# REQUIREMENTS DOCUMENT

# FOR

# SECONDARY MIRROR SYSTEM (M2S)

**TMT.OPT.DRD.07.004. CCR28**

November 30, 2007

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# 1. INTRODUCTION

## 1.1 INTRODUCTION

This document contains the design requirements for the Thirty Meter Telescope (TMT) secondary Mirror System (M2S). These requirements flow down from the Level 1 Requirements in the Observatory Architecture Document (OAD) and the Observatory Requirements Document (ORD). Requirements from the OAD and ORD will be referenced in this document but not repeated.

Section 1 describes this document. Section 2 describes the overall M2 System and Section 3 lists the requirements for the M2S. Paragraphs in Section 3 marked as "*Discussion*" are for information only and are not requirements.

## 1.2 PURPOSE

The purpose of this document is to provide a comprehensive list of the M2S design requirements. This document is to be used by the designer and fabricator of the M2S and any of its elements.

## 1.3 SCOPE

This document includes the Level 2 Requirements for the M2 System (M2S). The decomposition of the M2S is presented in the OAD, [REQ-1-OAD-0152]. This document does not include the external interfaces or any of the requirements for the M2 handling, cleaning or coating equipment.

It is anticipated that an adaptive secondary mirror will be developed in the future. If so, it would be installed in place of the M2S. The requirements for the adaptive secondary mirror are not addressed in this document.

## 1.4 APPLICABLE DOCUMENTS

Applicable documents contain information that shall be applied to the current document. In the event of a conflict between this document and the OAD and/or the ORD, the OAD and/or ORD will take precedence.

AD1 – Observatory Architecture Document (TMT.SEN.DRD.05.002)

AD2 – Observatory Requirements Document (TMT.SEN.DRD.05.001)

AD3 – Operations Concept Document (TMT.OPS.MGT.07.002)

## 1.5 REFERENCE DOCUMENTS

Reference documents contain information complementing, explaining, detailing, or otherwise supporting the information included in the current document.

## 1.6 CHANGE RECORD

| Revision | Date | Section | Modification |
|---|---|---|---|
| CCR28 | 30 Nov 2007 | First release. | |

## 1.7 Abbreviations and Acronyms

**AO –** Adaptive Optics

**APS –** Alignment and Phasing System

**CA** – Clear Aperture

**CLN –** Optical Cleaning System

**COAT –** Optical Coating System

**CTE –** Coefficient of Thermal Expansion

**D80 –** Diameter of the Point Spread Function that contains 80 percent of the energy.

**DRD –** Design Requirements Document

**ENC –** Enclosure

**GMS –** Global Metrology System

**ID –** Inside diameter

**HNDL –** Optical Handling System

**LGSF –** Laser Guide Star Facility

**LLT –** Laser Launch Telescope

**LUT –** Look-up Table

**M1 –** Primary Mirror

**M1CS –** M1 Control System

**M2 –** Secondary Mirror Assembly

**M2C –** M2 Cell structure

**M2CA –** M2 Cell Assembly

**M2CALF –** M2 Cell Assembly Lifting Fixture

**M2CSC –** M2 Control System for the Cell

**M2CSP –** M2 Positioner Control System

**M2H -** M2 Hexapod

**M2I -** M2 Interface Panel

**M2M –** Secondary Mirror

**M2PA –** M2 Positioner Assembly

**M2S –** Secondary Mirror System

**M2SS -** M2 Support System

**MTBF –** Mean Time Between Failure

**OAD –** Observatory Architecture Document

**OD -** Outside diameter

**OIWFS -** On-Instrument Wavefront Sensor

**ORD –** Observatory Requirements Document

**POWR –** Power, lighting and grounding system

**REQ –** Requirements

**RMS –** Root Mean Square

**STR –** Telescope Structure

**TBC –** This item still needs to be confirmed

**TBD –** This item still needs to be determined

**TCS –** Telescope Control System

**TINS –** Test Instruments

**TMT –** Thirty Meter Telescope

**TSS –** Telescope Safety System

* **–** Referenced by another requirement

**Units:**

**as** – arcsecond

**Hz** – Hertz

**K** – Kelvin

**m** – meter

**mas** – milliarcsecond

**mm** – millimeter

**MPa** – megapascal

**nm** – nanometer

**N-m** – Newton-meter

**Pa** – Pascal

**W** – Watt

**μm** – micrometer

# 2. OVERALL DESCRIPTION

## 2.1 PERSPECTIVE

The secondary Mirror System (M2S) of the Ritchey-Chrétien optical design reflects the light from the f/1 primary mirror and converts it to an f/15 beam for the science instruments. The mirror is a large convex hyperboloid. The entire M2S is mounted on the top end of the telescope structure and below the Laser Launch Telescope (LLT). The M2S consists of the M2 Positioner Assembly (M2PA) and the M2 Cell Assembly (M2CA) (Figure 1).

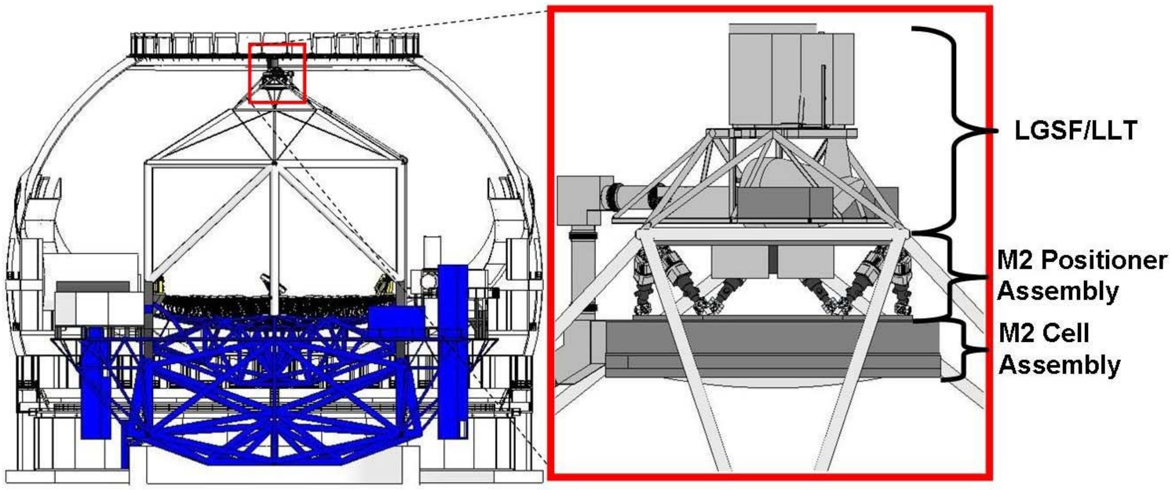


*Figure 1: Configuration of the telescope top end, including the M2 System and the Laser Launch Telescope.*

The rigid body position of the M2 Cell Assembly is controlled to compensate for telescope deformations caused by gravity and temperature. The shape of the mirror is also actively controlled to correct for polishing errors as well as gravitational and thermal deformations on the mirror surface. These corrections are made using Look-Up-Tables (LUT), which are updated using an external Alignment and Phasing System (APS).

The mirror surface will be periodically cleaned using $CO_2$ snow, water, and/or various detergents and solvents. It will also be periodically stripped of the old coating and recoated to maintain system throughput. A servicing platform will extend from the enclosure to allow access to the assembly when the telescope is pointed towards the horizon (90 degrees off zenith). The platform will provide access for installation, inspection, repair and in-situ cleaning of the M2M. The M2 Cell Assembly Lifting Fixture (M2CALF) will be used to remove the M2CA (Figure 2).

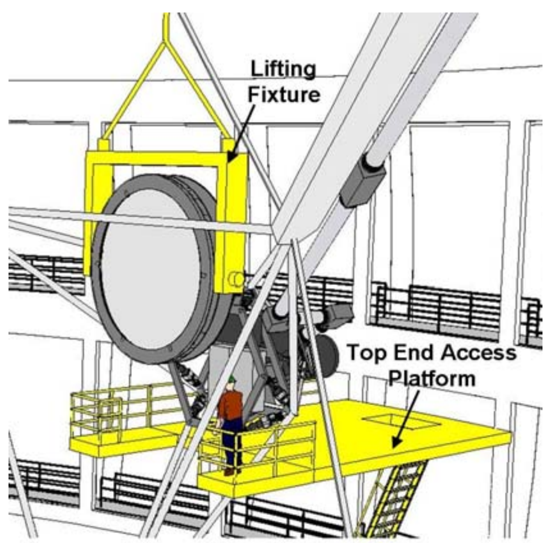


*Figure 2: Platform for servicing the M2S and removing the M2CA.*

## 2.2 SYSTEM FUNCTIONS

The M2 System is shown in Figure 3. The M2 Positioner Assembly (Figure 4) is a hexapod that controls the rigid body motion of the M2 Cell Assembly (Figure 5). The M2 Cell Assembly consists of the M2 Mirror Supports, electronics and software required to control the shape of the M2 Mirror. The Interface Panel is the junction for all electrical and fluid connections. The system decomposition is presented below with the acronyms in parentheses:

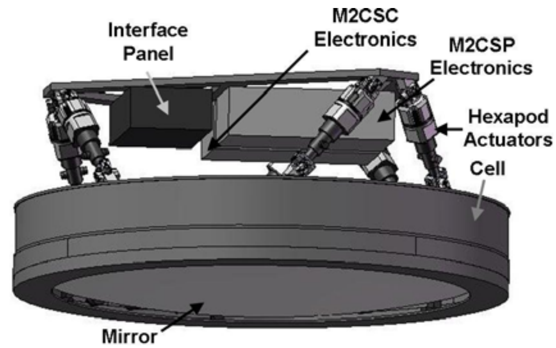


*Figure 3: Illustration of the M2S.*

**M2 System (M2S):**

**M2 Positioner Assembly (M2PA):** Controls the orientation of the M2 Mirror

**M2 Positioner Control System (M2CSP):** Electronics, software, sensors and cabling required to control the rigid body motion of the M2 Mirror.

**M2 Hexapod (M2H):** Actuators, base and platform.

**M2 Cell Assembly (M2CA):**

**M2 Cell Control System (M2CSC):** Electronics, software and sensors required to control the figure of the M2 Mirror.

**M2 Supports (M2SS):** Actuators, load cells, cabling necessary for the M2 Mirror supports.

**M2 Cell (M2C):** Cell structure.

**M2 Mirror (M2M):** Mirror blank and polishing.

**M2 Interface Panel (M2I):** The junction for all electrical and fluid connections.

The M2 Positioner Control System (M2CSP) provides local low bandwidth rigid body control of the M2 Cell Assembly via a hexapod positioner. Lookup Tables (LUT) within the M2CSP contain set-points for the six Degrees of Freedom of the hexapod as a function of zenith angle and temperature. The set-points are in terms of the Elevation Coordinate System ($\theta_x$, $\theta_y$, $\theta_z$, $\delta_x$, $\delta_y$, $\delta_z$), which is defined in the OAD.

On a real time basis, the M2CSP receives offset positions from the Telescope Control System (TCS). The M2CSP corrects the position of the M2 Cell Assembly via the hexapod by adding the offsets to the positions contained within the LUT. The M2CSP receives a new LUT from the TCS on a timescale of every two to four weeks, which is created using data gathered during a telescope optical alignment process. The control mode between the M2CSP and the TCS are the same during the alignment process as it is during normal operation.

The M2 Cell Control System (M2CSC) actively controls the shape of the M2 Mirror by commanding the Mirror Support actuators. The M2CSC receives a new LUT from the TCS approximately once each year. The TCS generated LUT is created using data gathered during a telescope optical alignment process. To update the LUTs, the TCS must have the ability to control the M2 Support actuators individually and read the M2 Support sensors. These commands from the TCS are given as incremental changes to the actuator forces.

The M2CSP and M2CSC send telemetry to the TCS continually, and the TCS provides the current zenith angle, azimuth angel, temperature and time. There is a diagnostic mode where the M2CSP and M2CSC perform internal tests and return data to the TCS. The TCS has the ability to perform M2S "Halts" in addition to controlled and emergency shutdowns.

