Integrated opto-dynamic modeling of the 4-m DAG telescope image quality performance

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Abstract

The Turkish DAG 4-m telescope is currently through the final design stage. It is to be located on a 3170 m mountain top in Eastern Anatolia. The telescope will be a state-of-the art device, alt-az mount with active primary and adjustable secondary and tertiary mirrors. Its optics design is specially aimed at being compatible with advance adaptive optics instrumentation. The ultimate performance of such a telescope results of multiple concurrent effects from many different components and active functions of the complex system.

The paper presents a comprehensive integrated (end-to-end) model of the telescope, comprising in one computational sequence all structural, electrodynamics and oactive optics performance that produce the image quality at the focal plane. The model is entirely programmed in Matlab/Simulink and comprises a finite element model of structure and mirrors, dynamics modal reduction, deformation analyses of structural and optical elements, active optics feedback control in the Zernike modal space.

Keywords: End-to-end modeling, integrated modeling.

1. INTRODUCTION

Modern astronomical telescopes are quite complex systems when it comes to sizing and finding the optimum relationship among multifold design parameters, which interact in many different manners to produce result performances.

Here a comprehensive end-to-end (E2E) model was developed to serve as a systems engineering design tool. Essentially this model allows to formulate inputs expressed in terms of general specification values such as overall geometry, displacement ranges, external disturbances, etc., and **compute in one run** a comprehensive set of performances.

2. OUTLINE

This parametric model, implemented in MATLAB, is schematically illustrated at the figure at the next page. On the left side, the various input data while the resulting performances are found along the right edge. Essentially this model takes inputs expressed in terms of general specification values such as overall geometry, displacement ranges, external disturbances, etc., and compute in one run a comprehensive set of telescope performances. The model makes use of specialized toolboxes for structural and optical (i.e. Zernike) analysis in particular.

The main telescope characteristics evaluated by the model are:

- Static analysis under gravity, seismic and wind loads

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- Complete structural dynamic analysis
- Eigenfrequencies and modes
- Zernike modes analysis for the primary mirror

