The preliminary thermo-mechanical design, simulation and optimization, of LAD onboard the eXTP space mission

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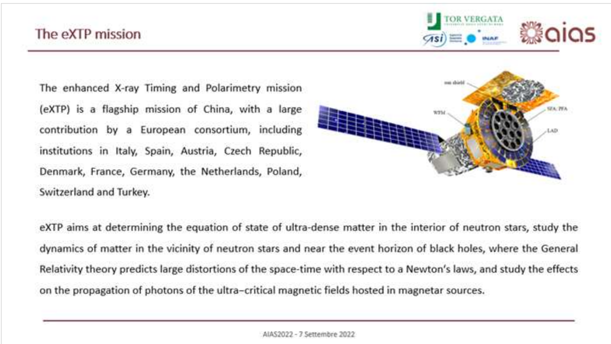
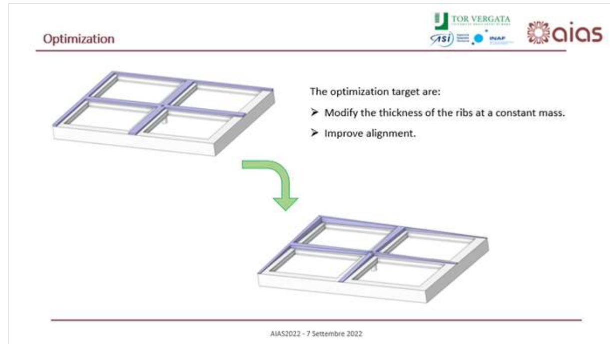
Overview