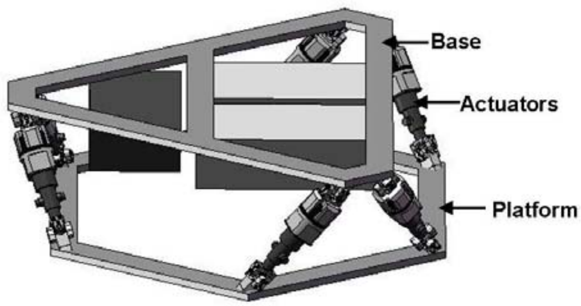


Figure 4: The M2 Positioner Assembly (M2PA).

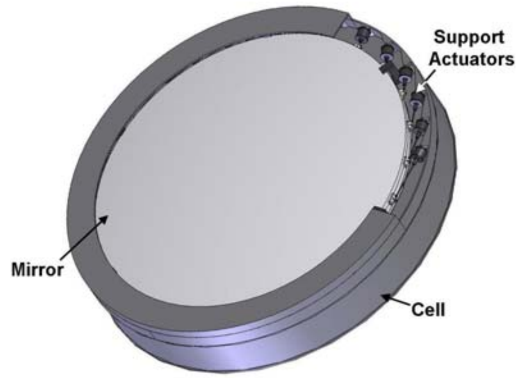


Figure 5: The M2 Cell Assembly (M2CA) with a cutaway showing an example of a Support System.

## 2.3 USER AND OPERATOR CHARACTERISTICS

The M2S will be operated during observations via the TCS-provided software interfaces. During subsystem tests, the engineers will command the M2 System with a Personal Computer (PC) via the facility data network. More information is provided in the control sections of the respective assemblies.

Observatory technicians will $CO_2$ snow clean the mirror in-situ monthly and liquid clean semi-annually. The M2 Cell will be removed from the telescope and the mirror will be recoated every 2 to 5 years, depending on the durability of the coating.

## 2.4 EXTERNAL INTERFACES

The Interface Control Documents (ICDs) for the M2S are listed in *Table* 1.

*Table 1: List of Interface Control Documents (ICDs) for the M2S.*

| |
|---|
| Enclosure (ENC) to M2 System (M2S) |
| Telescope Structure (STR) to M2 System (M2S) |
| M2 System (M2S) to Optical Cleaning Systems (CLN) |
| M2 System (M2S) to Optical Coating System (COAT) |
| M2 System (M2S) to Test Instruments (TINS) |
| M2 System (M2S) to Optical Handling System (HNDL) |
| M2 System (M2S) to Telescope Control System (TCS) |
| M2 System (M2S) to Telescope Safety System (TSS) |
| M2 System (M2S) to Engineering Sensors (ESEN) |
| M2 System (M2S) to Power, Lighting, and Grounding System (POWR) |
| Enclosure (ENC) to M2 System (M2S) |
| Telescope Structure (STR) to M2 System (M2S) |

## 2.5 CONSTRAINTS

Constraints are included in the ORD, section 2.1.

## 2.6 ASSUMPTIONS AND DEPENDENCIES

Some of the requirements in this document depend on the physical location of the telescope. The following environmental conditions vary with observatory location: altitude, humidity, wind and temperature. Though the actual location is still being determined, the requirements in this document are derived from the OAD and ORD, which assume the TMT baseline site of Armazones, Chile, a remote mountain at an elevation of 3064 meters.

# 3. SPECIFIC REQUIREMENTS FOR THE M2 SYSTEM (M2S)

## 3.1 REQUIREMENTS FOR THE OVERALL SYSTEM

*Discussion: Some of the requirements that relate to the overall M2S are Level 1 requirements and are found in the Observatory Requirements Document (ORD) and the Observatory Architecture Document (OAD).*

*The maximum diameter of the M2S, including cables and hoses, is stated in [REQ-1-OAD-1825]. The M2S coordinate system (M2CRS) is described in [REQ-1-OAD-9900]. The earthquake survival requirements for the telescope are stated in [REQ-1-ORD-1500] but preliminary studies indicate that the accelerations at the M2S are amplified by resonances of the telescope structure; therefore the earthquake survival requirements for the M2S, stated in REQ-2-M2-0350, are more stringent. The time required for inspecting, repairing and resuming operations after an earthquake are covered in [REQ-1-ORD-1500 through 1550]. Some of these requirements relate to all of the telescope systems. Allocations to the M2S are described in this document. The environment described in [REQ-1-ORD-1200] includes an external mean wind velocity range. The M2S is partially shielded from the effects of the external wind speed. The effects of the wind forces, attenuated by the enclosure, are addressed via static stiffness requirements.*

*The mass limit for the M2S is stated in the OAD, [REQ-1-OAD-0744].*

### 3.1.1 Performance

[REQ-2-M2-0100] The M2S shall meet all requirements stated in this document 100% of the time when the observatory is subjected to Performance Conditions as stated in [REQ-1-ORD-1100].

[REQ-2-M2-0110] The M2S shall meet all requirements stated in this document 100% (TBC) of the time when the observatory is subjected to Observing Operating Conditions as stated in [REQ-1-ORD-1200].

[REQ-2-M2-0120] The M2S shall meet all requirements stated in this document when mounted to the top end of the telescope with all cables and utility lines installed.

[REQ-2-M2-0130] The M2S shall meet all requirements stated in this document over temporal changes in the ambient air temperature up to and including +/-0.5 Kelvin per hour.

[REQ-2-M2-0140] The M2S shall meet all requirements stated in this document over spatial ambient air temperature gradients up to and including 0.25 Kelvin per meter in any direction.

[REQ-2-M2-0150] The M2S shall be able to operate over a telescope zenith angle range of -5 to 95 degrees without possibility of damage or personnel injury.

*Discussion: The zenith angle range of the telescope is 0 to 90 degrees. A conservative estimate of an additional 5 degrees on either end of travel is assumed to take into account travel limits, hard stops, etc.*

[REQ-2-M2-0160] The M2S shall meet all performance requirements stated in this document over a telescope zenith angle range of 0 to 65 degrees.

*Discussion: Any degradation of performance of the M2S outside the telescope zenith angle range of 0 to 65 degrees should be gradual.*

[REQ-2-M2-0170] The M2S shall be able to operate at telescope zenith angle rates up to and including +/- 0.052 radians per second without the possibility of damage or personnel injury.

*Discussion: The fastest telescope elevation axis slew speed is 0.052 radians/second (3.0 degrees/second).*

[REQ-2-M2-0180] Unless otherwise stated, the M2S shall meet all performance requirements stated in this document for zenith angle rates between 0 and +/- 150 microradians per second.

*Discussion: The maximum sidereal rate for the elevation axis is 15 arcseconds per second. The 150 microradians per second includes a factor of two safety margin.*

[REQ-2-M2-0190] Unless otherwise stated the M2S shall meet all performance requirements stated in this document for M2 Mirror rates in δx, δy, and δz (ECRS) between 0 and +/- 0.5 millimeters per second.

*Discussion: These rates bound the translation rates that the M2 Mirror experiences as a result of M2S tracking motions.*

[REQ-2-M2-0200] Unless otherwise stated the M2S shall meet all performance requirements stated in this document for M2 Mirror rates in $\theta_X$, and $\theta_Y$, (ECRS) between 0 and +/- 75.0 microradians per second.

*Discussion: The M2S rates identified above bound the rotation rates that the M2 Mirror experiences as a result of M2PA tracking motions.*

[REQ-2-M2-0210] Unless otherwise stated the M2S shall meet all performance requirements stated in this document with simultaneous motions in δx, δy, δz, $\theta_X$, and $\theta_Y$.

*Discussion: The range of motion of the M2S is defined in OAD requirements [REQ-1-OAD-1860] through [REQ-1-OAD-1864]. Any travel range required for limit switches, hard stops, etc will not reduce the travel range specified. The definition of δx, δy, δz, $\theta_X$, and $\theta_Y$ positions and their associated travel ranges are illustrated in Figure TBD.*

[REQ-2-M2-0220] Unless otherwise stated the M2S shall meet all performance requirements stated in this document over the travel ranges defined in [REQ-1-OAD-1860], [REQ-1-OAD-1862], and [REQ-1-OAD-1864].

### 3.1.2 Reliability

[REQ-2-M2-0230] No more than 2 hours of observing time shall be lost each year due to failures of the M2S.

*Discussion: This is flowed down from [REQ-1-OAD-0320]. This may require high Mean Time Between Failure (MTBF) on the components, redundant systems, ability to rapidly repair failures in-situ, performance monitoring for replacing components before they fail, and a maintenance plan for performing periodic maintenance and calibration during daytime.*

[REQ-2-M2-0240] The reliability of the design shall be compatible with a 5-year maintenance interval for any work that requires removal of the assembly from the telescope.

*Discussion: The design shall be compatible with all operational, survival and transportation environmental conditions stated in the ORD, [REQ-1-ORD-1050] through [REQ-1-ORD-1550], where applicable.*

### 3.1.3 Safety and Security

*Discussion: The design and the operating, servicing and maintenance procedures for M2S shall be subject to the Environmental, Health, Safety and Security Requirements stated in the ORD, [REQ-1-ORD-7000] through [REQ-1-ORD-7610].*

[REQ-2-M2-0250] The M2S shall be designed to not present safety hazards to personnel.

[REQ-2-M2-0260] All service panels and fasteners shall be captive.

[REQ-2-M2-0270] The M2S shall not be able to damage the M2M under any circumstance(s).

### 3.1.4 Maintainability

[REQ-2-M2-0280] Servicing of the M2S shall be performed when the telescope is pointing towards the horizon (90 degrees from zenith).

*Discussion: An enclosure-mounted service platform and jib crane will be available.*

*Discussion: The M2S shall adhere to the requirements related to preventive maintenance as stated in the ORD, [REQ-1-ORD-1000].*

*Discussion: The telescope optics shall be designed to be consistent with the servicing and replacement intervals and scenarios presented in the OAD, [REQ-1-OAD-2500].*

[REQ-2-M2-0290] All components of the M2S that have an MTBF of less than 50 years shall be designed to be serviceable on the telescope in less than 2 hours.

[REQ-2-M2-0300] All components of the M2S that have an MTBF of less than 50 years shall be replaceable while the M2 System is mounted on the telescope and in a horizontal orientation.

[REQ-2-M2-0310] Any material that goes into the coating chamber with the mirror shall be cleanable and vacuum compatible.

*Discussion: Material being cleanable implies that the cleaning process is not lengthy and/or difficult and will not damage the material.*

### 3.1.5 Thermal control

[REQ-2-M2-0320] Heat radiated to the night sky by the M2S shall be controlled to avoid sub-cooling of M2S surfaces below the ambient air temperature.

*Discussion: This might be accomplished with radiation shields or thermal control of various parts/areas.*

[REQ-2-M2-0330] The temperature of the coolant used by any element of the M2S shall not increase by more than 3 Kelvin.

*Discussion: The flow rate required to meet this requirement shall be calculated and documented with the design description.*

*Discussion: A glycol-water coolant shall be supplied by the observatory facility. The temperature of the coolant supplied will be ~ 3 Kelvin below ambient.*

[REQ-2-M2-0340] The design shall minimize thermal gradients to avoid seeing degradations. The temperature difference from the M2 Mirror optical surface to the ambient air shall be less than 0.65 Kelvin (TBC).

### 3.1.6 Earthquake Requirements

[REQ-2-M2-0350]* The M2S shall survive earthquake dynamic accelerations equivalent to a static acceleration of 6 g (TBC), due to a maximum likely earthquake described in [REQ-1-ORD-1500].

[REQ-2-M2-0360] The M2M shall be protected during a maximum likely earthquake, even if there is a loss of electrical power.

[REQ-2-M2-0370]* The lowest resonant frequency of the M2S, if it were attached to a perfectly rigid structure, shall be higher than 15 Hertz.

*Discussion: A lower resonant frequency would increase susceptibility to amplification of the ground acceleration in an earthquake.*

[REQ-2-M2-0380] In a maximum likely earthquake, as described in [REQ-1-ORD-1500], the maximum stress in the M2M shall be less than 10 megapascals.

