THIRTY METER TELESCOPE

REQUIREMENTS DOCUMENT

FOR

TERTIARY MIRROR SYSTEM (M3S)

TMT.OPT.DRD.07.006. 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) Tertiary Mirror System (M3S). 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 M3 System and Section 3 lists the requirements for the M3S. 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 Level 2 M3S design requirements. This document is to be used by the designer and fabricator of the M3S and any of its elements.

1.3 SCOPE

This document includes the Level 2 Requirements for the M3 System (M3S). The decomposition of the M3S is presented in the OAD, [REQ-1-OAD-0155]. This document does not include the external interfaces or any of the requirements for the M3 handling, cleaning or coating equipment.

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

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

HNDL – Optical Handling System

ID – Inside diameter

LGSF – Laser Guide Star Facility

LLT – Laser Launch Telescope

LUT – Look-up Table

M1 – Primary Mirror

M1CS – M1 Control System

M3C – M3 Cell structure

M3CA – M3 Cell Assembly

M3CALF – M3 Cell Assembly Lifting Fixture

M3CSC – M3 Cell Control System

M3CSP – M3 Positioner Control System

M3CW – M3 Cable Wrap

M3H - M3 Hexapod

M3I – M3 Interface Panel

M3M – Tertiary Mirror

M3PA – M3 Positioner Assembly

M3R – M3 Rotator

M3S – Tertiary Mirror System

M3SS - M3 Support System

M3T – M3 Tilt Mechanism

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 Tertiary Mirror System (M3S) of the Ritchey-Chrétien optical design reflects the light coming from the Secondary Mirror (M2S) to the science instruments. The M3S contains an elliptical plano-mirror, and is mounted on a tower in the center of the primary mirror. The M3S consists of the M3 Positioner Assembly (M3PA) and the M3 Cell Assembly (M3CA), as shown in Figure 1.

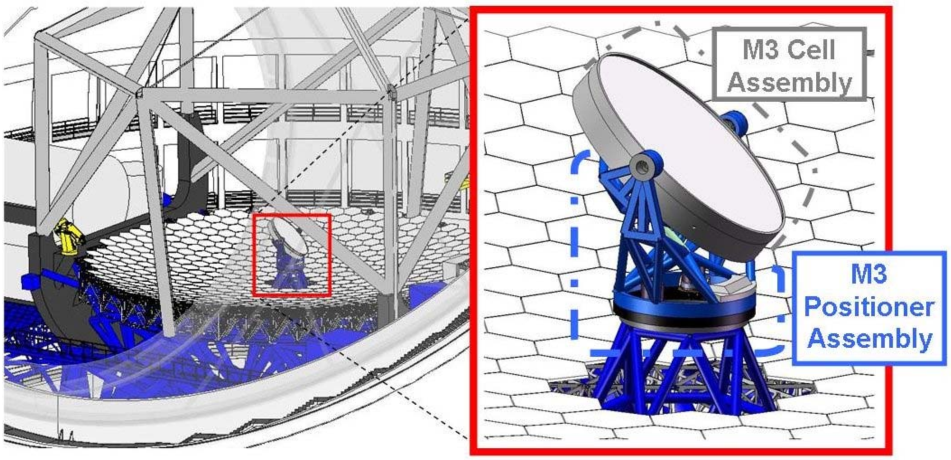


Figure 1:The M3 System shown in its location in the telescope.

The rigid body orientation of the M3 Cell Assembly is controlled to maintain the alignment of the telescope beam with science instruments mounted on the Nasmyth platforms. The shape of the mirror is also actively controlled to correct for polishing errors as well as gravitational and thermal deformations of the mirror surface. These corrections are made using Look-Up-Tables (LUT), which are created using measurements from the facility Alignment and Phasing System (APS).

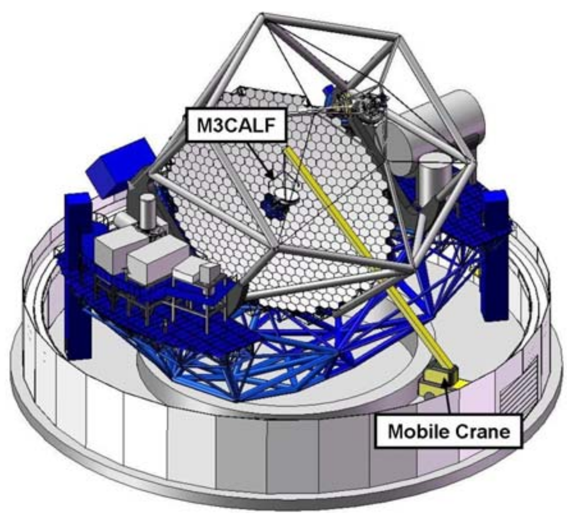


Figure 2: The M2CA being removed using the mobile crane with the telescope at 45^o.

Access is required for installation, inspection, cleaning and repair. The M3S will be accessed through a tower in the center of the primary mirror with the telescope pointed at zenith. The mirror surface will be periodically cleaned using CO_2 snow, water, and/or various detergents and solvents. Cleaning of the mirror with CO_2 snow will occur with the telescope at 45 degrees elevation and with the mirror rotated such that the optical surface faces the horizon. In-situ washing of the mirror will occur with the telescope at 45 degrees elevation and with the mirror facing upward. The M3CA will be periodically removed for mirror recoating. The M3 Cell Assembly Lifting Fixture (M3CALF) and a mobile crane will be used to remove the M3CA with the telescope at 45 degrees elevation and with the mirror facing upwards (Figure 2).

2.2 SYSTEM FUNCTIONS

The M3 System is shown in Figure 1. The M3 Positioner Assembly (Figure 3) is a 2 axis mount that controls the rotation and tilt motion of the M3 Cell Assembly (Figure 4). The M3 Cell Assembly contains the M3 Mirror Supports, electronics and software required to control the shape of the M3 Mirror. The Interface Panel is provided by TMT, and is the junction for all electrical and fluid connections. The system decomposition is presented below with the acronyms in parentheses:

M3 System (M3S):

- **M3 Positioner Assembly (M3PA):** Controls the orientation of the M3 Mirror.
  - **M3 Positioner Control System (M3CSP):** Electronics, software, sensors and cabling required to control the rigid body motion of the M3 Mirror.
  - **M3 Rotator (M3R):** Rotator Structure, Rotator Drive(s), Rotator Bearing, Counter-mass.
  - **M3 Tilt Mechanism (M3T):** Tilt Structure, Tilt Actuator, Tilt Bearings.
  - **M3 Cable Wrap (M3CW):** Routes all cables and hoses to the M3S.
- **M3 Cell Assembly (M3CA):**
  - **M3 Cell Control System (M3CSC):** Electronics, software and sensors required to control the figure of the M3 Mirror.
  - **M3 Supports (M3SS):** Actuators, load cells, cabling.
  - **M3 Cell (M3C):** Cell structure.
  - **M3 Mirror (M3M):** Mirror blank and polishing.
- **M3 Interface Panel (M3I):** The junction for all electrical and fluid connections.

The M3 Positioner Control System (M3CSP) provides local low bandwidth rigid body control of the M3 Cell Assembly via the 2-axis Positioner (M3PA) that provides rotation and tilt. Lookup Tables (LUT) within the M3CSP contain set-points for the two degrees of freedom of the rotation and tilt mount as a function of zenith angle and temperature required for each science instrument.

On a real time basis, the M3CSP receives offset positions from the Telescope Control System (TCS). The M3CSP corrects the position of the M3 Cell Assembly via the 2-axis Positioner by adding the offsets to the positions contained within the LUT.

The M3CSP 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 interface between the M3CSP and the TCS is the same during the alignment process as it is during normal operation.

The M3 Cell Control System (M3CSC) actively controls the shape of the M3 Mirror by commanding the Mirror Support actuators. The M3CSC receives a new LUT from the TCS approximately once each year. To update the LUTs, the TCS must have the ability to control the M3 Support actuators individually and read the M3 Support sensors. These commands from the TCS are given as incremental changes to the actuator forces. The M3CSP and M3CSC send telemetry to the TCS continually, and the TCS provides the current zenith angle, temperature and time. There is a diagnostic mode where the M3CSP and M3CSC perform internal tests and return data to the TCS. The TCS has the ability to perform M3S “Halts” in addition to controlled and emergency shutdowns.

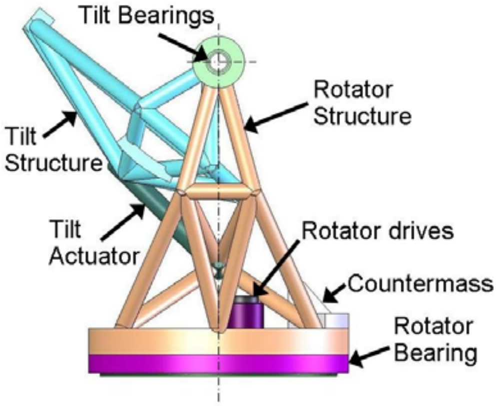


Figure 3: The M3 Positioner Assembly (M3PA).

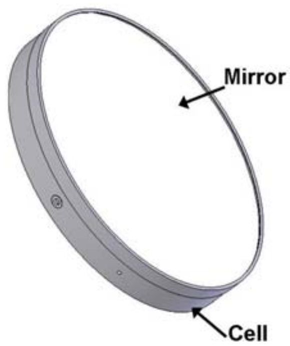


Figure 4: The M3 Cell Assembly (M2CA).

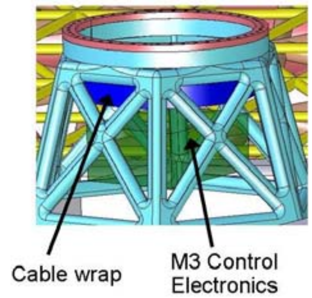


Figure 5: The cable wrap and electronics.

2.3 User and Operator Characteristics

The M3S will be operated during observations via the TCS-provided software interfaces. During subsystem tests, the engineers will command the M3 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 clean the mirror in-situ weekly using CO_2 snow and semi-annually using liquids. The M3 Cell Assembly 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 external Interface Control Documents (ICDs) for the M3S are listed in Table 1.

