DEPLOYABLE OPTICS FOR REMOTE SENSING APPLICATIONS: PERFORMANCES OF THE DEPLOYMENT MECHANISM. Igor Di Varano[1], Fabrizio Capaccioni[1], Gianrico Filacchione[1], Giovanna Rinaldi[1], Bortolino Saggin[2]. [1] INAF-IAPS, Institute for Space Astrophysics and Planetology, Rome, Italy, [2] Department of Mechanical Engineering, Politecnico di Milano, Lecco, Italy.

Introduction: The Deployable Optics for Remote sensing Applications (DORA) is a breadboard testbench to validate the performances of an innovative deployable full aperture Cassegrain telescope for space.

Since the entrance aperture and focal length of an imaging system are bound to the spacecraft dimensions, the objective of the study was the design of a deployable system offering compactness and a drastic reduction of the payload mass without compromising high quality optical performances [1, 2], capable of satisfying the needs of small satellites.

The DORA project, financially supported by the Italian Ministry of Research within the framework of Italian National Research Plan 2015-2020, benefits from the synergy among several research institutes (INAF-IAPS, Institute for Space Astrophysics and Planetology in Rome, INAF-OAPD, Padua Astronomical Observatory), Universities (Naples University "Parthenope", Politecnico of Milan) and private companies (SITAEL S.p.A., Steam S.r.l. and KAD3 S.r.l.).

The mechanism consists of four articulated double arms, each one deployed via four hinges driven by four microlinear actuators provided by Actuonix L16-140-150-12 P, with a maximum stroke of 140 mm, maximum load capacity of 200 N, gear ratio 150:1.

In the present project the telescope would be interfaced to a Fourier Transform IR spectrometer (MIMA - Mars Infrared Mapper – devoted to the monitoring the Earth environment through the detection of atmospheric pollutants [2, 3]). However, our final goal would be to design a deployable mechanism suitable to be matched to an imaging camera.

Opto-mechanical parameters: DORA is a Cassegrain type telescope, with an f/16 aperture, entrance pupil Ø300 mm, FOV≤ 0.16° and effective focal length of 4863.287 mm, with a maximum relative distance between the primary and secondary mirrors of 600 mm and back focal length of 1110.389 mm.

The optical design layout is highlighted more in detail in [4] and a summary is given in Table 1.

The surface form errors for both mirrors, measured via a non-contact profilometer MPR, have been implemented in Zemax to estimate the actual residual aberrations due to the manufacturing process [5].

Breadboard deployment verification: In order to measure the accuracy and the repeatability of the telescope deployment, and to check that the values retrieved are compliant with the tolerance analysis assumed by the optical design, a Hexagon absolute Romer arm has been used.

Table 1 DORA main optical parameters

	Radius of curvature [mm]	**Distance to next surface [mm]**	**Conic constant (K)**	**Diameter [mm]**
Entrance pupil				300.00
Primary mirror (M1)	-1560.34	-600	-1.00	max=300.00 min= 60.00
Secondary mirror (M2)	-430.14	1110.3896	-1.91	71.17

The Romer Hexagon absolute arm is a 7 axis articulated arm with interchangeable scanning probes. For our application we have used a Ø6 mm spherical tactile probe of Rubidium. An accuracy of 30 µm in measuring is estimated, linked to the dimension of the probe. Since our main target is to analyze the statistics of the repeatability during the deployment, it is more suitable to refer always to the same points on the structure. We adopted three Ø3 mm holes for pins insertion located on the supporting plate of the secondary mirror. The three holes are lying on a circumference, whose center ideally represents a point on the optical axis, intersecting the vertex of the secondary mirror. Assuming that the top ring plate where the measured pins are located is acting like a rigid body, we are interested in determining its displacements and rotations. Out of several deployment test sequences performed, ruling out the ones used to set up the proper reference system, we identified nine deployment cycles. At each cycle we performed three measurements of the absolute positions of the three holes. Then we computed the average value for the measurements for each cycle. The differences between these average values give us the sequential displacements, and their standard deviations the positioning errors.

In the meanwhile, we have fitted the pins positions with the intersecting circles, whose centers we assume to be related to the secondary mirror vertex. We determine the relative displacements for the centers of the circles between the cycles and their standard deviation, which provide us with the center displacements along the three directions Δx, Δy, Δz and therefore the decentering and despacing values necessary to run the tolerance analysis.