[REQ-2-M2-0390] After an earthquake, in-situ inspection of the M2S shall be designed to allow inspection in less than 2 hours and any damage incurred in a maximum likely earthquake shall be repairable in less than or equal to one week.

### 3.1.7 General Requirements

*Discussion: The M2S shall contain two independent low level control systems, one for the M2CA and one the M2PA, per [REQ-1-OAD-1890].*

[REQ-2-M2-0400] The M2S shall be designed so that nothing can fall from the M2S (including oil, coolant, cleaning fluids, particles, bolts, covers, etc.), even under the maximum likely earthquake conditions, as specified in the OAD.

[REQ-2-M2-0410] All hardware designed to be used at the observatory shall be corrosion resistant while exposed to the operational basis survival environmental conditions described in Section 3.1.2.5 of the ORD.

[REQ-2-M2-0420] The M2S shall not emit light or excessive electro-magnetic interference, vibration or heat.

[REQ-2-M2-0430] The M2S shall be designed with metric components and fasteners.

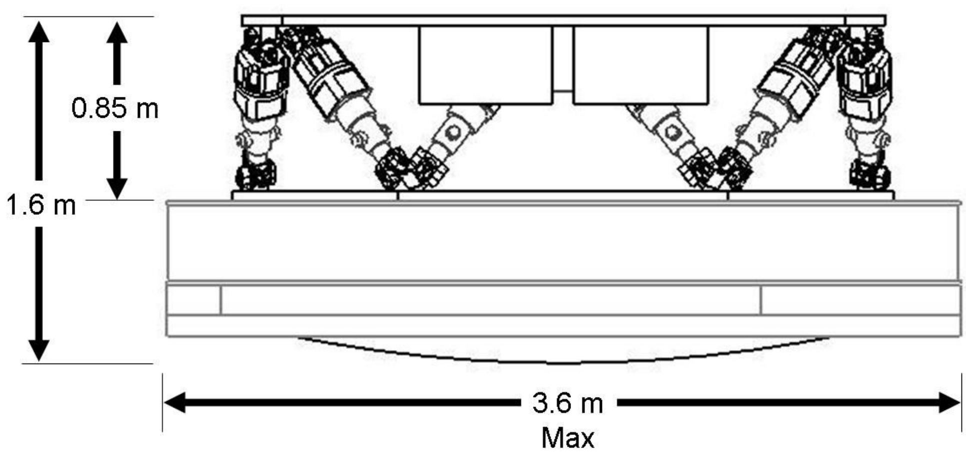


*Figure 6: Key dimensions of the M2S.*

*Discussion: [REQ-1-OAD-1825] specifies that the outer diameter of the M2S shall be less than or equal to 3.6 meters.*

[REQ-2-M2-0440] The distance between the vertex of the secondary mirror and the mounting surface interface between the M2S and the telescope structure shall be 1.60 meters, when the M2H is in the center of its range of motion.

## 3.2 M2 CELL ASSEMBLY (M2CA)

### 3.2.1 Requirements for the Overall Assembly

**Performance:**

[REQ-2-M2-0450] The M2CA shall maintain the M2 Mirror figure so that it meets the requirements of [REQ-2-M2-0890] without requiring updates from the M2CSC LUT for net angle changes of +/- 2.0 degrees, relative to the gravity vector over the zenith angle range of 1 to 65 degrees.

*Discussion: This requirement drives the M2CA design in terms of sensitivity to gravity.*

[REQ-2-M2-0460] The M2CA shall maintain the M2 Mirror figure so that it meets the requirements of [REQ-2-M2-0890] without requiring updates from the Cell Control LUT over differential ambient temperature changes of +/- 0.2 Kelvin over the temperature range of 275 to 288 k.

[REQ-2-M2-0470] The M2 Mirror shall settle to its final shape within 10 seconds of completion of any telescope or M2 Mirror move.

*Discussion: This requirement flows from the requirement on acquisition time as stated in the ORD, [REQ-1-ORD-1800]. For the purposes of this requirement, settling time commences after the completion of a zenith angle move.*

[REQ-2-M2-0480] The M2 Mirror shall settle to its final shape within 10 seconds of the M2CSC receiving a M2 Support command offset from the TCS.

*Discussion: This requirement is driven by the time allocated to complete calibration of the M2 Mirror shape. See the discussion in section 3.2.5.*

[REQ-2-M2-0490] The M2CA shall maintain the M2 Mirror figure so that it meets the requirements of [REQ-2-M2-0890] with spatial variations of wind pressure of up to 2 Pascals (TBC) across the surface of the M2 Mirror.

*Discussion: This requirement is driven by the operational wind conditions described in [REQ-1-ORD-1200], coupled with the enclosure attenuation of the wind speed.*

[REQ-2-M2-0500] The M2CA shall maintain the mirror figure so that it meets the requirements of [REQ-2-M2-0890] with only monthly bias updates (zero points) to the M2 Cell Control System LUT for periods of no less than one year.

*Discussion: This requirement is driven by the telescope availability requirement and hence the need to minimize the on-sky time required for aligning the optics. This requirement implies that only monthly LUT bias updates are required for periods of less than one year. This in turn implies that the APS, on a monthly basis, only needs to measure the M2 surface at one elevation angle and that the Cell Control LUT can be modified appropriately based on this measurement. It is acceptable to require a complete new Cell Control LUT, based on new APS measurements at multiple elevation angles, to be built at intervals greater than once per year.*

**Reliability and Maintenance:**

[REQ-2-M2-0510] The M2CA design shall allow for installation or removal of the M2 Cell Assembly within 2 hours using 3 personnel, plus crane operators and safety personnel.

*Discussion: The requirement for removal of the mirror for recoating is stated in the OAD, [REQ-1-1835].*

[REQ-2-M2-0520] Each scheduled maintenance and repair to the M2CA shall be achievable within 2 hours with the telescope pointed at the horizon and without removal of the M2PA and M2CA. No more than one such scheduled servicing operation shall be required per week, on the average.

*Discussion: This includes the removal and replacement of components including actuators.*

[REQ-2-M2-0530] The system shall be designed to allow for $CO_2$ snow cleaning and liquid cleaning the M2 Mirror while the telescope is in the horizontal orientation.

*Discussion: $CO_2$ cleaning requirements are stated in [REQ-1-OAD-1845].*

*Discussion: As a goal, the M2CA shall be designed to allow in-situ washing of the mirror as stated in [REQ-1-OAD-1850]*

**General:**

[REQ-2-M2-0540] The M2CA shall minimize the vibration transmitted to the telescope structure to less than TBD.

[REQ-2-M2-0550]* The lowest resonant frequency of the M2CA, if it were attached to a perfectly rigid structure in the same manner as it is attached to the M2PA, shall be higher than 20 Hertz.

*Discussion: This is driven by requirement [REQ-2-M2-0370].*

[REQ-2-M2-0560]* The aspheric optical figure of the M2M shall be centered in the M2CA, relative to the position of the interface features to the M2PA, within +/- 5 millimeters in X and Y in the M2 Coordinate System.

*Discussion: Centration errors of the M2M will increase the range of travel of the M2PA required to align the optics.*

[REQ-2-M2-0570]* The mass of the portion of the M2CA that is supported by the M2PA (i.e., not including the control electronics) shall be less than 4500 kilograms.

[REQ-2-M2-0580] The maximum transverse wind cross-sectional area of the M2CA, for air flow in any direction perpendicular to the optical axis, shall be less than 4.0 square meters (TBC). This includes the associated electronics and cables.

*Discussion: [REQ-1-OAD-1080] limits the maximum transverse wind cross-sectional area of the top end of the telescope. The following requirement is consistent with [REQ-1-OAD-1080].*

[REQ-2-M2-0590] The average drag coefficient of the M2CA, in any transverse direction (air flow direction perpendicular to the optical axis) shall meet the drag coefficient requirement stated in the OAD, [REQ-1-OAD-1085].

[REQ-2-M2-0600] The height of the M2CA from the vertex of the secondary mirror to the interface mounting surface to the M2PA shall be 0.75 meters.

*Discussion: See Figure 6.*

[REQ-2-M2-0610] The heat transmitted to the structure or atmosphere by the M2CA shall be less than 25 Watts.

*Discussion: A glycol-water coolant shall be supplied by the observatory facility. The temperature of the coolant supplied will be ~ 3 Kelvin below ambient.*

### 3.2.2 M2 Mirror (M2M)

#### 3.2.2.1 Mirror Blank

##### 3.2.2.1.1 Material Properties

[REQ-2-M2-0620] The M2M Blank material shall be a low-thermal-expansion glass or glass-ceramic.

**Chemical Resistance:**

*Discussion: The Optical Surface of the M2Mirror will be subject to periodic cleaning throughout the life of the Observatory.*

[REQ-2-M2-0630] The M2 Blank material shall not show any damage or increase of surface roughness on the polished surfaces after being subjected to cleaning.

*Discussion: The cleaning process will include any combination of $CO_2$ snow, alcohol, acetone, detergents and water.*

*Discussion: The reflective coating on the M2M will be subject to periodic removal throughout the expected life of the Observatory.*

[REQ-2-M2-0640] The M2 Blank material shall not show any damage or increase of surface roughness on polished surfaces after being subjected to any number of coating removals following processes typical of modern observatories.

*Discussion: The M2 blank material shall be compatible with the equipment and processes involved in stripping and recoating, as stated in [REQ-1-OAD-1840].*

*Discussion: Typical materials that may be used during coating removal are shown in Table 2.*

*Table 2: Materials that may be used during coating removal.*

| |
|---|
| Hydrochloric acid (37 percent concentration) |
| Cupric Sulfate |
| Potassium Hydroxide |
| Nitric Acid (70 percent concentration) |
| Ceric Ammonium Nitrate |
| Calcium Carbonate |
| Potassium Ferrocyanide solutions |
| Sodium Thiosulfate solutions |

**Dimensional Stability:**

[REQ-2-M2-0650] The M2 blank material must be elastic over a stress range of 0 to 10 megapascals, and over a temperature range of 200 Kelvin to 400 Kelvin.

**Polishability:**

[REQ-2-M2-0660] The M2 Blank material shall be able to be polished using conventional optical finishing processes and materials to a surface roughness of 1 nanometer RMS or less.

**Coefficient of Thermal Expansion (CTE):**

[REQ-2-M2-0670] The Average CTE of the M2 Blank over the temperature range of 9 to 22 C shall be small enough to ensure that the metrology uncertainty during optical testing is within the error budget for that testing in the presence of spatial and temporal temperature variations.

[REQ-2-M2-0680] The Average CTE of the M2 Blank over the temperature range of 270 Kelvin to 300 Kelvin shall be small enough to ensure that the M2M shall meet all of its performance requirements over the range of operational temperatures specified in REQ-1-ORD-1105.

*Discussion: Non-zero CTE will cause the figure of the M2M to change between the acceptance test in the optics shop and the use environment at the observatory, and to change over the operational range of temperatures.*

[REQ-2-M2-0690] The Average CTE of the M2 Blank over the range of operational temperatures specified in REQ-1-ORD-1105 shall be small enough to ensure that the M2M shall meet all of its performance requirements when subjected to the operational temperature gradients.

[REQ-2-M2-0700] The spatial variation of the CTE in the M2 Blank, relative to the average CTE of the M2 Blank, shall be small enough to ensure that the M2M shall meet all of its performance requirements over the range of operational temperatures specified in REQ-1-ORD-1105.

*Discussion: Non-uniform CTE will cause changes in the M2M figure as its temperature changes.*

**Residual Stress:**

[REQ-2-M2-0710] The residual stress in the M2 Blank material, at room temperature, shall be less than 1.0 megapascals at all points.