Table 1: List of Interface Control Documents (ICDs) for the M3S.

Summit Facilities (SUM) to M3 System (M3S)
Telescope Structure (STR) to M3 System (M3S)
M1 System (M1S) to M3 System (M3S)
M3 System (M3S) to Optical Cleaning Systems (CLN)
M3 System (M3S) to Optical Coating System (COAT)
M3 System (M3S) to Test Instruments (TINS)
M3 System (M3S) to Optical Handling System (HNDL)
M3 System (M3S) to Telescope Control System (TCS)
M3 System (M3S) to Telescope Safety System (TSS)
M3 System (M3S) to Engineering Sensors (ESEN)
M3 System (M3S) to Power, Lighting, and Grounding System (POWR)

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 M3 SYSTEM (M3S)

3.1 REQUIREMENTS FOR THE OVERALL SYSTEM

Discussion: Some of the requirements that relate to the overall M3S are Level 1 requirements and are found in the Observatory Requirements Document (ORD) and the Observatory Architecture Document (OAD). The Level 1 requirements applicable to the M3S are listed in Appendix A.

The M3S coordinate system (M3CRS) is described in [REQ-1-OAD-9900]. The earthquake survival requirements for the telescope are stated in [REQ-1-ORD-1415] and [REQ-1-ORD-1500] but preliminary studies indicate that the accelerations at the M3S are amplified by resonances of the telescope structure; therefore the earthquake survival requirements for the M3S, stated in [REQ-2-M3-0570] and [REQ-2-M3-0590], 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 M3S are described in this document in Section 3.1.6.

The mass limit for the M3S is stated in the OAD, [REQ-1-OAD-0746].

Discussion: Throughout this document the term tracking refers to the M3 rigid body trajectory required when observing a science object and the term slewing refers to the M3 rigid body trajectory required when moving between two different science objects or instruments.

3.1.1 Performance

[REQ-2-M3-0100] The M3S 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-M3-0110] The M3S 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-M3-0120] The M3S shall meet all requirements stated in this document when mounted to the telescope atop the tertiary tower with the M3 Cable Wrap (M3CW) installed and filled with the operational set of cables and utility lines.

Discussion: This requirement places a limitation on the magnitude and frequency characteristics of cable wrap disturbances that can compromise the M3PA requirements on motion and positioning. The wrap is assumed to be passive but an active wrap is acceptable if deemed necessary to meet the M3PA requirements.

[REQ-2-M3-0130] The M3S shall not require re-calibration more frequently than once per year. Zero point updates shall be permissible once per month.

[REQ-2-M3-0140]* The driven torsional stiffness of the M3S in rotation shall be greater than 10 $\times 10^6$ Newton-meters per Radian.

Discussion: The torsional stiffness is defined as a torque applied about the rotation axis on the geometric center of the M3 Mirror divided by the rotation angle resulting from the torque.

Discussion: This requirement is derived assuming a maximum low frequency wind disturbance torque of 1 Newton-meter and an error allocation of 20 milliarcseconds. This assumes that the torque is applied to the M3 Mirror surface. The stiffness includes the structural stiffness of the M3CA and M3PA as well as the stiffness of the M3CSP in rotation.

[REQ-2-M3-0150] The torsional stiffness of the M3S in tilt shall be greater than 10 $\times 10^6$ Newton-meters per Radian.

Discussion: The torsional stiffness is defined as a torque applied about the tilt axis on the geometric center of the M3 Mirror divided by the tilt angle resulting from the torque.

Discussion: See discussion for [REQ-2-M3-0140].

[REQ-2-M3-0160] The linear stiffness of the M3S in the M3CRS Z-direction shall be greater than 1.2 $x10^6$ Newtons per meter.

Discussion: The linear stiffness is defined as a force applied in the Z-direction placed on the geometric center of the M3 Mirror divided by the translation in the Z-direction resulting from that force.

Discussion: This requirement is derived assuming a maximum low frequency wind disturbance force of 3.5 Newtons and an error allocation of 3 microns. This assumes that the force is applied to the M3 Mirror surface.

[REQ-2-M3-0170] The M3S 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-M3-0180]* The M3S 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-M3-0190] The M3S 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-M3-0200] The M3S shall meet all requirements stated in this document over a telescope zenith angle range of 0 to 65 degrees.

Discussion: Any degradation of performance of the M3S outside the telescope zenith angle range of 0 to 65 degrees should be gradual.

[REQ-2-M3-0210] The M3S 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 per second (3.0 degrees per second).

[REQ-2-M3-0220] Unless otherwise stated, the M3S 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-M3-0230] The jitter of the M3 Mirror surface geometric center point along the M3CRS Z axis shall be no greater than 5.0 microns RMS over time periods of up to 100 seconds.

Discussion: The intention of this requirement is to bound the jitter in the M3CRS Z direction that is caused by motion in rotation and tilt.

[REQ-2-M3-0240] The motion of the M3 Mirror surface geometric center point along the M3CRS Z axis shall be repeatable to better than 175 microns RMS over all thermal and gravitational changes.

Discussion: M3 motion along the M3CRS Z. axis results in image motion, pupil shift, and focus errors. This requirement is driven by the pointing budget contained in OAD section 3.5.

[REQ-2-M3-0250] For any elevation motion of the telescope within the operational zenith angle range specified in [REQ-1-ORD-2630], the M3S shall be able to reposition and settle the M3 Mirror within the accuracy and jitter requirements described in [REQ-2-M3-0350, 0360, 0410, 0420] 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 the 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.

General Rotation and Tilt Requirements:

[REQ-2-M3-0260] The rotation and tilt axes of the M3S shall satisfy Figure 6.

[REQ-2-M3-0270] Unless otherwise stated, the M3S shall meet all performance requirements stated in this document over the rotation and tilt ranges defined in Table 7.

Discussion: This flowed down from [REQ-1-OAD-2000].

Discussion: Figure 7 defines the M3 rotation and tilt rotation coordinate system. A zero rotation is defined as the orientation when the M3CRS and ECRS x-axes align. A zero tilt is defined as orientation when the M3 Mirror normal vector is aligned with the ECRS z-axis.

[REQ-2-M3-0280] Unless otherwise stated, the M3S shall meet all performance requirements in this document with independent and simultaneous motions in rotation and tilt.

Discussion: This requirement places constraints on the residual cross axis sensitivity allowed after calibration.

[REQ-2-M3-0290] The mirror surface motion in the M3CRS Z axis direction shall be less than 30 microns peak during rotation and tilt increments of +/- 15 arcseconds.

Discussion: This requirement places a maximum on cross axis coupling allowed over small differential moves. This will drive derived requirements on the relative location of the M3 optical surface, rotation axis, and tilt axis

[REQ-2-M3-0300] Unless otherwise stated, the M3S shall meet all performance requirements in this document for M3 Mirror rates in rotation between 0 and ±10 arcseconds per second and tilt between 0 and ±5 arcseconds per second.

Discussion: The rotation and tilt speeds required for tracking assume an ideal telescope. The actual rotation and tilt rates are +/-7.0 and +/-3.5 arcseconds per second, respectively, and depend on the range of instrument locations on the Nasmyth Platform. The rate requirements listed above are slightly increased to account for deviations from an ideal telescope. It is important to note that the M3S will need to track accurately through zero speed; in other words through a turn-around.

Discussion: The range of motion of the M3S is defined in OAD requirements [REQ-1-OAD-2005] and [REQ-1-OAD-2007]. Any travel range required for limit switches, hard stops, etc will not reduce the travel range specified. The definition of rotation (λ) and tilt (μ) are illustrated in Figure 7.

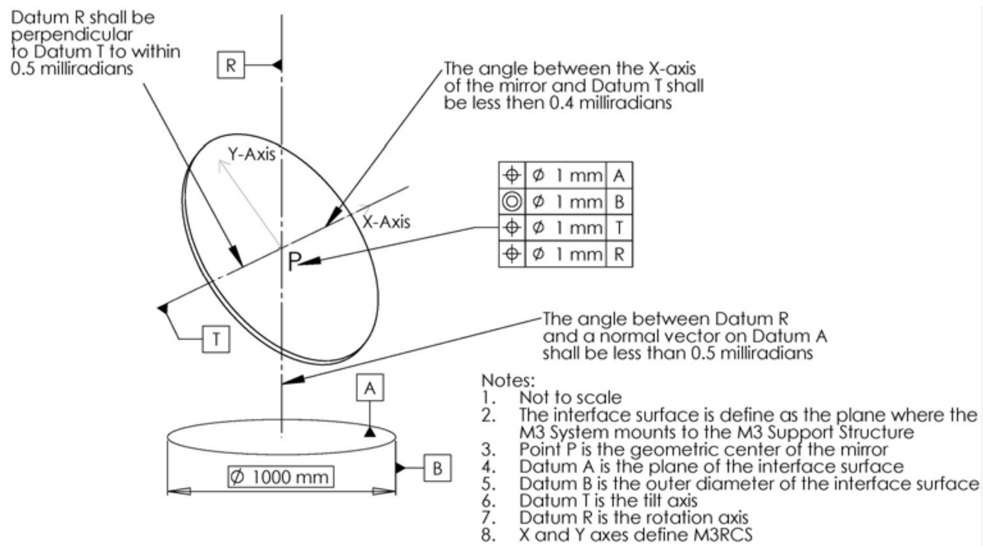


Figure 6: The tolerances for the M3S rotation and tilt axes.

