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ABSTRACT

The Maunakea Spectroscopic Explorer (MSE) project aims to build a 10-meter class telescope that will be fully dedicated to spectroscopic exploration of the universe. With an ability to simultaneously measure thousands of objects with a spectral resolution range spanning from 2,500 to 40,000, this one-of-a-kind facility will offer unique scientific opportunities to the astrophysics community in the study of the chemistry and dynamics of the Cosmos.

Maunakea is one of the best sites in the world for astronomy and, at the same time, a culturally and environmentally sensitive area. The location of the current 3.6m Canada France Hawaii Telescope (CFHT) is arguably one of the best observation points in Maunakea, and thus, it was resolved to minimize impact on the site by redeveloping the 3.6 meter CFHT Telescope and using their former facility building and telescope pier to build and host a larger 10-meter class telescope for the MSE Project.

The MSE – CFHT Corporation entrusted IDOM with the Conceptual Design of the MSE Telescope. The telescope design developed by IDOM features a novel architecture that combines well-proven and robust technologies, integrated in a telescope assembly that delivers optomechanic and mechatronic performances exceeding the 10-meter class telescopes currently in operation.

The developed solution offers a very high stiffness-to-mass ratio that leads to optimal seeing performance. It also incorporates a high efficiency seismic protection system and other remarkable features.

Keywords: MSE, CFHT, Maunakea, spectroscopic, efficient, stiffness-to-mass ratio, aerothermal.

1. INTRODUCTION

In August 2016, IDOM was commissioned by the MSE project to develop a conceptual design of a new telescope mount replacing the current 3.6m CFHT telescope with a modern 10m-class telescope. The telescope mount will house a 11.25m segmented primary mirror, which is more than three times bigger, and support a prime focus station at its top-end. The telescope tube must fit within a similar spherical interior volume as in the current CFHT dome but with a diametric increase of 10% linearly, and weight no more than the current CFHT telescope with its payload. The major payloads are the prime focus station systems, also known as top end assembly, including a hexapod carrying a large wide field corrector optical barrel that delivers a 1.5 square degree field of view to more than 4,000 robotic positioners distributed uniformly on the focal surface; the primary mirror system with 60 1.44m hexagonal segments and its actively controlled whiffletree support system; and multiple spectrographs on two instrument platforms provided by the telescope mount.

The telescope mount is essentially part of an optical system, hence it must meet stringent stiffness requirements to maintain alignment between the optical elements, which are the primary mirror and prime focus station, as its elevation

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structure, also known as altitude structure or telescope tube, tilts during the observation. The mount must be opened geometrically to allow air flow across the optical path between the optical elements to eliminate the thermally induced seeing effects. Moreover, the mount must have dynamic characteristics to allow smooth tracking of celestial objects while in motion without jitter or wind shake and able to protect its delicate payload during earthquakes by limiting the seismic loads.

IDOM took on the engineering challenge and developed a novice telescope mount design compliant with these requirements.