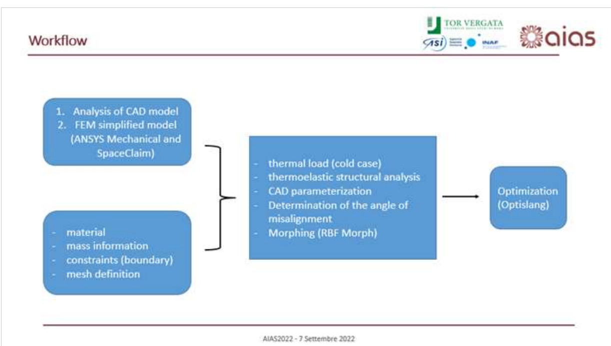
- ➤ eXTP Mission and Instrument



- ➤ Optimization



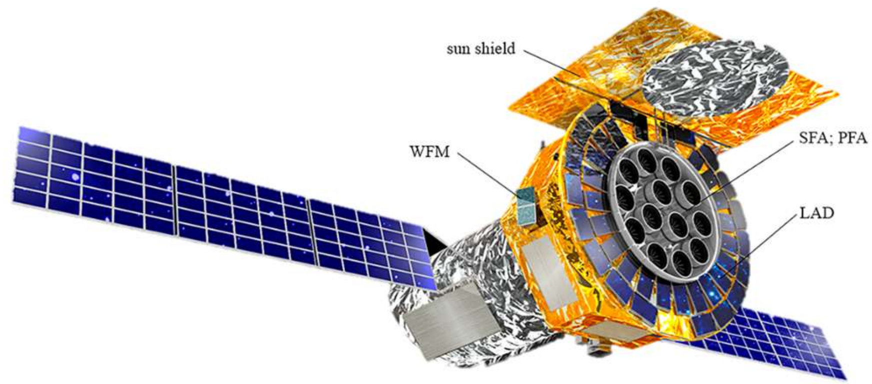
- ➤ Numerical Simulation



- ➤ Conclusion

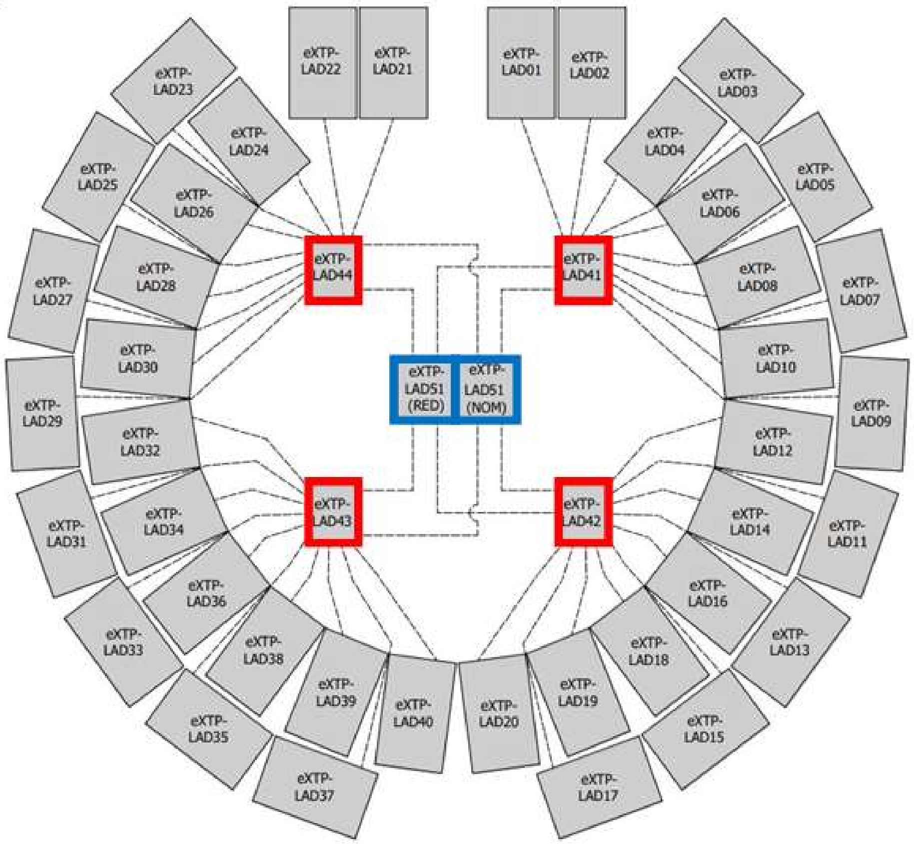
The eXTP mission

The enhanced X-ray Timing and Polarimetry mission (eXTP) is a flagship mission of China, with a large contribution by a European consortium, including institutions in Italy, Spain, Austria, Czech Republic, Denmark, France, Germany, the Netherlands, Poland, Switzerland and Turkey.



eXTP aims at determining the equation of state of ultra-dense matter in the interior of neutron stars, study the dynamics of matter in the vicinity of neutron stars and near the event horizon of black holes, where the General Relativity theory predicts large distortions of the space-time with respect to a Newton's laws, and study the effects on the propagation of photons of the ultra−critical magnetic fields hosted in magnetar sources.

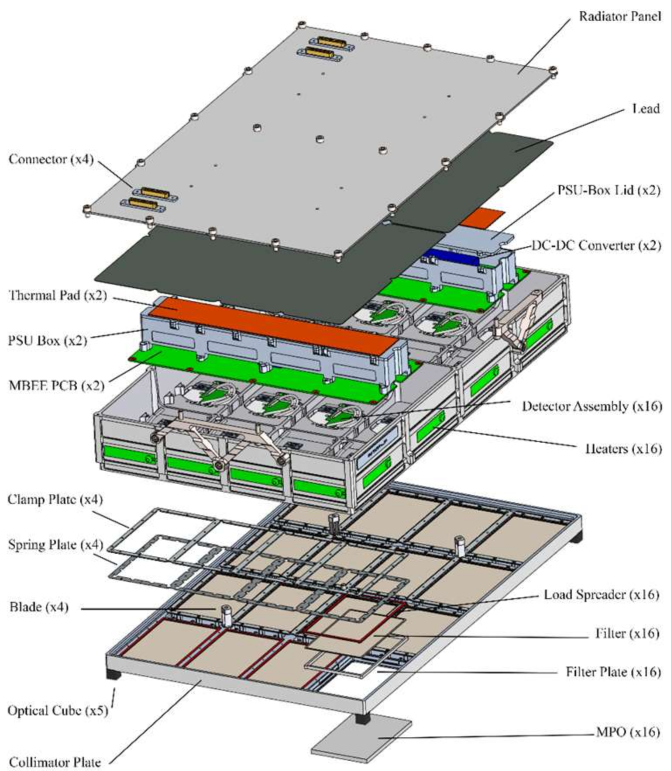
Large Area Detector



The Large Area Detector (LAD) is designed to be the most sensitive spectral-timing instrument for bright Galactic and extra galactic sources to date, an innovative and highly efficient technology and design allow to deploy in space an effective area as large as 3.2 m2 - class at 8 keV, adopting a modular configuration.

The LAD is organized as a modular instrument, composed of 40 coaligned Modules, each one hosting a set of 16 large area Silicon Drift Detectors (SDDs) and 16 corresponding capillary plate collimators (MPO).
The Modules are hierarchically interfaced by a set of 4 Panel Back End Electronics (PBEE), that are in turn connected to an Instrument Control Unit.

The Module



The module contains:

- A **Collimator Frame** containing 16 co−aligned **Micro Pore Optics** (**MPO**);
- A **Detector Frame** containing 16 **Silicon Drift Detector** (**SDD**) + **Front End Electronic** (**FEE**).
- **Module Back End Electronics** (**MBEE**). Controls the ASICs and High Voltage Power Supply Unit (HV PSU) and reads out the digitized events. the MBEE is hosted in the same mechanical and electrical framework of the Detector Frame;
- **HV/MV/LV PSU**: The power supply for the SDDs; the PSU is hosted in the same mechanical and electrical framework of the Detector Frame;
- A 300 µm **lead back-shield**, to reduce the background events in the SDDs;
- A **radiator** to dissipate heat from the module (lower SDD temperature improves the energy resolution);

An **heater belt** is placed around the module. The heating process during annealing recovering the damages induced by particle radiation and balance the thermal gradient, following the mission’s requisite, generated during the satellite orbits.

Workflow

1. Analysis of CAD model
2. FEM simplified model (ANSYS Mechanical and SpaceClaim)

- material
- mass information
- constraints (boundary)
- mesh definition

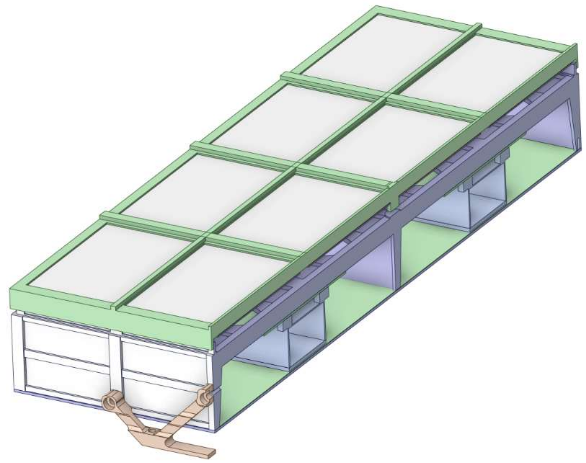
- thermal load (cold case)
- thermoelastic structural analysis
- CAD parameterization
- Determination of the angle of misalignment
- Morphing (RBF Morph)