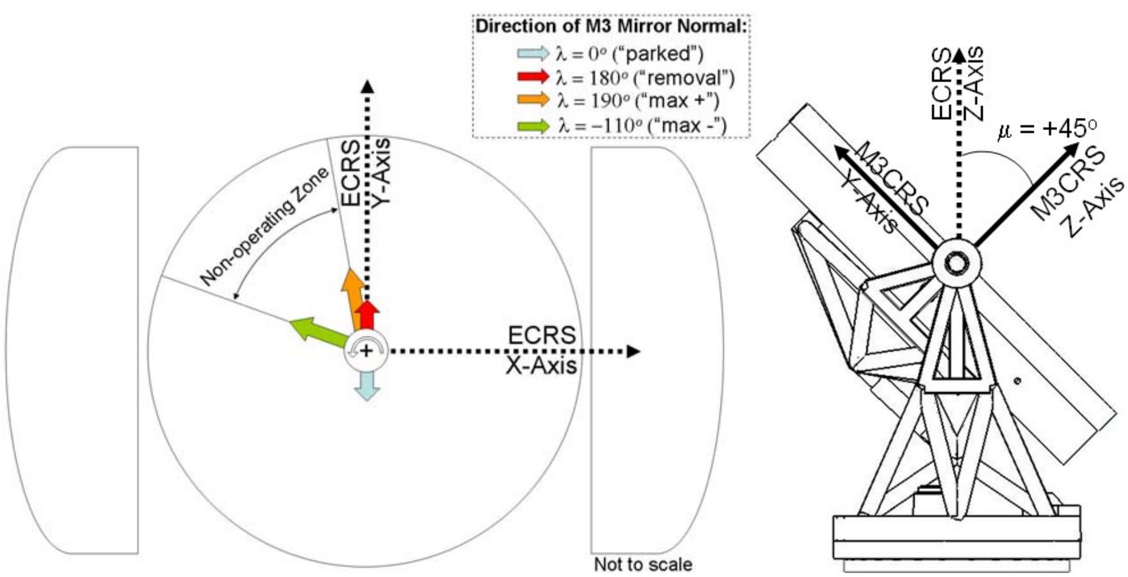


Figure 7: The coordinate systems for rotation (λ) and tilt (μ) and rotation, respectively, of the M3S. The image on the left also shows the maximum and minimum rotation angle during slewing.

Table 2: Rotation and Tilt ranges for the M3S during Pointing.

Requirement Number	Degree of Freedom	Range of M3 Motion During Pointing
[REQ-2-M3-0310]*	Rotation	62 to 98 degrees -62 to -98 degrees
[REQ-2-M3-0320]*	Tilt	32 to 48 degrees

Table 3: Rotation range for the M3S during slewing.

Requirement Number	Degree of Freedom	Range of M3 During Slewing
[REQ-2-M3-0330]*	Rotation	-110 to 190 degrees

Discussion: The slewing range is larger due to installation and removal requirements.

Rotation Requirements:

[REQ-2-M3-0340]* The M3S shall be able to rotate the M3 Mirror anywhere within the range defined in [REQ-2-M3-0310] with an accuracy of 3000 milliarcseconds RMS or less.

Discussion: This requirement is driven by the System 1 arcsecond RMS pointing requirement from the Observatory System 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. This requirement is, in effect, the residual positioning error after any real time calibration correction.

[REQ-2-M3-0350]* The M3S shall be able to rotate the M3 Mirror over a relative rotation increment of +/-15 arcseconds with an accuracy of 100 milliarcseconds RMS or less.

Discussion: This requirement is derived from the ORD requirements on offsetting; [REQ-1-ORD-2750, 2755, 2756 and 2757]. There is as much as a 12 degree change in tilt or 16 degrees in rotation over 65 degrees in elevation depending on instrument position. This equates to 0.185 tilt degrees per Elevation degrees or 0.246 rotation degrees per Elevation degree. During a 60 arcsecond telescope offset the tilt angle could change as much as 11 arcseconds and the rotation angle as much as 15 arcseconds. This equates to 1 arcsecond of image motion (using 0.09 for sensitivity for tilt) and 0.7 arcseconds of image motion from rotation which is large compared to the required offsetting accuracy of 50 milliarcseconds over 60 arcseconds. Assuming the 50 milliarcseconds offsetting budget is split into 7 equal parts (mount (az, el), M2 (tip, tilt), M3 (tip, tilt, piston)), the error allocation for the M3PA in each of 2 DOF will be 19 milliarcseconds on the sky or 211 milliarcseconds mechanical. This may not be the optimal breakdown but it provides a quick look at what might be necessary. The 19 milliarcseconds of piston equates to 29 microns (using 0.65 for sensitivity).

[REQ-2-M3-0360]* The time synchronized residual M3 rotation jitter shall be no greater than 100 milliarcseconds RMS.

Discussion: The residual M3 rotation jitter is defined as the RMS difference between the time synchronized commanded rotation trajectory (TCS commands at 40 Hertz) and the actual time synchronized rotation trajectory, as measured on the M3 Mirror surface, with the trend removed in the resultant difference. The intention of this requirement is to bound the self induced jitter from M3 rotation and to also bound the jitter introduced into M3 rotation as a result of M3 tilt motion.

[REQ-2-M3-0370] The M3S shall be able to rotate the M3 Mirror anywhere within the range defined in [REQ-2-M3-0310] and settle within the accuracy requirement described in [REQ-2-M3-0340] and the jitter requirement described in [REQ-2-M3-0360] respectively within 270 seconds (4.5 minutes) or less. As a goal the rotation repositioning time for the conditions defined above shall be 150 seconds (2.5 minutes).

Discussion: This requirement is driven by ORD requirement [REQ-1-ORD-1810] which defines the allowable time to re-position the telescope when an instrument switchover or reconfiguration occurs. Two hundred and seventy seconds is specified rather than 300 seconds to allow time for guiding offsets that may be required during the acquisition process. Note that this requirement is relevant for moves from one to the other of the ranges defined in [REQ-2-M3-0310]; for example from -90 to +90 degrees.

[REQ-2-M3-0380] The M3S shall be able to rotate the M3 Mirror over 20 degrees anywhere within the range defined in [REQ-2-M3-0310] and settle within the accuracy requirement described in [REQ-2-M3-0340] and the jitter requirement described in [REQ-2-M3-0360], both within 60 seconds or less.

Discussion: This requirement is driven by ORD requirement [REQ-1-ORD-1800] which defines the allowable time to re-position the telescope without an instrument switchover or reconfiguration.

[REQ-2-M3-0390]* M3S shall be able to rotate the M3 Mirror over a relative rotation increment of +/-5 arcseconds and settle within the accuracy and jitter requirements described in [REQ-2-M3-0340] and [REQ-2-M3-0360] respectively in 10 seconds or less.

Discussion: This requirement is intended to minimize the acquisition time for short moves, which places a sensible bound on settling time.

Tilt Requirements:

[REQ-2-M3-0400]* The M3S shall be able to tilt the M3 Mirror anywhere within the range defined in [REQ-2-M3-0320] with an accuracy of 1500 milliarcseconds RMS or less.

Discussion: See discussion for [REQ-2-M3-0340].

[REQ-2-M3-0410]* The M3S shall be able to tilt the M3 Mirror over a relative rotation increment of +/-15 arcseconds with an accuracy of 100 milliarcseconds RMS or less.

Discussion: See discussion for [REQ-2-M3-0350].

[REQ-2-M3-0420]* The time synchronized residual M3 tilt jitter shall be no greater than 100 milliarcseconds RMS.

Discussion: The residual M3 tilt jitter is defined as the RMS difference between the time synchronized commanded tilt trajectory (TCS commands at 40 Hertz) and the actual time synchronized tilt trajectory, as measured on the M3 Mirror surface, with the trend removed in the resultant difference. The intention of this requirement is to bound the self induced jitter from M3 rotation but to also bound the jitter introduced into M3 tilt as a result of M3 rotation motion.

[REQ-2-M3-0430] The M3S shall be able to tilt the M3 Mirror anywhere within the range defined in [REQ-2-M3-0320] and settle within the accuracy requirement described in [REQ-2-M3-0400] and the jitter requirement described in [REQ-2-M3-0420], both within 60 seconds or less.

Discussion: This requirement is driven by ORD requirement [REQ-1-ORD-1800] which defines the allowable time to re-position the telescope. Given the small tilt range required only 60 seconds is allocated. The maximum tilt motion required during acquisition is primarily drive by instruments located at the extreme minus side of either Nasmyth platform; the required tilt motion of the M3S is only slightly increased when switching instruments.

[REQ-2-M3-0440] M3S shall be able to tilt the M3 Mirror over a relative rotation increment of +/-5 arcseconds and settle within the accuracy and jitter requirements described in [REQ-2-M3-0400] and [REQ-2-M3-0420] respectively within 10 seconds or less.

Discussion: See discussion for [REQ-2-M3-0390].

3.1.2 Reliability

[REQ-2-M3-0450] No more than 2 hours of observing time shall be lost each year due to failures of the M3S.

Discussion: This is flowed down from [REQ-1-OAD-0322]. 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-M3-0460] The reliability of the design shall be compatible with a 5-year maintenance period and a 25-year lifetime with a goal of 50 years.

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 procedures for M3S 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-M3-0470] The M3S shall be designed to not present safety hazards to personnel.

[REQ-2-M3-0480] All service panels and fasteners shall be captive.

[REQ-2-M3-0490] The M3S shall not be able to damage the M3M under any circumstance(s).

[REQ-2-M3-0500] The M3S shall not be able to damage the telescope primary mirror or any other telescope subsystem under any circumstance(s).

3.1.4 Maintainability

[REQ-2-M3-0510] Servicing of the M3S shall be performed when the telescope is pointing at 45 degrees from zenith.

Discussion: A mobile crane will be available for the removal of the M3CA.

Discussion: The M3S 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-M3-0520] All components of the M3S that have an MTBF of less than 50 years shall be designed to be serviceable in the field in less than 2 hours.

[REQ-2-M3-0530] All components of the M3S that have an MTBF of less than 50 years shall be replaceable while the M3 System is mounted on the telescope in a zenith-pointing orientation.

[REQ-2-M3-0540] Any material that goes into the coating chamber with the mirror shall be cleanable and vacuum compatible.

3.1.5 Thermal control

[REQ-2-M3-0550] The temperature of the coolant used by any element of the M3S shall not increase by more than 3 Kelvin.