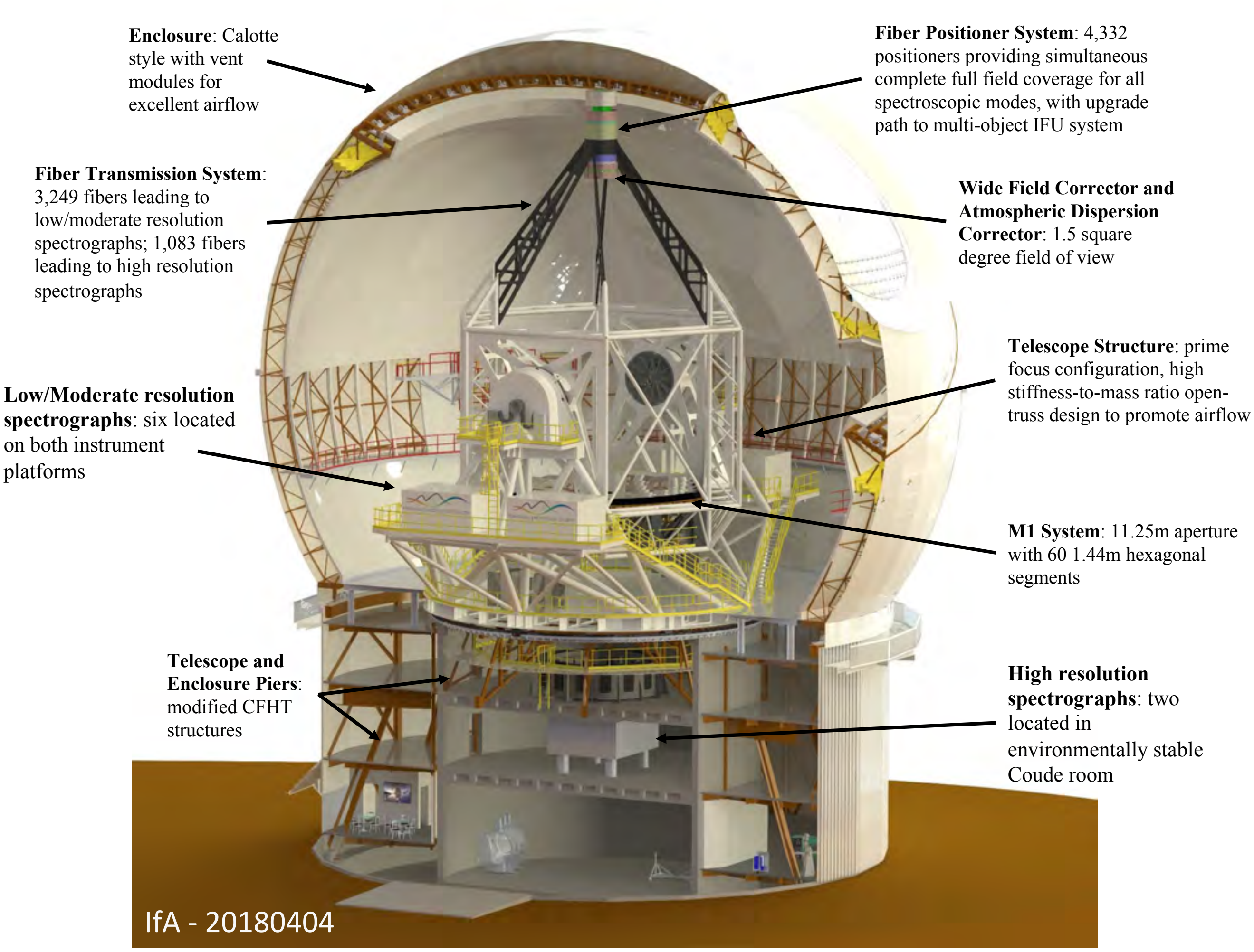

Figure 1. Section view of the Observatory showing the MSE Mount inside (Courtesy MSE Project Office)

2. DESIGN DRIVERS

The design drivers from the design requirements document were early identified in the conceptual design process and are summarized in this section.

The optical system is composed of a **segmented primary mirror** located below the elevation axis and composed of 60 hexagonal segments and support systems -1.44m across points and 600mm deep- and a **top end assembly (TEA)** which includes the wide field corrector, the atmospheric dispersion corrector and the fiber positioner system. The resulting focal length is 19072.34mm.

As in any telescope, the main design driver is to provide an appropriate structural load path to the existing optics. Among them, the support of the top end assembly while minimizing the obscuration and ensuring an appropriate dynamic performance is key.

The optical system is completed with two spectrograph platforms located in two symmetric positions in the Azimuth Structure as if they were Nasmyth Platforms, but away from the elevation axis. These platforms drive the design of the Azimuth Structure.

Due to the observatory layout, the elevation axis for the telescope is required to be away from the primary mirror resulting on a naturally unbalanced system. This is solved partially by strategically located counterweights in the proposed design.

Another design driver imposed by the fact that the telescope is assembled on the pier of an existing telescope (the CFHT), therefore a strict and immovable mass limitation is imposed by the existing concrete structure and its foundation. Not only that, the existing pier also defines the interface geometry with the Telescope Mount and the load transmission paths between it and the pier. The enclosure is also limited in size and mass by the existing enclosure pier, this makes the interface with the enclosure, in terms of avoiding interferences, quite challenging.

Last and not least, the aerothermal performance of the mount is also quite critical to make sure that natural ventilation between the enclosure vents and M1 is enhanced and thermal inertia minimized.

3. PROPOSED MOUNT CONCEPT

The mount concept proposed by IDOM is a yoke type telescope in which the telescope tube is solved with an innovative highly efficient structure based on well proven solutions.

The proposed **Altitude Structure** has an unusually high stiffness-to-weight ratio which allows complying with all the requirements with a lightweight solution,

- the Top End support structure (spider) provides a direct load path between the TEA and the Elevation Ring minimizing the M1 obscuration by using 80mm wide elements, which could be even reduced by using carbon fiber reinforced plastic (CFRP) reinforcements if neccesary
- the Elevation Ring is implemented with a double layer space frame with a large relative stiffness and transparent to incoming air to enhance the aerothermal performance
- the M1 Cell is an isogrid welded structure which provides stiff interface points for the M1 segment units and a very good access for maintenance.

The **Azimuth Structure** consists of two pillars of lattice towers supporting each one of the Altitude Trunnions and transferring the load to three points on the Telescope Pier perimeter. The Azimuth Floor and some additional bracing join the two pillars into a single structure.

