Methodology for the analysis of a thermo-mechanically deformed optical system

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INTRODUCTION

The performance of as-built optical instruments strongly depends on thermal and structural loads, since these boundary conditions can affect the geometry of optical surfaces.

A coupling methodology between the thermo-structural analysis and the ray-tracing optical analysis is described in this work.

STOP ANALYSIS

The multi-physics linkage of a STOP (Structural-Thermal-Optical Performance) analysis is summed up in Figure 1.

The procedure devised by the authors may be divided in three steps:

- Thermo-structural FEM analysis in COMSOL
- Results post-processing in MATLAB
- Ray-tracing analysis in ZEMAX

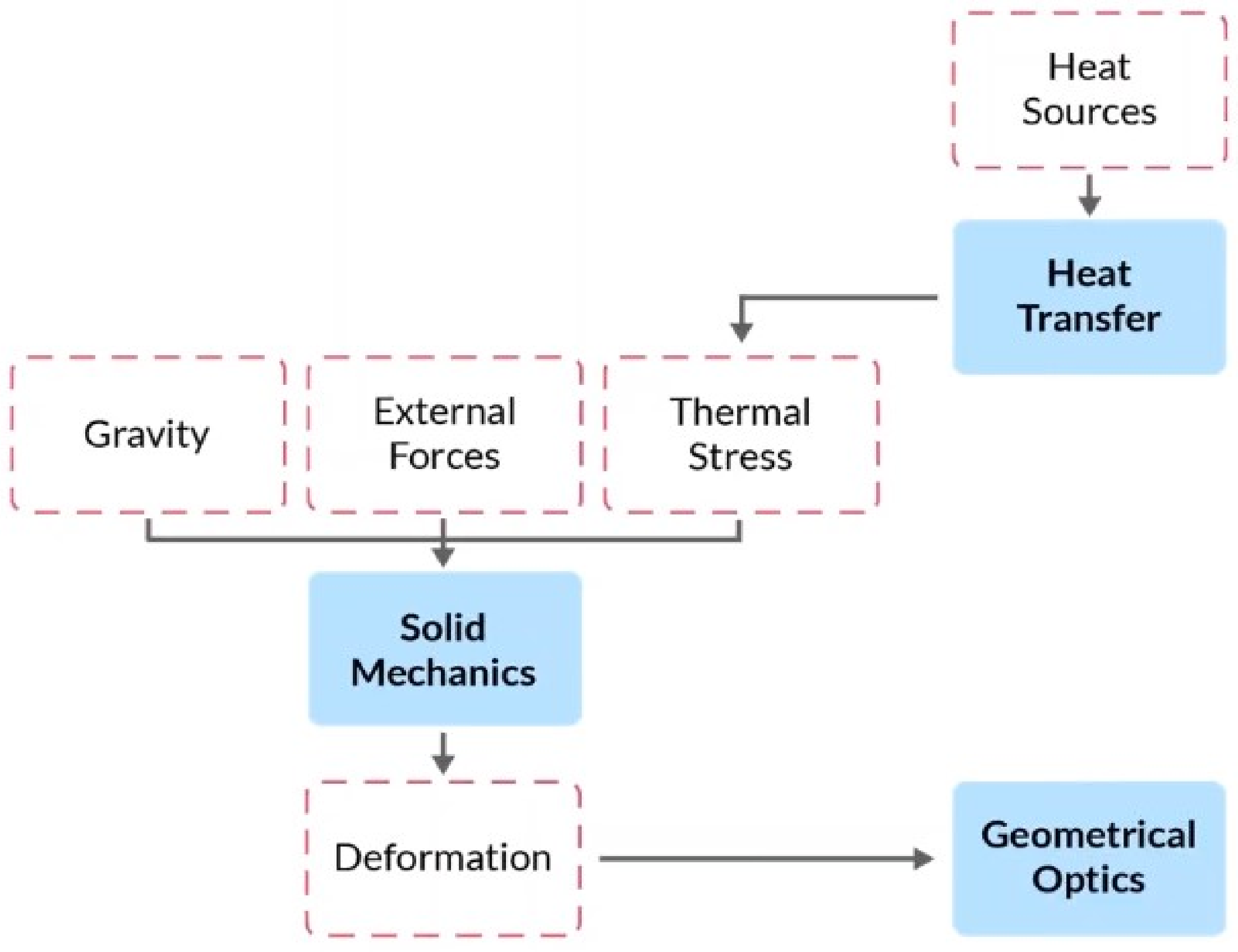

Fig.1 Summary chart of the multi-physics connections in a STOP analysis

THERMO-STRUCTURAL FEM ANALYSIS

The geometry and the materials of the instrument are such as to guarantee not only the required optical performance, but also the needed stiffness along the load direction. In addition to stiffness, other parameters are important for the materials' choice, like density, thermal conductivity and thermal expansion.

Coefficient of thermal expansion (CTE)

A good knowledge and control of this term is crucial for a thermo-structural analysis, as it links these two fields of physics. It may depend on temperature, like the aluminium CTE (Figure 2). In a FEM analysis, it can be set as average (secant) or instantaneous (tangent).