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-M3-0560] The design shall minimize thermal gradients to avoid seeing degradations. The temperature difference from the M3 Mirror optical surface to the ambient air shall be less than 0.65 Kelvin (TBC).

3.1.6 Earthquake Requirements

[REQ-2-M3-0570]* The M3S shall survive without damage earthquake dynamic accelerations equivalent to a static acceleration of 2 g (TBC), due to an Operational Basis Survival earthquake as described in [REQ-1-ORD-1415].

[REQ-2-M3-0580] After an earthquake, it shall be possible to perform in-situ inspection of the M3S to identify any damage in less than 2 hours, with the telescope zenith pointing.

[REQ-2-M3-0590]* The M3S shall survive earthquake dynamic accelerations equivalent to a static acceleration of 3 g (TBC), due to a maximum likely earthquake described in [REQ-1-ORD-1500], with no damage to the mirror and only limited damage to the mechanical or electronic components, such that all damages shall be repairable in less than or equal to one week.

[REQ-2-M3-0600] The M3M shall be protected during a maximum likely earthquake, even if there is a loss of electrical power.

[REQ-2-M3-0610]* The lowest resonant frequency of the M3S, 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.

3.1.7 General Requirements

Discussion: The M3S shall contain two independent low level control systems, one for the M3CA and one for the M3PA, per [REQ-1-OAD-2050].

[REQ-2-M3-0620] The portion of the M3S above the main rotation bearing shall be balanced about the rotation axis, such that the center of mass of that portion of the M3S shall be coincident with the rotation axis within 5 mm when the M3CA is at any rotation and tilt orientations.

[REQ-2-M3-0630] The M3S shall be designed so that nothing can fall from the M3S (including oil, coolant, cleaning fluids, particles, bolts, covers, etc.), even under the maximum likely earthquake conditions, as specified in the OAD.

[REQ-2-M3-0640] All hardware designed to be used at the observatory shall be corrosion resistant while exposed to the survival environmental conditions described in Section 3.1.2.5 of the ORD.

[REQ-2-M3-0650] The M3S shall not emit light or excessive electro-magnetic interference, vibration or heat.

[REQ-2-M3-0660] The M3S shall be designed with metric components and fasteners.

[REQ-2-M3-0670] The heat transmitted to the connecting structure or atmosphere by the M3S shall be less than 50 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.

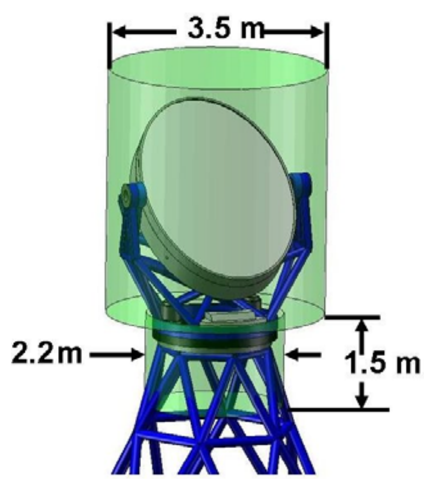


Figure 8: M3S volume constraints.

[REQ-2-M3-0680] At any operational tilt angle as defined in [REQ-2-M3-0320], the M2S shall fit inside a two layered cylindrical volume: The first layer starts at the M1 vertex and has a diameter of 2.20 meters and a height of 1.50 meters. The second cylinder is stacked on top with a diameter of 3.50 meters.

Discussion: See Figure 8.

Discussion: The lower cylinder provides clearance for the M1 segment handling crane.

Discussion: [REQ-1-OAD-1985] specifies that the entire M3 Assembly must fit within a 3.50 meter diameter cylinder centered about the M1 optical axis, at all observing orientations.

[REQ-2-M3-0690]* The M3S shall limit vibration transmitted to the telescope structure to less than TBD.

3.2 M3 Cell Assembly (M3CA)

3.2.1 Requirements for the Overall Assembly

Performance:

[REQ-2-M3-0700] The M3CA shall maintain the M3 Mirror figure so that it meets the requirements of [REQ-2-M3-1040] without requiring updates from the M3CSC LUT for net changes of +/- 2.0 degrees in the angle of the M3CRS Z-axis relative to the gravity vector.

Discussion: This requirement drives the M3CA design in terms of sensitivity to gravity.

[REQ-2-M3-0710] The M3CA shall maintain the M3 Mirror figure so that it meets the requirements of [REQ-2-M3-1040] without requiring updates from the M3CSC LUT over differential ambient temperature changes of +/- 0.2 Kelvin.

[REQ-2-M3-0720] The M3 Mirror shall settle to its final optical surface shape within 15 seconds of completion of any telescope or M3 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-M3-0730] The M3 Mirror shall settle to its final optical surface shape within 15 seconds of the M3CSC receiving a M3 Support command offset from the TCS.

Discussion: This requirement is driven by the time allocated to complete calibration of the M3 Mirror shape.

[REQ-2-M3-0740] The M3CA shall maintain the M3 Mirror figure so that it meets the requirements of [REQ-2-M3-1040] with spatial variations of wind pressure of up to 2 Pascals (TBC) across the surface of the M3 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, as well as the desired ventilation of the M1 to reduce seeing effects.

[REQ-2-M3-0750] The M3CA shall maintain the mirror figure so that it meets the requirements of [REQ-2-M3-1040] with only monthly bias updates (zero point updates) to the M3 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 at least one year. This in turn implies that the APS, on a monthly basis, only needs to align the M3 at one elevation angle and that the Cell Control LUT can be

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-M3-0760] The M3CA design shall allow for the installation or removal of the M3 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-1-1960].

[REQ-2-M3-0770] All scheduled maintenance and repair to the M3CA shall be achievable within 2 hours with the telescope pointed at the zenith and without removal of the M3PA and M3CA. Scheduled maintenance shall be required no more often than once per week.

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

[REQ-2-M3-0780] Provisions and a plan shall be developed for CO_2 snow cleaning and liquid cleaning the M3 Mirror while the telescope is pointed at 45 degrees from zenith.

Discussion: CO_2 cleaning requirements are stated in [REQ-1-OAD-1970].

Discussion: The M3CA shall be designed to allow in-situ washing of the mirror as stated in [REQ-1-OAD-1975]

3.2.2 M3 Mirror (M3M)

3.2.2.1 Mirror Blank

3.2.2.1.1 Material Properties

[REQ-2-M3-0790] The M3M Blank material shall be a low-thermal-expansion glass or glass-ceramic.

Chemical Resistance:

Discussion: The Optical Surface of the M3Mirror will be subject to periodic cleaning throughout the life of the Observatory.

[REQ-2-M3-0800] The M3 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 M3M will be subject to periodic removal throughout the expected life of the Observatory.

[REQ-2-M3-0810] The M3 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 M3 blank material shall be compatible with the equipment and processes involved in stripping and recoating, as stated in [REQ-1-OAD-1965].

Discussion: Typical materials that may be used during coating removal are shown in Table 4.

Table 4: 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-M3-0820] The M3 Blank must be elastic over a stress range of 0 to 20 megapascals, and over a temperature range of 200 Kelvin to 400 Kelvin.

Polishability:

[REQ-2-M3-0830] The M3 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-M3-0840] The Average CTE of the M3 Blank over the temperature range involved in optical testing in the polishing shop shall be small enough to ensure that the measurement uncertainty is within the error budget for that testing in the presence of spatial and temporal temperature variations.

[REQ-2-M3-0850] The Average CTE of the M3 Blank over the temperature range of 270 Kelvin to 300 Kelvin shall be small enough to ensure that the M3M 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 M3M 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-M3-0860] The Average CTE of the M3 Blank over the range of operational temperatures specified in [REQ-1-ORD-1105] shall be small enough to ensure that the M3M shall meet all of its performance requirements when subjected to the operational temperature gradients produced by the ambient air temperature gradients specified in [REQ-2-M3-0180] plus the temperature gradients created by the operation of the M3S.

[REQ-2-M3-0870] The spatial variation of the CTE in the M3 Blank, relative to the average CTE of the M3 Blank, shall be small enough to ensure that the M3M 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 M3M figure as its temperature changes.

Residual Stress:

[REQ-2-M3-0880] The residual stress in the M3 Blank material shall be less than 1.0 megapascals at all points.

Discussion: Residual stress in the M3 Blank would increase its susceptibility to brittle fracture.

Inclusions and Defects:

Discussion: Inclusions are defined as any foreign matter in the M3 Blank that is not the zero-expansion material from which the M3 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: Defects are defined as cracks inside the M3 Blank material.

Discussion: The Critical Zone is defined as the volume directly under the front surface of the mirror. It is defined as the volume enclosed by a thickness of 5 millimeters from the optical surface of the blank extending over the Clear Aperture.

[REQ-2-M3-0890] Within the Critical Zone, inclusions with a mean diameter greater than 2.5 millimeters are not allowed.

[REQ-2-M3-0900] Within the Critical Zone, no visible defects are allowed.

[REQ-2-M3-0910] No visible refractory material shall be allowed within the Critical Zone.

[REQ-2-M3-0920] Outside of the Critical Zone, Inclusions with a mean diameter greater than 10 millimeters shall not be allowed.

[REQ-2-M3-0930] Outside of the Critical Zone, the maximum dimension of any defect in any direction shall be less than 5 millimeters.

[REQ-2-M3-0940] 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 meter of mirror surface.

[REQ-2-M3-0950] 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-M3-0960] Outside of the Critical Zone, the number of defects shall total 2 or less.

[REQ-2-M3-0970] If the M3 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-M3-0980] The dimensions of the M3 Blank shall be determined by the design of the M3CA with adequate allowance for any material removal required by the optical finishing processes.

3.2.2.1.3 Surface Condition

[REQ-2-M3-0990] The surfaces of the M3 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 Finished M3 Mirror

3.2.2.2.1 Global Properties

Discussion: As stated in [REQ-1-OAD-1062], the TMT tertiary mirror is an elliptical plano-mirror.

3.2.2.2.2 Back Surface and edges

[REQ-2-M3-1000] The back surface and edges shall receive a commercial polish or etch sufficient to remove subsurface damage.