As far as the Euler angles are concerned, we start from the assumption that from the three pins locations we can always retrieve two vectors lying on the same plane with a constant angle between them and determine via the cross product the vector normal to that plane. This way we can construct a Rodrigues rotation matrix which is related to Euler matrix embedding three consecutive rotations (pitch, roll and yaw) and retrieve the Euler angles (see Table 2).

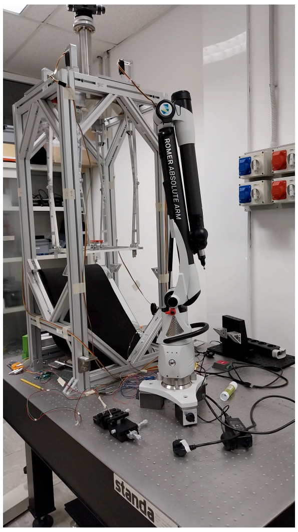

Figure 1 DORA in action in the deployed configuration in the lab with Romer Hexagon absolute arm standing in front of it.

The deployment causes shift of the line of sight by less than 100 μm along the three axis. In particular the defocus (Δz) is limited to 4.4 μm.
Subsequently we introduced these displacements (as decentering, tilt and thickness variation) in the Zemax model of the telescope and verified their impact on the optical quality with respect to a fixed telescope and for mirrors with a surface irregularity of ±λ/4 , selecting as reference wavelength λ=0.6 μm.

Table 2 Euler displacements and angles representing the input parameters for the tolerance analysis in Zemax

Euler parameters	Standard deviation [mm]
Δx [mm]	±0.093432975
Δy [mm]	±0.075918875
Δz [mm]	±0.004409
Δα [degrees]	5.4e-03
Δβ [degrees]	9.194e-04
Δγ [degrees]	0.029

Fig. 2 reports the Zemax simulation with a perfectly aligned telescope (Fig.2 Top) and and the spot diagram of the telescope performances after a simulated deployment using the Table 2 parameters. The bottom part of Fig.2 shows the corresponding MTF for the diffraction limited case (perfectly aligned telescope) and the deployed telescope with the above parameters.

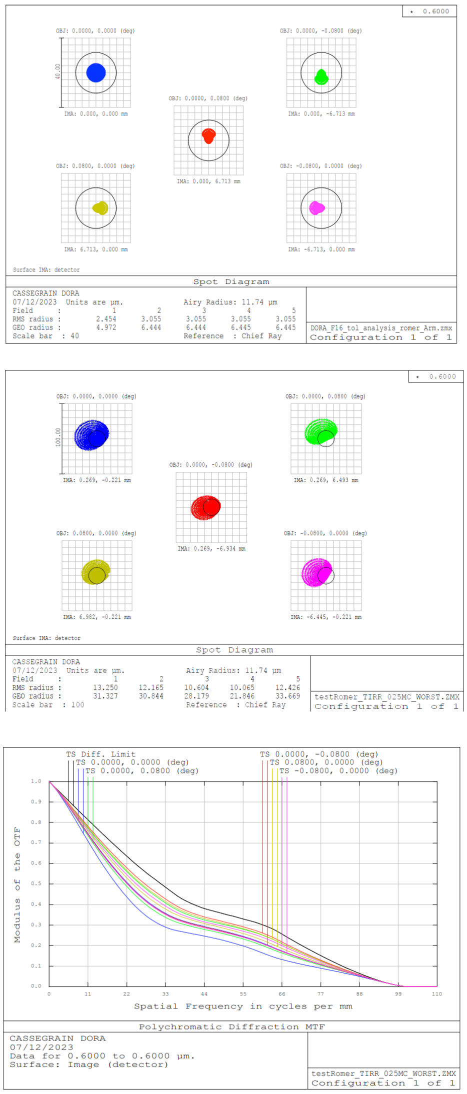

Figure 2 Top: spot diagrams relative to the worst case when we apply Euler parameters with ±λ/4 surface irregularity on both mirrors; center: for the case of ideal surfaces all spots are inside the Airy disk; bottom: MTF for the worst case ±λ/4 compared with the diffraction limited case.

References:

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