UNIVERSITÀ
DEGLI STUDI
DI PADOVA

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

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PhD Course in Science, Technologies and Measurements for Space

Admission to second year - 08/09/2021

Summary

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  - *Amplification Mechanism*
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- Work Activity

- **Industrial Doctorate**

- **Officina Stellare**

  an innovative SME active in the design and production of telescopes, optomechanical and aerospace instrumentation for Ground and Space based applications

Introduction

Space telescopes

- Earth observation
- Outer space observation

Problem

Line-of-sight and image performances affected by:

- Thermal gradients;
- Misalignment due to launch vibrations;
- Platform jitter (due to reaction wheels);
- Fuel slosh;
- Ground errors (manufacturing, integration, ...)

Necessity to correct optical components position

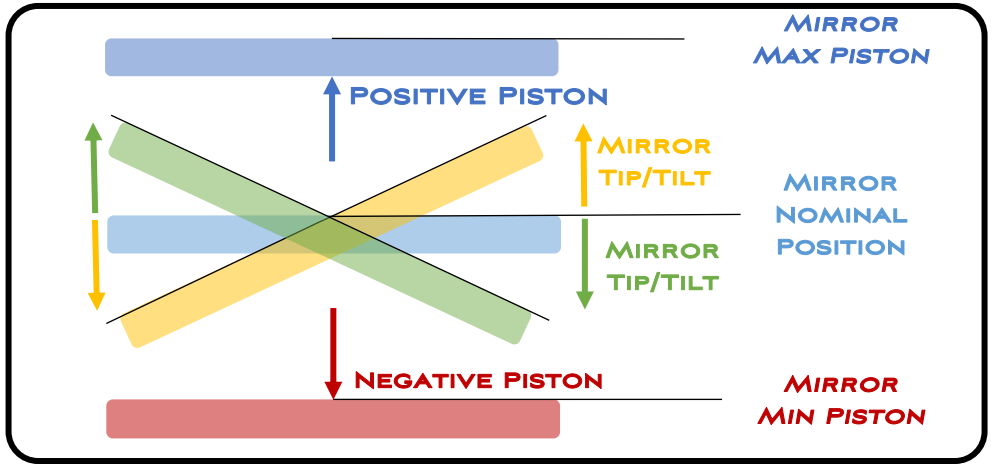
A solution

active mechanism to adjust the position/orientation of optical elements

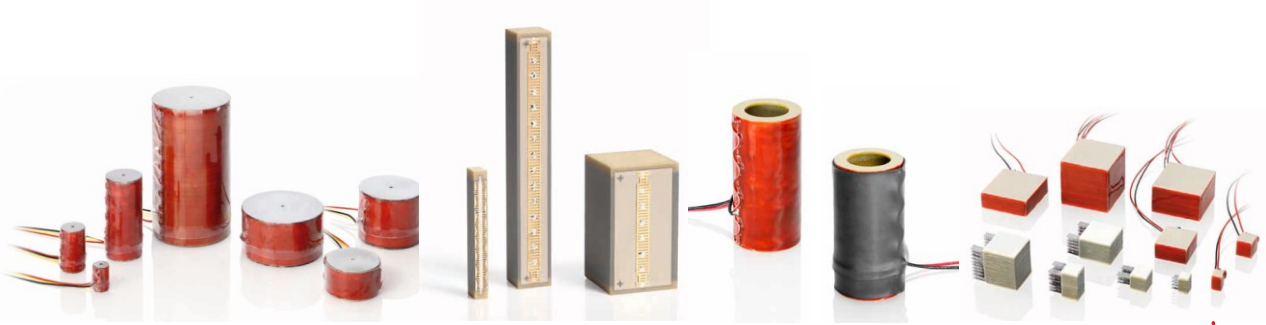
Research Project Objectives

- **Design** and **Realization** of a fine steering mechanism equipped with piezoelectric actuators
- **Space qualification** of the fine steering mechanism
- Acquisition of know-how in the **piezoelectric actuators** field
- Acquisition of experience in the **active optics** field

An Overview of the Mechanism



- Movement generated by **piezoelectric actuators**:
  - **PROs**
    - High resolutions
    - No stick-slip
    - No lubrifications
    - High vacuum operations
    - Low power consumption
    - Low heat dissipation
  - **CONs**
    - Limited stroke
    - High Voltage



