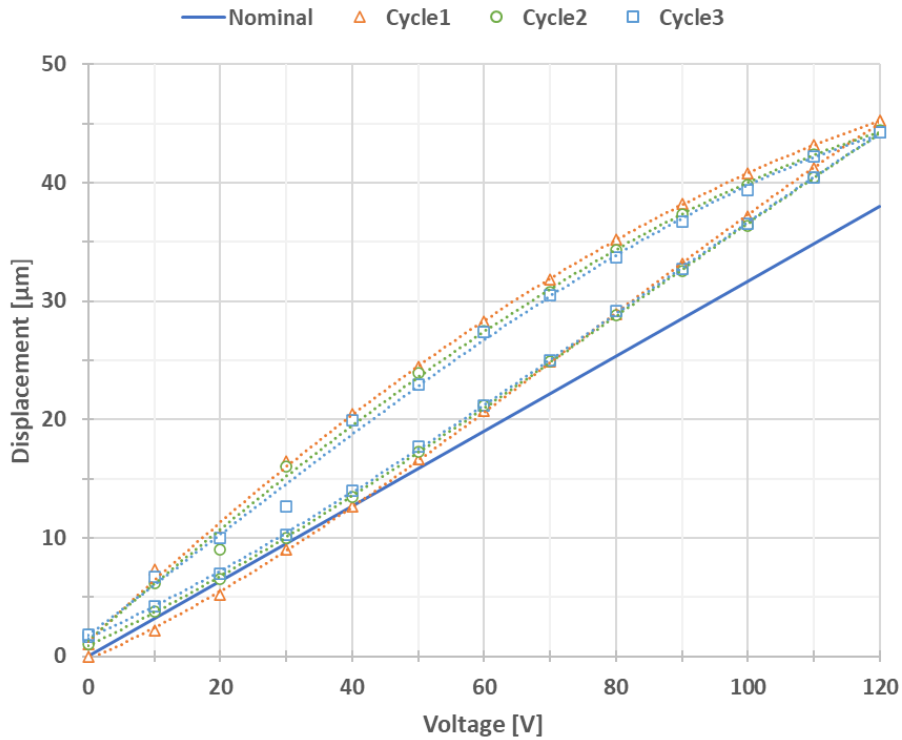



# Piezo actuator tests: free displacement

- **Purpose**: characterize piezo free displacement as a function of the applied voltage (from 0 to 120 V).
- **Unit Under Test**: piezoelectric actuator (glued on a metallic baseplate).
- **Measurement Device**: CMM (Coordinate Measuring Machine).



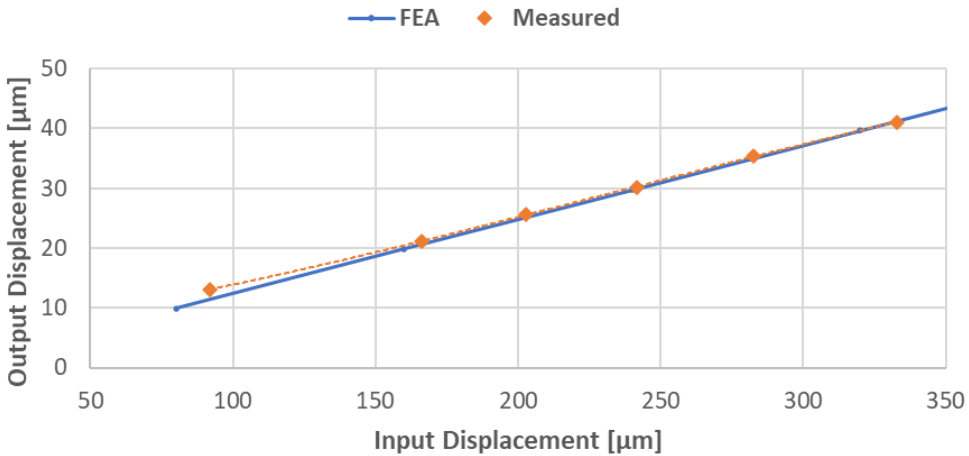



- **Results:**
  - free displacement @ 120 V = **44.5 µm:** 17 % > nominal free displacement (38 µm)
  - displacement curve shows a strong hysteresis (as expected, due to open-loop control)

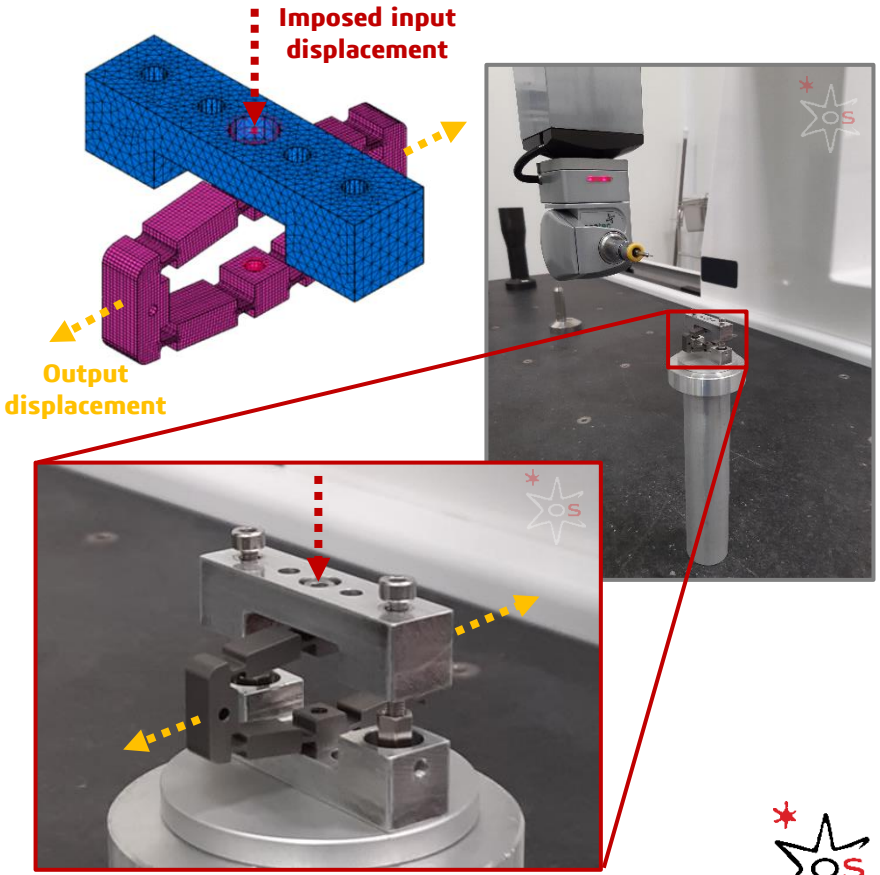
# CoMA tests: imposed displacement



- **Purpose**: characterize CoMA output displacements (along major axis), as a function of an imposed input displacement (along minor axis) to validate FE model.
- **Unit Under Test**: Compliant Mechanical Amplifier (CoMA), mounted on a GSE used to impose an input displacement.
- **Measurement Device**: CMM (Coordinate Measuring Machine)