Mechanisms are based on commercially available solutions configured in a way to provide a clear and statically determinate (isostatic) load path, including self-aligning features enhancing their robustness against structural misalignments.

In this sense, the design proposed for the **Azimuth Mechanism** considers establishing a central bearing to resist the radial loads, while the only vertical loads are supported on the Azimuth Track. This concept has the following advantages,

- it provides a clean load distribution,
- it simplifies the azimuth track design for fabrication and alignment processes,
- it improves the runout on the encoder system reducing the encoder error
- it allows the implementation of a simple 2D base isolation system to reduce the accelerations on hosted units

The **Azimuth Mechanism** is mainly composed of a set of hydrostatic bearings supporting axial loads and a central bearing supporting radial loads, a set of synchronous linear motors operating on a magnets track concentric with the Azimuth Track, hydraulic brakes, an encoder system, limit switches, end stops and a cable wrap.

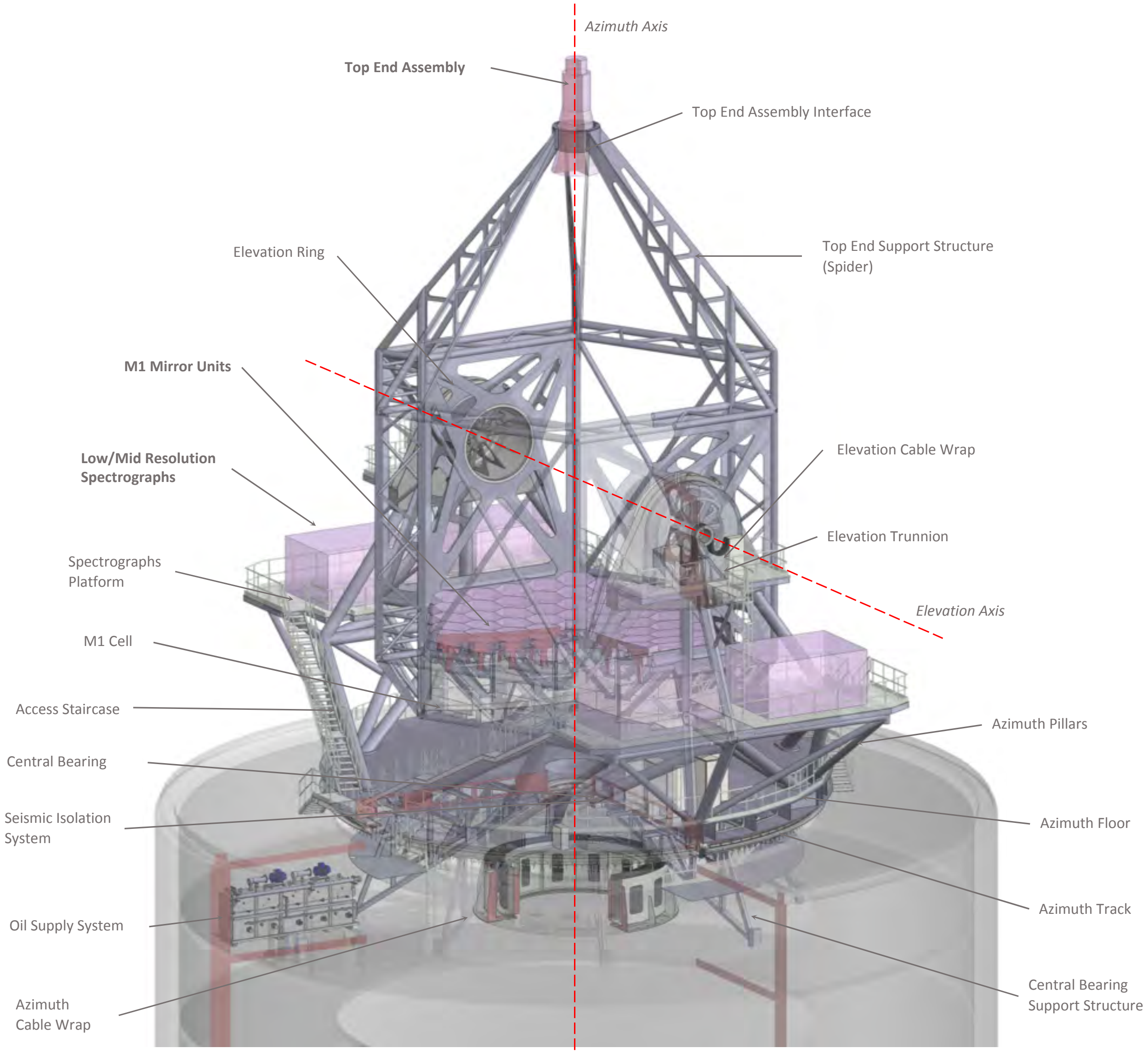

Figure 2. Descriptive view of the MSE Mount as assembled on the telescope pier.