[from Physik Instrumente*]*

First Year Completed Activities

- **First year activities completed**:
  - ✓ Requirement definition
  - ✓ Bibliographic review
  - ✓ System configuration trade-off
  - ✓ Design and analysis of the amplification mechanism
  - ✓ Preliminary design and analysis of the system (amplified piezo actuators + optical payload + IF platform)

Requirements Definition

- A definition of the Fine Steering Tip/Tilt Mechanism requirements has been performed

GENERAL

- The Fine Steering Tip Tilt Mechanism (FSTTM) shall move a mirror

FUNCTIONAL & PERFORMANCE

- Tip/Tilt ≥ ±120 arcsec (accuracy ≤ 0.2 arcsec)
- Piston ≥ ±60 µm (accuracy ≤ 0.5 µm)

ENVIRONMENTAL

- Survival Temperature Range -45 to +80 °C
- Operative Temperature Range -30 to +55°C
- First eigenfrequency ≥ 120 Hz
- 30g Quasi-Static Load (all directions not simultaneously)
- ±20g Quasi-Static Load (all directions)

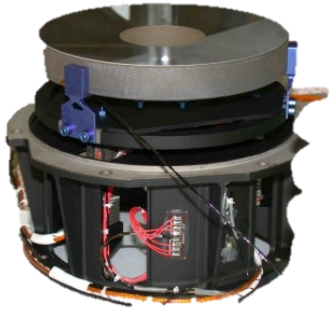
PHYSICAL

- Allowable envelope: ϕ 140 mm x 60 mm
- Allowable mass: ≤ 500 g
- Optical Payload allowable mass: ≤ 750 g

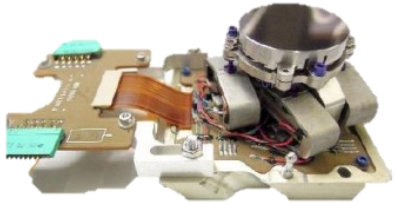
Bibliographic Review

- A bibliographic review have been conducted on:
  - **Piezoelectric actuators**
  - **3 DoF mechanisms** with piezoelectric actuators

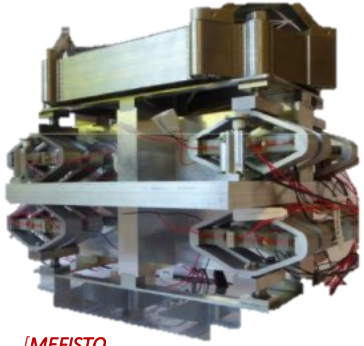
    Particular attention on:
    - those mechanisms performing one translation, and two rotations
    - those mechanisms used (or that will be used) in space missions



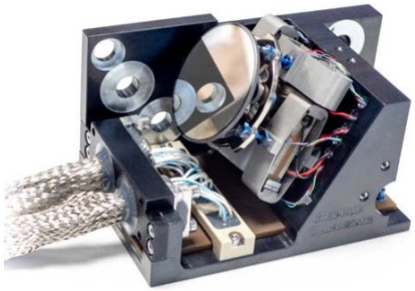
[SODISM Pointing Mechanism, from Meftah, et. Al., 2011]



[ATLID BSA, from Claeyssen, et. Al., 2018]



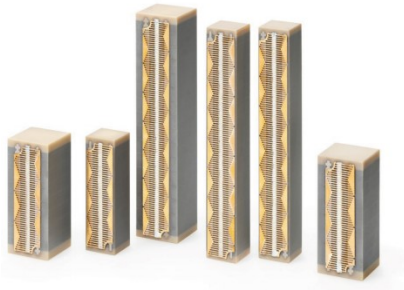
[MEFISTO, from Claeyssen, et. Al., 2018]



[Point Ahead Mechanism (PAM), from Guignabert, et. Al., 2020]

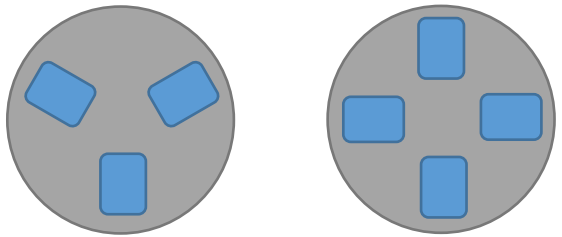
System configuration trade-off

- A system configuration trade-off, to define **type** and **number** of piezo actuators has been done.
- **TYPE:**
  - **Multi-layer piezo** (or piezo stack) **actuators selected** → if equipped with an amplification mechanism, they guarantee both high free displacements and reasonable free force values.