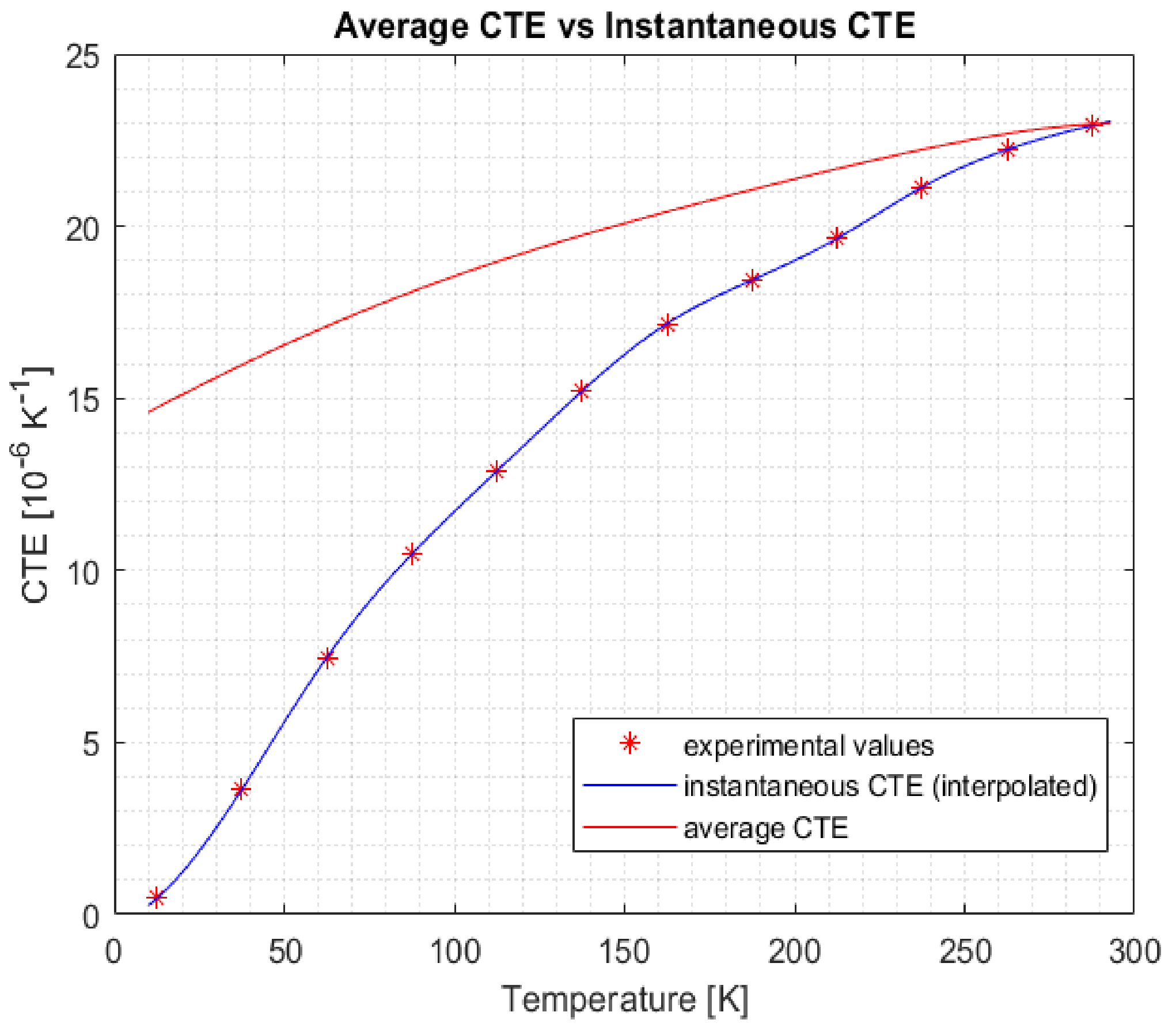

Fig. 2 Experimental values and curves of instantaneous CTE and average CTE of aluminium 6061 T651.

A finer and regular mesh is recommended especially over the optical surfaces.

RESULTS POST-PROCESSING

Polynomial fitting

The FEM displacement results are exported as a data spreadsheet. This file is processed by a MATLAB routine in order to obtain the coefficients of the polynomial expansion that best fits the imported surface [1].

polymodel = polyfitn([X,Y],Z,n)

Best fit sphere

For a curved optical surface, the determination of the best fit sphere [2] may be a useful reference index of deformation.

[Center,Radius] = sphereFit(data)

Ray-tracing analysis

In ZEMAX, for our present study an *Extended Polynomial* surface type has been considered suitable to be used. This choice allows to create an optical surface through a series of polynomial coefficients and a normalization radius.