3.2.2.2.3 Mirror surface figure accuracy

[REQ-2-M3-1010] The Clear Aperture of M3M shall be an ellipse with major axis of 3.470 meters and a minor axis of 2.454 meters as shown in TMT-DWG-TBD (See Appendix B: Blank - Tertiary Mirror).

[REQ-2-M3-1020] Unless otherwise stated, all requirements for the optical surface apply over the clear aperture.

[REQ-2-M3-1030] When the M3M is installed in the telescope the Clear Aperture of the M3M shall be centered on the intersection of the telescope elevation axis and primary mirror optical axis within 2 millimeters.

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-M3-1040]* At all separation distances (x), within any beam footprint as defined in [REQ-2-M3-1050], the value of the structure function that describes the surface error of the M3M (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

$$A = \cos(45^0)^2\left(\frac{500nm}{2\pi}\right)^2\left(\frac{30m}{r_0}\right)^{5/3}$$

A = Leading coefficient = 105508

B = High frequency surface error (surface roughness) = 2 nanometers

x = Separation between point pairs

d = Diameter of beam footprint = 1.33 meters

r_0 = Quasi-Fried's parameter = 4.0 meters

The value of r_0 used in this equation was chosen to be consistent with the encircled energy requirement in [REQ-1-OAD-0436].

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 9.

[REQ-2-M3-1050]* The optical surface figure of the M3M shall not exceed the structure function described in Equation 1 and shown in Figure 9, over any elliptical area with major axis of 1.88 meters and minor axis of 1.33 meters aligned in the same orientation as the clear aperture, when the telescope is zenith pointing.

[REQ-2-M3-1060] When the telescope is pointing away from the zenith, the optical surface figure of the M3M shall not exceed the structure function specifying the optical surface of M3M multiplied by secant(Z), where Z is the zenith angle.

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

[REQ-2-M3-1070] 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-M3-1080] During acceptance testing in the optical shop, the M3SS may be used to make active optics corrections of the mirror figure, over the Clear Aperture, using the following low-order aberrations: focus – up to 100 nanometers RMS surface; 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. Within these limits, the corrections may be varied with mirror orientation.

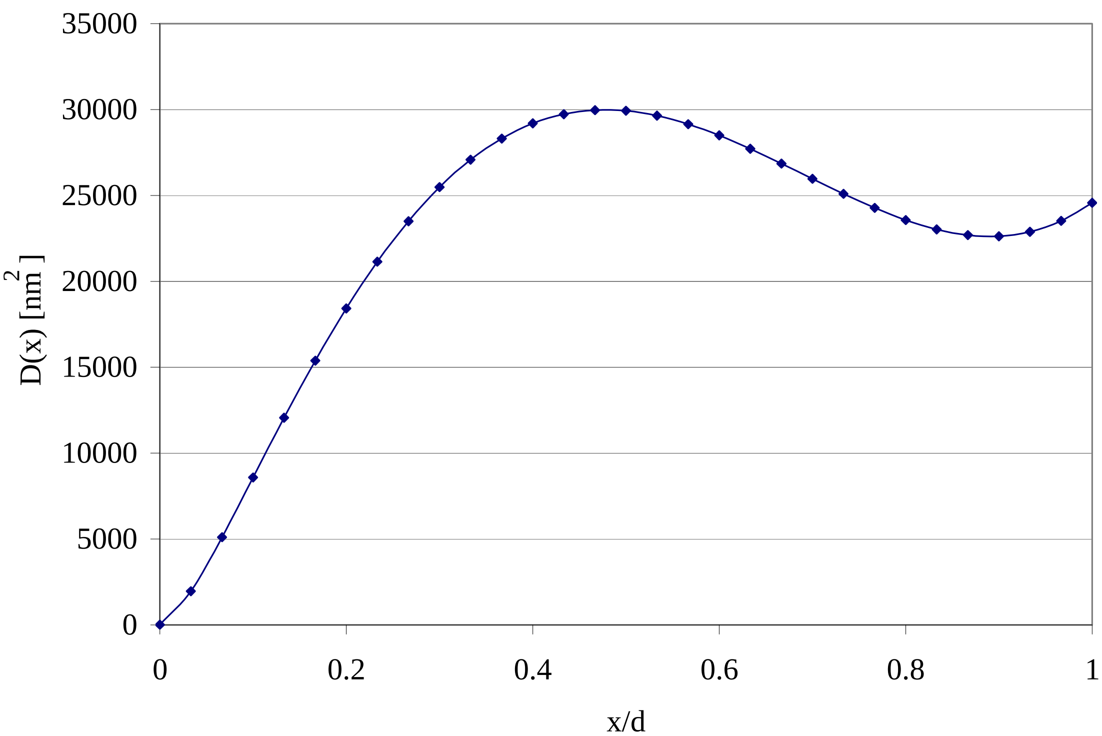


Figure 9: The Structure Function for the M3M surface error.

3.2.2.2.4 Surface roughness

[REQ-2-M3-1090] The optical surface of the M3M shall be polished to less than 2 nanometers RMS surface roughness.

3.2.2.2.5 Scratch-Dig Specification

[REQ-2-M3-1100] The scratch-dig specification for the M3M Optical Surface shall be 60-40.

Discussion: The first number is the maximum width of a scratch in microns 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 M3M. A Chip is defined as a hollow depression in a surface of the M3M, usually formed where a flake has broken out of the surface.

[REQ-2-M3-1110] The entire clear aperture shall be polished out, meaning that all subsurface damage from grinding shall be removed (no “gray” shall be left).

[REQ-2-M3-1120] No surface imperfection of surface area larger than 10 square millimeters shall be allowed within or partially within the Clear Aperture.

[REQ-2-M3-1130] 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-M3-1140] No surface imperfection of surface area larger than 100 square millimeters shall be allowed on any surface of the M3M.

[REQ-2-M3-1150] The sum of the areas of all surface imperfections on all surfaces of the M3M outside of the clear aperture shall be less than 500 square millimeters.

[REQ-2-M3-1160] No subsurface damage shall be allowed to remain in any surface.

[REQ-2-M3-1170] All surfaces of a Chip shall be ground out by the contractor to remove sharp edges and cracks.

[REQ-2-M3-1180] No visible cracks shall be allowed on any surface of the M3M.

[REQ-2-M3-1190] 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 M3 Support System (M3SS)

Discussion: [REQ-1-OAD-1880] states that the M3SS shall be an active support system capable of correcting several specified low order aberrations. The open-loop operation of the M3SS, over varying zenith angles and temperatures, shall meet the requirements stated in the OAD, [REQ-1-OAD-1885].

[REQ-2-M3-1200] The M3SS 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-M3-1210] The M3SS shall support the M3M with sufficient stiffness to meet the requirements of [REQ-2-M3-0610].

[REQ-2-M3-1220] The M3SS shall be designed such that the M3M will meet the structure function requirement in the presence of a uniform wind pressure of 10 Pascals on the optical surface.

[REQ-2-M3-1230] The M3SS 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 by the M3SS.

[REQ-2-M3-1240] The M3SS shall be able to correct the low-order aberrations specified in Table 5 with residual errors less than the amount specified. To verify that the M3SS has the required capacity to apply these corrections simultaneously, the actuator force amplitudes for the six cases may be summed in quadrature.

Table 5: Required active optics correction capability.

Aberration term	Required Amplitude (nanometers RMS)	Residual After Correction (RMS residual / RMS correction)
Focus, Z_{20}	1000	5 percent
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-M3-1250] 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-M3-1260] Any force combination that the M3SS is capable of applying to the mirror shall not be able to damage the mirror or the actuators.

[REQ-2-M3-1270] The M3SS 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, with the surface of the mirror exceeding the structure function by no more than 50% for any spatial separation.

Discussion: Operator intervention to command corrective M3SS forces is permissible in meeting this requirement.

[REQ-2-M3-1280] The repeatability of installing the M3 Mirror in its Cell, on the supports, shall be less than 0.1 millimeters in any direction.

[REQ-2-M3-1290] The M3SS shall stabilize the position of the M3 Mirror, relative to the interface between the M3CA and the M3PA, to less than 0.5 microns of relative motion in any direction per minute of tracking of the telescope, at any operational orientation and temperature.

[REQ-2-M3-1300] The M3SS shall stabilize the orientation of the M3 Mirror, relative to the interface between the M3CA and the M3PA, to less than 0.5 microradians of tilt in θ_x *and* θ_y per minute of tracking of the telescope, at any operational orientation and temperature.

[REQ-2-M3-1310] The M3SS shall stabilize the position of the M3 Mirror, relative to the interface between the M3CA and the M3PA, to less than 50 microns in any direction, over any operational orientation and temperature, for any length of time.

[REQ-2-M3-1320] The M3SS shall stabilize the orientation of the M3 Mirror, relative to the interface between the M3CA and the M3PA, to less than 50 microradians of tilt in θ_x *and* θ_y, over any operational orientation and temperature, for any length of time.

Discussion: In order for the M3PA motion control trajectories to be effective, the position of the M3M relative to the M3PA must be stable.

3.2.4 M3 Cell (M3C)

Discussion: The M3 Cell (M3C) is the structure that supports the M3 Mirror and the M3 Support System. The M3C is also where the M3CA is attached to the M3PA. The M3 Support System attaches the M3 Mirror to the M3C.

[REQ-2-M3-1330] The M3C shall be designed so that under all conditions of operation, maintenance, servicing, installation and removal, including a maximum likely earthquake as specified in [REQ-2-M3-0590], the material in the M3C shall not be stressed to more than 50 percent of the elastic limit.

[REQ-2-M3-1340] The M3C shall incorporate features that allow it to be locked to the M3PA by the remote controlled locking mechanisms specified in [REQ-2-M3-1900].

[REQ-2-M3-1350] The M3C shall be designed to allow for the inspection of all mirror supports without removing structural parts.

[REQ-2-M3-1360] The M3C shall be designed to allow for the removal and replacement of any mirror support while the M3S is mounted on the telescope.