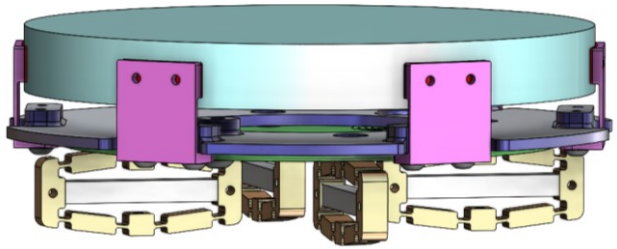


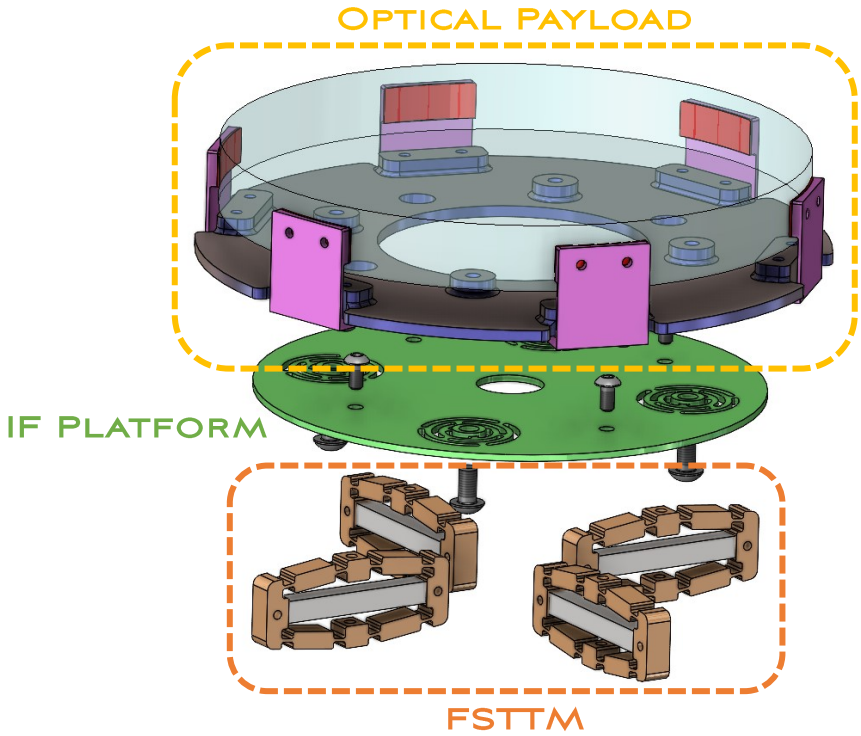
[from Physik Instrumente*]*

- **NUMBER:**
  - From literature review, 3-DoF mechanisms, able to perform 2 rotations and 1 translations, can be equipped with 3 or 4 piezo actuators
  - **4 actuator configuration selected**
    - Stiffer system
    - Control system easier
    - Lower required stroke for tip/tilt