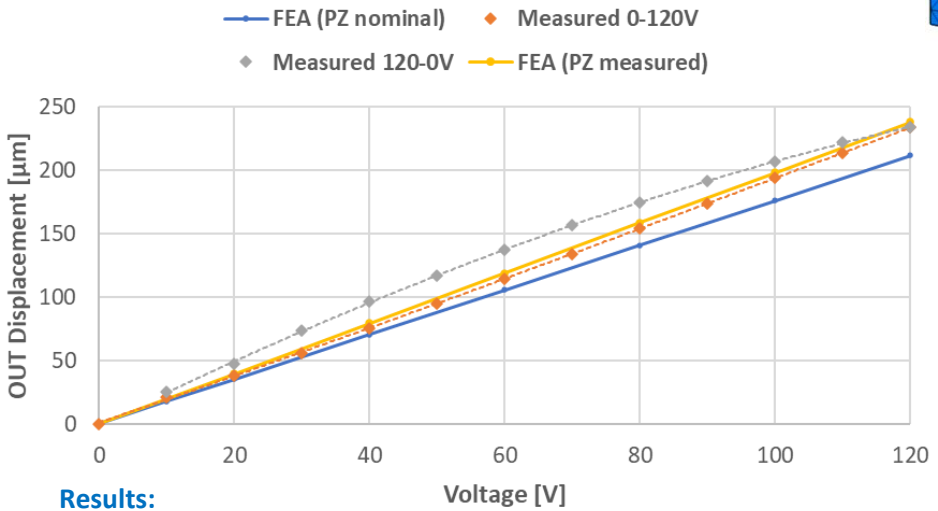

- **Results:** measured output displacements agree with FEA results

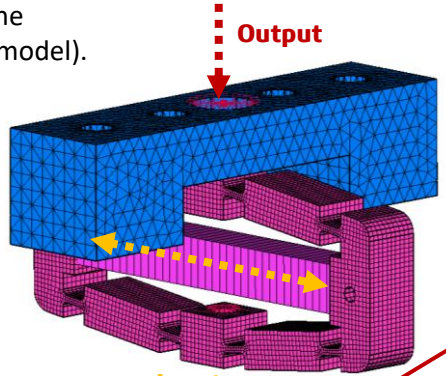


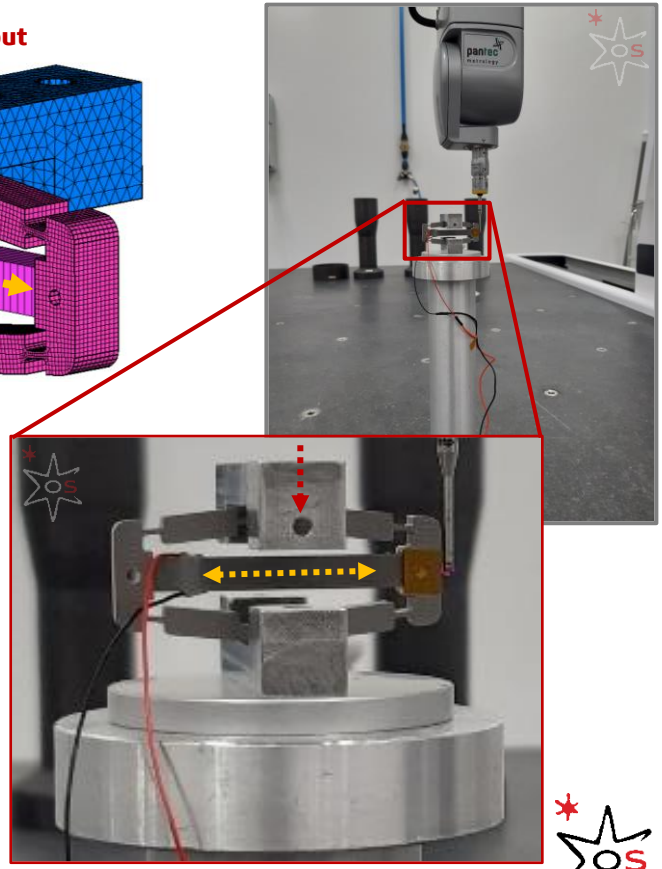
# MAiA tests: free displacement



- **Purpose**: characterize MAiA free output displacement, as a function of the applied voltage on the piezo actuator (always to validate mathematical model).
- **Unit Under Test**: Mechanically Amplified Piezoelectric Actuator (MAiA)
- **Measurement Device**: CMM (Coordinate Measuring Machine)



