Thermo-mechanical design and birefringence analysis for the MezzoCielo assembly

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INTRODUCTION

MezzoCielo is a novel concept of global Field of View (FoV) optical instruments: it aims to simultaneously survey the whole sky observable from a single site on Earth. In order to achieve this goal (a FoV of ~10^4 deg^2), MezzoCielo exploits several properties: 1) optical design of a central sphere[1]; 2) dodecahedral frame structure carrying 12 equals 1-m aperture BK7 lenses; 3) filling of the sphere inner volume with low refractive index optical fluid for convergence on the (curved) focal plane. From a mechanical standpoint, the lenses are subjected to hydrostatic pressure, in addition to their own weight: a lenses thickness of 12 cm should be sufficient to limit the maximum displacements to 10 μm^2. The telescope will operate in a mountain location: a thermal sizing is required in order to minimize stresses, strains and limit the focal length variation. A birefringence analysis has been employed as instrument to select the final optimum lenses shape: circular or pentagonal one.

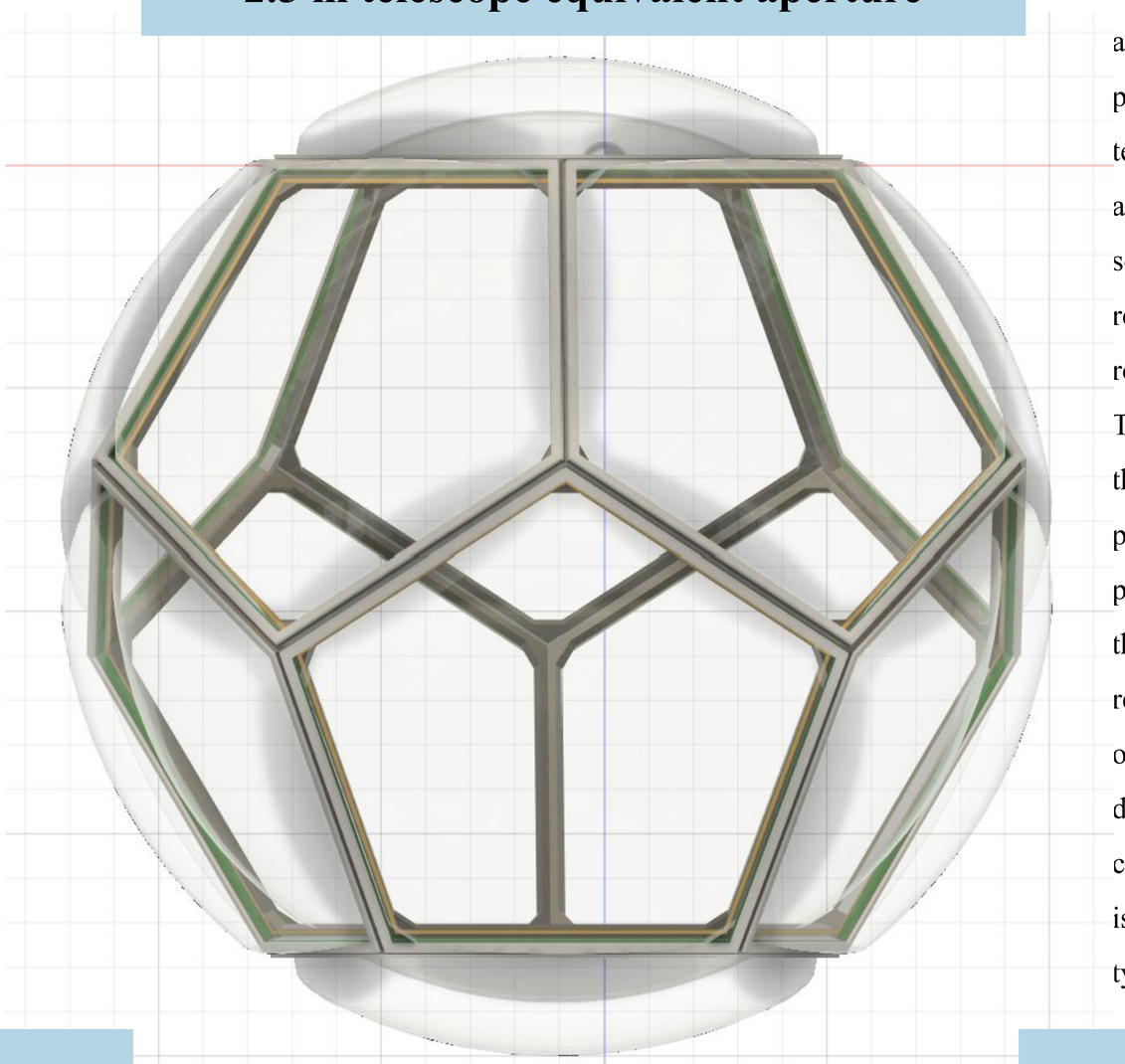
Thermo-mechanical sizing

The focal length of such monocentric system depends upon the refractive indices of glass, n_1, and fluid, n_2, and on the lenses radius of curvature R_1 and R_2. However, as verified, the main parameter is n_2 whose small alterations (for example, due to temperature variations) produce significant focal changes. A solution could be maintaining constant the liquid temperature, associating to the system a recirculation device for fluid temperature control.