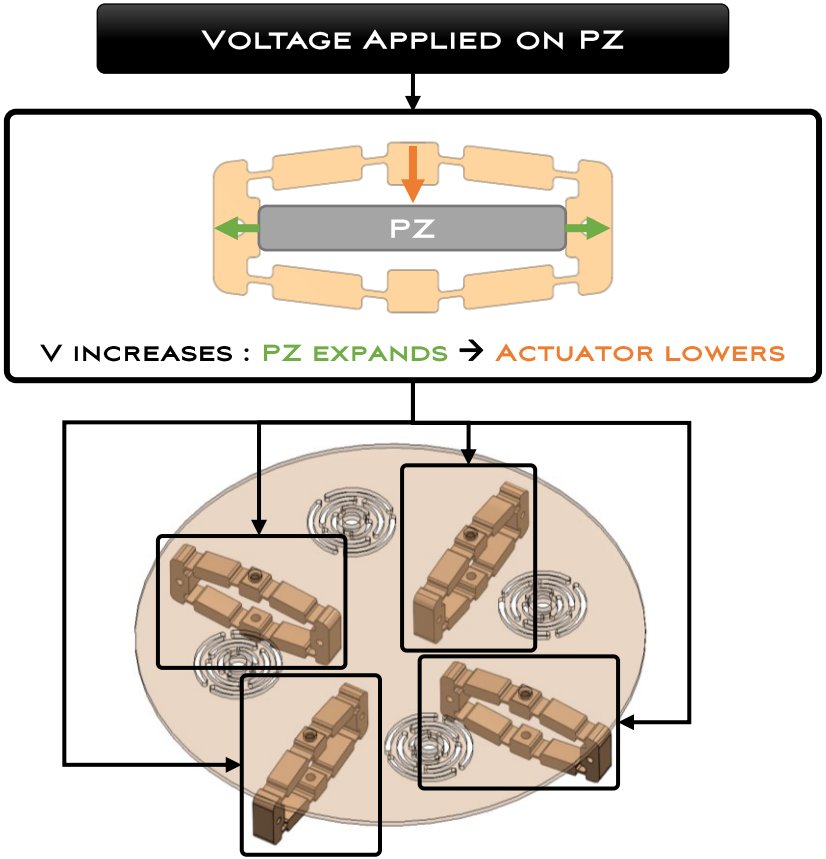
Preliminary System Design – an overview

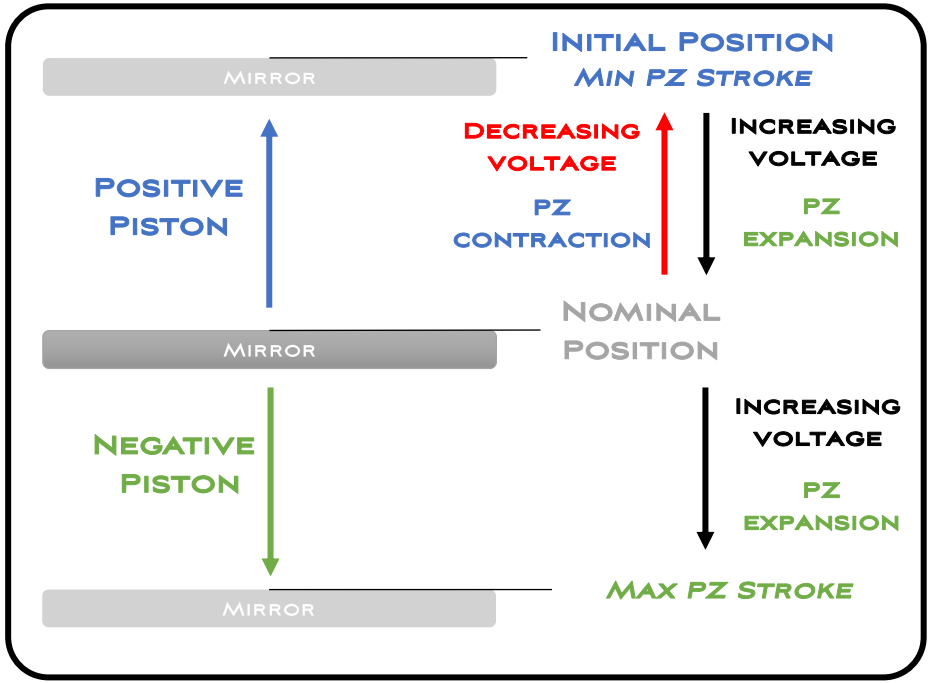




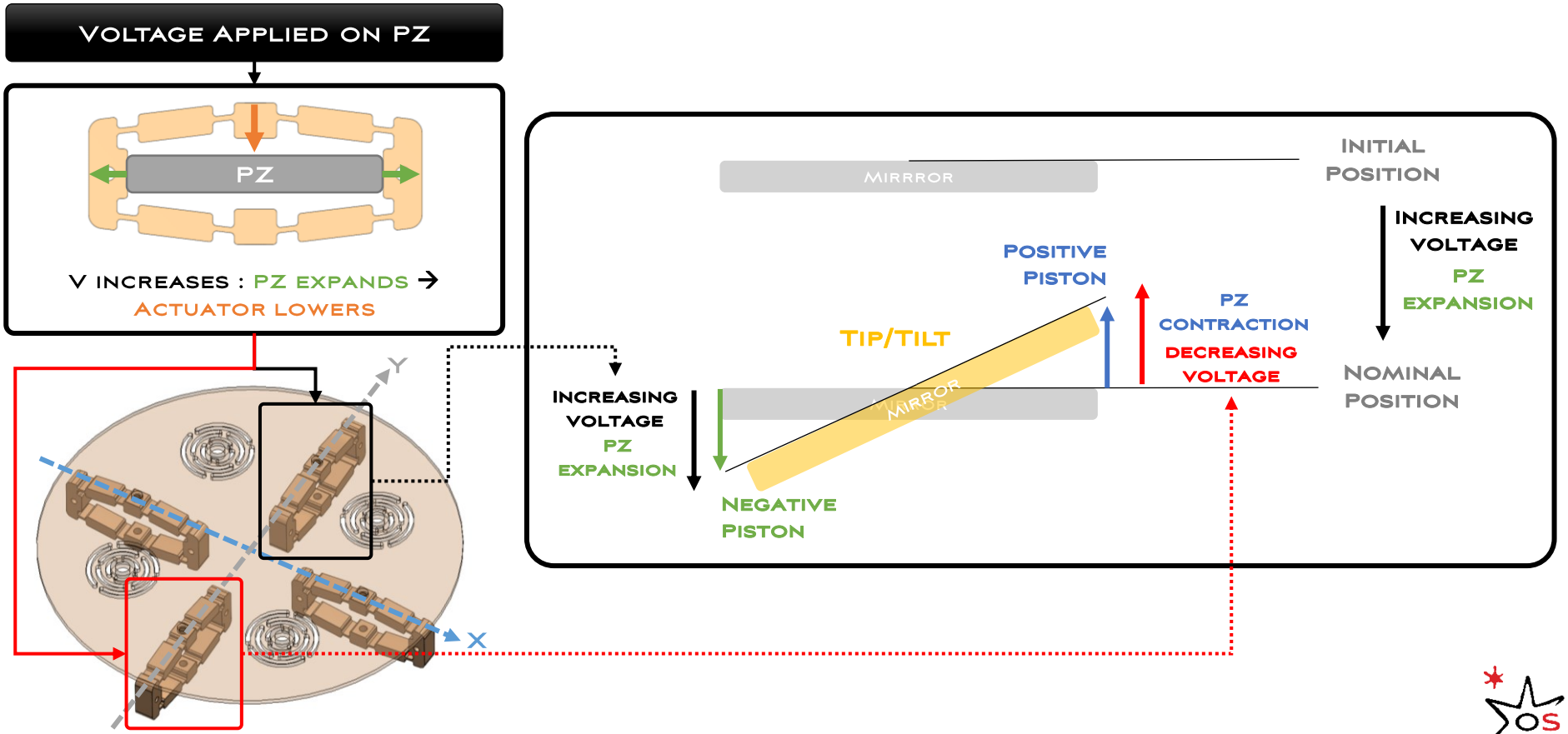
- Three sub-systems can be identified:
  - **Fine Steering Tip/Tilt Mechanism** (FSTTM), consisting of 4 amplified piezo stack actuators
  - **Optical Payload**, consisting of a mirror, and its supporting cell
  - **IF platform**, connecting the FSTTM to the optical payload