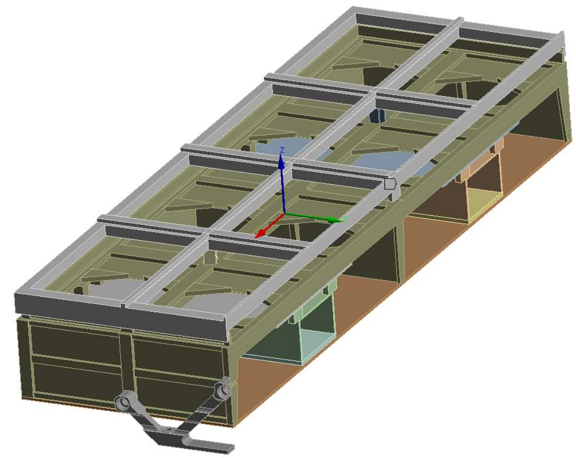
→

Optimization (Optislang)

Numerical Simulation

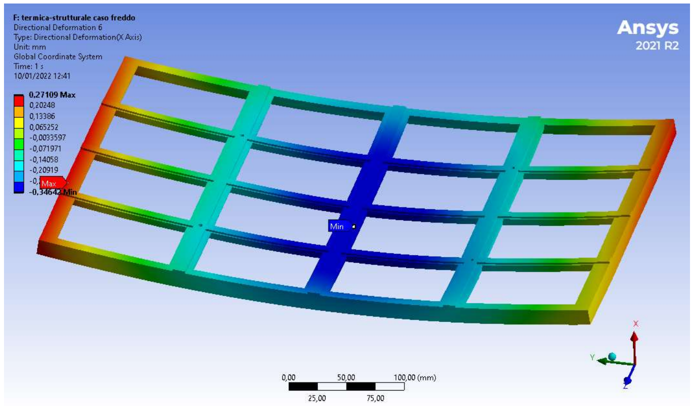
This study described the preliminary study that led the design mechanical solutions adopted for the most important thermo-mechanical drivers of the Module.

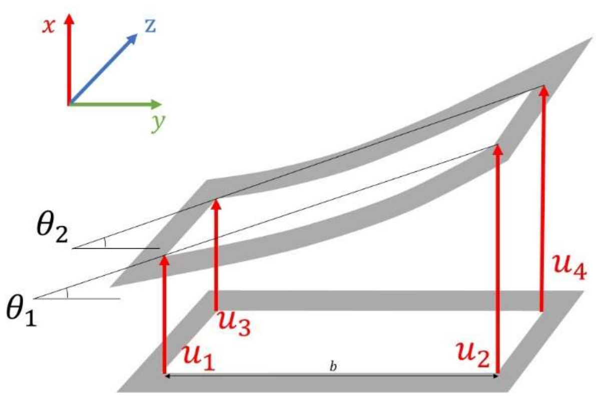




In particular we report the mechanical design, the evaluation of the thermo-elastic deformation of a simplified module, the results of a static structural simulation of a parametric model with an accurate mesh, optimazed throught some mesh morphing tools, the processing and the preliminary optimization of a critical component, the Collimator frame.

Misalignment angle





Collimator Frame has been divided into quadrants and the internal longitudinal sides of each quadrant numbered in matrix logic.

This relation was used for the calculation of each single angle, expressed as a function of the displacements along all directions:

$$\theta = atan\left(\frac{u_{max} - u_{min}}{b}\right)$$

$$\theta^* = mean(\theta_1, \theta_2, \ldots \theta_{32})$$

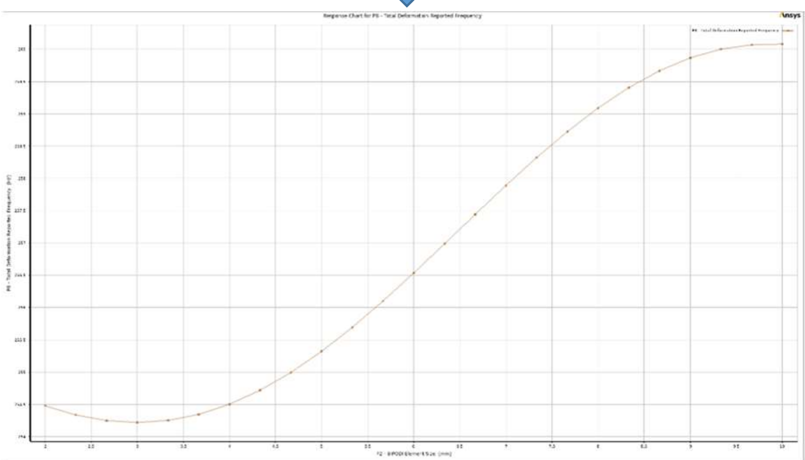
Θ∗ represents the value of the misalignment calculated into the original configuration, it will be a necessary condition for the success of the optimization to obtain an angle Θ≤Θ∗.

Mesh Analysis

A starting mesh was obtained with the general settings and some controls crucial surfaces that was candidates to receive further refinement.

A constrained **modal analysis** was performed without preload.