The transfer of radial reactions from the central bearing is made by means of a dedicated structure directly connected to the concrete wall of the pier. In these conditions the removal of the top slab of the pier is recommended such that,

- access for maintenance to the Azimuth Mechanism is easier

- the trusses which support the central bearing would have more direct load path
- the removal of the concrete slab would lead to a weight reduction of about 140ton
- the system eigenvalues would increase due to the mass reduction
- the overall structural integrity of the pier improves if the slab is removed

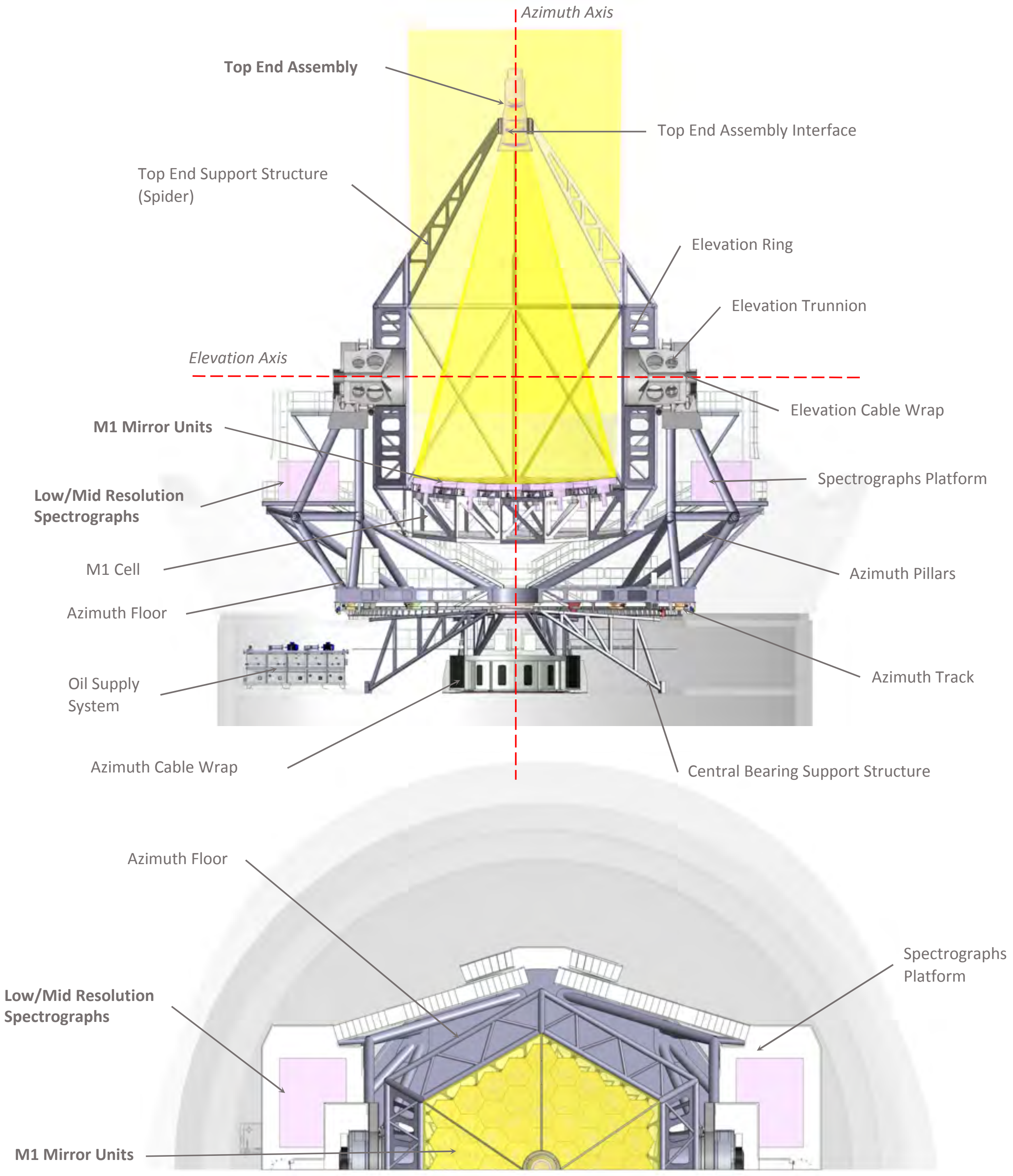

Figure 3. MSE Mount descriptive front and top views.