Preliminary System Design – Piston Principle

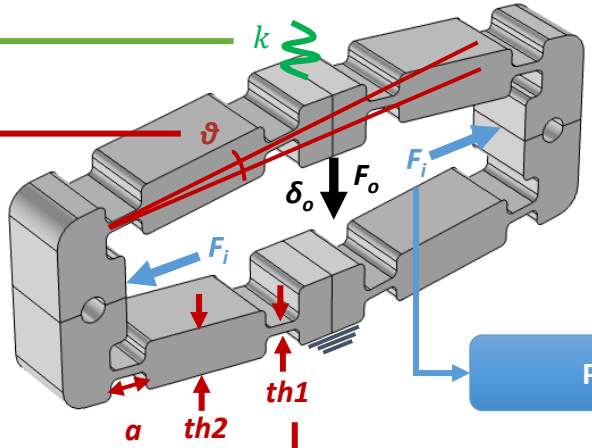




Preliminary System Design – Tip/Tilt Principle



Amplification Mechanism – Parametric Design



Geometrical Advantage
$\frac{\delta_o}{\delta_i}$

Amplified displacement
δ_o

Piezo characteristics

Piezo Stroke
δ_i

Amplification Mechanism Stiffness

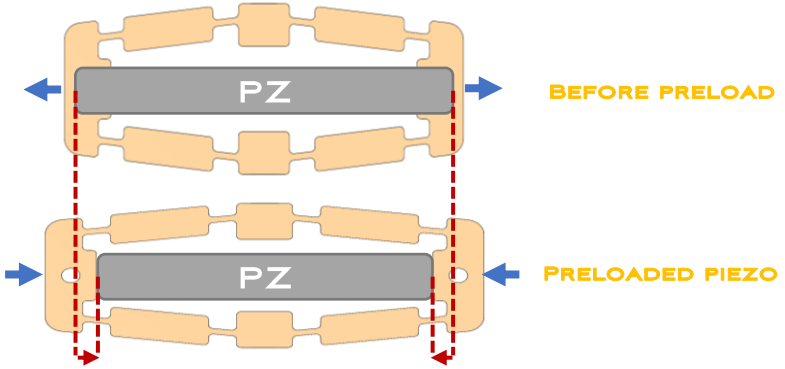
Amplification Mechanism Geometry

IF Platform Stiffness

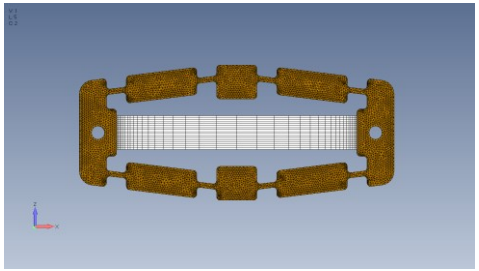
Tip/Tilt

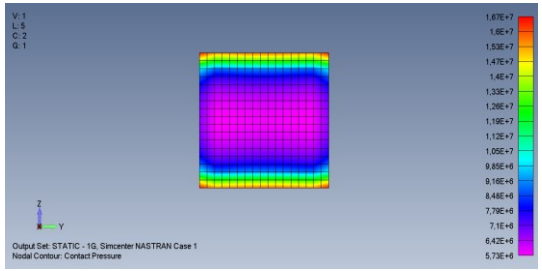
Amplification Mechanism – Piezo Preload Analysis

- Pizoelectric actuator has to be preloaded.
- A preload ≤ 15 MPa is recommended by piezo manufacturer.
- Preload realized through the Amplification Mechanism → AM axial length < Piezo length



LOAD CONDITION	AVERAGE PRESSURE [MPA]	PRESSURE VARIATION [MPA]
20°C (no gravity)	9.12	/
-45°C (no gravity)	14.4	+5.31
-30°C (no gravity)	13.3	+4.16
+ 55°C (no gravity)	6.04	-3.07
+ 85°C (no gravity)	4	-5.12
gravity	8.65	-0.47

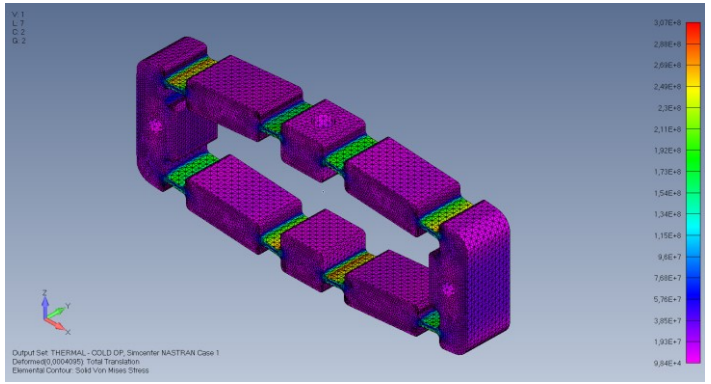


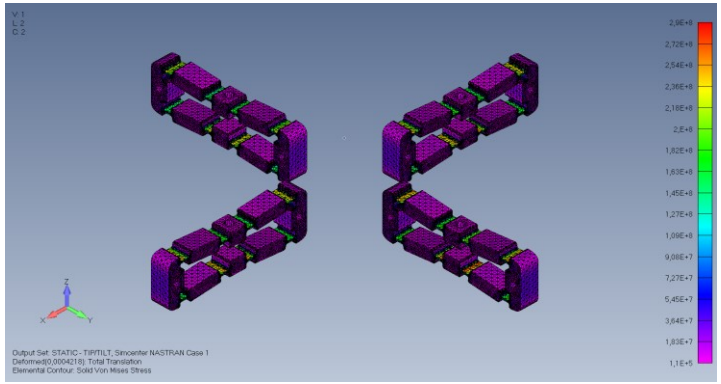


- A preload compression of about 9 MPa has been selected.
- FE analyses performed to analyze the preload variation due to gravity and thermal loads.