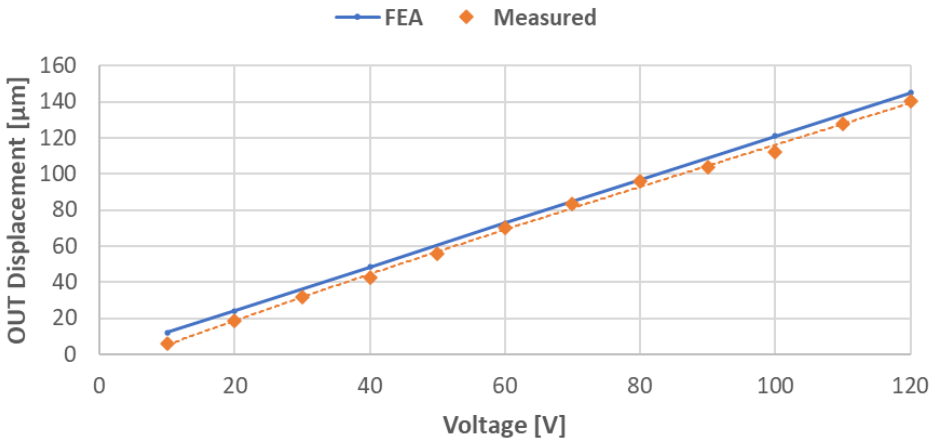



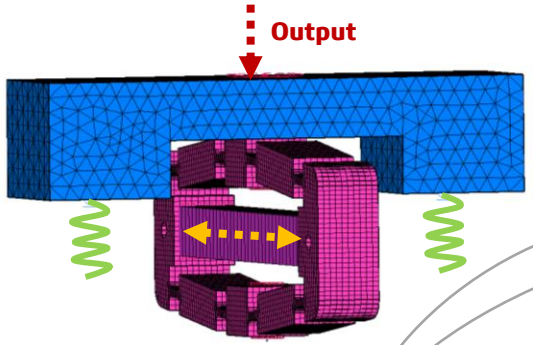



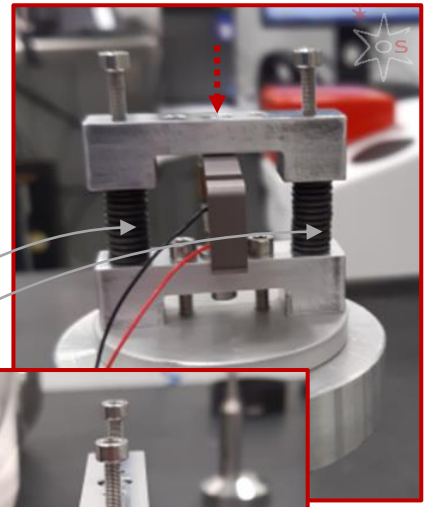
- **Results:**
  - measured output displacements agree with FEA results, if piezo free displacement measurement values are assumed
  - piezo hysteresis visible in the displacement curve

# MAiA test: displacement against a load

- **Purpose**: characterize MAiA output displacements when it works against a load having a stiffness K (this load stiffness simulates the stiffness of the optical payload).
- **Unit Under Test**: Mechanically Amplified Piezoelectric Actuator (MAiA), mounted in a GSE including two stacks of belleville springs (having a resulting stiffness K).
- **Measurement Device**: CMM (Coordinate Measuring Machine)



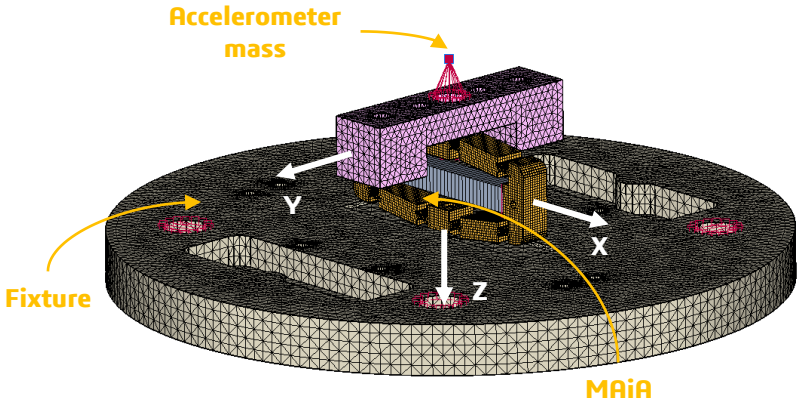



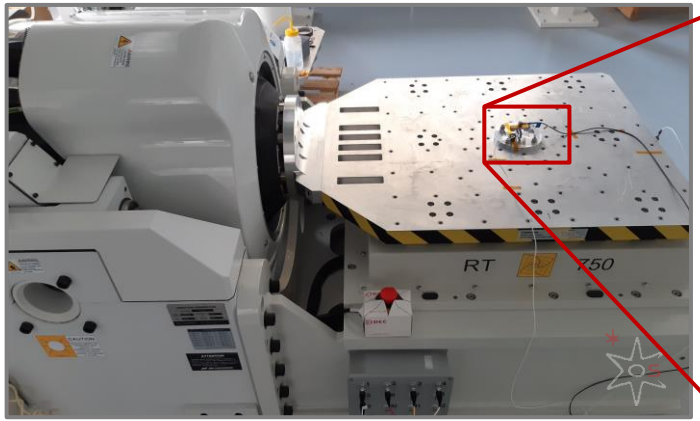
**Belleville Springs:**
2 stacks
K = 1.5e5 N/m

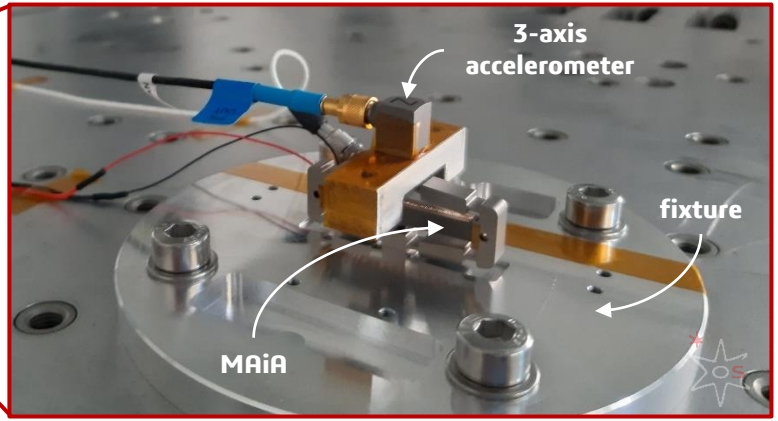
- **Results:** measured output displacements are slightly less than FEA displacements

# MAiA tests: modal survey

- **Purpose**: FE model validation, determining first frequency of MAiA
- **Unit Under Test**: Mechanically Amplified Piezoelectric Actuator (MAiA), including a support element helping accelerometer assembly (note: accelerometer dimensions are not negligible in this case)
- **Measurement Device**: Shaker