The **Altitude Mechanism** is built around the Altitude Trunnions which provide bearing surfaces for the Hydrostatic Bearing System and the mounting frame for the frameless torque motor used as the Drive System. Other components allocated in these trunnions are hydraulic brakes, locking pins, an encoder system, limit switches, end stops and a cable wrap.

A remarkable feature implemented in the design is the high frequency over-constraint (HFOC) strategy on the axial support of the Altitude Structure, which allows bearing axial loads on both ends of the structure improving the dynamic performance and the strength in case of a seismic event.

To study the **Control System**, the operational concept and scenarios have been analyzed, including to operational and maintenance scenarios, the necessary scenarios during the development and implementation phases. In this case, in addition to the control system specified in the requirements, the Telescope Safety System and Mount Control System, IDOM has determined new needs and proposes two additional systems. A Development and Acceptance control system acting as a Telescope Control System and/or Observatory Safety System emulator, and a simulation mode for the Mount Control System, to be used for early software development and verification, without the necessity of the real hardware.

The **Mechanical and Electrical Equipment**, includes the Oil Supply System (integral part of the Hydrostatic Bearing System), the Cooling System (distribution manifolds and cooling lines), the Compressed Air System and the Electrical System (distribution cabinets, cables and specific lighting in shaded areas not properly illuminated by the Dome lighting system).

4. CONCEPT VERIFICATION

From an analytical point of view, the proposed design is verified by,

- ✓ a set of detailed Structural Analyses which includes several Finite Element Analyses,
  - modes and frequencies analysis
  - static analyses at various elevation angles to check relative deflections during operation
  - non-linear time series analysis to determine the integrity of the telescope and hosted units during seismic events as assembled on the telescope pier with the seismic isolation system
  - a dedicated concrete pier integrity analysis

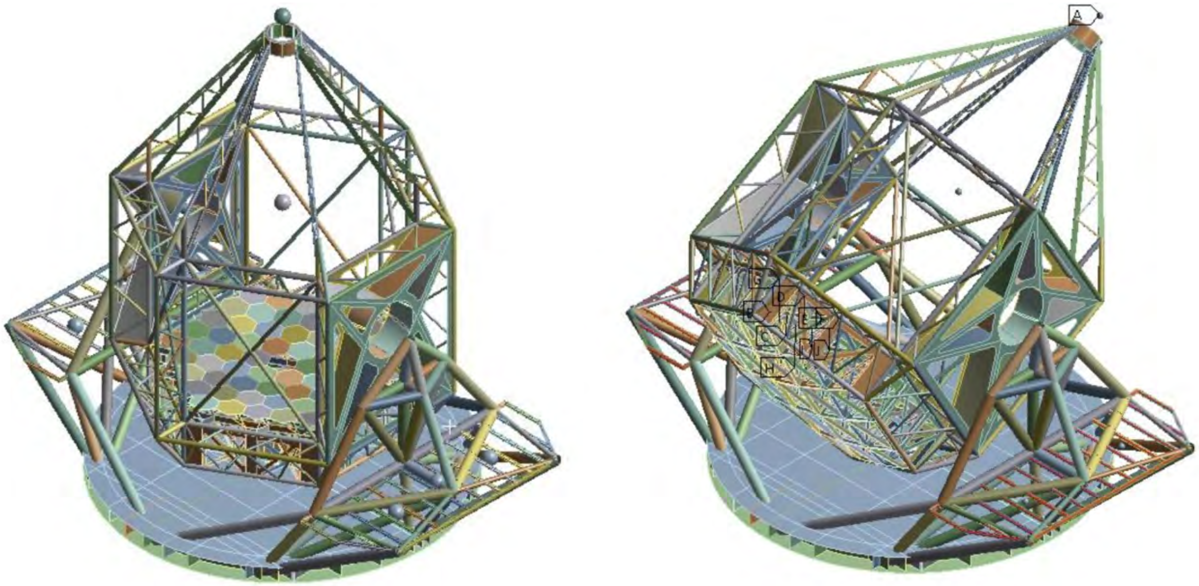

Figure 4. MSE Mount Finite Element Model. Structural components are represented by means of beam and shell elements, hosted units are represented by means of lumped mass/inertia elements.