Amplification Mechanism – Fatigue Analysis

- A fatigue analysis on the amplification mechanism has been performed.
- Its endurance (or fatigue) limit has been estimated, considering degradation due to surface condition, reliability and other miscellaneuos effects.
- Assuming a worst case scenario, the amplification mechanism **can survive to an infinite number of cycles.**
- Stress values from system FEA have been used.



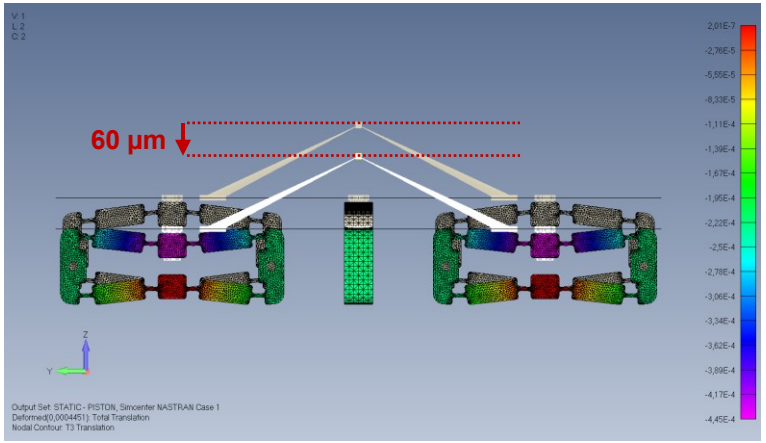


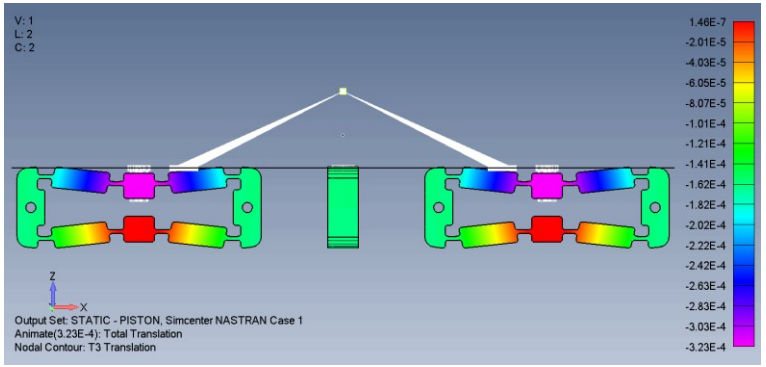
LOAD CONDITION	MAX TENSILE STRESS ON AMPLIFICATION MECHANISM [MPA]
Only Preload (0 V), @ T_{amb}	219
Min Piston (-60 µm), @T_{amb} – preload included	318
Max Piston (+60 µm), @T_{amb} – preload included	231
Max Tip (120 arcsec), @ T_{amb} – preload included	290 (max value)
	259 (min value)
Hot Survival Temperature (0 V) – included preload	104
Cold Survival Temperature (0 V) – included preload	334

Preliminary System Design - FEA

- The preliminary system designed, has been analysed with several FE analyses.
- FE model consisting in:
  - Amplification mechanisms without piezo, but replaced by their forces;
  - IF platform, connected to the AMs through rigid elements;
  - Optical payload modelled as a point mass, and connected to the IF platform through a rigid element.
- Performed analyses:
  - A maximum **tip/tilt case** (simulating a rotation of 120 arcsec)
  - Maximum and minimum **piston case** (simulating a translation of ±60 µm)
  - **Modal analysis**
  - Stress analysis