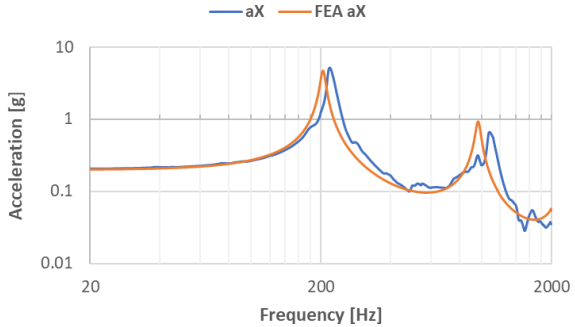


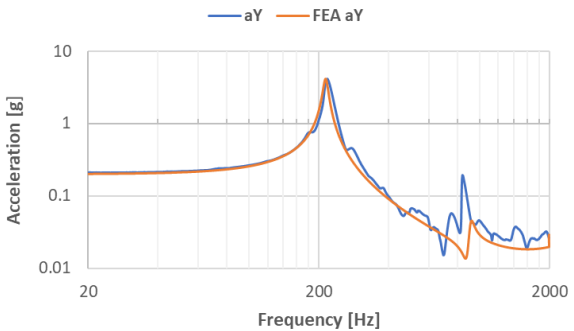



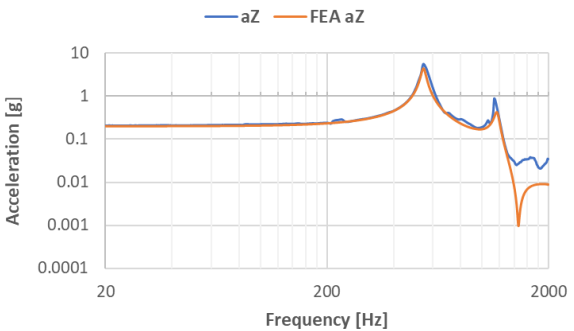


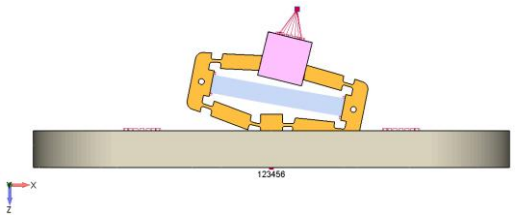

## Test specs

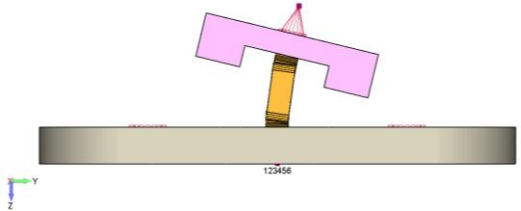
**Acceleration :** 0.2 g
**Frequency:** 20-2000 Hz
**Sweep rate:** 2 Oct/min

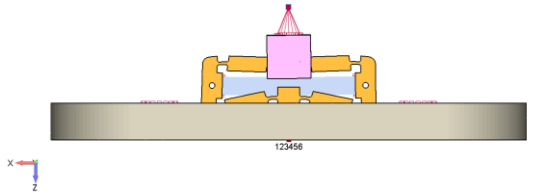






| | X input | | Y input | | Z input | |
|---|---|---|---|---|---|---|
| | Test | FEA | Test | FEA | Test | FEA |
| Max Acceleration Response [g] | 5.2 | 4.75 | 4.09 | 4.17 | 5.66 | 4.45 |
| Frequency [Hz] | 218 | 204.6 | 218 | 214.3 | 545 | 546.6 |

- **Results:**
  - a good match between measured and calculated response curves is visible;
  - major discrepancy is visible when input acceleration is applied along X axis.

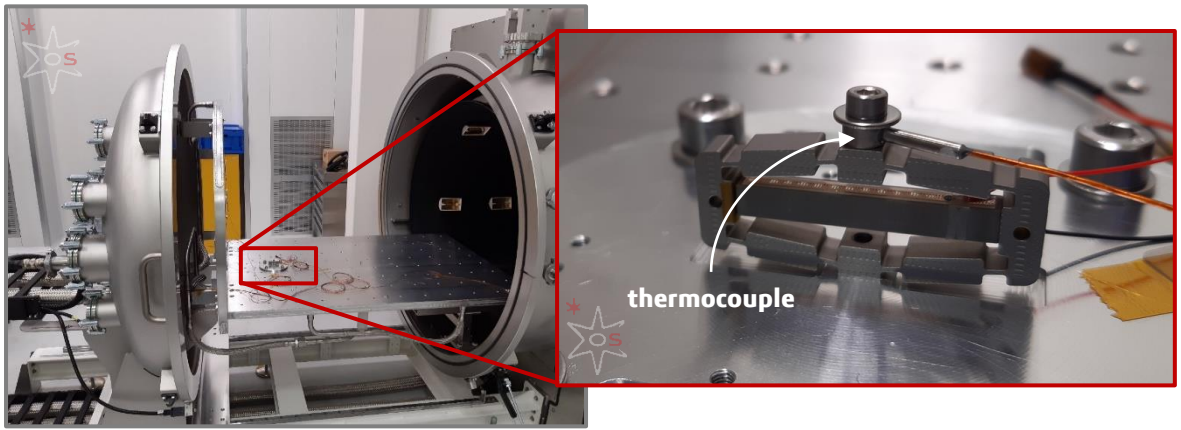
# MAiA tests: thermal-vacuum

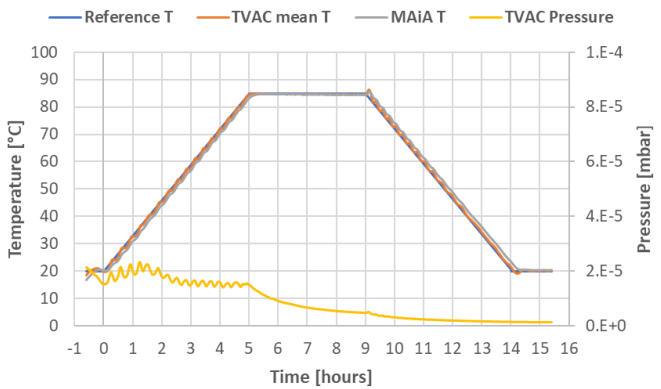


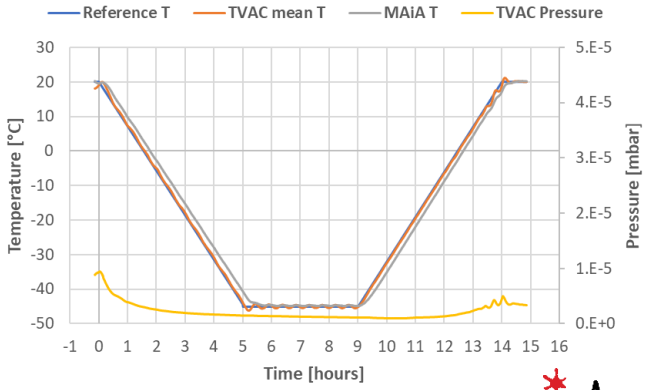
- **Purpose**: verify piezo actuator preload at extreme survival temperatures (-45°C and +85°C).
- **Unit Under Test**: Mechanically Amplified Piezoelectric Actuator (MAiA).
- **Measurement Device**: Thermal-Vacuum Chamber (TVAC).
- **Results:**
  - two separated tests performed at -45°C and +85°C;
  - piezo preload is maintained at extreme temperatures;
  - MAiA has been tested after each test, showing a nominal behaviour.