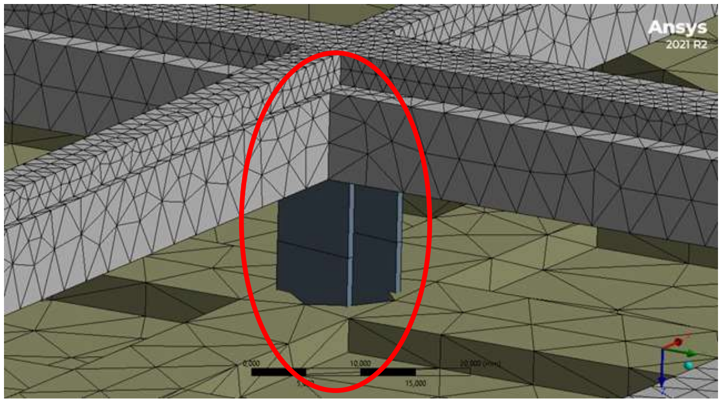
The optimization of the mesh was performed through the instrument "response surface", ANSYS tool that allows you to modify the values by adapting them with a parameterization.

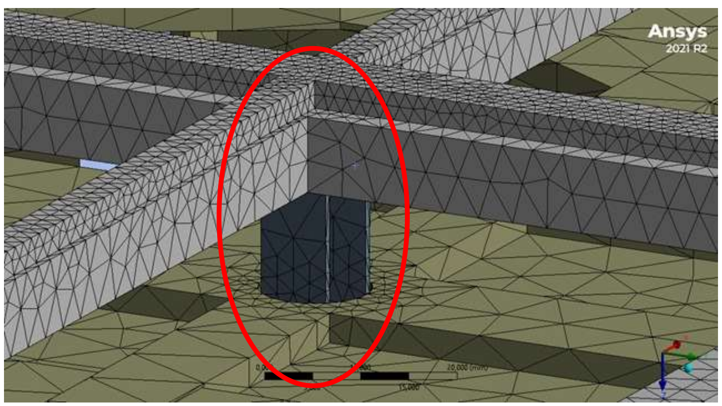


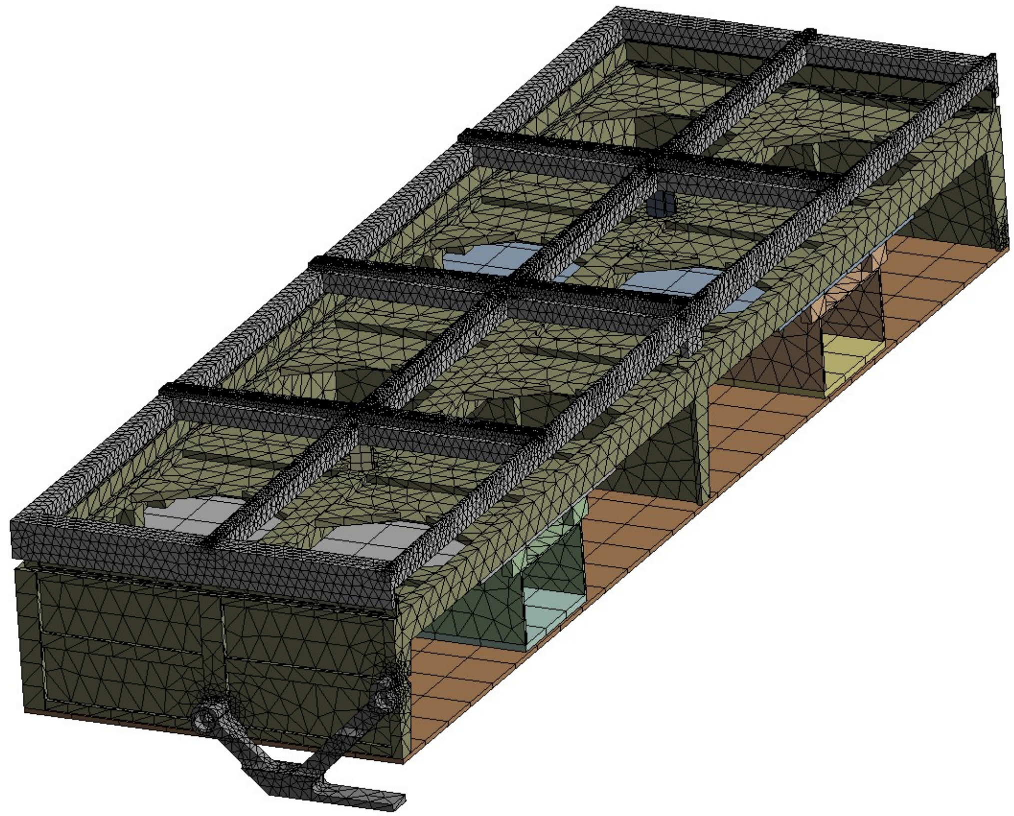
The optimization constraints are:

- total number of nodes, as a trade−off between computing power and a dense mesh;
- constrain the first natural frequency above 120 Hz.