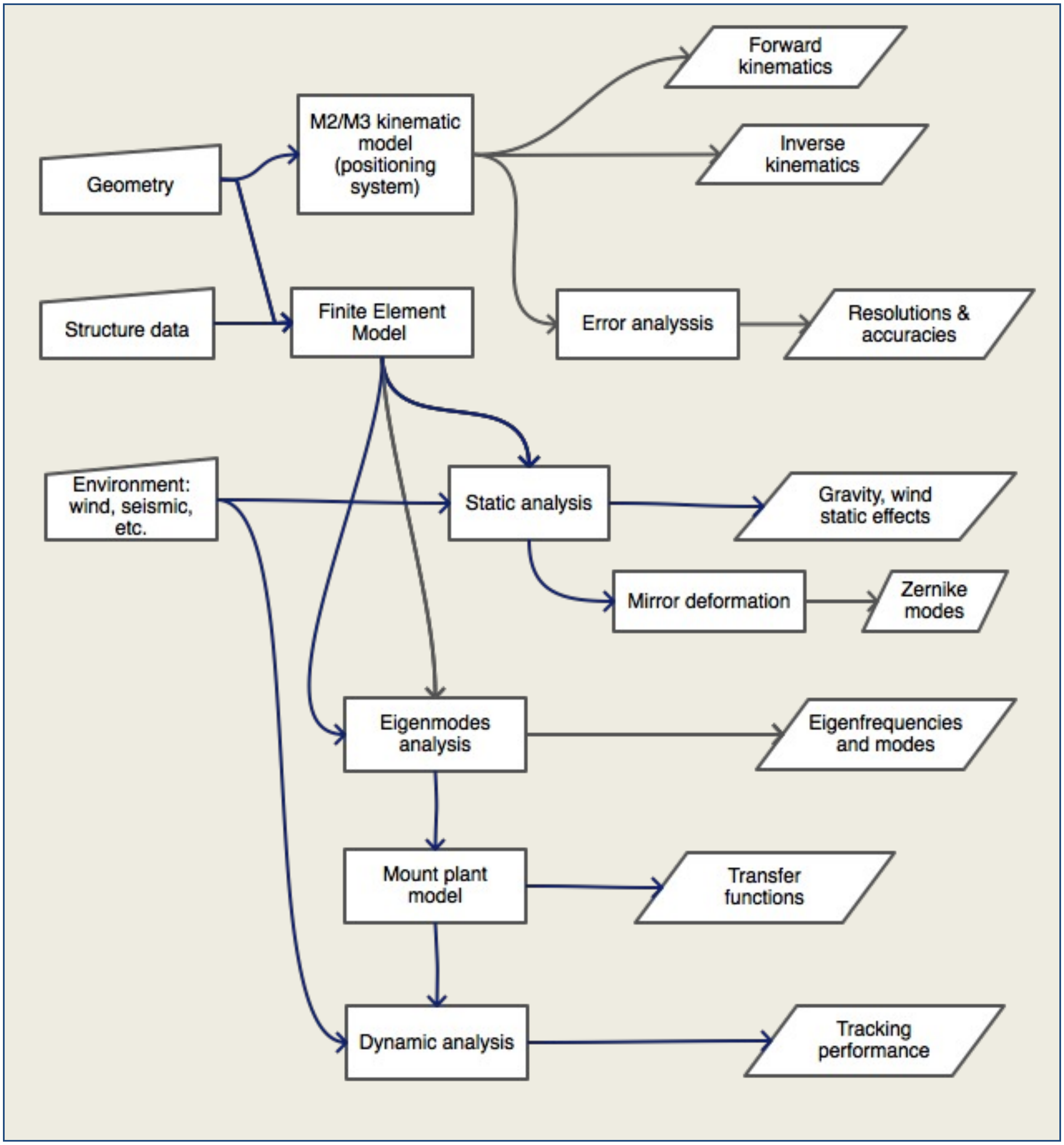

Figure 1. Structure and articulation of the DAG telescope integrated model.

The model comprises various functional modules, all with parametric input. All sizing input data are read from a single m-file. Data also include tolerances and any kind of statistical variations.

3. EXAMPLE: INTEGRATED TRACKING PERFORMANCE EVALUATION

A complete description of the integrated telescope model would be too long here. We therefore limit the scope of this paper to the model subset in charge of the evaluation of the telescope tracking performance.

The E2E model has at his core a finite element model (based on the CalFem and OpenFem toolboxes) which, albeit relatively simple, is nevertheless capable of producing a rather complete set of output data required to assess with good accuracy the influence of all structural aspects, in particular with respect to stiffness, strength, and dynamics.