**Test specs**

**Hot survival temperature:** +85°C
**Cold survival temperature:** -45°C
**Pressure:** < 2e-5 mbar
**Dwell Time:** 4 hours
**Ramp rate:** 0.21°C/min

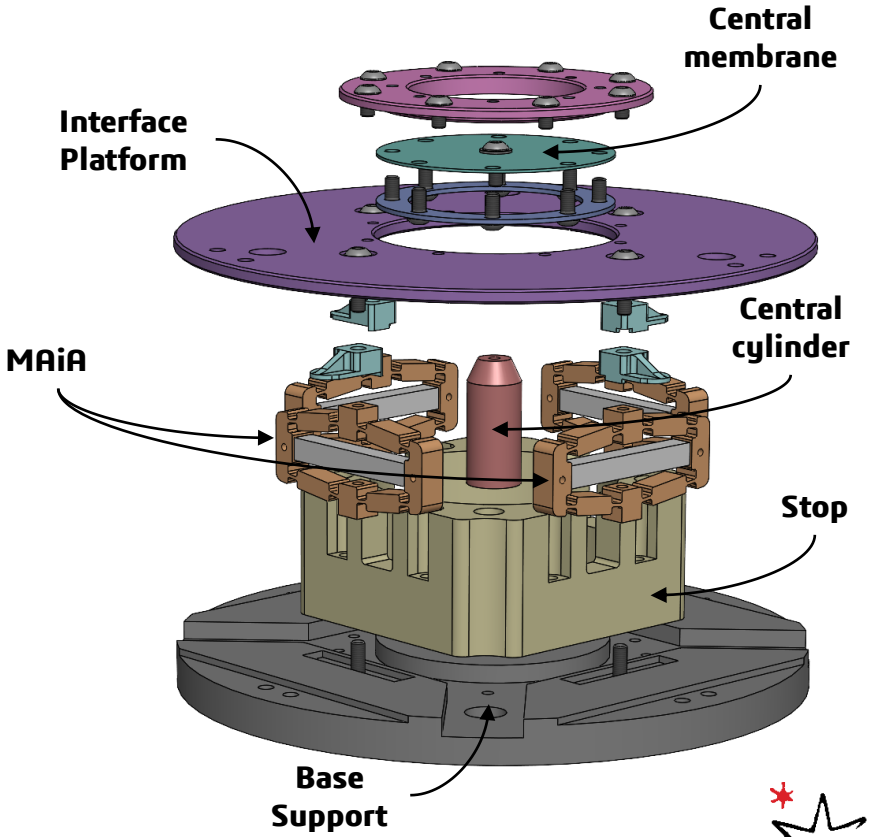


# Mechanism: critical design

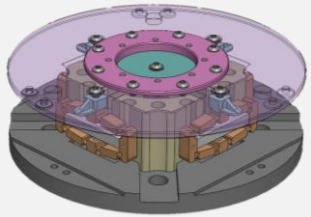
- Preliminary mechanism designed during the first year, has been defined considering breadboard results.
- The Fine Steering Tip/Tilt Mechanism (FSTTM) consists of:
  - **base support**: the actuators are fixed on it through screws (it works also as a fixture for the environmental tests).
  - **4 MAiA**: actuators providing the displacements necessary to perform the required DoF (tip/tilt and piston).
  - **interface platform**: element connecting actuators to the optical payload.
  - **central membrane**: flexure attached to the Interface platform through screws, and to the base support through a central cylinder, it stiffens the mechanism against launch loads.
  - **stop**: element fixed on the base support, whose aim is to limit the piezo preload decrement under axial loads (Z axis).




## FSTTM Dimensions

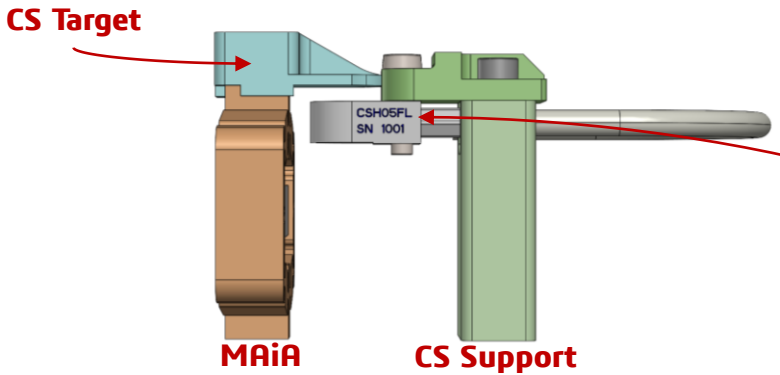
**Diameter :** 140 mm
**Height:** 42.5 mm *
**Mass:** 1.55 kg *