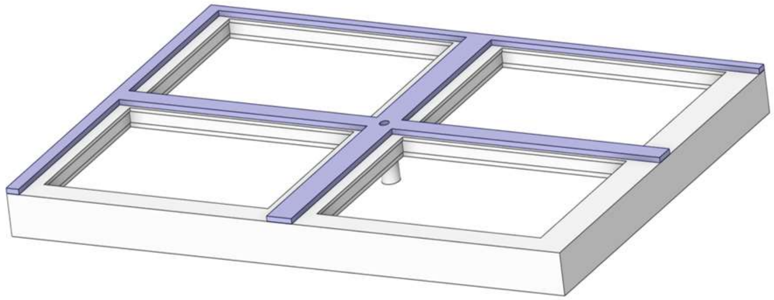
Mesh Convergence





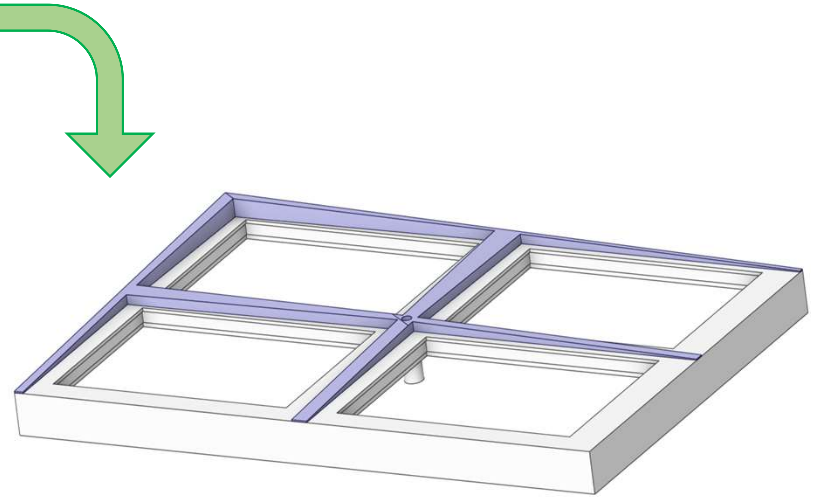


Optimization



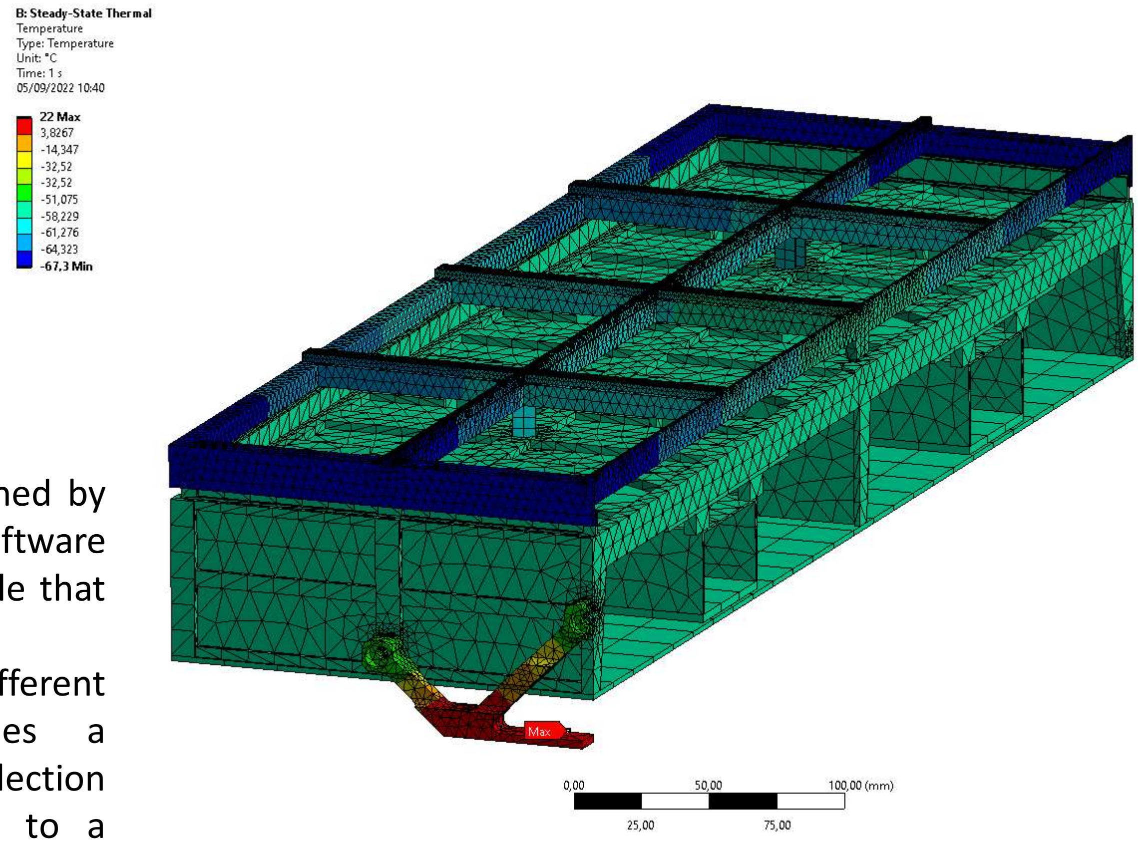
The optimization target are:

- Modify the thickness of the ribs at a constant mass.
- Improve alignment.