3.2.5 M3 Cell Control System (M3CSC)

Discussion: The M3 Cell Control System (M3CSC) provides local control for the M3 Cell Assembly (M3CA). The M3CSC will be independent and separate from the M3 Positioner Control System (M3CSP) which provides local control for the M3 Positioner Assembly (M3PA). The primary external M3CSC control interface is with the Telescope Control System (TCS).

Figure 10 is for illustrative purposes only and assumes a control model where M3 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 M3CA vendor. Zenith angle and temperature are provided to the M3CSC by the TCS in real time at a constant rate of 0.1 Hertz.

On yearly intervals the M3CA will be calibrated and new Cell Control LUT values determined. During calibration of the M3CA the M3CSC receives force deltas from the TCS at rates equal to or less than 0.1 Hertz.

Figure 10 also illustrates that the M3CSC receives high level commands from the TCS and provides fault messages to the TCS. In addition, the M3CSC provides the TCS a telemetry stream that consists of various M3CSC parameters such as currents, sensor values, etc.

All control, power, utility, utility interlocks, engineering sensor, and local control interfaces are via the M3 Interface Panel. All control and data transmission between the TCS and M3CSC will be via a single Ethernet connection.

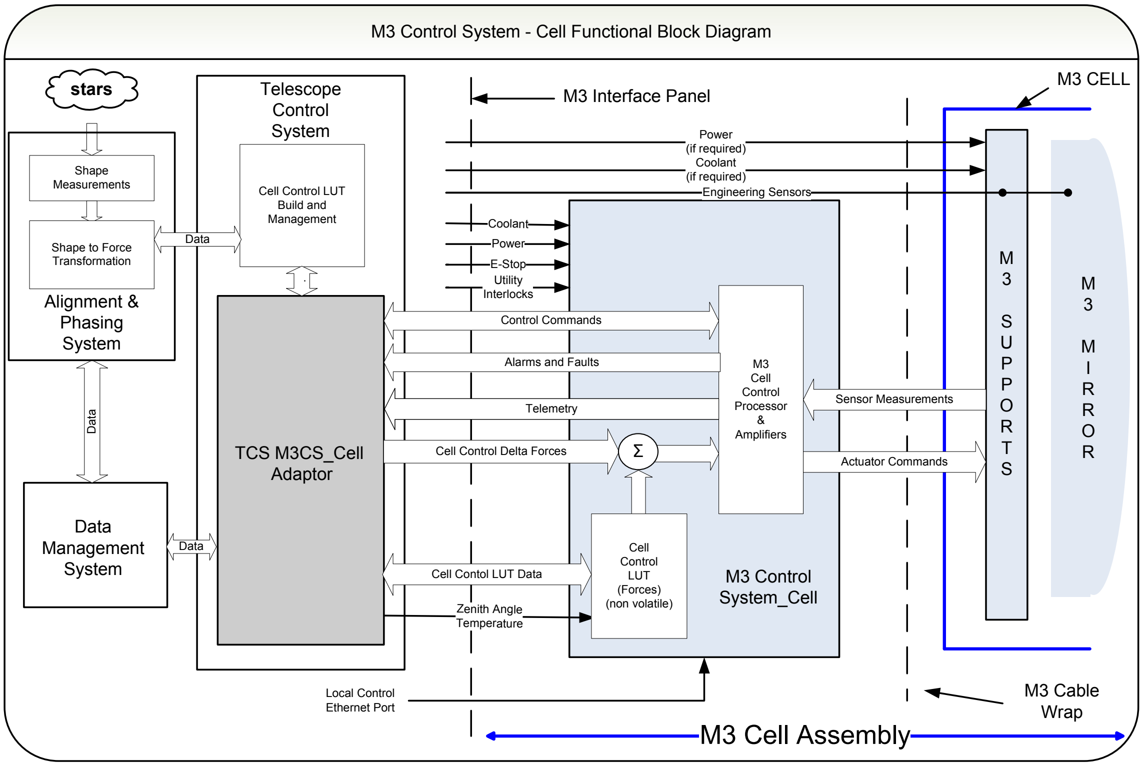


Figure 10: A functional block diagram of the M3 Cell Control System (M3CSC); for illustrative purposes only. The software interface (command and control, faults, telemetry, data) with the M3CSC is via the Telescope Control System (TCS). The Alignment and Phasing System (APS) and the Data Management System (DMS) are shown for completeness but neither interfaces directly to the M3CSC. 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-M3-1370] The M3CSC shall include a non-volatile Cell Control LUT that contains M3SS command set-points as a function of telescope zenith angle, M3S rotation angle, M3S tilt angle and temperature.

[REQ-2-M3-1380] The M3CSC shall have the ability to receive and execute M3SS command offsets from the TCS at rates up to and including once per second.

[REQ-2-M3-1390] The M3CSC 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 M3 Mirror shape is controlled but is not adjusting for gravity, temperature, or receiving M3 support command offsets from the TCS.

[REQ-2-M3-1400] The M3CSC shall support a user defined mode that utilizes user defined actuator commands and does not update the actuator commands as a function of gravity orientation and temperature.

[REQ-2-M3-1410] The Cell Control LUT shall be readable by the TCS.

[REQ-2-M3-1420] The M3CA shall be capable of operating within 30 seconds of the M3CSC receiving new Cell Control LUT values.

[REQ-2-M3-1430] All communication between the M3CSC and the TCS shall utilize a single Ethernet connection.

[REQ-2-M3-1440] The M3CSC shall acknowledge the successful receipt of all commands.

[REQ-2-M3-1450] The M3CSC shall acknowledge the successful completion of all commands.

[REQ-2-M3-1460] The M3CSC 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-M3-1470] The M3CSC shall monitor the M3CA for all conditions that can result in a Critical Fault.

[REQ-2-M3-1480] The M3CSC shall take immediate action to place the M3CA in a safe condition when a Critical Fault is identified, internally or by the TCS.

Discussion: Acceptable M3CSC actions upon sensing a critical fault include shutting itself down and removing all power to the M3CA. Critical faults include, but are not limited to, shorts, over currents, over voltages, and over temperatures.

[REQ-2-M3-1490] The M3CSC shall immediately notify and identify Critical Faults to the TCS.

[REQ-2-M3-1500] The M3CSC shall monitor the M3CA 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 M3CA components and assemblies and to the cost of implementing the monitor for any specific fault.

[REQ-2-M3-1510] The M3CSC shall immediately notify and identify General Faults to the TCS.

[REQ-2-M3-1520] The M3CSC shall insure that the M3CA cannot be damaged by the issuance of any command from the TCS.

[REQ-2-M3-1530] The M3CSC shall insure that the M3CA cannot be damaged from power and coolant out of specification conditions (including removal of power and/or coolant).

[REQ-2-M3-1540] The M3CSC shall shut the M3CA down and remove power upon receipt of an Emergency Stop from the Observatory Safety System.

[REQ-2-M3-1550] The M3CSC shall monitor the Utility interlocks that are generated by the M3 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-M3-1560] The M3CSC 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-M3-1570] The M3CSC 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 M3CA performance.

[REQ-2-M3-1580] 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-M3-1590] The M3CA shall meet the requirements defined within this document during a “Fast Data Capture” event.

Initialization, Power Up, and Power Down:

[REQ-2-M3-1600] The M3CSC shall control the power up and initialization sequence of the M3CA.

[REQ-2-M3-1610] The M3CA shall provide the capability for the power required for the M3CSC to be controlled remotely via Ethernet.

Discussion: M3CSC power needs to be brought up remotely prior to initiating the overall M3CA power up and initialization sequence.

[REQ-2-M3-1620] The M3CSC shall power up and initialize the M3CA upon receipt of the appropriate TCS command.

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

[REQ-2-M3-1630] The M3CA power up and initialization sequence shall complete within 30 seconds of receipt of the appropriate TCS command.

Discussion: Initialization is complete when the M3 Mirror is properly supported and controlled via the actuator commands contained within the Cell Control LUT.

[REQ-2-M3-1640] The M3CSC shall inform the TCS when the power up and initialization sequence is complete.

[REQ-2-M3-1650] The M3CSC shall insure that the power up and initialization sequence does not cause personnel injury or damage to equipment.

[REQ-2-M3-1660] The M3CSC 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-M3-1670] The M3CSC shall control the power down sequence of the M3CA.

[REQ-2-M3-1680] The M3CSC shall power down the M3CA upon receipt of the appropriate TCS command.

[REQ-2-M3-1690] The M3CSC shall execute and complete the M3CA power down sequence within 30 seconds of receipt of the appropriate TCS command.

[REQ-2-M3-1700] The M3CSC shall insure that the power down sequence does not cause personnel injury or damage to equipment.

[REQ-2-M3-1710] The M3CSC power down sequence shall place the M3CA in a state supported by the power up and initialization commands and sequences.

Diagnostics and Calibration:

[REQ-2-M3-1720] The M3CSC 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-M3-1730] The M3CSC self test results shall provide a high probability indication that the M3CA is performing per the requirements.

[REQ-2-M3-1740] The M3CSC self-test shall take no more than 5 minutes to complete after receipt of a self-test command from the TCS.

[REQ-2-M3-1750] The M3CSC shall include a diagnostic and calibration mode, which supports the control of individual actuators and the reading of individual sensors.

[REQ-2-M3-1760] The M3CSC diagnostic and calibration mode shall support the on-sky measurement of individual actuator influence functions.

[REQ-2-M3-1770] The M3CSC 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-M3-1780] The M3CSC shall contain an Ethernet port for a laptop that enables local control of the M3CA.

Interfaces:

[REQ-2-M3-1790] The M3CSC shall allow the in-situ replacement of any electronic assembly including printed circuit boards and power supplies in less than 15 minutes.

3.2.6 Interaction with the M3 Cell Assembly Lifting Fixture (M3CALF)

Discussion: The M3 Cell Assembly Lifting Fixture (M3CALF) will be used to remove the M3CA (Figure 2).

[REQ-2-M3-1800] The M3CA and M3CALF shall be designed so that the M3CALF cannot hit the M3 Mirror (M3M) 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 M3CA.