In order to verify the lenses capability of withstanding the thermal gradients during the winter activity, we have considered as a case study an environmental temperature of -5°C and natural convection.

Based on the materials thermal properties, analytical thermal computations have showed that, after 12 hours, the minimum temperature reached by the lenses is around 14.5°C. The related radius change is lesser than the tolerance for precise optics.

Case study:
R_1 = 1.12 m, R_2 = 1 m, 1 m aperture lenses, 2.5 m telescope equivalent aperture



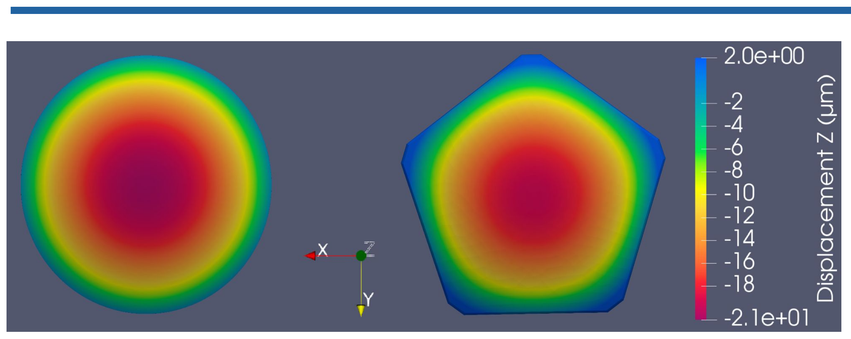
Finite Element Analysis

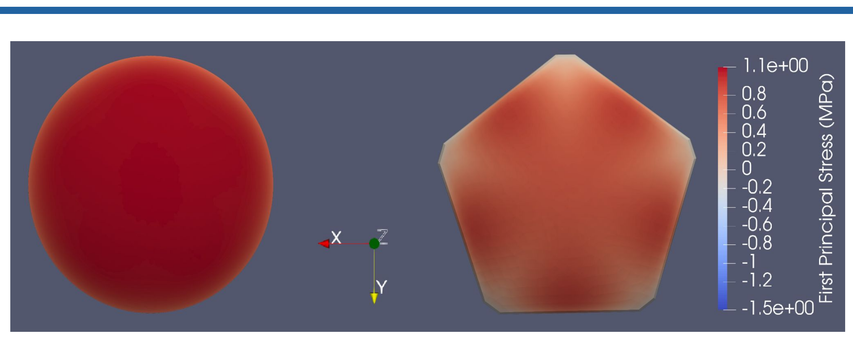
The Finite Elements Analysis have been carried out for all the lenses of the assembly (both circular and pentagonal in shape) with the aim of verifying the temperatures and displacements distributions. Stresses and safety factors have been computed in the worst-case scenario: both thermal and gravitational loads acting. The results are promising since they assure the frame robustness and no criticalities in terms of lenses integrity. The stress components have then been used to quantify the birefringence, that is the refractive index (and, hence, phase) difference established between the directions parallel and normal to that of the stress. Actually, among the three principal stresses (which should be used to represent a point state stress), only the first and second ones are relevant in terms of birefringence. Their difference, multiplied by the BK7 stress optical coefficient, suggests that the central portion of each lens is birefringence-free; along the edges, Δn is ~10^{-6}, a typical value for astronomical instruments[3].