Thermal load – Cold case

I/F Bipod - Truss	20 °C
I/F Bipod – DF	-48 °C
Short Side	-67,3 °C
Detector Frame	-52 °C
Blades	-61°C
Central Bolt	-55,5 °C



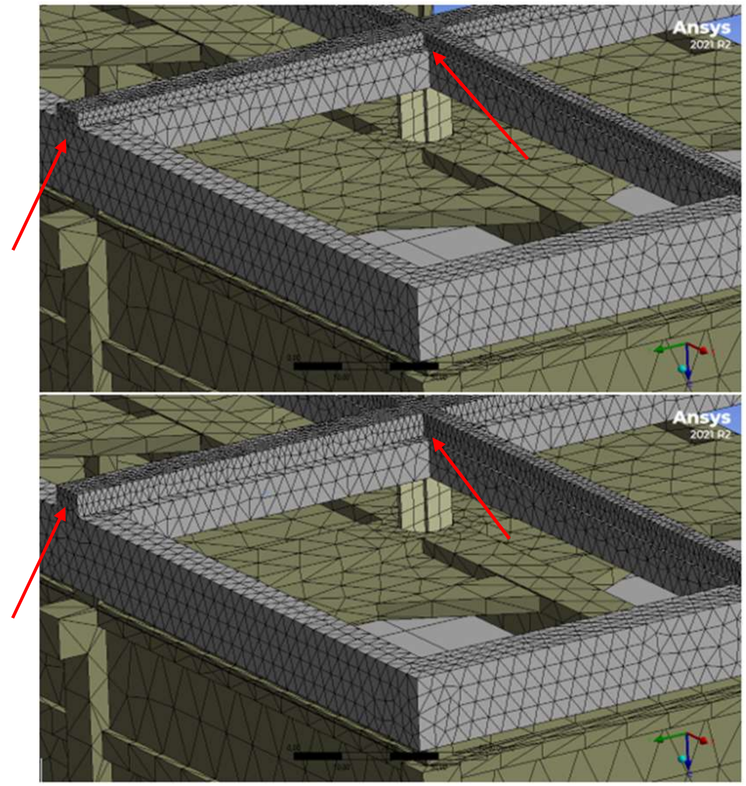
The thermal load (coldest case) was defined by thermal analysis conducted with software **Systema Thermica**, considering the module that orbit around Earth with the satellite.

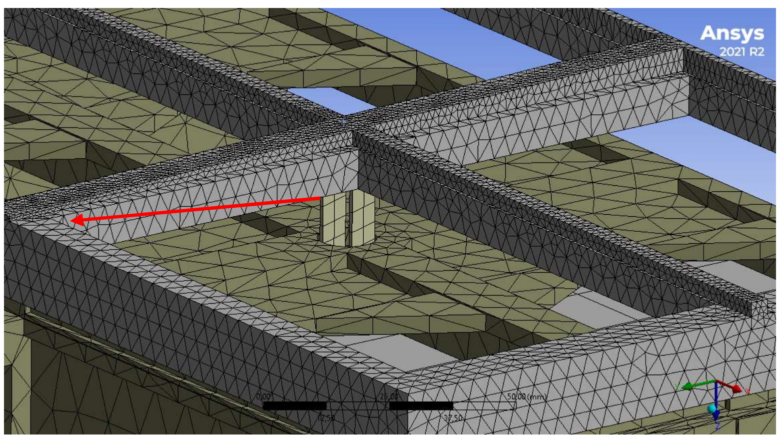
Thermoelastic analysis reveals that the different temperature on the module causes a misalignment of the structure and an inflection of the Collimator Frame that involves to a misalignment of the MPO.

RBF Morph

Radial basis functions (RBFs) based mesh morphing allows to adapt the shape of a computational grid onto a new one by updating the position of all its nodes.

The mesh morphing that produces the overall shape changes (mesh refiniment) is given, in that case, by the sum of three discrete operations, a surface offset (the RBF region **Offset**), a surface rotation (the RBF region **Tilt**) and a second surface offset (the RBF region **thinning**).