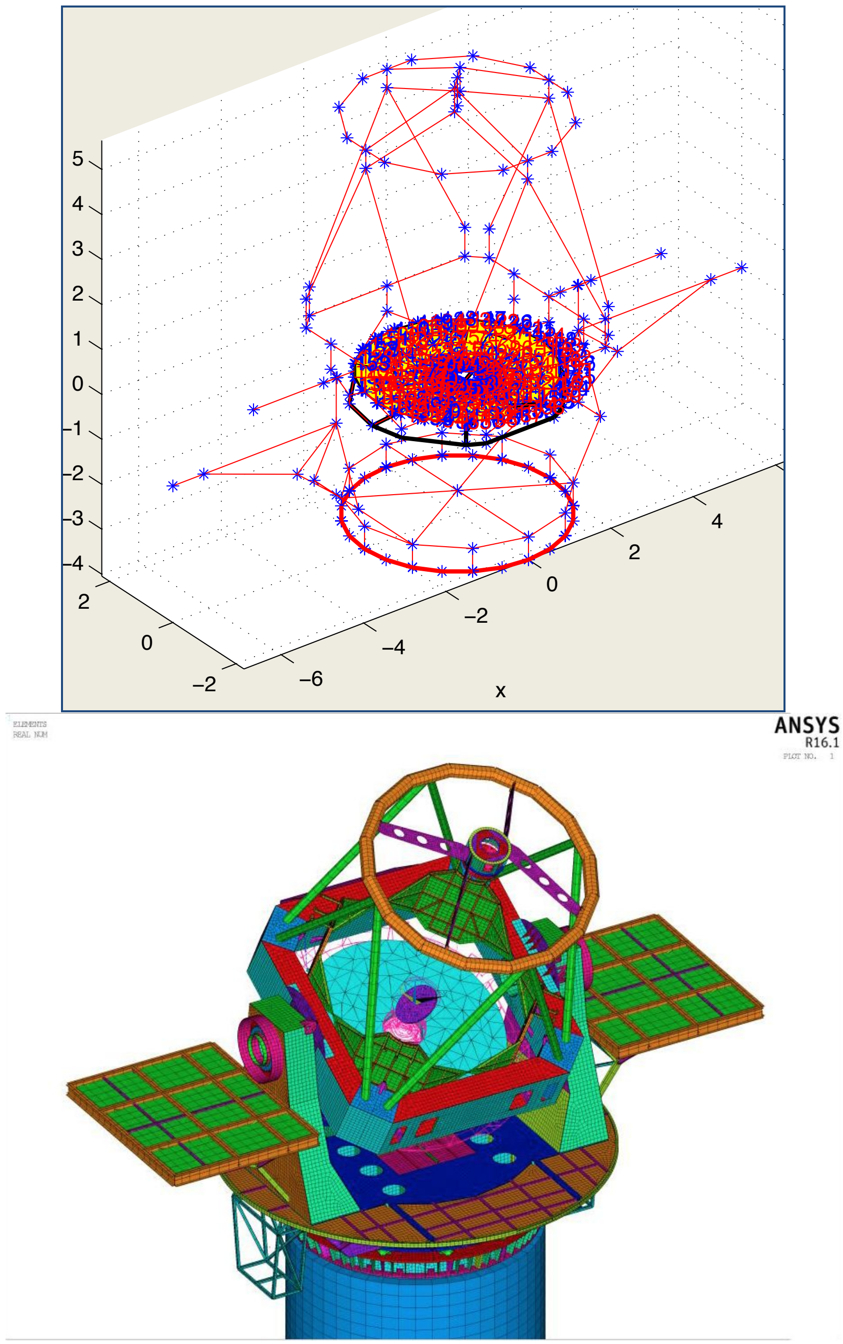

Figure 2. Above: the simplified finite element model employed by the E2E model, the telescope structure is constituted of beam elements, while the primary mirror is modeled by shell elements. Below: the full detailed ANSYS model used by the telescope contractor.

Although this model is much simpler than a full FEM, as its meshes are much coarser, it nonetheless does provide already a very good representation for many purposes, in particular modal analysis and all kinds of dynamic and kinematic simulation. Its main advantage is that it can be run with a different set of inputs in a few seconds, thus allowing a very fast turnout for evaluating the impact of design changes in the concept phase. Then, being run as Matlab functions, its output can be seamlessly piped to further analyses, such the Zernike modes analysis.

This simplified finite element model may then be considered a functional realistic representation of the structural characteristics.

The adequacy of the simplified model can be demonstrated by comparing the eigenmode results with those of the detailed ANSYS model.