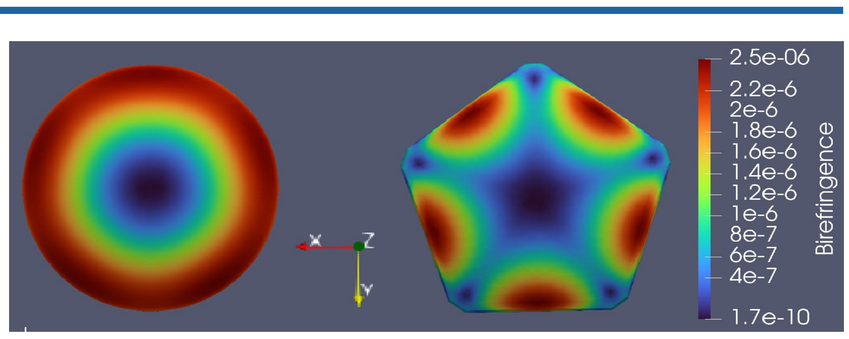
Optical materials:
BK7 glass: n_1 = 1.5168,
FC-72 optical fluid: n_2 = 1.2512
at T = 20°C and λ = 580.7 nm

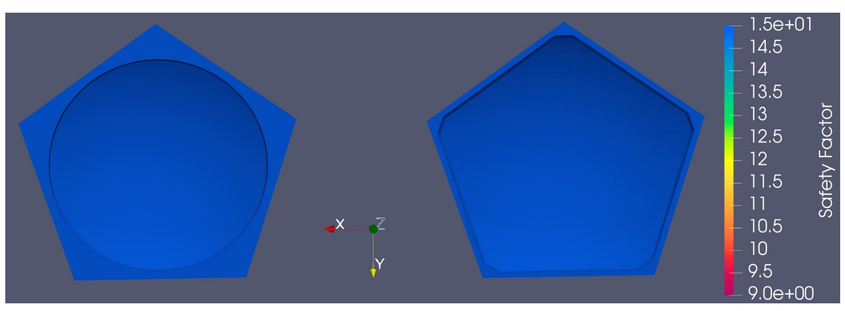
Structural materials:
Kovar (iron-nickel-cobalt alloy) frame, Milbond and 2214 regular epoxies as structural and sealing adhesives, polyurethane layer for insulation

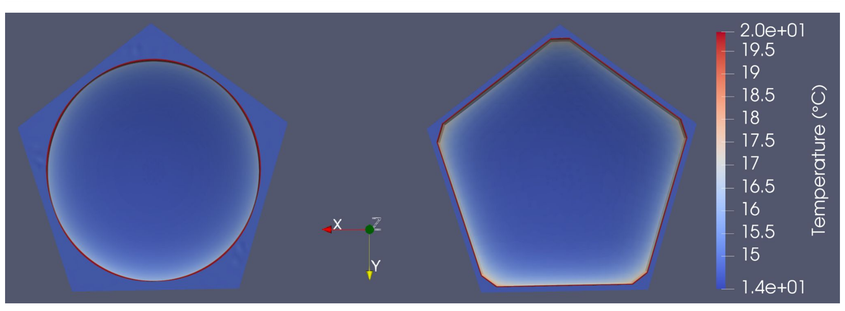
RESULTS











CONCLUSIONS

- Thermal and gravitational loads do not produce displacements greater than 30 μm: radius changes are less than 0.035%, safety factors everywhere greater than 10;

- the numerical analysis confirm that the minimum temperature is around 14.5°C for both lenses type; for circular lenses, displacements, stresses and birefringence are higher than pentagonal lenses ones. The latter could be employed for the MezzoCielo assembly in order to reduce the frame obstruction. Opto-mechanical tests have to be carried out to verify their suitability.

REFERENCES

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3. Schott, *Stress in Optical glass, Technical Information, Adv. Optics* (2004)