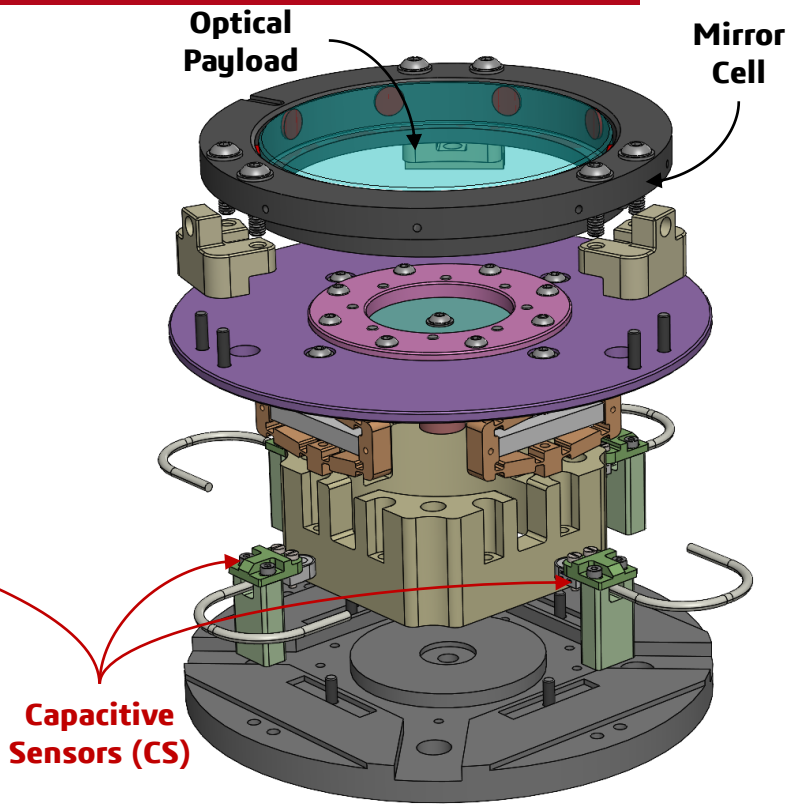
** base support included*



# Mechanism: critical design

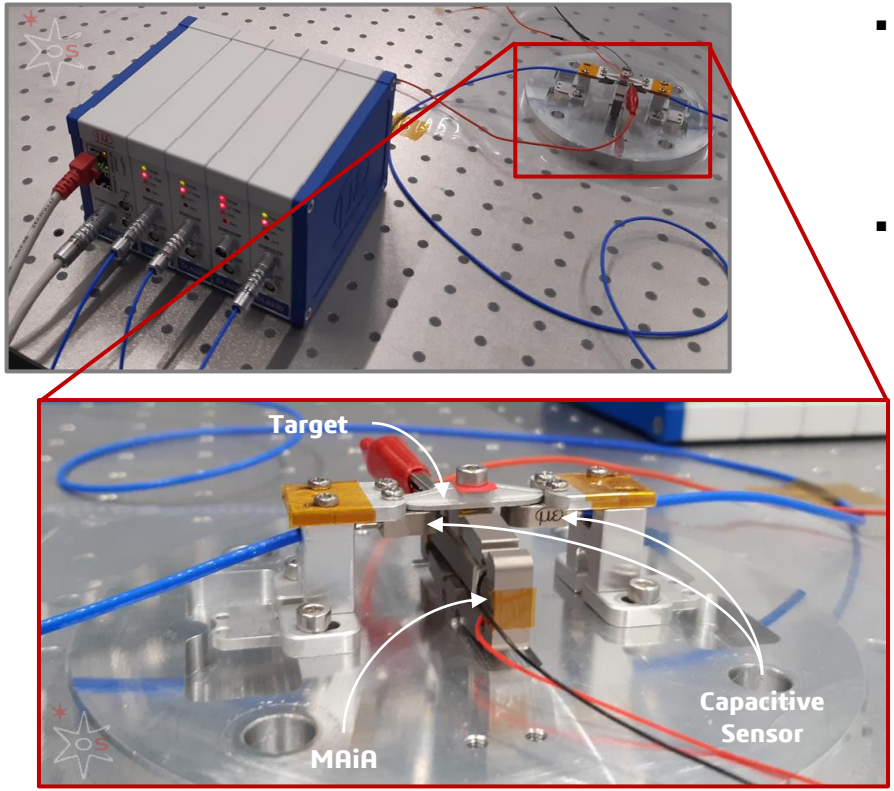
- In addition to the FSTTM:
  - **Optical Payload:** a flat mirror ϕ = 90 mm, glued in an INVAR cell through RTV pads (this is a generic payload, not properly designed for this research project).
  - **Actuator position control system:** to control MAiA displacements in closed loop, each actuator has a dedicate capacitive sensor.



# Tests with Capacitive Sensors

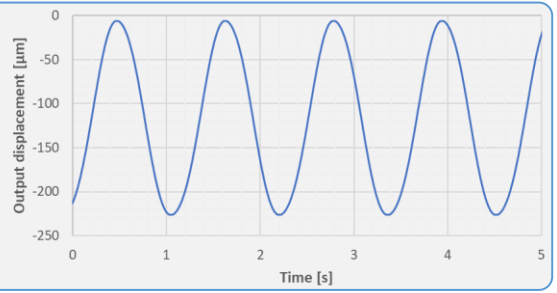


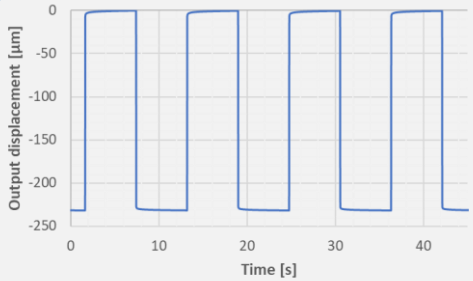



- Several tests have been performed using selected capacitive sensors to:
  - verify the proposed control strategy;
  - measure MAiA output displacement, as a function of the applied voltage.
- Other tests have to be done, to properly set-up the capacitive sensors control system.

**Input Signal**

- **waveform:** sine
- **wave period:** 1 s
- **p-p amplitude:** 120V



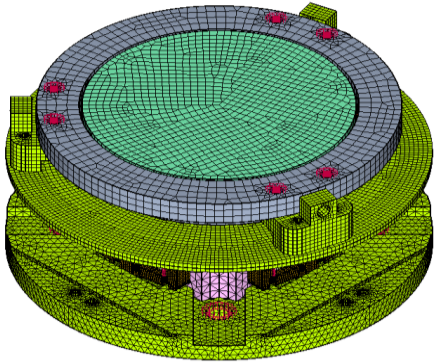



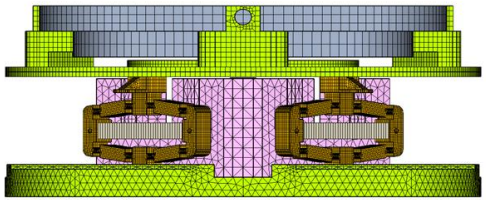

**Input Signal**

- **waveform:** square
- **wave period:** 10 s
- **p-p amplitude:** 120V

# FEA: requirements

- Several Finite Element Analyses (FEA) have been performed on the FSTTM, to verify following requirements:
  - ❑ 1st eigenfrequency > 120 Hz (≥ 10% mass fraction);
  - ❑ survival under environmental loads:
    - 30g QSL in any orientation (not simultaneously);
    - 20g QSL in any orientation simultaneously;
    - Sine in any orientation (not simultaneously);
    - Random in any orientation (not simultaneously);
    - Shock in any orientation (not simultaneously);
    - Operative temperature range [-30 ; +55] °C;
    - Survival temperature range [-45 ; +85] °C.