*Discussion: Residual stress in the M2 Blank would increase its susceptibility to brittle fracture.*

**Inclusions and Defects:**

*Discussion: Inclusions are defined as any foreign matter in the M2 Blank that is not the zero-expansion material from which the M2 Blank is made. For purposes of this specification, bubbles are considered to be Inclusions. The mean diameter of an Inclusion is defined as the diameter of a sphere having the same volume as the Inclusion. Inclusions with a mean diameter smaller than 0.5 millimeters are not considered in this requirement.*

*Discussion: The Critical Zone is defined as the volume directly under the front surface. It is defined as the volume enclosed by a thickness of 5 millimeters from the convex surface of the blank extending from the inside diameter of 0.2 meters to the outside diameter of 3.046 meters.*

[REQ-2-M2-0720] Within the Critical Zone, inclusions with a mean diameter greater than 2.5 millimeters are not allowed.

[REQ-2-M2-0730] Within the Critical Zone, no visible defects are allowed.

*Discussion: Defects are defined as cracks inside the M2 Blank material.*

[REQ-2-M2-0740] No visible refractory material shall be allowed within the Critical Zone.

[REQ-2-M2-0750] Outside of the Critical Zone, inclusions with a mean diameter greater than 10 millimeters shall not be allowed.

[REQ-2-M2-0760] Outside of the Critical Zone, the maximum dimension of any defect in any direction shall be less than 5 millimeters.

[REQ-2-M2-0770] The number of Inclusions, of mean diameter greater than 0.5 millimeters, partially or totally within the Critical Zone, shall total 10 or less per square meters of mirror surface.

[REQ-2-M2-0780] Outside of the Critical Zone, the number of Inclusions of mean diameter greater than 0.5 millimeters shall total 10 or less per any 1000 cubic centimeter volume.

[REQ-2-M2-0790] Outside of the Critical Zone, the number of defects shall total 2 or less.

[REQ-2-M2-0800] If the M2 Blank is constructed by fusing together pieces of glass from separate boules, the fusion seams between the boules shall be greater than 99 percent sealed, which is defined as follows: the area occupied by blisters and Inclusions, collectively, as measured in the plane of the fusion seam shall not exceed 1.0 percent of the total area of such fusion seam.

#### 3.2.2.1.2 Dimensions

[REQ-2-M2-0810] The dimensions of the M2 Blank shall be determined by the design of the M2CA with adequate allowance for any material removal required by the optical finishing processes.

#### 3.2.2.1.3 Surface Condition

[REQ-2-M2-0820] The surfaces of the M2 Blank shall be generated to a surface finish that is compatible with the planned optical shop finishing processes, with a level of subsurface damage low enough to ensure that the blank will be robust for transportation to the optical shop.

### 3.2.2.2 M2 Mirror Polishing

#### 3.2.2.2.1 Global Properties

*Discussion: As stated in REQ-1-OAD-1058 and REQ-1-OAD-1060, the TMT secondary mirror is a hyperboloid with a conic constant K = -1.31823 and the paraxial radius of curvature R = -6.22768 meters.*

#### 3.2.2.2.2 Back Surface

[REQ-2-M2-0830] The Back Surface shall receive a commercial polish or etch sufficient to remove subsurface damage.

#### 3.2.2.2.3 Mirror surface figure accuracy

*Discussion: The precise geometrical shape of M2M is in accordance with the Baseline Optical Prescription specified in the OAD (Section 4.1.1).*

[REQ-2-M2-0840] The radius of curvature of the M2M shall be -6.22768 +/- TBD meters.

*Discussion: The negative sign indicates the optical surface is convex.*

[REQ-2-M2-0850] The conic constant of the M2M shall be -1.31823 +/- TBD.

[REQ-2-M2-0860] The outside diameter of the Clear Aperture (CA) of M2M shall be 3.046 meters and the inside diameter shall be 0.22 meters.

*Discussion: The M2 mirror may have a hole in the center as long as it doesn't interfere with the polishing process and the CA requirements.*

[REQ-2-M2-0870] All requirements for the optical surface apply over the clear aperture.

[REQ-2-M2-0880] The centering of the aspheric M2M surface figure relative to the mechanical features of the M2M shall be consistent with achieving the tolerances specified in REQ-2-M2-0560.

*Discussion: In order to control the amplitude of surface figure errors as a function of their spatial frequency, the requirement for surface figure accuracy is stated in terms of a structure function. The value of the structure function for each separation distance shall be calculated in terms of the phase difference for each pair of points in the phase map.*

[REQ-2-M2-0890]* At all separation distances (x), the value of the structure function that describes the surface error of the M2M (normal incidence) shall be less than:

$$D(x) = A\left[10.60\left(\frac{x}{d}\right)^{5/3} - 13.75\left(\frac{x}{d}\right)^{2} + 3.42\left(\frac{x}{d}\right)^{3}\right] + 2B^{2}$$

Where:

D(x) is the structure function in nanometers squared

$$A = \left(\frac{1}{2}\right)^{2}\left(\frac{500nm}{2\pi}\right)^{2}\left(\frac{30m}{r_0}\right)^{5/3}$$

A = Leading coefficient = 65989

B = High frequency surface roughness = 2 nanometers

x = Separation between point pairs

d = Diameter of beam footprint = 3.046 meters

$r_0$ = Quasi-Fried's parameter = 3.20 meters

The value of $r_0$ used in this equation was chosen to be consistent with the encircled energy requirement in REQ-1-OAD-0424.

This structure function is in terms of surface error with piston and tilt subtracted from the phase map, and is in units of squared nanometers. This curve is illustrated in Figure 7.

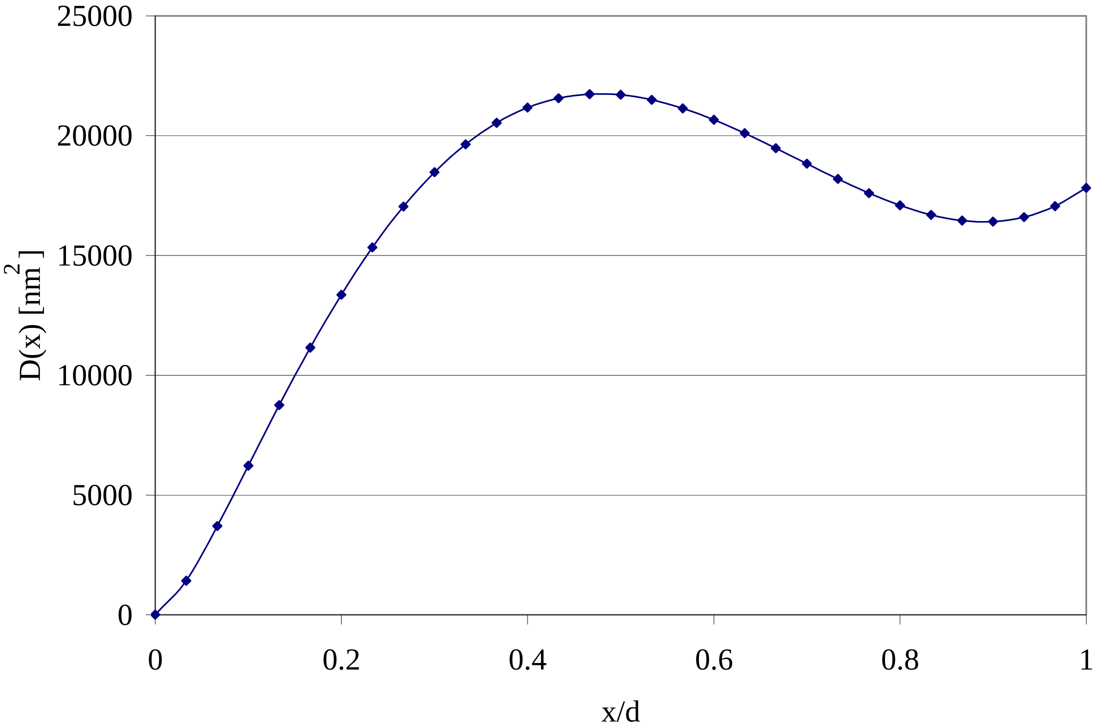


*Figure 7: The Structure Function for the M2M Surface Error.*

[REQ-2-M2-0900] The equation describing the optical surface of M2M shall not exceed the structure function described in Equation 1 and shown in Figure 7 when the telescope is zenith pointing.

[REQ-2-M2-0910] When the telescope is pointing away from the zenith, the structure function specifying the optical surface of M2M shall be multiplied by secant(Z), where Z is the zenith angle.

*Discussion: The telescope image quality is allowed to degrade with zenith by an amount comparable to atmospheric seeing.*

[REQ-2-M2-0920] The limits imposed by the structure function shall be for all error sources except look-up table errors. These errors shall include: figuring, optical test measurement uncertainty, thermal distortion, gravitational orientation, passive support, active support, and dynamic support effects.

[REQ-2-M2-0930] During acceptance testing in the optical shop, the M2SS may be used to make active optics corrections of the mirror figure using the following low-order aberrations: astigmatism – up to 200 nanometers RMS surface; coma – up to 20 nanometers RMS surface; trefoil – up to 50 nanometers RMS surface. These corrections are defined relative to the nominal mirror support forces.

[REQ-2-M2-0940] A permanent fiducial mark shall be placed on the side and back of the polished mirror to allow for proper clocking of the mirror when installing it in the cell.

#### 3.2.2.2.4 Surface roughness

[REQ-2-M2-0950] The optical surface of the M2M shall be polished to less than 2 nanometers RMS surface roughness.

3.2.2.2.5 Scratch-Dig Specification

[REQ-2-M2-0960] The scratch-dig specification for the M2M Optical Surface shall be 60-40.

*Discussion: The first number is the maximum width of a scratch in micrometers and the second number is the maximum depth of digs in units of 0.01 millimeters.*

3.2.2.2.6 Surface imperfections

*Discussion: Surface imperfections are defined as inclusions (including bubbles) or chips that intersect the surface of the M2M. A Chip is defined as a hollow depression in a surface of the M2M, usually formed where a flake has broken out of the surface.*

[REQ-2-M2-0970] The entire optical surface shall be polished out, meaning that all subsurface damage from grinding shall be removed (no "gray" shall be left).

[REQ-2-M2-0980] No surface imperfection of surface area larger than 10 square millimeters shall be allowed within or partially within the Clear Aperture.

[REQ-2-M2-0990] The sum of the areas of all surface imperfections within or partially within the Clear Aperture shall be less than 20 square millimeters.

[REQ-2-M2-1000] No surface imperfection of surface area larger than 100 square millimeters shall be allowed on any surface of the M2M.

[REQ-2-M2-1010] The sum of the areas of all surface imperfections on all surfaces of the M2M outside of the clear aperture shall be less than 500 square millimeters.

[REQ-2-M2-1020] No subsurface damage shall be allowed to remain in any surface.

[REQ-2-M2-1030] All surfaces of a Chip shall be ground out by the contractor to remove sharp edges and cracks.

[REQ-2-M2-1040] No visible cracks shall be allowed on any surface of the M2M.

[REQ-2-M2-1050] Cracked material shall be removed by a combination of grinding and etching. Resulting surfaces shall be smooth, with a radius of curvature no less than 1 mm, anywhere.

Discussion: A ground out spherical depression shall be considered to be a Chip as defined in this specification.

### 3.2.3 M2 Support System (M2SS)

*Discussion: [REQ-1-OAD-1880] states that the M2SS shall be an active support system capable of correcting several specified low order aberrations. The open-loop operation of the M2SS, over varying zenith angles and temperatures, shall meet the requirements stated in the OAD, [REQ-1-OAD-1885].*

[REQ-2-M2-1060] The M2SS shall support the mirror's weight at all telescope orientations and shall maintain the mirror figure to meet the structure function requirement at all operational telescope orientations.

[REQ-2-M2-1070] The M2SS shall also be able to support the M2M in a face up orientations, for testing, cleaning and servicing.

[REQ-2-M2-1080] The M2SS shall support the M2M with sufficient stiffness to meet the requirements of REQ-2-M2-0550.

[REQ-2-M2-1090] The M2SS shall be designed such that the M2M will meet the structure function requirement in the presence of a uniform wind pressure of 10 Pascals on the optical surface.

[REQ-2-M2-1100] The M2SS shall be designed such that low-order mirror distortions caused by the change in temperature between the acceptance test and the observatory operating conditions can be corrected.