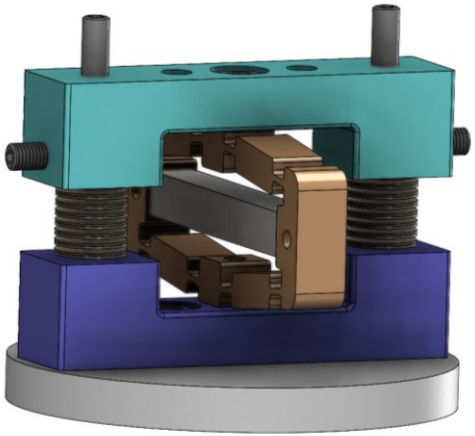
Piston Case: ±60 µm





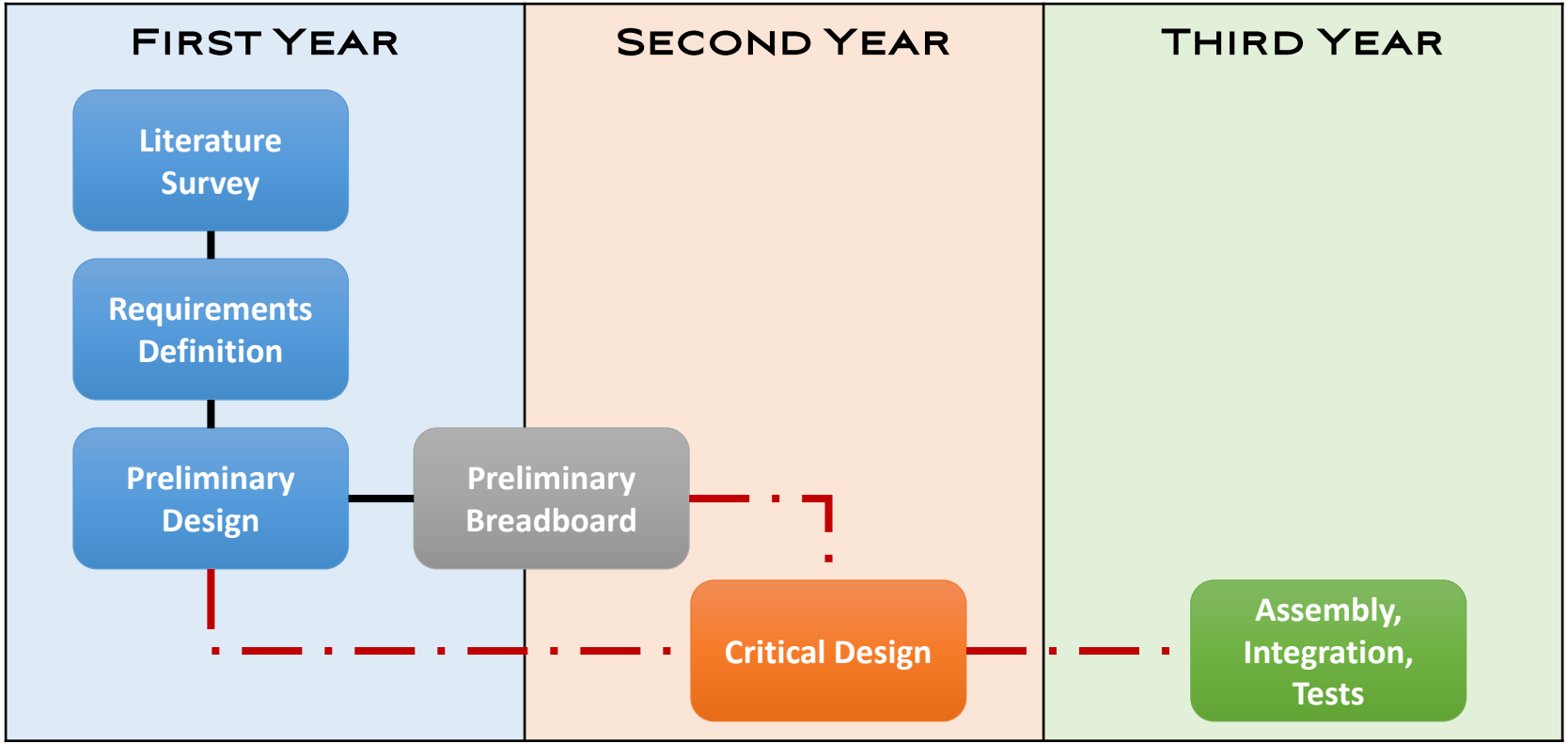
Next Steps in 2nd Year

- Realizazion of a **breadboard**
  - consisting in:
    - Amplification Mechanism
    - Piezoelectric Actuator
    - Voltage amplifier and controller
    - GSE to simulate payload stiffness
  - to verify results obtained by FEA



- From test results, a **critical design** of the system will be performed.

Work Activity – Main Steps



Thanks for the attention