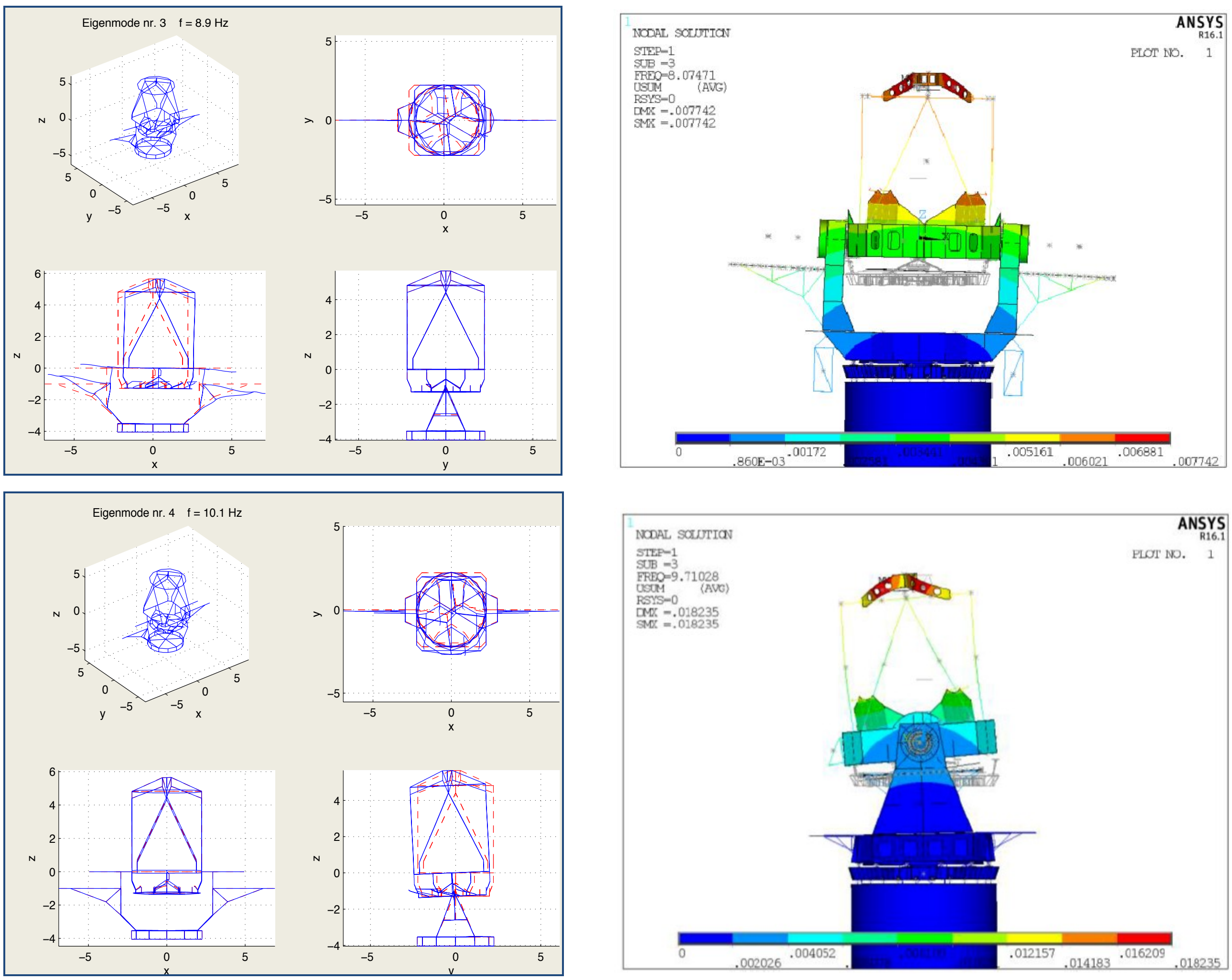

Figure 3. The first two structural eigenmodes of the telescope. Left the outcome of the E2E model, right that of the detailed FEM computation with ANSYS, which shows very similar results.

The eigenmode results are then converted to state space formulation and used to create the plant model of the telescope for a Matlab/Simulink computation.