[REQ-2-M2-1110] The M2SS shall be able to correct the low-order aberrations specified in Table 3 with residual errors less than the amount specified. To verify that the M2SS has the required capacity to apply these corrections simultaneously, the actuator force amplitudes for the six cases may be summed in quadrature.

*Table 3: Required active optics correction capability.*

| Aberration term | Required Amplitude (nanometers RMS) | Residual After Correction (RMS residual / RMS correction) |
|---|---|---|
| Astigmatism, $Z_{22}$ | 2000 | 2 percent |
| Astigmatism, $Z_{2-2}$ | 2000 | 2 percent |
| Coma, $Z_{31}$ | 100 | 15 percent |
| Coma, $Z_{3-1}$ | 100 | 15 percent |
| Trefoil, $Z_{33}$ | 200 | 5 percent |
| Trefoil, $Z_{3-3}$ | 200 | 5 percent |

[REQ-2-M2-1120] The resolution of the active optics force control shall be sufficient to ensure that the figure errors caused by quantization of the forces will comply with an error budget that meets the structure function requirement.

[REQ-2-M2-1130] Any force combination that the M2SS is capable of applying to the mirror shall not be able to damage the mirror or the actuators.

[REQ-2-M2-1140] The M2SS shall not induce more than 3 megapascals maximum principal stress in the M2 Blank.

[REQ-2-M2-1150] The M2SS shall be robust, and shall be able to continue operation in case of failure of an actuator, even in the case of an actuator maintaining its maximum force.

[REQ-2-M2-1160] The repeatability of installing the M2 Mirror in its Cell, on the supports, shall be less than 0.1 millimeters in any direction.

[REQ-2-M2-1170] The M2SS shall stabilize the position of the M2 Mirror, relative to the interface between the M2CA and the M2PA, to less than 0.5 micrometers of relative motion in any direction per minute of tracking of the telescope, at any operational orientation and temperature.

[REQ-2-M2-1180] The M2SS shall stabilize the orientation of the M2 Mirror, relative to the interface between the M2CA and the M2PA, to less than 0.5 microradians of tilt in $\theta_x$ *and* $\theta_y$ per minute of tracking of the telescope, at any operational orientation and temperature.

[REQ-2-M2-1190] The M2SS shall stabilize the position of the M2 Mirror, relative to the interface between the M2CA and the M2PA, to less than 50 micrometers in any direction, over any operational orientation and temperature, for any length of time.

[REQ-2-M2-1200] The M2SS shall stabilize the orientation of the M2 Mirror, relative to the interface between the M2CA and the M2PA, to less than 50 microradians of tilt in $\theta_x$ *and* $\theta_y$, over any operational orientation and temperature, for any length of time.

*Discussion: In order for the M2PA motion control trajectories to be effective, the position of the M2M relative to the M2PA must be stable.*

### 3.2.4 M2 Cell (M2C)

*Discussion: The M2 Cell (M2C) is the structure that supports the M2 Mirror and the M2 Support System. The M2C is also where the M2CA is attached to the M2H. The M2 Support System attaches the M2 Mirror to the M2C.*

[REQ-2-M2-1210] The M2C shall be designed so that under all conditions of operation, maintenance, servicing, seismic conditions, installation and removal, the material in the M2C shall not be stressed to more than 50 percent of the elastic limit.

[REQ-2-M2-1220] The M2C shall incorporate features that can interface with the M2 Cell Assembly Lifting Fixture (M2CALF). These features shall allow attachment of the M2CALF on either side of the M2C in line with the center of mass of the M2CA, so that the M2CA may be removed from the telescope and then rotated about its center of mass by the M2CALF in order to set the M2CA down onto a handling cart with the mirror face up.

[REQ-2-M2-1230] The M2C shall be designed to allow for the inspection of all mirror supports without removing structural parts with the telescope horizon pointing.

[REQ-2-M2-1240] The M2C shall be designed to allow for the removal and replacement of mirror supports while the M2S is mounted on the telescope and oriented in a horizontal position.

### 3.2.5 M2 Cell Control System (M2CSC)

*Discussion: The M2 Cell Control System (M2CSC) provides local control for the M2 Cell Assembly (M2CA). The M2CSC will be independent and separate from the M2 Positioner Control System (M2CSP) which provides local control for the M2 Positioner Assembly (M2PA). The primary external M2CSC control interface is with the Telescope Control System (TCS).*

*Figure 8 is for illustrative purposes only and assumes a control model where M2 support is achieved actively and utilizes force actuators and load sensors; other schemes that meet the requirements stated within this document are acceptable. A "Cell Control" look up table (LUT) contains the set-points for each force actuator as a function of zenith angle and temperature. The values contained in the Cell Control LUT are provided by the TCS. Initial values for the Cell Control LUT will be developed during laboratory testing and supplied by the M2CA vendor. Zenith angle and temperature are provided to the M2CSC by the TCS in real time at a constant rate of 0.1 Hertz.*

*On yearly intervals the M2CA will be calibrated and new Cell Control LUT values determined. During calibration of the M2CA the M2CSC receives force deltas from the TCS at rates equal to or less than 0.1 Hertz.*

*Figure 8 also illustrates that the M2CSC receives high level commands from the TCS and provides fault messages to the TCS. In addition, the M2CSC provides the TCS a telemetry stream that consists of various M2CSC parameters such as currents, sensor values, etc.*

*All control, power, utility, utility interlocks, engineering sensor, and local control interfaces are via the M2 Interface Panel. All control and data transmission between the TCS and M2CSC will be via a single Ethernet connection.*

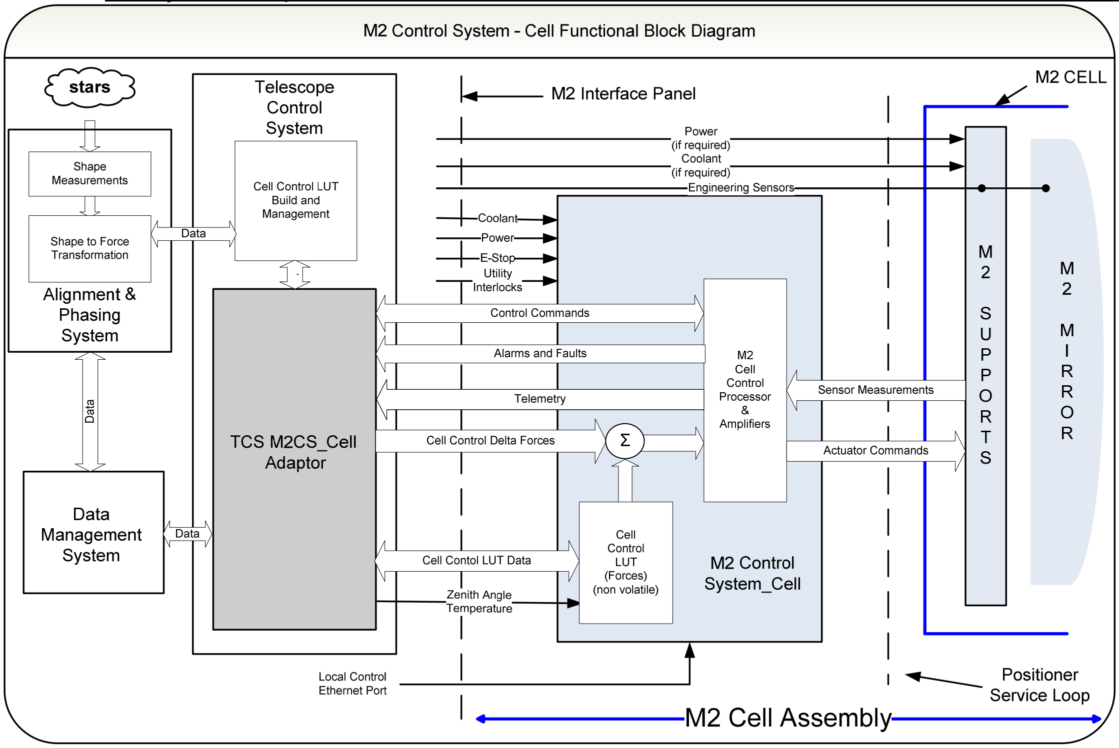


*Figure 8: A functional block diagram of the M2 Cell Control System (M2CSC); for illustrative purposes only. The software interface (command and control, faults, telemetry, data) with the M2CSC is via the Telescope Control System (TCS). The Alignment and Phasing System (APS) and the Data Management System (DMS) are shown for completeness but neither interfaces directly to the M2CSC. The illustrated design assumes that the mirror cell supports are actively controlled via force actuators and sensors; alternate schemes that meet the requirements stated within this document are acceptable. A Cell Control LUT is utilized to store the actuator set-points as a function of zenith angle (gravity) and temperature. Delta forces are added to the forces stored in the LUT on a real time basis during calibration.*

**Command and Control:**

[REQ-2-M2-1250] The M2CSC shall include a non-volatile Cell Control LUT that contains M2SS command set-points as a function of zenith angle and temperature.

[REQ-2-M2-1260] The M2CSC shall have the ability to receive and execute M2SS command offsets from the TCS at rates up to and including once per second.

[REQ-2-M2-1270] The M2CSC shall be able to receive and install new Cell Control LUT values from the TCS, when in a standby state.

*Discussion: A standby state indicates that the M2 Mirror shape is controlled but is not adjusting for gravity, temperature, or receiving M2 support command offsets from the TCS.*

[REQ-2-M2-1280] The M2CSC shall support a user defined mode that utilizes user defined actuator commands and does not update the actuator commands as a function of gravity and temperature.

[REQ-2-M2-1290] The Cell Control LUT shall be readable by the TCS.

[REQ-2-M2-1300] The M2CA shall be capable of operating within 30 seconds of the M2CSC receiving new Cell Control LUT values.

[REQ-2-M2-1310] All communication between the M2CSC and the TCS shall utilize a single Ethernet connection.

[REQ-2-M2-1320] The M2CSC shall acknowledge the successful receipt of all commands.

[REQ-2-M2-1330] The M2CSC shall acknowledge the successful completion of all commands.

[REQ-2-M2-1340] The M2CSC shall be autonomous and capable of operating without connection to any other observatory system other than power and coolant.

**Safety and Fault Monitoring:**

*Discussion: Two fault levels are identified. "Critical Faults" are those that can result in personnel injury or equipment damage and "General Faults" are those that may degrade performance but not cause personnel injury or equipment damage.*

[REQ-2-M2-1350] The M2CSC shall monitor the M2CA for all conditions that can result in a Critical Fault.

[REQ-2-M2-1360] The M2CSC shall take immediate action to place the M2CA in a safe condition when a Critical Fault is identified, internally or by the TCS.

*Discussion: Acceptable M2CSC actions upon sensing a critical fault include shutting itself down and removing all power to the M2CA. Critical faults include, but are not limited to, shorts, over currents, over voltages, and over temperatures.*

[REQ-2-M2-1370] The M2CSC shall immediately notify and identify Critical Faults to the TCS.

[REQ-2-M2-1380] The M2CSC shall monitor the M2CA for conditions that can result in a General Fault.

*Discussion: The selection of which General Faults will be monitored should result from an understanding of the reliability of the various M2CA components and assemblies and to the cost of implementing the monitor for any specific fault.*

[REQ-2-M2-1390] The M2CSC shall immediately notify and identify General Faults to the TCS.

[REQ-2-M2-1400] The M2CSC shall insure that the M2CA cannot be damaged by the issuance of any command from the TCS.

[REQ-2-M2-1410] The M2CSC shall insure that the M2CA cannot be damaged from power and coolant out of specification conditions (including removal of power and/or coolant).

[REQ-2-M2-1420] The M2CSC shall shut the M2CA down and remove power upon receipt of an Emergency Stop from the Observatory Safety System.

[REQ-2-M2-1430] The M2CSC shall monitor the Utility interlocks that are generated by the M2 interface panel and take the appropriate action when an interlock is detected.

*Discussion: Utility interlocks include but are not limited to coolant flow and coolant temperature.*

**Telemetry:**

[REQ-2-M2-1440] The M2CSC shall make telemetry data available to the TCS at a 1 Hertz rate.