AN APPLICATION EXAMPLE: THE ARIEL PTM

In COMSOL, a FEM analysis is performed on the demonstrator of the primary mirror of Ariel's telescope; gravity and temperature variation are set as boundary conditions. In MATLAB, the surface's polynomial fitting allows to obtain a set of coefficients which are thus imported in ZEMAX optical program to perform ray-tracing analyses on the deformed mirror's surface.

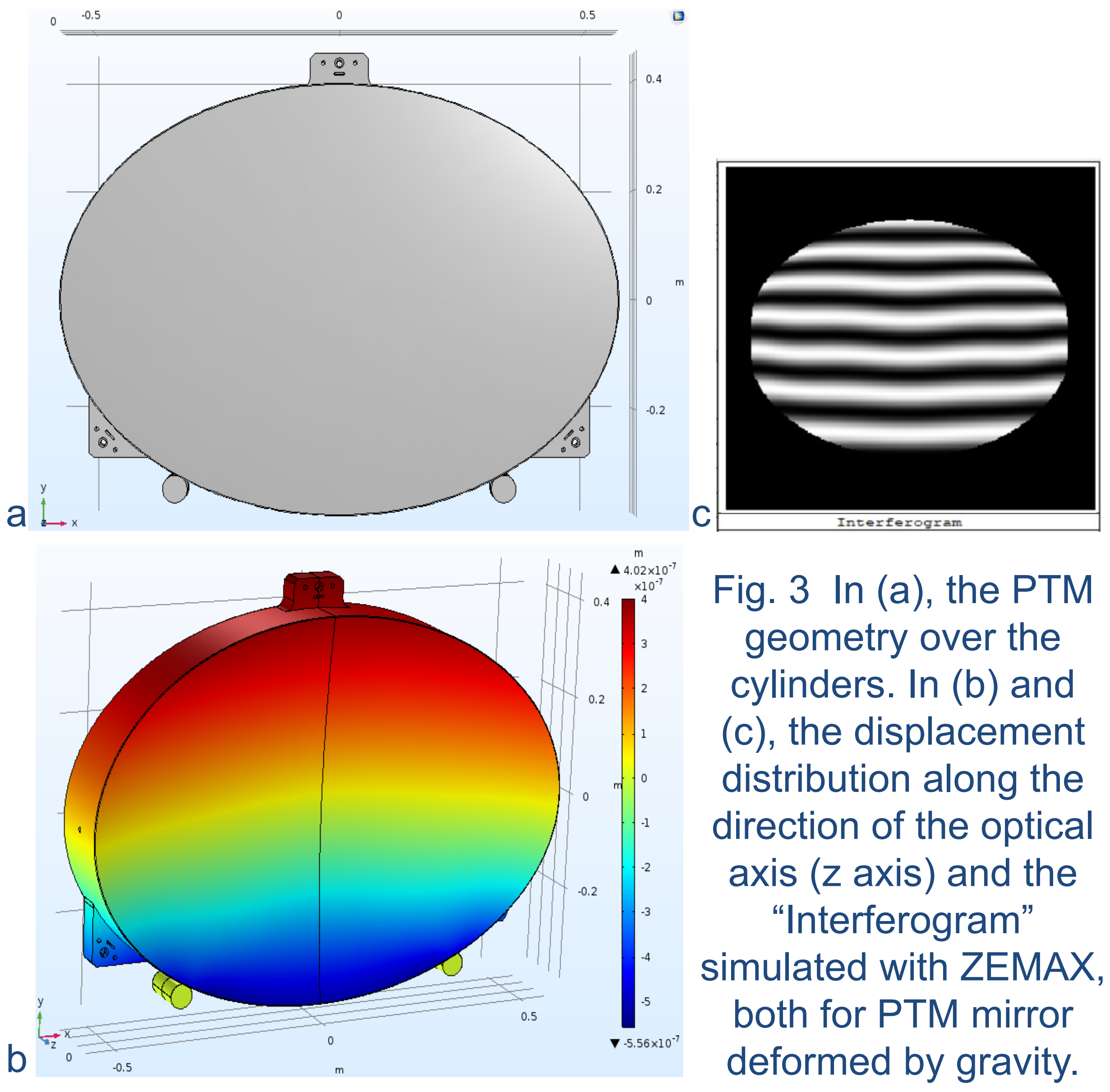

Fig. 3 In (a), the PTM geometry over the cylinders. In (b) and (c), the displacement distribution along the direction of the optical axis (z axis) and the "Interferogram" simulated with ZEMAX, both for PTM mirror deformed by gravity.

CONCLUSIONS

A good definition of the FEM model is a key step to predict the deformed shape of the instrument optical surfaces, which can be processed and analysed in a ray-tracing program. The surface's polynomial fitting is the recommended strategy, because it generates a series of coefficients which can be easily imported in the optical design software, so that these surfaces can be studied.

An application of this method consists of the optical analysis of the thermo-mechanically deformed demonstrator of the ARIEL primary mirror.

An in-depth optical analysis of these deformed surfaces is in progress, especially about the mirror at cryogenic temperatures, as it implies a refocusing adjustment of the optical system.

REFERENCES

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