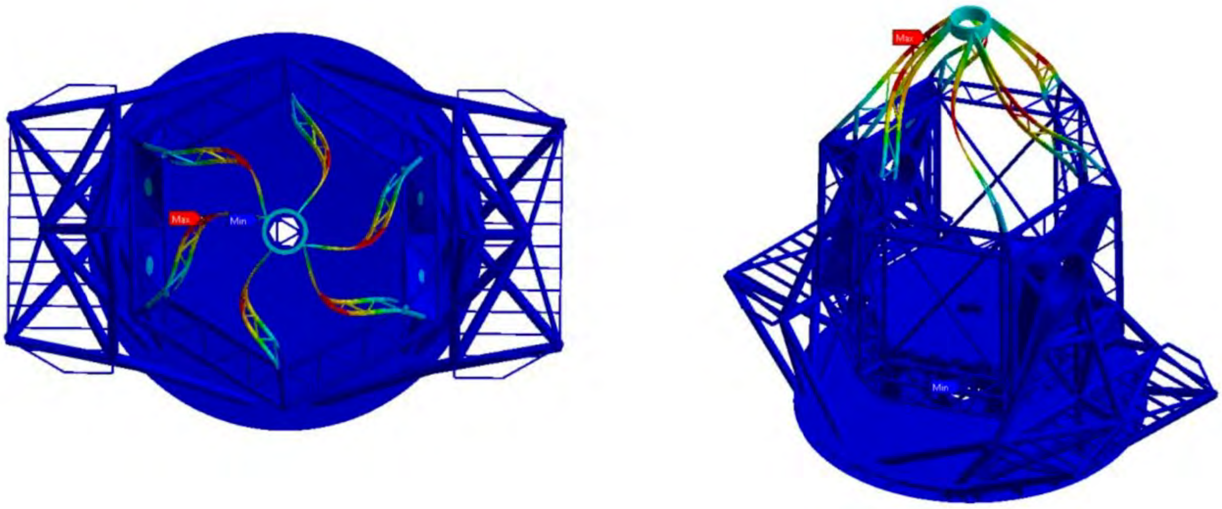

Figure 5. MSE Mount First Torsional Mode at 4.5Hz.

- ✓ a set of Mechanical Analyses justifying the selection of the main mechanical components and including a Finite Element Analysis of the most significant mechanism parts.

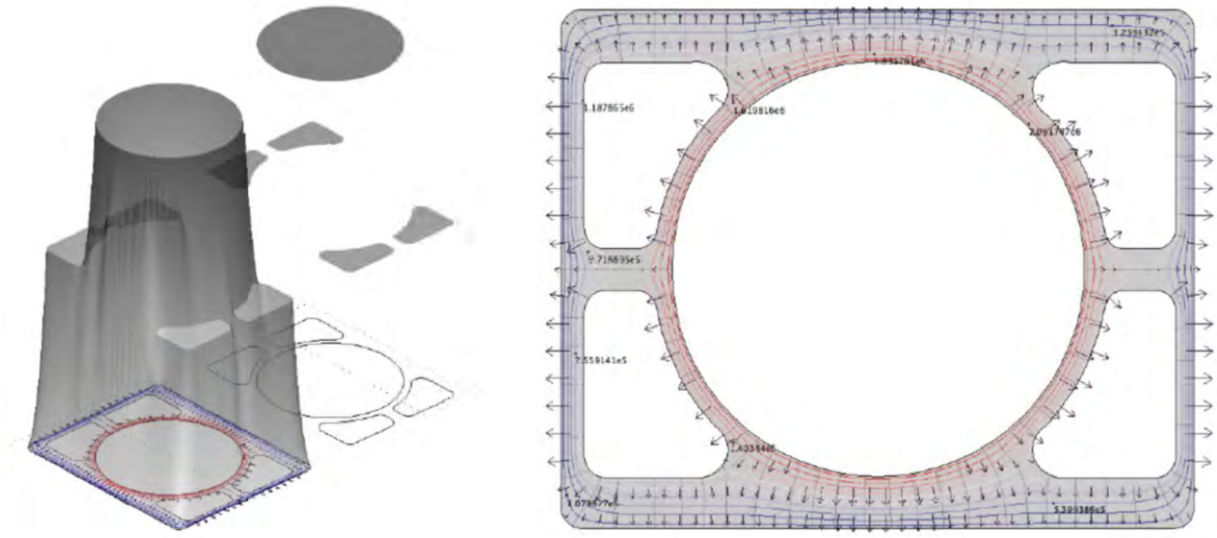

Figure 6. Oil Pressure/Flow results obtained from the analysis of the Hydrostatic Bearing System pads using IDOM in-house developed Finite Element Diffusion Models

- ✓ a set of Control System Analyses considering the structural properties of the structure, mechanisms, disturbances (as the wind buffeting, non-linear friction, cogging and torque ripple) and control system loops to determine the expected tracking error and jitter associated with the control system.