*Discussion: Telemetry data includes, but is not limited to, all actuator commands, sensor readings, primary active control parameters, temperatures, and power supply voltages.*

[REQ-2-M2-1450] The M2CSC shall support a "Fast Data Capture" telemetry mode which enables a definable subset of the telemetry data to be captured at a 400 Hertz rate for 20 seconds.

*Discussion: The Fast Data Capture mode will be used as a diagnostic tool. An example might be to look at the high rate variations of a load cell to understand the effect of ground-based vibrations on M2CA performance.*

[REQ-2-M2-1460] The data captured in Fast Data Capture mode shall be cached locally during the acquisition process and made available to the TCS after completion of the acquisition event.

[REQ-2-M2-1470] The M2CA shall continue to meet it's performance requirements defined within this document during a "Fast Data Capture" event.

**Initialization, Power Up, and Power Down:**

[REQ-2-M2-1480] The M2CSC shall control the power up and initialization sequence of the M2CA.

[REQ-2-M2-1490] The M2CSC shall be controlled remotely via Ethernet.

*Discussion: M2CSC power needs to be brought up remotely prior to initiating the overall M2CA power up and initialization sequence.*

[REQ-2-M2-1500] The M2CSC shall power up and initialize the M2CA upon receipt of the appropriate TCS command.

*Discussion: It is permissible to have separate power up and initialization commands.*

[REQ-2-M2-1510] The M2CA power up and initialization sequence shall complete within 30 seconds of receipt of the appropriate TCS command.

*Discussion: Initialization is complete when the M2 Mirror is properly supported and controlled via the actuator commands contained within the Cell Control LUT.*

[REQ-2-M2-1520] The M2CSC shall inform the TCS when the power up and initialization sequence is complete.

[REQ-2-M2-1530] The M2CSC shall insure that the power up and initialization sequence does not cause personnel injury or damage to equipment.

[REQ-2-M2-1540] The M2CSC shall provide the option, based on initialization command parameters, to utilize the Cell Control LUT values saved in the on–board non-volatile memory or a LUT provided by the TCS as part of the initialization command.

[REQ-2-M2-1550] The M2CSC shall control the power down sequence of the M2CA.

[REQ-2-M2-1560] The M2CSC shall power down the M2CA upon receipt of the appropriate TCS command.

[REQ-2-M2-1570] The M2CSC shall execute and complete the M2CA power down sequence within 30 seconds of receipt of the appropriate TCS command.

[REQ-2-M2-1580] The M2CSC shall insure that the power down sequence does not cause personnel injury or damage to equipment.

[REQ-2-M2-1590] The M2CSC power down sequence shall place the M2CA in a state supported by the power up and initialization commands and sequences.

**Diagnostics and Calibration:**

[REQ-2-M2-1600] The M2CSC shall include a self test mode that results in a report sent to the TCS with pass/fail test results as well as the specific test results.

[REQ-2-M2-1610] The M2CSC self test results shall provide a high probability indication that the M2CA is performing per the requirements.

[REQ-2-M2-1620] The M2CSC self-test shall take no more than 5 minutes to complete after receipt of a self-test command from the TCS.

[REQ-2-M2-1630] The M2CSC shall include a diagnostic and calibration mode, which supports the control of individual actuators and the reading of individual sensors.

[REQ-2-M2-1640] The M2CSC diagnostic and calibration mode shall support the on-sky measurement of individual actuator influence functions.

[REQ-2-M2-1650] The M2CSC diagnostic and calibration mode shall provide a means to measure, update, and report to the TCS, all scale factors and parameters that need to be re-calibrated on a regular basis.

[REQ-2-M2-1660] The M2CSC shall contain an Ethernet port for a laptop that enables local control of the M2CA.

**Interfaces:**

[REQ-2-M2-1670] The M2CSC shall be designed to allow the replacement of any electronic assembly including printed circuit boards and power supplies in less than 15 minutes in-situ with the telescope horizon pointing.

### 3.2.6 Interaction with the M2 Cell Assembly Lifting Fixture (M2CALF)

*Discussion: The M2 Cell Assembly Lifting Fixture (M2CALF) will be used to remove the M2CA (Figure 2).*

[REQ-2-M2-1680] The M2CA and M2CALF shall be designed so that the M2CALF cannot hit the M2 Mirror (M2M) if the observatory is subjected to a maximum likely earthquake as specified in REQ-1-ORD-1500 at a moment when the Fixture is being lowered down towards the M2CA.

*Discussion: This may require mechanical guides that capture the M2CALF as it is being lowered into position.*

[REQ-2-M2-1690] The M2CA and the M2CALF shall be designed so that the maximum tensile stresses in the M2 Mirror are less than 2.0 megapascals (TBC) during the normal removal or installation process and less than 10 megapascals (TBC) during a maximum likely earthquake that occurs during a removal or installation process.

## 3.3 M2 Positioner Assembly (M2PA)

*Discussion: The M2 Positioner is defined to be a six-legged Stewart platform (hexapod). A conceptual design of the M2 Positioner, optimized to meet the requirements for payload capacity, stiffness and motion resolution, is shown in Figure 4.*

*The M2 hexapod is a 6 Degrees of Freedom positioning mechanism that incorporates a fixed Base and a moving Platform, and uses six actuators to create high precision motions.*

*Throughout this document the term tracking refers to the M2 rigid body trajectory required when gathering data on a science object and the term slewing refers to the M2 rigid body trajectory required when moving between two different science objects or instruments.*

*An option is being considered to replace the conventional secondary with an adaptive secondary mirror (AM2), making use of the M2PA to support the AM2. The OAD states that the telescope shall be designed to support interchangeability of the conventional M2S with the AM2, [REQ-1-OAD-1800]. However, until the characteristics of the AM2 have been defined, support of the AM2 will not be covered in this requirements document.*

### 3.3.1 Requirements for the Overall Assembly

**Performance:**

[REQ-2-M2-1700] The M2PA shall meet all of the requirements stated in this document with the M2CA attached.

[REQ-2-M2-1710] The M2PA shall be designed to operate with and without the M2CA attached.

[REQ-2-M2-1720] The M2PA shall be able to move independently and simultaneously in each of five Degrees of Freedom; δx, δy, δz, $\theta_x$, and $\theta_y$.

[REQ-2-M2-1730] The M2PA shall be able to reposition and settle the M2 Mirror within the accuracy and jitter requirements described in [REQ-2-M2-1740, 1750, 1800, 1810] within 150 seconds.

*Discussion: This requirement is driven by ORD requirement REQ-1-ORD-1800 which defines the allowable time to re-position the telescope including mounted optics. One hundred and fifty seconds is specified rather than 180 seconds to allow time for guiding offsets that may be required during the acquisition process.*

[REQ-2-M2-1740]* The M2PA shall be able to accurately translate the M2 Mirror in *δx, δy,* and *δz* to within 30 micrometers RMS.

*Discussion: This requirement is driven by the observatory system 1 arcsecond RMS pointing requirement as well as the pupil alignment budget. The resulting accuracy requirement derived from the pointing requirement is tighter than the repeatability requirement derived from pupil alignment. The "on sky" pointing budget is contained in the OAD in section 3.5. The requirement is in effect the residual positioning error after any real time calibration correction.*

*Discussion: The capture range, in post-segment exchange mode, for tip/tilt, piston, decenter and surface shape shall be as stated in [REQ-1-OAD-2296] through [REQ-1-OAD-2302].*

[REQ-2-M2-1750]* The M2PA shall be able to accurately rotate the M2 Mirror in $\theta_x$, $\theta_y$ *and* $\theta_z$ to within 1000 milliarcseconds RMS.

*Discussion: The capture range, in post-segment exchange mode, for tip/tilt, piston, decenter and surface shape shall be as stated in [REQ-1-OAD-2296] through [REQ-1-OAD-2302].*

*Discussion: See discussion for [REQ-2-M2-1740]*

[REQ-2-M2-1760]* The M2PA shall be able to position the M2 Mirror in *δx, δy,* and *δz* to an accuracy of 2.5 micrometers RMS over a range of +/- 100 micrometers.

*Discussion: This requirement is derived from the image blur allocation of the OAD overall image quality error budget for on axis - seeing limited observations.*

[REQ-2-M2-1770] The M2PA shall be able to position the M2 Mirror in $\theta_x$ *and* $\theta_y$ to an accuracy of 500 milliarcseconds RMS over a range of +/- 10 arcseconds.

*Discussion: This requirement is derived from the image blur allocation of the OAD overall image quality error budget for on axis - seeing limited observations.*

[REQ-2-M2-1780]* The M2PA shall be able to translate the M2 Mirror 100 micrometers in *δx, δy,* and *δz* and settle within the accuracy and jitter requirements described in [REQ-2-M2-1740 and 0965] respectively within 10 seconds.

*Discussion: This requirement is driven by ORD requirement [REQ-1-ORD-1800] which defines the allowable time to re-position the telescope. Although the ORD requirement defines a maximum repositioning time the intention is to minimize the acquisition time for all moves, long and short. The intention of this requirement is to place a sensible bound on settling time.*

[REQ-2-M2-1790] The M2PA shall be able to tilt the M2 Mirror 5 arcseconds in $\theta_x$ and $\theta_y$ and settle within the accuracy and jitter requirements described in [REQ-2-M2-1750 and 1760] respectively within 10 seconds.

*Discussion: See discussion for [REQ-2-M2-1780].*

[REQ-2-M2-1800]* The residual M2 Mirror jitter in *δx, δy,* and *δz* shall be no greater than 1 micrometers RMS.

*Discussion: The residual M2 Mirror jitter is defined as the RMS difference between the commanded trajectory (TCS commands at 40 Hertz) and the actual trajectory, as measured on the M2 Mirror* *surface, with the trend removed in the resultant difference. The intention of this requirement is to bound the self induced jitter from a particular M2 motion but to also bound the jitter introduced into M2 as a result of simultaneous M2 motion in other directions.*

[REQ-2-M2-1810]* The residual M2 Mirror jitter in $\theta_x$ *and* $\theta_y$ shall be no greater than 50 milliarcseconds RMS.

*Discussion: The residual M2 Mirror jitter is defined as the RMS difference between the commanded trajectory (TCS commands at 40 Hertz) and the actual trajectory, as measured on the M2 Mirror surface, with the trend removed in the resultant difference. The intention of this requirement is to bound the self induced jitter from a particular M2 motion but to also bound the jitter introduced into M2 as a result of simultaneous M2 motion in other directions.*

[REQ-2-M2-1820] The residual M2 Mirror jitter in $\theta_z$ shall be no greater than TBD milliarcseconds RMS.

*Discussion: See discussion for [REQ-2-M2-1810]. One percent decenter of an AO subaperture on the edge of the M2 Mirror represents 68 arcseconds of M2 rotation.*

[REQ-2-M2-1830] The M2PA shall not require re-calibration more frequently than once per year. Zero point updates shall be permissible once per month.

[REQ-2-M2-1840] The M2PA cross coupling shall be less than 1 micrometer in position and 60 milliarcseconds in angle.

*Discussion: For example, any commanded move in δx should result in less than 1 micrometer of motion in δx and δz, and less than 60 milliarcseconds in* $\theta_x$*,* $\theta_y$*.* $\theta_z$*.*

[REQ-2-M2-1850] The stiffness of the M2PA in the $\delta_x$ and $\delta_y$ directions shall be greater than $4x10^6$ Newtons per meter

*Discussion: This requirement is derived assuming a maximum low frequency wind disturbance force of 2 Newtons and an error allocation of 0.5 micrometers RMS. The stiffness includes the structural stiffness of the M2PA as well as the stiffness of the M2CSP in translation.*

[REQ-2-M2-1860] The driven stiffness of the M2PA in the $\theta_x$ *and* $\theta_y$ directions shall be greater than 10 $x10^6$ Newton-meters/radian.

*Discussion: This requirement is derived assuming a maximum low frequency wind disturbance torque of 1 Newton-meter and an error allocation of 20 milliarcseconds RMS. The stiffness includes the structural stiffness of the M2PA as well as the stiffness of the M2CSP in rotation.*

[REQ-2-M2-1870] The driven stiffness of the M2PA in the $\theta_z$, direction shall be greater than TBD Newton meters/radian.