Discussion: This may require mechanical guides that capture the M3CALF as it is being lowered into position.

[REQ-2-M3-1810] The M3CA shall incorporate features that can interface with the M3 Cell Assembly Lifting Fixture (M3CALF). These features shall allow attachment and detachment of the M3CALF under remote control, to allow the M3CA to be installed in and removed from the telescope. The M3CALF attachment hardware shall incorporate fail-safe characteristics that prevent damage to the M3S or to any other part of the telescope caused by operator error or incorrect operation of the M3CALF attachment features.

[REQ-2-M3-1820] The M3CA shall incorporate features that automatically register it onto the M3PA when it is installed, with the telescope tilted 45 degrees from the zenith and the M3PA rotated to face upwards.

Discussion: It is permissible for the electrical connections between the M3PA and the M3CA to be made manually by a person working within the structure of the M3PA.

[REQ-2-M3-1830] The M3CA and the M3CALF shall be designed so that the maximum tensile stresses in the M3 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 M3 Positioner Assembly (M3PA)

3.3.1 Requirements for the Overall Assembly

Performance:

[REQ-2-M3-1840] The M3PA shall meet all of the requirements stated in this document with the M3CA attached.

[REQ-2-M3-1850] The M3PA shall be designed to operate with and without the M3CA attached.

[REQ-2-M3-1860] The M3PA 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 M3PA, and back-drive resistance, or a suitable alternative scheme.

Reliability and Maintenance:

[REQ-2-M3-1870] All scheduled maintenance and repair to the M3PA shall be achievable within 2 hours with the telescope pointed at the zenith and without removal of the M3PA and M3CA.

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

[REQ-2-M3-1880] The M3PA 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.

[REQ-2-M3-1890]* The M3PA shall include provisions to accommodate safe access for personnel to service the M3PA and the M3CA when the telescope is zenith pointing, as specified in [REQ-1-OAD-1995].

Discussion: Access provisions may include ladders, service platforms, guard rails, safety covers, etc., as required.

General:

[REQ-2-M3-1900]* The M3PA shall incorporate registration features that allow the M3CA to be automatically aligned onto the M3PA when it is lowered using the M3CALF, with the telescope tilted 45 degrees from the zenith and the M3PA facing upwards.

[REQ-2-M3-1910] The M3PA shall incorporate locking features that can be operated under remote control to attach the M3CA to the M3PA when it is installed. These locking features shall incorporate fail-safe characteristics that prevent damage to the M3S or to any other part of the telescope caused by operator error or incorrect operation of the locking features.

3.3.2 M3 Positioner Control System (M3CSP)

Discussion: The M3 Positioner Control System (M3CSP) provides local servo control of the M3 Rotator (M3R) and the M3 Tilt Mechanism (M3T). The M3 Cable Wrap (M3CW) is assumed passive but may require limit switches for safety. The M3CSP will be independent and separate from the M3 Cell Control System (M3CSC) that provides local control for the M3 Cell Assembly (M3CA). The primary external M3CSP control interface is with the Telescope Control System (TCS).

Figure 11 is for illustrative purposes and assumes that the demanding requirements on the M3R and the M3T will require a closed loop position control system; the M3 Rotator/Tilt Control Processor in the figure. Alternate schemes that meet the requirements stated within this document are acceptable. The M3CSP will receive a stream of rotator and tilt position commands from the TCS at a 40 Hertz rate. It is the responsibility of the M3CSP to minimize the difference between the commanded and actual positions of the rotator and tilt mechanisms per the requirements stated within this document. The commanded positions are only correct for a particular instant in time; this implies that position samples will also require synchronization with absolute time. Telescope zenith angle and temperature are available to the M3CSP via the TCS at a constant rate of 0.1 Hertz.

The M3CSP will include one or more LUTs (M3 Calibration LUTs) that will store the calibration terms required to transform measured rotation and tilt angles into actual (corrected) rotation and tilt angles. The corrections that might be necessary include cross axis coupling, zenith angle dependence, encoder cyclic errors, etc. The M3 Calibration LUTs will be read and write accessible by the TCS enabling calibration as required.

Figure 11 also illustrates that the M3CSP receives high level commands from the TCS and provides fault messages to the TCS. In addition the M3CSP provides the TCS a telemetry stream that consists of various M3CSC parameters such as currents, sensor values, etc.

All control, power, utility, utility interlocks, engineering sensor, and local control interfaces are via the M3 Interface Panel. All control and data transmission between the TCS and M3CSP will be via a single Ethernet connection.

Throughout this document the term tracking refers to the M3 trajectory required when gathering data on a science object and the term slewing refers to the M3 trajectory required when moving between two different science objects.

Science instruments are located on the left and right Nasmyth platforms as shown in the OAD. The angular range of possible science instrument locations constrains the space over which the M3S is required to meet requirements associated with tracking. On the other hand, positioning requirements are relevant when moving to a new science object or to a different instrument.

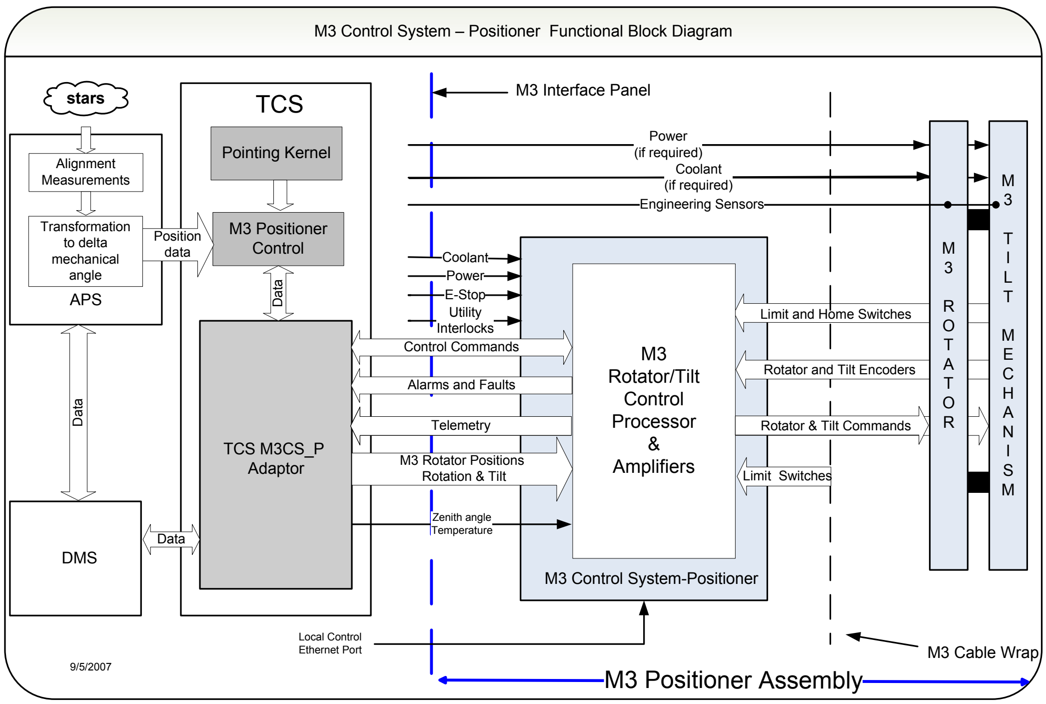


Figure 11: A functional block diagram of the M3 Positioner Control System (M3CSP); for illustrative purposes only. The software interface (command and control, faults, telemetry, data) with the M3CSP is via the Telescope Control System (TCS). The Alignment and Phasing System (APS) and the Data Management System (DMS) are shown for completeness but neither interfaces directly to the M3CSP. The diagram assumes that the rotator and tilt mechanisms are 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-M3-1920] The M3CSP shall have the capability of receiving and executing M3 position commands from the TCS at rates up to and including 40 Hertz.

[REQ-2-M3-1930] The M3CSP shall have the capability of receiving zenith angle updates from the TCS at rates up to and including 1 Hertz.

[REQ-2-M3-1940] The M3CSP shall have the capability of receiving and utilizing the observatory wide Universal Time (UT) broadcast.

Discussion: UT will be required to synchronize the rotation and tilt commands to the actual rotation and tilt positions. UT will be distributed via IRIG B or a standard GPS-based Network Time Protocol (NTP) service.

[REQ-2-M3-1950] The M3CSP shall include calibration LUTs that contain the calibration terms required to transform measured rotation and tilt angles into actual (corrected) rotation and tilt angles.

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

[REQ-2-M3-1960] The M3CSP shall control the locking features described in [REQ-2-M3-0672].

[REQ-2-M3-1970] The M3CSP shall provide the TCS with read and write access to all of the M3CSP calibration LUT tables.

Discussion: The TCS requires access to the calibration LUTs contained within the M3CSP so as to enable recalibration of the system as a result of long terms drifts, exchanged components, etc.

[REQ-2-M3-1980] It shall be possible to import the M3CSP calibration LUTs into the TCS and bypass the LUTs contained within the M3CSP.

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

[REQ-2-M3-1990] All communication between the M3CSP and the TCS shall utilize a single Ethernet connection.

[REQ-2-M3-2000] The M3CSP shall acknowledge the successful receipt of all commands.

[REQ-2-M3-2010] The M3CSP shall acknowledge the successful completion of all commands.

[REQ-2-M3-2020] The M3CSP 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-M3-2030] The M3CSP shall monitor the M3PA for all conditions that can result in a Critical Fault.

[REQ-2-M3-2040] The M3CSP shall take immediate action to place the M3PA in a safe condition when a Critical Fault is identified.

Discussion: Acceptable M3CSP actions upon sensing a critical fault include shutting down and removing all power to the M3PA. Critical faults include, but are not limited to, shorts, over currents, over voltages, and over temperatures.

[REQ-2-M3-2050] The M3CSP shall immediately notify and identify Critical Faults to the TCS.

[REQ-2-M3-2060] The M3CSP shall monitor the M3CA 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 M3PA components and assemblies and the cost for implementing the monitor for any specific fault.