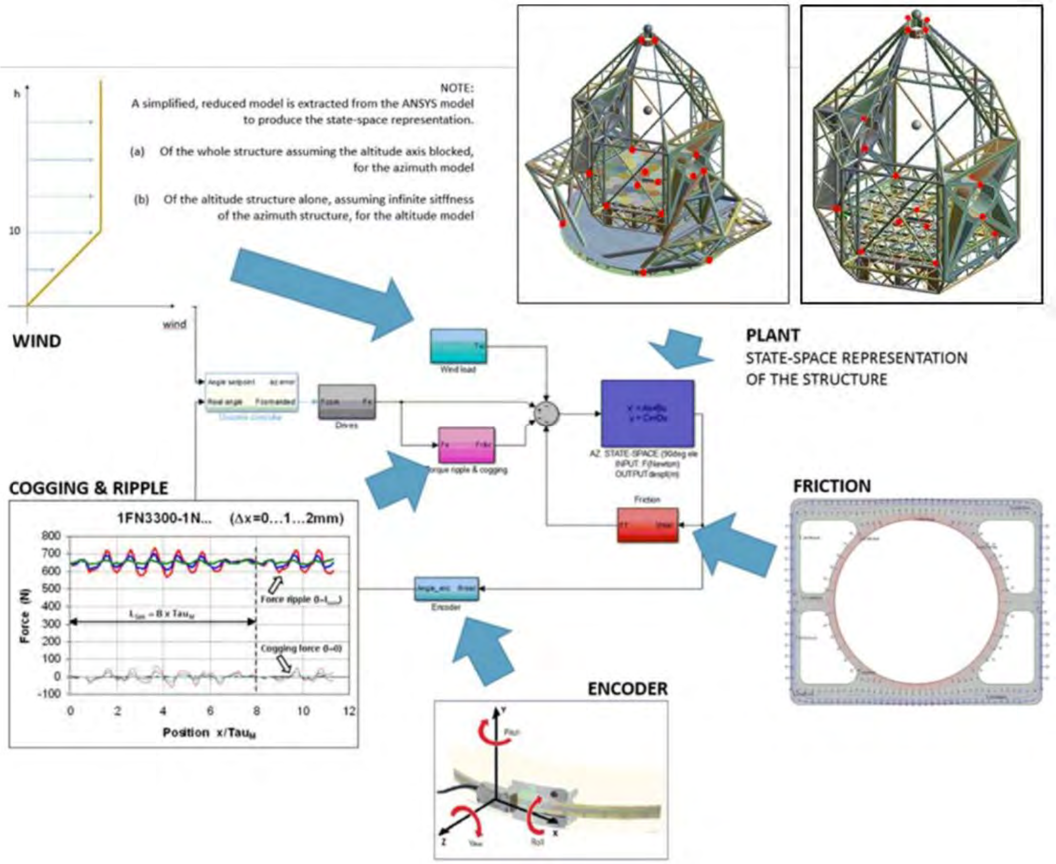

Figure 7. Control System Analysis Strategy: over the control loop the different elements are described, the structure derived from the FEM as a state space model, the friction on the bearing system, torque ripple and cogging from the drives, wind disturbances and encoder discretization error among others.

- ✓ a preliminary Error Budget summarizing the estimated main contributions to the pointing and tracking error and to the jitter.

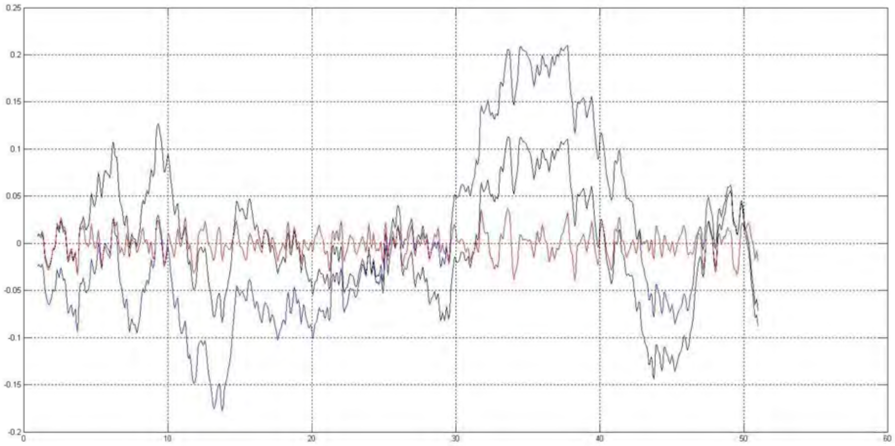

Figure 8. Simulated contribution from the Azimuth Track Roughness to the pointing error budget.