[REQ-2-M2-1880] The M2PA shall not freely move at any telescope zenith angle between -5 and 95 degrees with the power removed.

*Discussion: This requirement can be accomplished via the use of a power off brake, a combination of balancing the M2PA, and back-drive resistance, or a suitable alternative scheme.*

**Reliability and Maintenance:**

[REQ-2-M2-1890] All scheduled maintenance and repair to the M2PA shall be achievable within 2 hours with the telescope pointed at the horizon and without removal of the M2PA and M2CA.

*Discussion: This includes the removal and replacement of components including actuators.*

[REQ-2-M2-1900] The M2PA must be able to operate for 10 hours continuously each night, with a total expected operating lifetime of 50 years at 50 percent duty cycle.

**General:**

[REQ-2-M2-1910] The total mass of the M2PA shall be less than or equal to 500 kilograms.

[REQ-2-M2-1920] The maximum transverse wind cross-sectional area of the M2PA, for air flow in any direction perpendicular to the optical axis, shall be less than 1.0 square meters. This includes the associated electronics and cables.

*Discussion: [REQ-1-OAD-1080] Limits the maximum transverse wind cross-section of the top end of the telescope.*

[REQ-2-M2-1930] The average drag coefficient of the M2PA, in any transverse direction (air flow direction perpendicular to the optical axis) shall meet the drag coefficient requirement stated in the OAD, [REQ-1-OAD-1085].

[REQ-2-M2-1940] The height of the M2PA between the mounting surface interface to the telescope structure and the mounting surface interface to the M2CA shall be 0.85 meters, when the M2H is in the center of its range of motion.

*Discussion: See Figure 6.*

[REQ-2-M2-1950] The M2PA zero points for $\delta x$, $\delta y$,, $\delta z$, $\theta_x$, and $\theta_y$ shall be midway in each of their respective travel ranges.

[REQ-2-M2-1960] The heat transmitted to the structure or atmosphere by the M2PA shall be less than 25 Watts.

*Discussion: A glycol-water coolant shall be supplied by the observatory facility. The temperature of the coolant supplied will be 3 Kelvin below ambient.*

[REQ-2-M2-1970] The M2PA shall limit vibration transmitted to the telescope structure to less than TBD.

### 3.3.2 M2 Hexapod (M2H)

*Discussion: The hexapod functions as a positioning mechanism for the entire M2 system, correcting for optical system misalignments and de-space between M1 and M2. The hexapod moves the M2 in a smooth controlled trajectory at a commanded speed and acceleration relative to the telescope structure.*

*The location of the pupil image is partially controlled through the control of M2 pointing. The M2S allocation for pupil shift is shown in the OAD, [REQ-1-OAD-0709]. This requirement will be met if all other requirements for M2H stability and accuracy are met.*

*Discussion: The hexapod shall provide 6 Degrees of Freedom, as stated in [REQ-1-OAD-1855].*

*Discussion: One degree of freedom, rotation about the optical axis, is controlled to be stationary, in order to maintain the orientation of the M2 with respect to the alignment and phasing system.*

[REQ-2-M2-1980] The M2H range of motion requirements for piston, tip/tilt and X and Y decenter, stated in the OAD, [REQ-1-OAD-1860] through [REQ-1-OAD-1864], shall be met simultaneously.

*Discussion: The M2H bandwidths for tip/tilt and decenter shall meet the requirements stated in the OAD, [REQ-1-OAD-1870].*

[REQ-2-M2-1990] The hexapod shall be designed to support the mass of the M2CA as specified in [REQ-2-M2-0570].

[REQ-2-M2-2000] The stiffness of the hexapod actuators shall be sufficient to satisfy [REQ-2-M2-0370]. This implies that the actuator stiffness shall be greater than TBD.

### 3.3.3 M2 Positioner Control System (M2CSP)

*Discussion: The M2 Positioner Control System (M2CSP) provides local servo control of the M2 hexapod. The M2CSP will be independent and separate from the M2 Cell Control System (M2CSC) that provides local control for the M2 Cell Assembly (M2CA), as specified in [REQ-1-OAD-1890]. The primary external M2CSP control interface is with the Telescope Control System (TCS).*

*Figure 9 is for illustrative purposes. It assumes that the demanding requirements on the M2 hexapod will require a closed loop position control system; the M2 Hexapod Control Processor in the figure. Alternate schemes that meet the requirements stated within this document are acceptable. The M2CSP will receive a stream of hexapod position commands from the TCS at a 40 Hertz rate. It is the responsibility of the M2CSP to minimize the difference between the commanded and actual position of the hexapod's six* Degrees *of* Freedom *per the requirements stated within this document. Telescope zenith angle and temperature are available to the M2CSP via the TCS at a constant rate of 0.1 Hertz.*

*The position commands (δx, δy, δz, θx, θy, θz ) from the TCS will be based in the elevation coordinate reference system (ERCS). The M2CSP will include one or more LUTs (M2 Calibration LUTs) that will store the calibration terms required to transform TCS commands into the appropriate independent hexapod actuator commands. The calibration terms will not only correct for the theoretical geometric relationship between the ECRS and the six legs of the actuator but will also correct for fabrication errors in the as built geometry, encoder errors, etc. The M2 Calibration LUTs will be read and write accessible by the TCS enabling calibration as required.*

*Figure 9 also illustrates that the M2CSP receives high level commands from the TCS and provides fault messages to the TCS. In addition the M2CSP provides the TCS a telemetry stream that consists of various M2CSC parameters such as currents, sensor values, etc.*

*All control, power, utility, utility interlocks, engineering sensor, and local control interfaces are via the M2 Interface Panel. All control and data transmission between the TCS and M2CSP will be via a single Ethernet connection.*

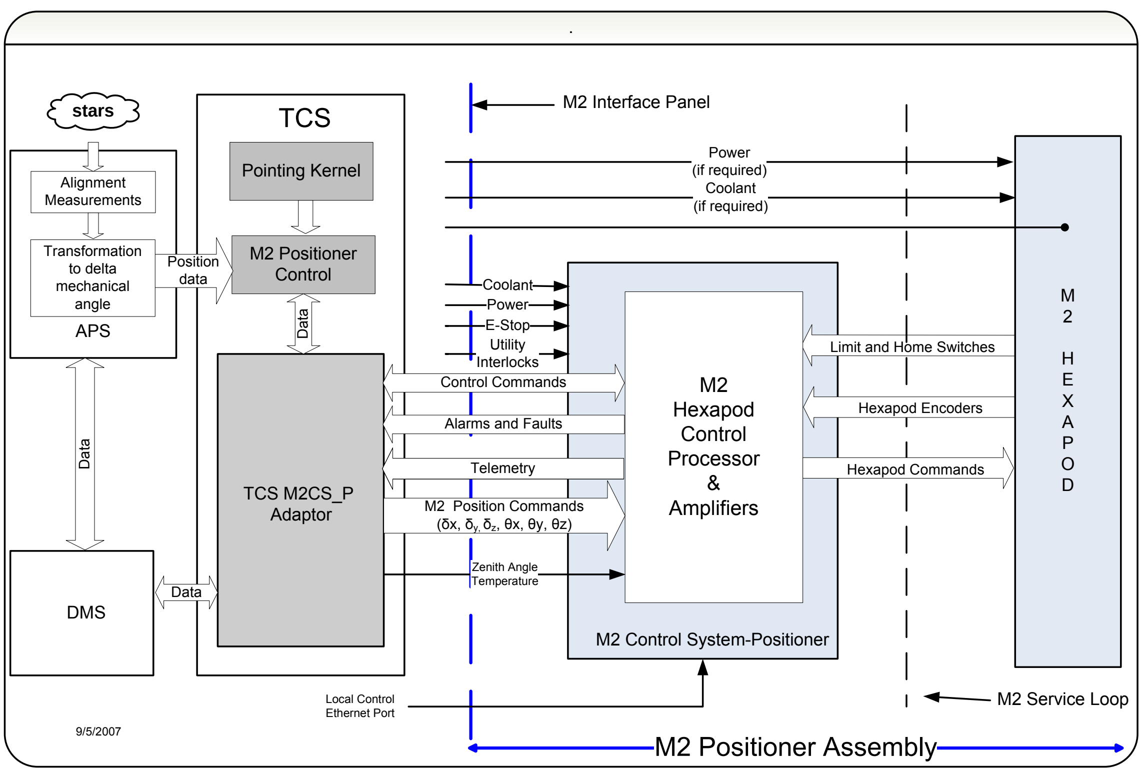

*Figure 9: A functional block diagram of the M2 Positioner Control System (M2CSP); for illustrative purposes only. The software interface (command and control, faults, telemetry, data) with the M2CSP is via the Telescope Control System (TCS). The Alignment and Phasing System (APS) and the Data Management System (DMS) are shown for completeness but neither interfaces directly to the M2CSP. The diagram assumes that the hexapod is controlled via a closed loop position control system; alternate schemes that meet the requirements stated within this document are acceptable.*

**Command and Control:**

[REQ-2-M2-2010] The M2CSP shall have the capability of receiving and executing M2 position commands from the TCS at rates up to and including 40 Hertz.

[REQ-2-M2-2020] The M2CSP shall have the capability of receiving zenith angle updates from the TCS at rates up to and including 1 Hertz.

[REQ-2-M2-2030] The M2CSP shall have the capability of receiving and utilizing the observatory wide Universal Time (UT) broadcast.

*Discussion: UT will be distributed via IRIG B or a standard GPS-based Network Time Protocol (NTP) service.*

[REQ-2-M2-2040] The M2CSP shall include calibration LUTs that contain the calibration terms required to transform measured position into actual (corrected) positions.

*Discussion: These terms will be determined initially at the supplier during lab testing.*

[REQ-2-M2-2050] The M2CSP shall provide the TCS with read and write access to all of the M2CSP calibration LUT tables.

*Discussion: The TCS requires access to the calibration LUTs contained within the M2CSP so as to enable recalibration of the system as a result of long terms drifts, exchanged components, etc.*

[REQ-2-M2-2060] It shall be possible to import the M2CSP calibration LUTs into the TCS and bypass the LUTs contained within the M2CSP.

*Discussion: In the long term it may be optimal to centralize all of the active optic LUTs within the TCS.*

[REQ-2-M2-2070] All communication between the M2CSP and the TCS shall utilize a single Ethernet connection.

[REQ-2-M2-2080] The M2CSP shall acknowledge the successful receipt of all commands.

[REQ-2-M2-2090] The M2CSP shall acknowledge the successful completion of all commands.

[REQ-2-M2-2100] The M2CSP shall be capable of operating without connection to any other observatory system excluding power and coolant.

**Safety and Fault Monitoring:**

*Discussion: Two fault levels are identified. "Critical Faults" are those that can result in personnel injury or equipment damage and "General Faults" are those that may degrade performance but not cause personnel injury or equipment damage.*

[REQ-2-M2-2110] The M2CSP shall monitor the M2PA for all conditions that can result in a Critical Fault.

[REQ-2-M2-2120] The M2CSP shall take immediate action to place the M2PA in a safe condition when a Critical Fault is identified.

*Discussion: Acceptable M2CSP actions upon sensing a critical fault include shutting down and removing all power to the M2PA. Critical faults include, but are not limited to, shorts, over currents, over voltages, and over temperatures.*

[REQ-2-M2-2130] The M2CSP shall immediately notify and identify Critical Faults to the TCS.

[REQ-2-M2-2140] The M2CSP shall monitor the M2CA for conditions that can result in a General Fault.

*Discussion: The selection of which General Faults will be monitored should result from an understanding of the reliability of the various M2PA components and assemblies and the cost for implementing the monitor for any specific fault.*

[REQ-2-M2-2150] The M2CSP shall immediately notify and identify General Faults to the TCS.

[REQ-2-M2-2160] The M2CSP shall insure that the M2PA cannot be damaged by the issuance of any command from the TCS.

[REQ-2-M2-2170] The M2CSP shall insure that the M2PA cannot be damaged from power and coolant out of specification conditions (including removal of power and/or coolant).