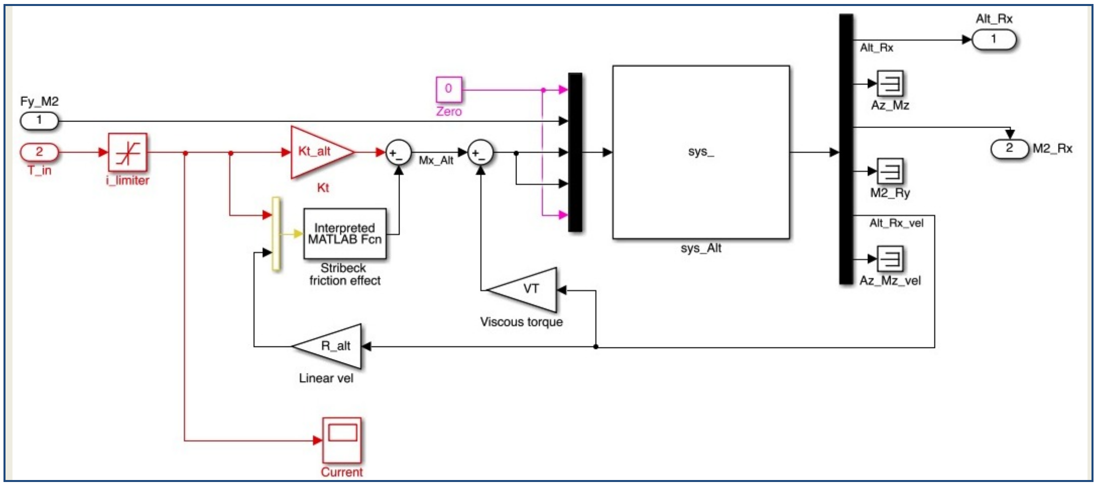

Figure 4. Plant model of the telescope for pointing and tracking.

Various effects related to the bearings (friction) and drives (viscous torque, cogging, …) are also included at this stage.

Then the Simulink model of the telescope mount (both axes) is created adding a suitable controller. Sensor accuracy is taken into account, and various cases can then be evaluated: slewing, tracking, etc..

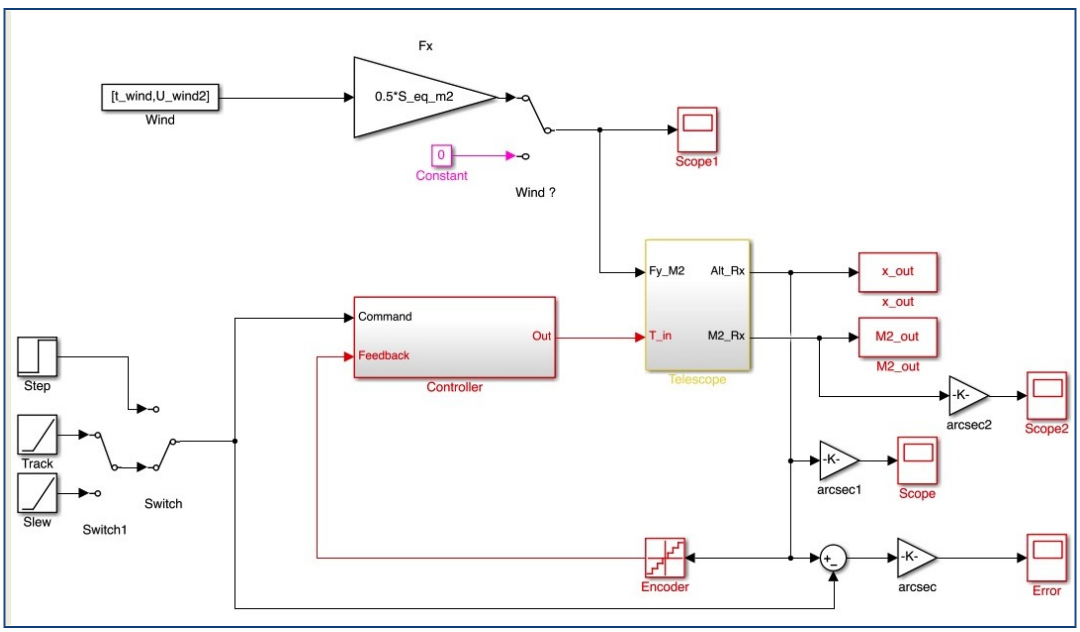

Figure 5. System model with controller

The aerodynamic effect of turbulent wind on the telescope is taken into account as specified for the conditions inside the enclosure: maximum mean wind speed 4 m/s, turbulence intensity 0.2, turbulence scale 2 m (mainly created by the slit width). The specified Von Karman spectrum was first corrected for the aerodynamic attenuation due to the telescope size, then a corresponding wind time sequence is computed.