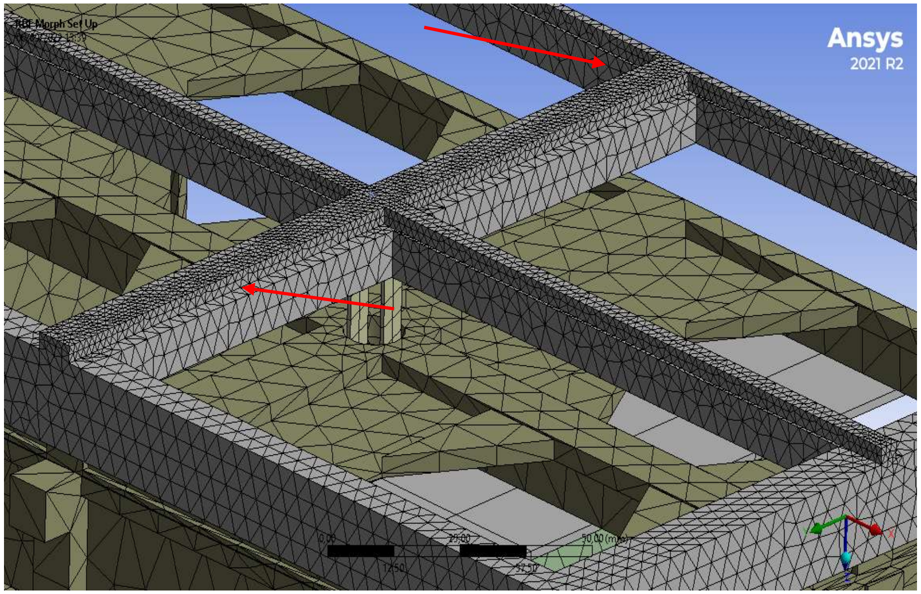


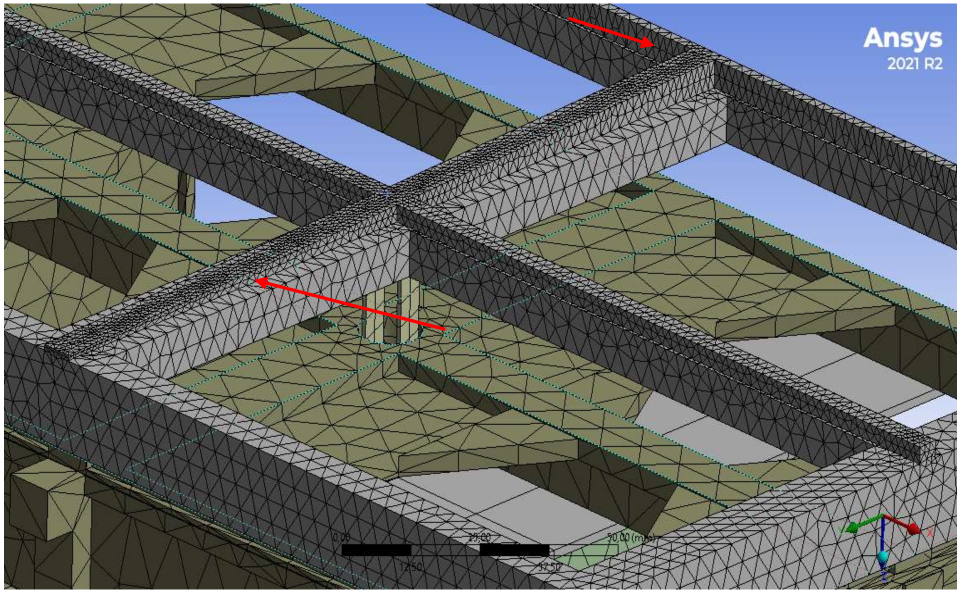


RBF Morph

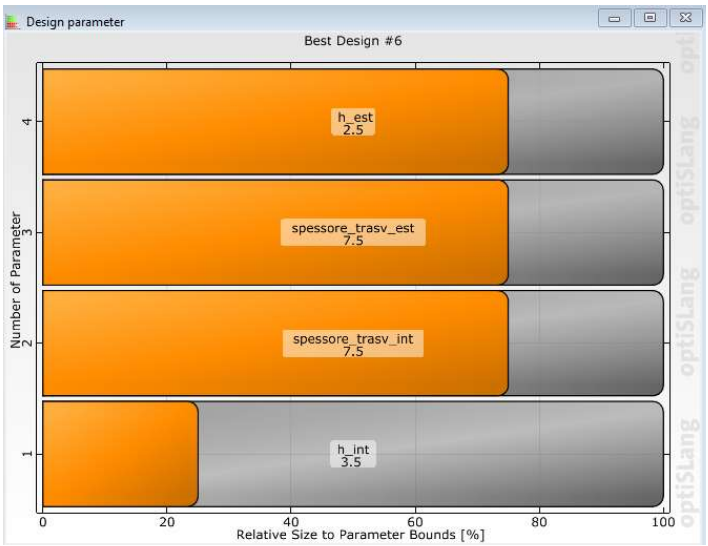
Through the "Parameter Set" some dimensions have been defined, corresponding to the various instances of mesh morphing:

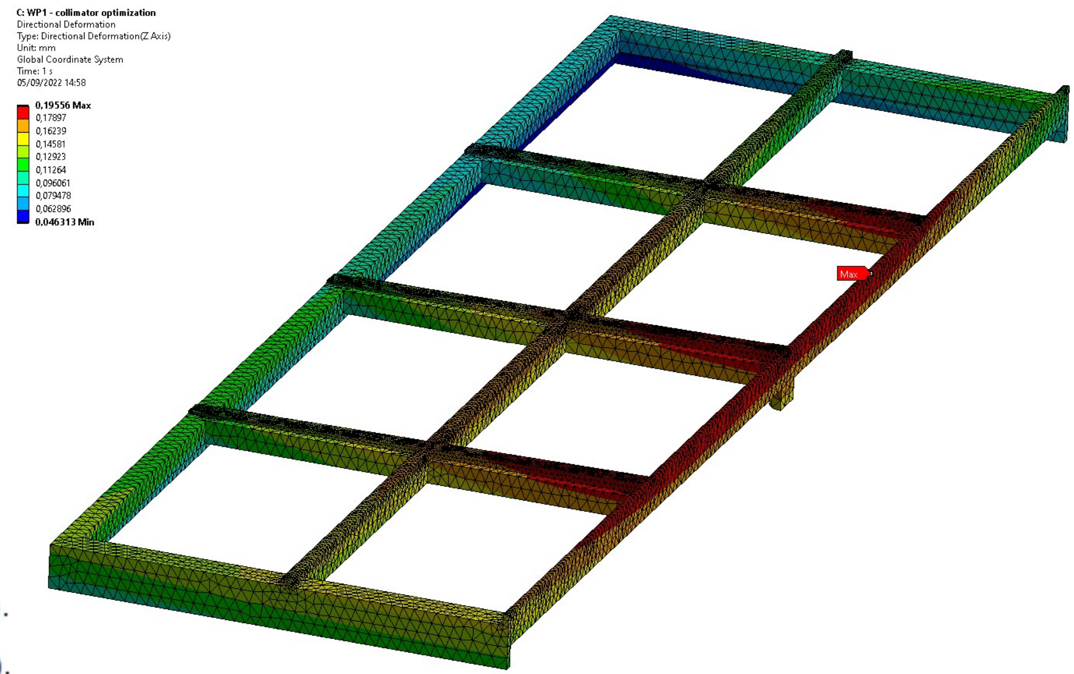
- **h_int**: height at the center of the rib.
- **h_est**: height adjacent to the perimeter of the rib.
- **thickness_trasv_int**: thickness of the internal transverse rods.
- **thickness_trasv_est**: thickness of the external transversal rods.