[REQ-2-M2-2180] The M2CSP shall immediately stop all M2PA motion and remove power upon receipt of an Emergency Stop from the Observatory Safety System.

[REQ-2-M2-2190] The M2CSP shall monitor the utility interlocks that are generated by the M2 interface panel and take the appropriate action when an interlock is detected.

*Discussion: Utility interlocks include but are not limited to coolant flow and coolant temperature.*

**Telemetry:**

[REQ-2-M2-2200] The M2CSP shall make telemetry data available to the TCS at a 1 Hertz rate.

*Discussion: Telemetry data includes, but is not limited to, all actuator commands, sensor readings, primary active control parameters, temperatures, and power supply voltages.*

[REQ-2-M2-2210] The M2CSP shall support a “Fast Data Capture” telemetry mode, which enables a definable subset of the telemetry data to be captured at a 400 Hertz rate for 20 seconds.

*Discussion: The Fast Data Capture mode will be used as a diagnostic tool. An example might be to look at the high rate variations of a position encoder to understand the effect of ground-based vibrations on M2S performance.*

[REQ-2-M2-2220] The data captured in Fast Data Capture mode shall be cached locally during the acquisition process and made available to the TCS after completion of the acquisition event.

[REQ-2-M2-2230] The M2CSP shall meet all requirements defined within this document during a “Fast Data Capture” event.

**Initialization, Power Up, and Power Down:**

[REQ-2-M2-2240] The M2CSP shall control the power up and initialization sequence of the M2PA.

[REQ-2-M2-2250] The M2CSP shall employ remote power on/off capability.

*Discussion: Power needs to be brought up remotely prior to initiating the overall M2PA power up and initialization sequence.*

[REQ-2-M2-2260] The M2CSP shall power up and initialize the M2PA upon receipt of the appropriate TCS command.

*Discussion: It is permissible to have separate power up and initialization commands.*

[REQ-2-M2-2270] The M2PA power up and initialization sequence shall complete within 30 seconds, independent of the initial $\delta x$, $\delta y$, $\delta z$, $\theta_x$, $\theta_y$, and $\theta_z$ positions, of receipt of the appropriate TCS command.

*Discussion: Initialization is complete when the 6 M2PA Degrees of Freedom are being controlled to a known position.*

[REQ-2-M2-2280] The M2CSP shall inform the TCS when the power up and initialization sequence is complete.

[REQ-2-M2-2290] The M2CSP shall insure that the power up and initialization sequence does not cause personnel injury or damage to equipment.

[REQ-2-M2-2300] The M2CSP shall provide the option, based on initialization command parameters, to position the M2 in rotation and tilt to default positions or to positions provided by the TCS as part of the initialization command.

[REQ-2-M2-2310] The M2CSP shall control the power down sequence of the M2PA.

[REQ-2-M2-2320] The M2CSP shall power down the M2PA upon receipt of the appropriate TCS command.

[REQ-2-M2-2330] The M2CSP power down sequence of the M2PA shall complete within 30 seconds of receipt of the appropriate TCS command.

[REQ-2-M2-2340] The M2CSP shall insure that the power down sequence of M2PA does not cause personnel injury or damage to equipment.

[REQ-2-M2-2350] The M2CSP power down sequence of the M2PA shall place the M2PA in a state supported by the power up and initialization commands and sequences.

**Diagnostics and Calibration:**

[REQ-2-M2-2360] The M2CSP shall include a self-test mode of the M2PA that results in a report sent to the TCS with pass/fail test results as well as the specific test results.

[REQ-2-M2-2370] The M2CSP self-test results shall provide a high probability indication that the M2PA is performing per the requirements.

[REQ-2-M2-2380] The M2CSP self test of the M2PA shall take no more than 5 minutes to complete after receipt of a self-test command from the TCS.

[REQ-2-M2-2390] The M2CSP shall include a diagnostic and calibration mode which supports the individual control of each M2PA degree of freedom in actuator space, $\delta x, \delta y, \delta z, \theta_x, \theta_y, \theta_z$ space, and the reading of individual sensors.

[REQ-2-M2-2400] The M2CSP diagnostic and calibration mode shall provide a means to measure, update, and report to the TCS, all scale factors and parameters that may require re-calibration on a regular basis.

[REQ-2-M2-2410] The M2CSP shall contain an Ethernet port for a laptop that enables local control of the diagnostic and calibration modes.

**Interfaces:**

[REQ-2-M2-2420] The M2CSP shall allow the in-situ replacement of any electronic assembly including printed circuit boards and power supplies in less than 15 minutes with the telescope horizon pointing.

## 3.4 M2 INTERFACE PANEL (M2I)

[REQ-2-M2-2430] All hoses, wires and cables shall be terminated at the interface plate.

# 4. APPENDICES

## 4.1 APPENDIX A: SUMMARY OF OAD AND ORD REFERENCES TO THE M2S

Items in italic font, marked as Discussion, are for information only and are not requirements.

*Discussion: All Level 1 requirements are presented in the Observatory Requirements Document (ORD) and the Observatory Architecture Document (OAD). This document flows the Level 1 requirements down to the Level 2 requirements. Table 4 and Table 5 provide a summary list of the Level 1 requirements contained in the ORD and the OAD that pertain to the M2 System*

*Table 4: Level 1 requirements in the OAD pertaining to the M2S.*

| OAD Requirement Number | OAD Section (Bold font)<br>Parameter Specified (not Bold font) | Referenced in M2S DRD |
|---|---|---|
| | **2.1.2.10 M2 System** | |
| [REQ-1-OAD-0152] | M2 System Decomposition | 2.2 |
| | **3.1 Reliability and Availability Budgets** | |
| [REQ-1-OAD-0320] | M2 System Downtime Allocation | 3.2.1 |
| | **Table 3 On-axis jitter and blur error budget in milliarcseconds:** | |
| [REQ-1-OAD-0424] | M2 Shape (D80 Image Jitter and Blur) | 3.2.2.2.3 |
| [REQ-1-OAD-0452] | Optical Alignment, image jitter (M2 relative to M1) | |
| [REQ-1-OAD-0460] | Optical Alignment, Image blur (M2 relative to M1) | |
| | **Table 4 – Facility AO System (NFIRAOS) Error Budget** | |
| [REQ-1-OAD-0560] | Facility AO Error Budget for M2 Shape | |
| | **Table 5 Pointing Error Budget** | |
| [REQ-1-OAD-0669] | Telescope Pointing Error Budget for M2 Alignment relative to M1 | |
| | **Table 6 Pupil Shift Budget** | |
| [REQ-1-OAD-0709] | Pupil shift budget for M2 stability | 3.3.2 |
| | **4.1.5 M2 System** | |
| [REQ-1-OAD-1800] | Interchangeable conventional M2 with Adaptive M2 | 3.3.3 |
| [REQ-1-OAD-1080] | M2CA and M2PA maximum cross section | 3.2.1, 3.3.1 |
| [REQ-1-OAD-1085] | M2 average drag coefficient | 3.2.1, 3.3.1 |
| [REQ-1-OAD-1820] | M2 System Mass | 3.1 |

| | | |
|---|---|---|
| [REQ-1-OAD-1825] | M2 outer diameter | 3.1 |
| [REQ-1-OAD-1830] | Alignment features for GMS | |
| [REQ-1-OAD-1835] | M2 removal for coating | 3.2.1 |
| [REQ-1-OAD-1840] | Compatible with stripping and coating processes | 3.2.1 |
| [REQ-1-OAD-1845] | Allow $CO_2$ cleaning | 3.2.1 |
| [REQ-1-OAD-1850] | Allow in-situ washing | 3.2.1 |
| [REQ-1-OAD-1855] | Degrees of Freedom motion | 3.3.1 |
| [REQ-1-OAD-1860] | Piston | 3.3.1 |
| [REQ-1-OAD-1862] | Tip and Tilt | 3.3.1 |
| [REQ-1-OAD-1864] | X and Y decenter | 3.3.1 |
| [REQ-1-OAD-1870] | Bandwidth for tip/tilt and de-center | 3.3.3 |
| [REQ-1-OAD-1875] | Bandwidth for piston | 3.3.3 |
| [REQ-1-OAD-1880] | M2 Mirror active supports functional requirements | 3.2.3 |
| [REQ-1-OAD-1885] | Calibration of M2 supports | 3.2.3 |
| [REQ-1-OAD-1890] | M2 Control System functions | 3.2.5 and 3.3.3 |
| [REQ-1-OAD-1895] | M2 Control System vs. Telescope Control System | 3.3.3 |
| [REQ-1-OAD-1900] | M2 figure updates | 3.2.5 |
| [REQ-1-OAD-1910] | M2 optical surface quality | |
| | **Table 12 Alignment maintenance mode capture range** | |
| [REQ-1-OAD-2266] | M2 tip/tilt alignment capture range | |
| [REQ-1-OAD-2268] | M2 piston alignment capture range | |
| [REQ-1-OAD-2270] | M2 X/Y decenter capture range | |
| [REQ-1-OAD-2272] | M2 surface shape capture range | |
| | **Table 13 Post-segment exchange mode capture range** | |
| [REQ-1-OAD-2296] | M2 tip/tilt alignment capture range, for post segment exchange mode | 3.3.2 |
| [REQ-1-OAD-2298] | M2 piston alignment capture range, for post segment exchange mode | 3.3.2 |
| [REQ-1-OAD-2300] | M2 X/Y decenter capture range, for post segment exchange mode | |
| [REQ-1-OAD-2302] | M2 surface shape capture range, for post segment exchange mode | 3.3.1 |
| | **4.1.9 Servicing and Maintenance** | |

| | | |
|---|---|---|
| [REQ-1-OAD-2500] | Telescope Optics servicing and replacement intervals | 3.1.3 |
| | **4.3 Services** | |
| [REQ-1-OAD-4500] thru [REQ-1-OAD-4855] | Services | |
| | **4.6.5 Enclosure Safety** | |
| [REQ-1-OAD-7350] | Safety | |
| | **5.1.4 Active and Adaptive Optics Control Architecture** | |
| [REQ-1-OAD-8415] | Active optics control architecture, M2 position | |
| [REQ-1-OAD-8420] | Active optics control architecture, M2 shape | |
| [REQ-1-OAD-8615] | Compensation strategy, M2 piston bandwidth | |
| [REQ-1-OAD-8625] | Compensation strategy, M2 tilt bandwidth | |
| | **6.1 Coordinate System** | |
| [REQ-1-OAD-9900] | M2 coordinate system | 3.1 |

*Table 5: Level 1 requirements in the ORD pertaining to the M2S.*

| **ORD Requirement Numbers** | **ORD Section is Bold**<br>**Parameter Specified not in Bold** | **Referenced in DRD** |
|---|---|---|
| [REQ-1-ORD-1000] thru [REQ-1-ORD-1005] | General Constraints | 3.1.3 |
| | **Environmental Constraints** | |
| [REQ-1-ORD-1050] | Site location | 3.1.3 |
| [REQ-1-ORD-1100] | Performance Conditions | 3.1.5 |
| [REQ-1-ORD-1200] thru [REQ-1-ORD-1260] | Observing Operating Conditions | 3.1 |
| [REQ-1-ORD-1400] thru [REQ-1-ORD-1435] | Operational Basis Survival Conditions | 3.1.6 |
| [REQ-1-ORD-1500] thru [REQ-1-ORD-1550] | Maximum Likely Earthquake Conditions | 3.2.6 |
| | **Image Quality** | |

| | | |
|---|---|---|
| [REQ-1-ORD-2850] | Plate Scale Uniformity | |
| | **Environmental, Health and Safety Requirements** | |
| [REQ-1-ORD-7000] thru [REQ-1-ORD-7015] | Safety | 3.1.2 |
| [REQ-1-ORD-7200] | Health | |
| [REQ-1-ORD-7400] thru [REQ-1-ORD-7410] | Environmental | |
| [REQ-1-ORD-7600] thru [REQ-1-ORD-7610] | Security | |

## 4.2 APPENDIX B: BLANK - SECONDARY MIRROR

This drawing of the TMT conceptual design of the M2 Mirror Blank is for illustration purposes only and does not constitute a requirement.