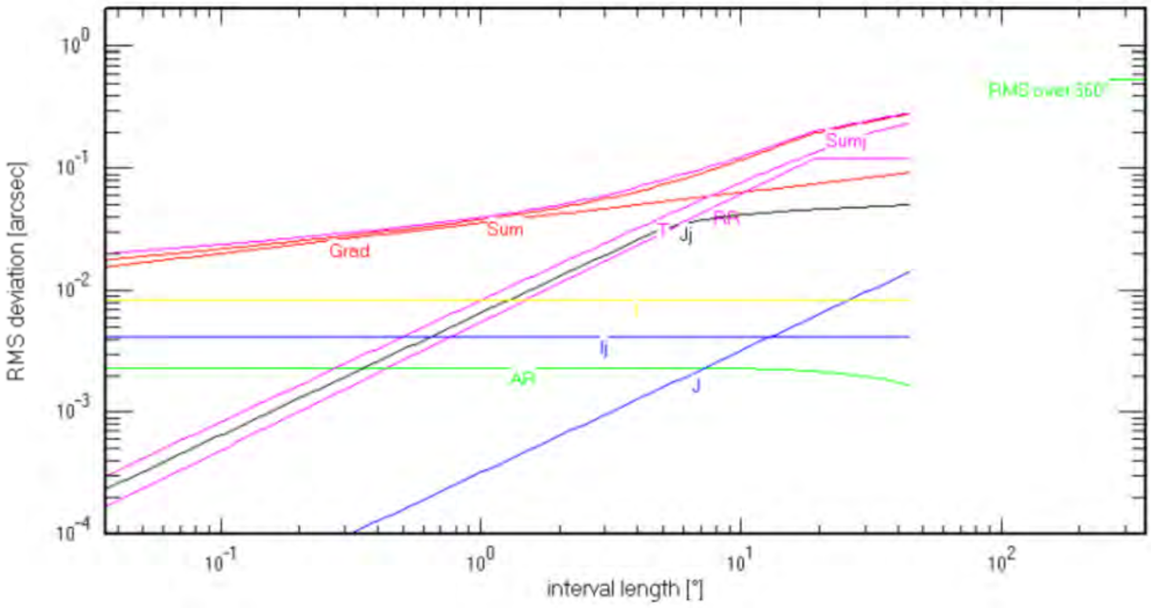

Figure 9. Error budget for the Encoder System (courtesy of HEIDENHAIN).

- ✓ a set of CFD Analyses including a comparative analysis of the aerothermal performance of the two telescope configurations considered and a more detail analysis of the selected option.

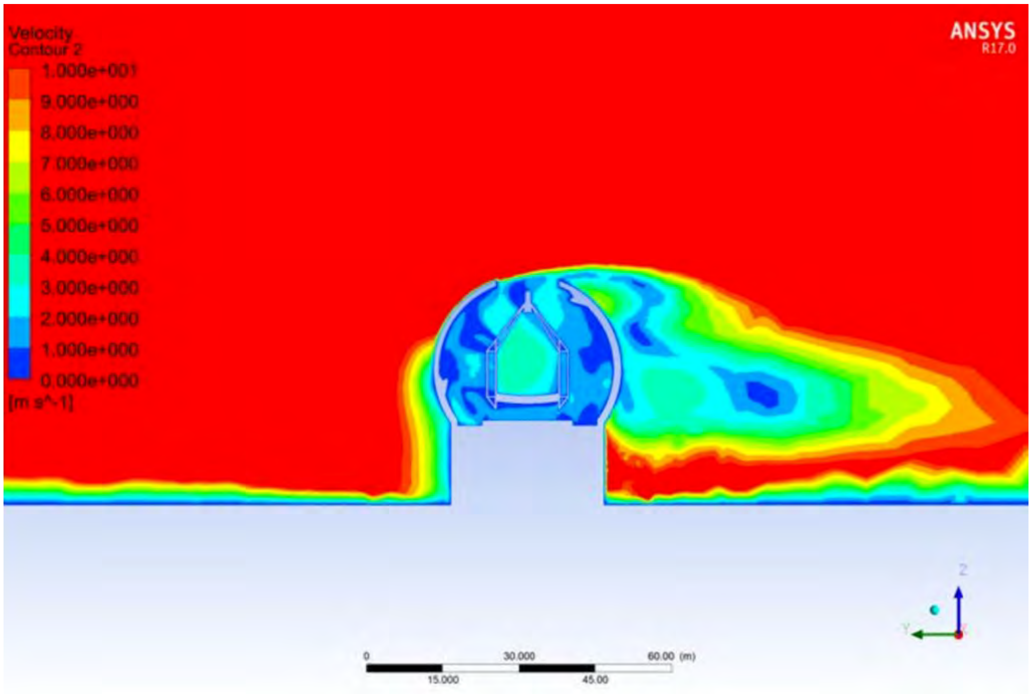

Figure 10. CFD Analysis of the proposed concept representing the telescope mount and the dome.

5. CONCLUSIONS

The solution proposed by IDOM for the Maunakea Spectroscopic Explorer (MSE) Mount provides a stiff support for all the optical elements being both lightweight and transparent to incoming air.

Different alternatives for the mechanisms have been subjected to a trade-off and hydrostatic bearings and different kind of direct drives have been selected for both axes.

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