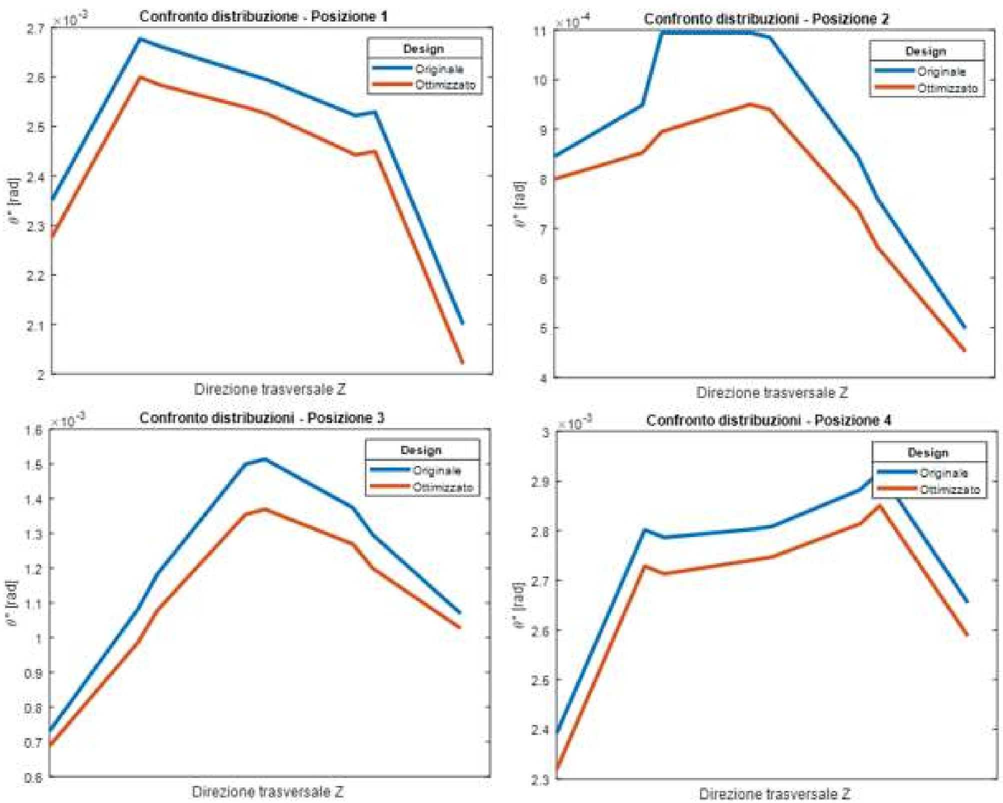
Results





- **h_int**: variable between 3mm and 5mm (reference value 3mm).
- **h_est**: variable between 1mm and 3mm (reference value 3mm).
- **thickness_trasv_int**: variable between 6mm and 8mm (reference value 8mm).
- **thickness_trasv_est**: variable between 6mm and 8mm (reference value 8mm).

Results



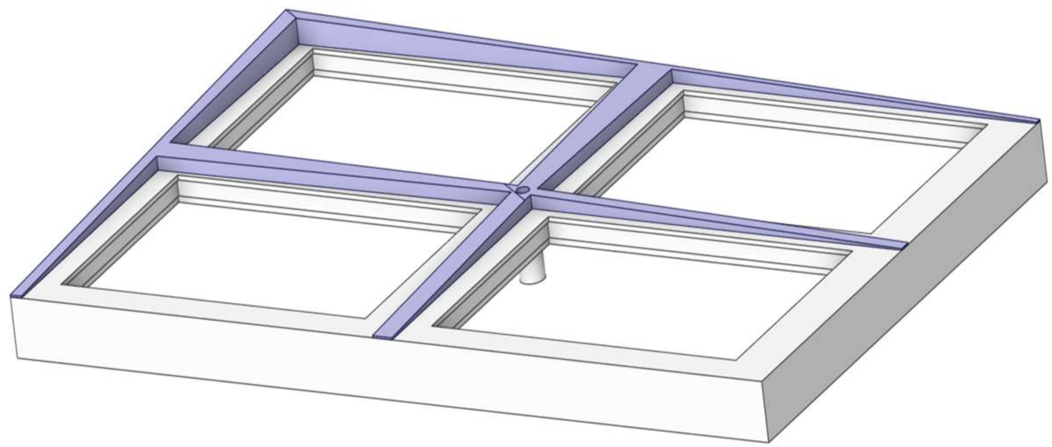
The study produced a reduction in misalignment of approximately 2%.

Looking to the optimized design, taken in comparison with the original one, it is possible to show the evolution of each of the angles respect the output that has been obtained.

The distribution of misalignment's is better overall.

Future Developments

The optimized angle has been successfully verified in terms of misalignment, obtaining a value of about 2% less than the initial angle.
It should be emphasized improving computational times and power, indeed the team had choice to reduce the degrees of freedom of the parameterization, by coupling some of the parameters in a symmetrical way.



Therefore, the future development is to study solutions that allow the complete decoupling of the latter, calculating the angle of misalignment directly on the collimators, neglected in the study to minimize the computational burden.

Thank you
for attention!

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