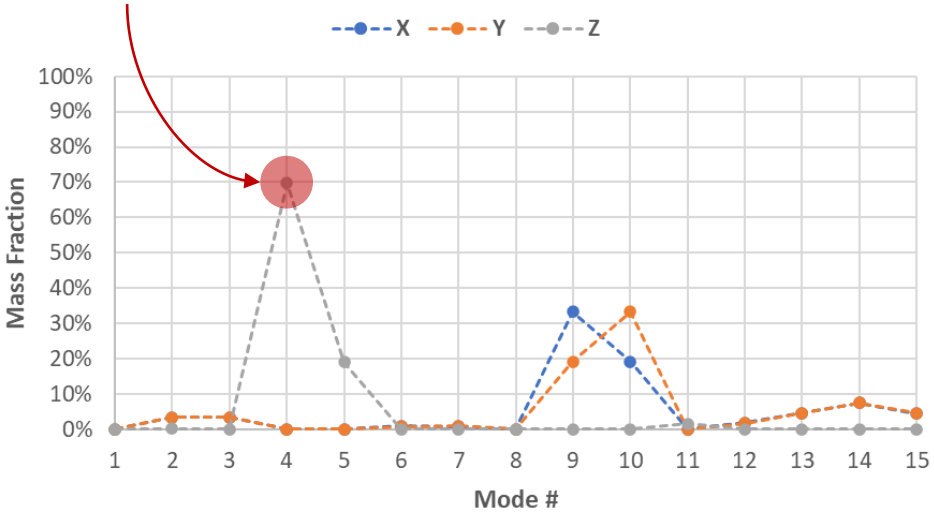


| Sine | |
|---|---|
| 5 Hz | 0.55 g |
| 21 Hz | 9.76 g |
| 21-60 Hz | 20 g |
| 60-100 Hz | 6 g |

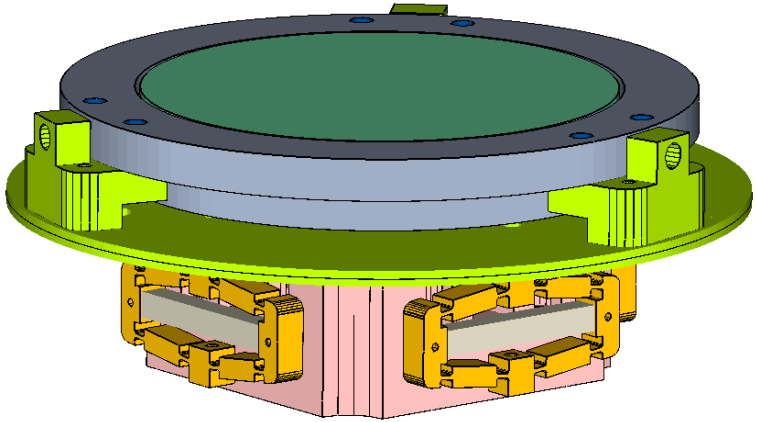
| Random | |
|---|---|
| 20-100 Hz | 0.05 $g^2$/Hz |
| 100-300 Hz | 0.25 $g^2$/Hz |
| 300-2000 Hz | 0.0016 $g^2$/Hz |
| **g RMS** | **10.24** |

| Shock | |
|---|---|
| 100 Hz | 20 g |
| 1000 Hz | 500 g |
| 5000 Hz | 300 g |

- 1st eigenfrequency (having a mass fraction > 10%) : 165 Hz > required 120 Hz

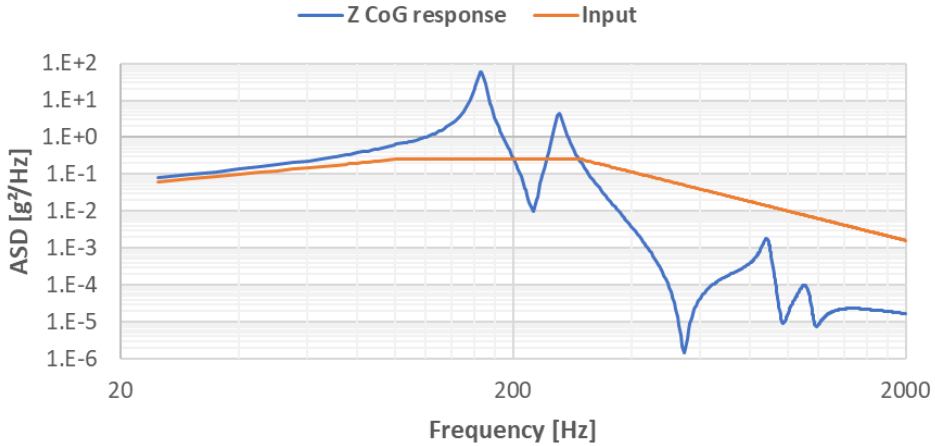


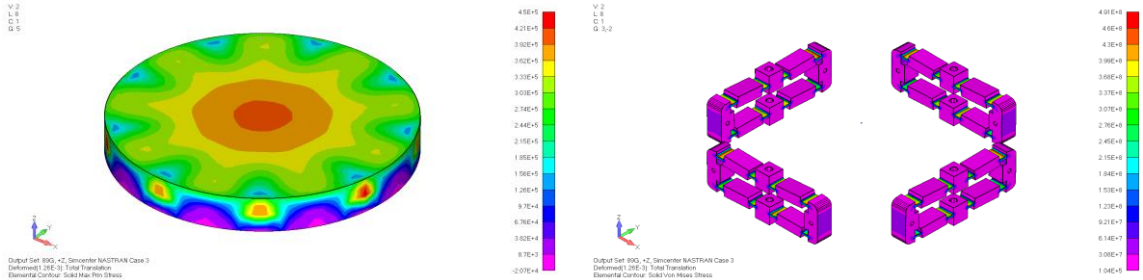

| # Mode | Frequency | Mass Fraction | Note |
|---|---|---|---|
| 1 | 100.8 | < 1% | Torsion |
| 2 | 142.58 | 3.5% (X,Y) | Tip/Tilt |
| 3 | 142.65 | 3.5% (X,Y) | Tip/Tilt |
| 4 | 165.9 | 69.7% (Z) | Piston |
| 5 | 262.17 | 20% (Z) | Piston |



**4th mode: 165 Hz**
Piston of the system

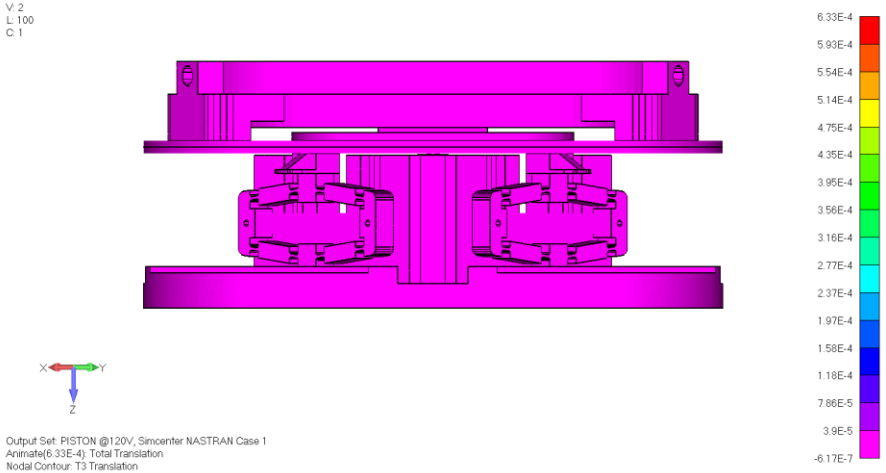
- Worst analysed case
  - Random vibrations:
    - 59 g RMS (3σ) CoG response along X;
    - 59 g RMS (3σ) CoG response along Y;
    - 89 g RMS (3σ) CoG response along Z.
- FSTTM survives at Quasi-Static loads:
  - up to 59 g along X;
  - up to 59 g along Y;
  - up to 89 g along Z.
- Assumed Factor of Safety (FoS) for QSL:
  - Metallic parts:
    - FoSy = 1.375
    - FoSu = 1.5625
  - Glass/Glue parts:
    - FoSu = 3.125