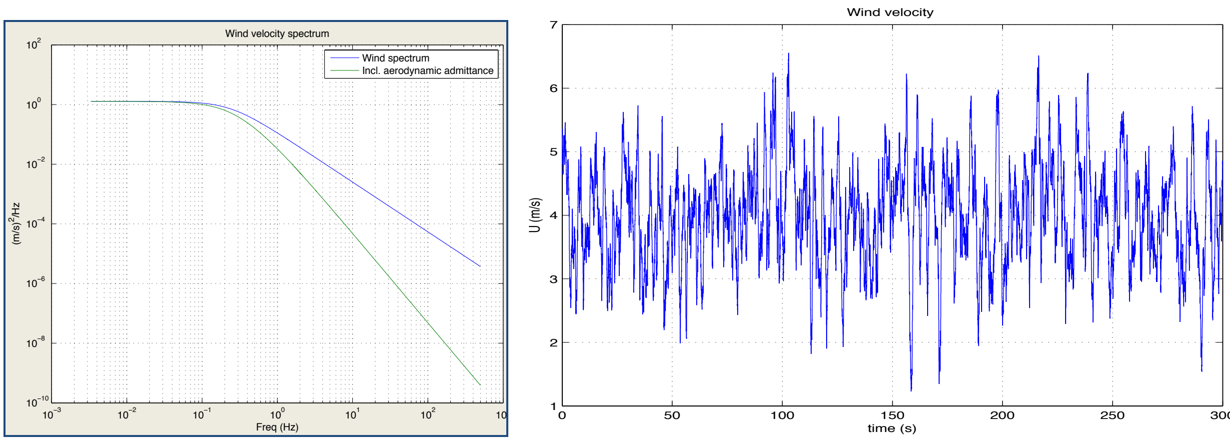

Figure 6. Wind spectrum and its correction due to the aerodynamic admittance of the telescope structure which decreases the effects of high frequency vortices. Right the computed time sequence.

The tracking performance is then computed about both axes.

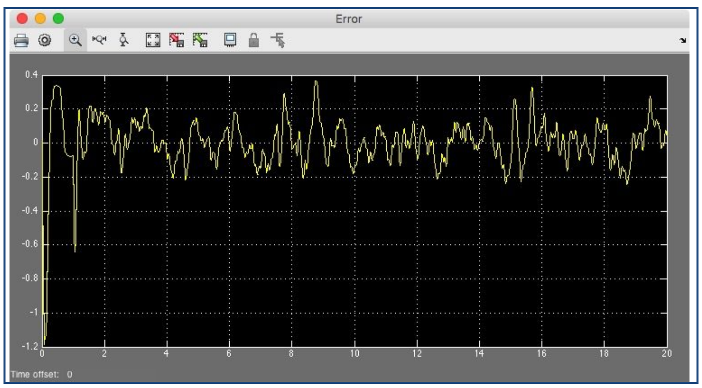

Figure 7. Currently evaluated DAG tracking performance in closed loop. The *rms* is about 0.10 arcsec.

4. CONCLUSION

The integrated model of the DAG telescope includes multifold functional modules, all with parametric input. All sizing input data are read from a single m-file. At its core the E2E model has a finite element model, which in spite of its apparent simplicity, is in fact capable of representing all main functional and performance aspects. This provides the possibility to easily change any sizing parameter and **compute in one fast run** a comprehensive set of telescope performances.

5. ACKNOWLEDGMENTS

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