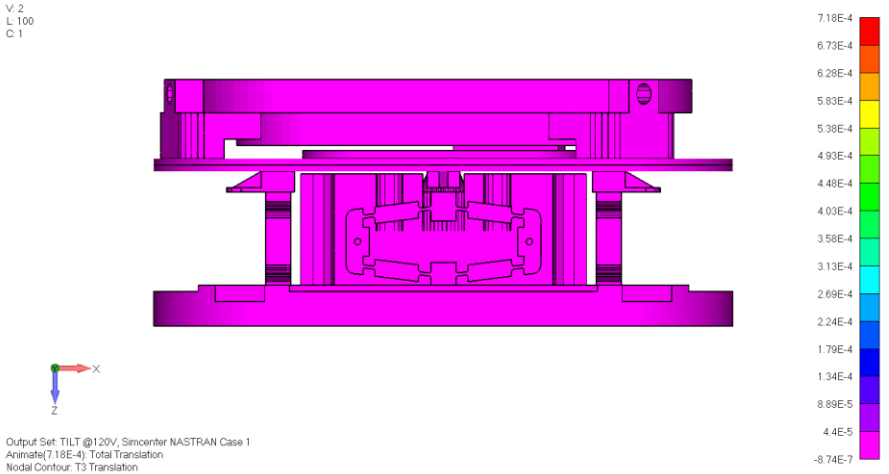


# FEA: operative cases

- Operative analyses performed to evaluate the maximum performance of the mechanism, in terms of piston and tip/tilt




- **Max resulting piston**:
  - 159 µm *(>120 µm required)*

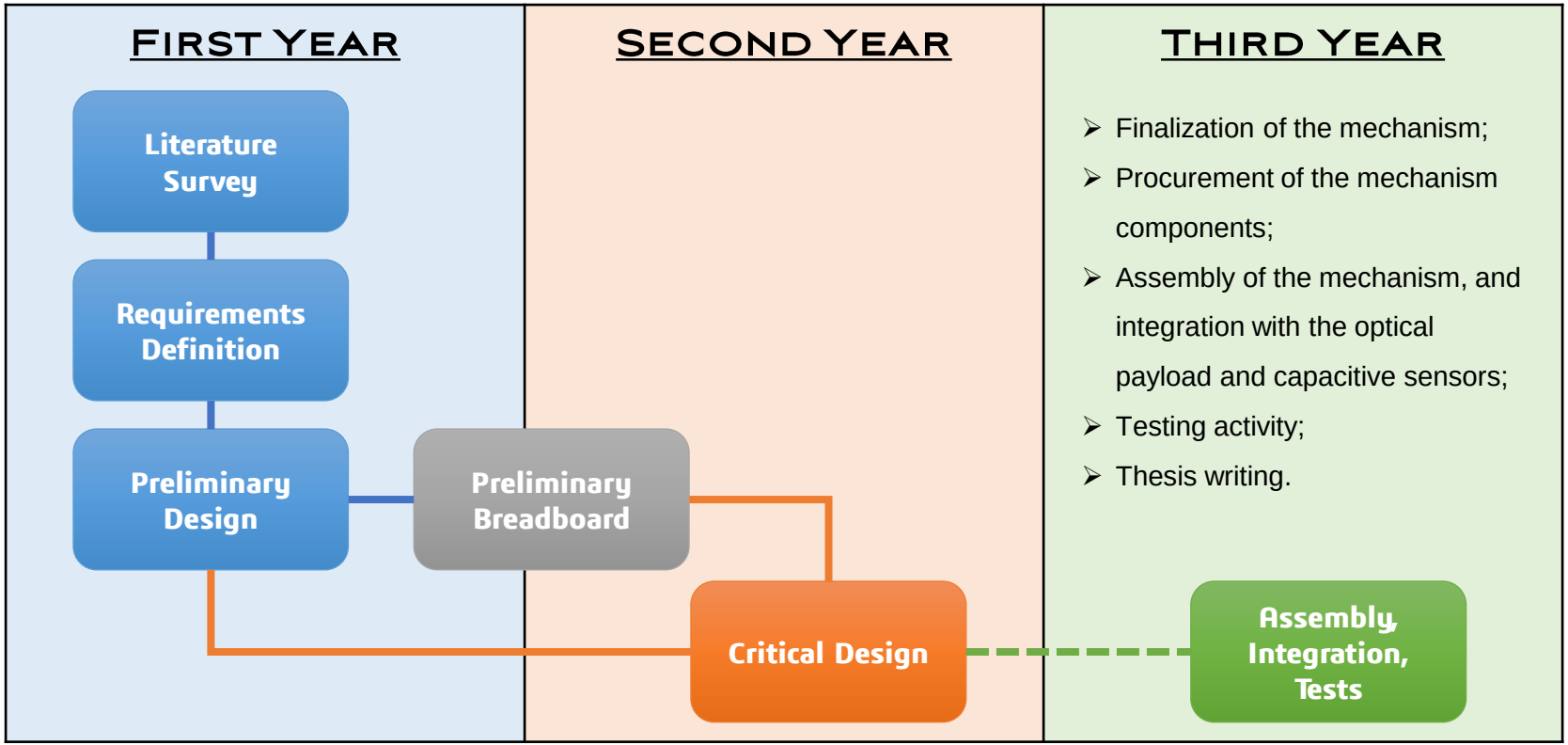
    *[@1g, T=20°C]*

- **Max resulting tip/tilt**:
  - 500 arcsec *(>120 arcsec required)*

    ≈ 2.4 mrad

    *[@1g, T=20°C]*

# Work Activity: main steps



# Thanks for the attention