[REQ-2-M3-2070] The M3CSP shall immediately notify and identify General Faults to the TCS.

[REQ-2-M3-2080] The M3CSP shall insure that the M3PA cannot be damaged by the issuance of any command from the TCS.

[REQ-2-M3-2090] The M3CSP shall insure that the M3PA cannot be damaged from power and coolant out of specification conditions (including removal of power and/or coolant).

[REQ-2-M3-2100] The M3CSP shall immediately stop all M3PA motion and remove power upon receipt of an Emergency Stop from the Observatory Safety System.

[REQ-2-M3-2110] The M3CSP shall monitor the utility interlocks that are generated by the M3 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.

[REQ-2-M3-2120] The installation/removal position for the M3 Mirror while installed in the telescope is at a M3S rotation angle of 180 degrees and a M3S tilt angle of 45 degrees with the telescope positioned at a 45 degree zenith angle. The M3CSP shall employ a fail safe mechanical system to lock the M3PA such that it cannot rotate or tilt during installation or removal of the M3CA.

Telemetry:

[REQ-2-M3-2130] The M3CSP 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-M3-2140] The M3CSP 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 M3S performance.

[REQ-2-M3-2150] 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-M3-2160] The M3CSP shall meet all requirements defined within this document during a “Fast Data Capture” event.

Initialization, Power Up, and Power Down:

[REQ-2-M3-2170] The M3CSP shall control the power up and initialization sequence of the M3PA.

[REQ-2-M3-2180] The M3CSP shall employ remote power on/off capability.

Discussion: Power needs to be brought up remotely prior to initiating the overall M3PA power up and initialization sequence.

[REQ-2-M3-2190] The M3CSP shall power up and initialize the M3PA upon receipt of the appropriate TCS command.

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

[REQ-2-M3-2200] The M3PA power up and initialization sequence shall complete within 30 seconds, independent of the initial rotation and tilt angles, of receipt of the appropriate TCS command.

Discussion: Initialization is complete when the M3PA rotation and tilt axis are being controlled to a known position.

[REQ-2-M3-2210] The M3CSP shall inform the TCS when the power up and initialization sequence is complete.

[REQ-2-M3-2220] The M3CSP shall insure that the power up and initialization sequence does not cause personnel injury or damage to equipment.

[REQ-2-M3-2230] The M3CSP shall provide the option, based on initialization command parameters, to position the M3 in rotation and tilt to default positions or to positions provided by the TCS as part of the initialization command.

[REQ-2-M3-2240] The M3CSP shall control the power down sequence of the M3PA.

[REQ-2-M3-2250] The M3CSP shall power down the M3PA upon receipt of the appropriate TCS command.

[REQ-2-M3-2260] The M3CSP power down sequence of the M3PA shall complete within 30 seconds of receipt of the appropriate TCS command.

[REQ-2-M3-2270] The M3CSP shall insure that the power down sequence of M3PA does not cause personnel injury or damage to equipment.

[REQ-2-M3-2280] The M3CSP power down sequence of the M3PA shall place the M3PA in a state supported by the power up and initialization commands and sequences.

Diagnostics and Calibration:

[REQ-2-M3-2290] The M3CSP shall include a self-test mode of the M3PA that results in a report sent to the TCS with pass/fail test results as well as the specific test results.

[REQ-2-M3-2300] The M3CSP self-test results shall provide a high probability indication that the M3PA is performing per the requirements.

[REQ-2-M3-2310] The M3CSP self test of the M3PA shall take no more than 5 minutes to complete after receipt of a self-test command from the TCS.

[REQ-2-M3-2320] The M3CSP shall include a diagnostic and calibration mode which supports the individual control of rotation and tilt and the reading of individual sensors.

[REQ-2-M3-2330] The M3CSP 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-M3-2340] The M3CSP shall contain an Ethernet port for a laptop that enables local control of the diagnostic and calibration modes.

Interfaces:

[REQ-2-M3-2350] The M3CSC shall allow the in-situ replacement of any electronic assembly including printed circuit boards and power supplies in less than 15 minutes.

3.3.3 M3 Cable Wrap

[REQ-2-M3-2360] The M3PA shall include a cable wrap that accommodates the M3PA rotation over the full range specified in [REQ-2-M3-0330] at any zenith angle without damage to the cables or hoses that pass from the telescope to the M3S.

[REQ-2-M3-2370] The M3PA Cable Wrap shall not introduce vibration that violates [REQ-2-M3-0690].

[REQ-2-M3-2380] The M3PA Cable Wrap shall not introduce resistance to the motion of the M3PA that will violate [REQ-2-M3-0360].

[REQ-2-M3-2390] The M3PA Cable Wrap shall not obstruct the personnel access specified in [REQ-2-M3-1890], nor pose any safety hazard to personnel servicing the M3S.

3.4 M3 Interface Panel (M3I)

[REQ-2-M3-2400] All hoses, wires and cables shall be terminated at the TMT provided interface plate using TMT specified connectors/methods.

4. APPENDICES

4.1 APPENDIX A: SUMMARY OF OAD AND ORD REFERENCES TO THE M3S

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 6 and Table 7 provide a summary list of the Level 1 requirements contained in the ORD and the OAD that pertain to the M3 System

Table 6: Level 1 requirements in the OAD pertaining to the M3S.

OAD Requirement Number	OAD Section (Bold font) Parameter Specified (not Bold font)	Referenced in M3S DRD
	2.1.2.11 M3 System	
[REQ-1-OAD-0155]	M3 System Decomposition	2.2.
	3.1 Reliability and Availability Budgets	
[REQ-1-OAD-0322]	M3 System Downtime Allocation	3.1.2
	Table 3 On-axis seeing limited error budget at 0.5 µm	
[REQ-1-OAD-0436]	M3 Shape (D80 Image Jitter and Blur)	3.2.2.2.3
[REQ-1-OAD-0454]	Optical Alignment, image jitter (M3 relative to M1)	
[REQ-1-OAD-0462]	Optical Alignment, Image blur (M3 relative to M1)	
	Table 4 – Facility AO System (NFIRAOS) Error Budget	
[REQ-1-OAD-0562]	Facility AO Error Budget for M3 Shape	
	3.4.4 Wavefront Corrector Stroke Allocation	
[REQ-1-OAD-0610]	Budgeted wavefront corrector stroke	
	Table 5 Pointing Error Budget	
[REQ-1-OAD-0672]	Telescope Pointing Error Budget for M3 Alignment relative to M1	
	Table 6 Pupil Shift Budget	
[REQ-1-OAD-0712]	Pupil shift budget for M3 stability	
	Table 7 Summary of the optical design	
[REQ-1-OAD-1062]	Tertiary mirror focal length (flat)	3.2.2.2.1
	4.1.7.1 M3 System General	
[REQ-1-OAD-1950]	Optical surface position	
[REQ-1-OAD-1955]	M3 alignment features	

	4.1.7.2 Removal, Cleaning and Coating	
[REQ-1-OAD-1960]	Removal of mirror for recoating	
[REQ-1-OAD-1965]	Compatible with coating processes	3.2.2.1.1
[REQ-1-OAD-1970]	Compatible with in situ CO2 cleaning	3.2.1
[REQ-1-OAD-1975]	Designed to allow in-situ washing of mirror	3.2.1
[REQ-1-OAD-1980]	Mass limit	3.1
[REQ-1-OAD-1985]	Diametric space envelope	3.1.7
[REQ-1-OAD-1990]	Clearance for segment handling crane	
[REQ-1-OAD-1995]	Access to M3 System in telescope zenith-pointing orientation	
	4.1.7.3 Control	
[REQ-1-OAD-2000]	M3 System motion degrees of freedom	3.1.1
[REQ-1-OAD-2005]	Range of M2 tilt motion	3.1.1
[REQ-1-OAD-2007]	Range of M2 rotation motion	3.1.1
[REQ-1-OAD-2010]	Motion control bandwidths	
[REQ-1-OAD-2015]	Time allowed to move beam between instruments	
[REQ-1-OAD-2020]	Track for any instrument	
[REQ-1-OAD-2025]	Tracking error requirement	
[REQ-1-OAD-2030]	Pointing repeatability on rotation axis	
[REQ-1-OAD-2035]	Pointing repeatability on tilt axis	
[REQ-1-OAD-2040]	Active capability of M3 support	
[REQ-1-OAD-2045]	M3 open-loop performance	
[REQ-1-OAD-2050]	M3 System independent control systems	3.1.7
[REQ-1-OAD-2055]	Receive and execute commands from the Telescope Control System	
[REQ-1-OAD-2060]	Accept and execute mirror figure updates from the Telescope Control System	
	4.1.7.3 Optical Quality	
[REQ-1-OAD-2070]	Surface finish	
	Table 12 Alignment maintenance mode capture range	
[REQ-1-OAD-2266]	M3 tip/tilt alignment capture range	
[REQ-1-OAD-2268]	M3 piston alignment capture range	
[REQ-1-OAD-2270]	M3 X/Y decenter capture range	
[REQ-1-OAD-2272]	M3 surface shape capture range	

	Table13 Post-segment exchange mode capture range	
[REQ-1-OAD-2296]	M3 tip/tilt alignment capture range, for post segment exchange mode	
[REQ-1-OAD-2298]	M3 piston alignment capture range, for post segment exchange mode	
[REQ-1-OAD-2300]	M3 X/Y decenter capture range, for post segment exchange mode	
[REQ-1-OAD-2302]	M3 surface shape capture range, for post segment exchange mode	
	4.1.9 Servicing and Maintenance	
[REQ-1-OAD-2500]	Telescope Optics servicing and replacement intervals	3.1.4
	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, M3 position	
[REQ-1-OAD-8420]	Active optics control architecture, M3 shape	
[REQ-1-OAD-8615]	Compensation strategy, M3 piston bandwidth	
[REQ-1-OAD-8625]	Compensation strategy, M3 tilt bandwidth	
	6.1 Coordinate System	
[REQ-1-OAD-9900]	M3 coordinate system	3.1

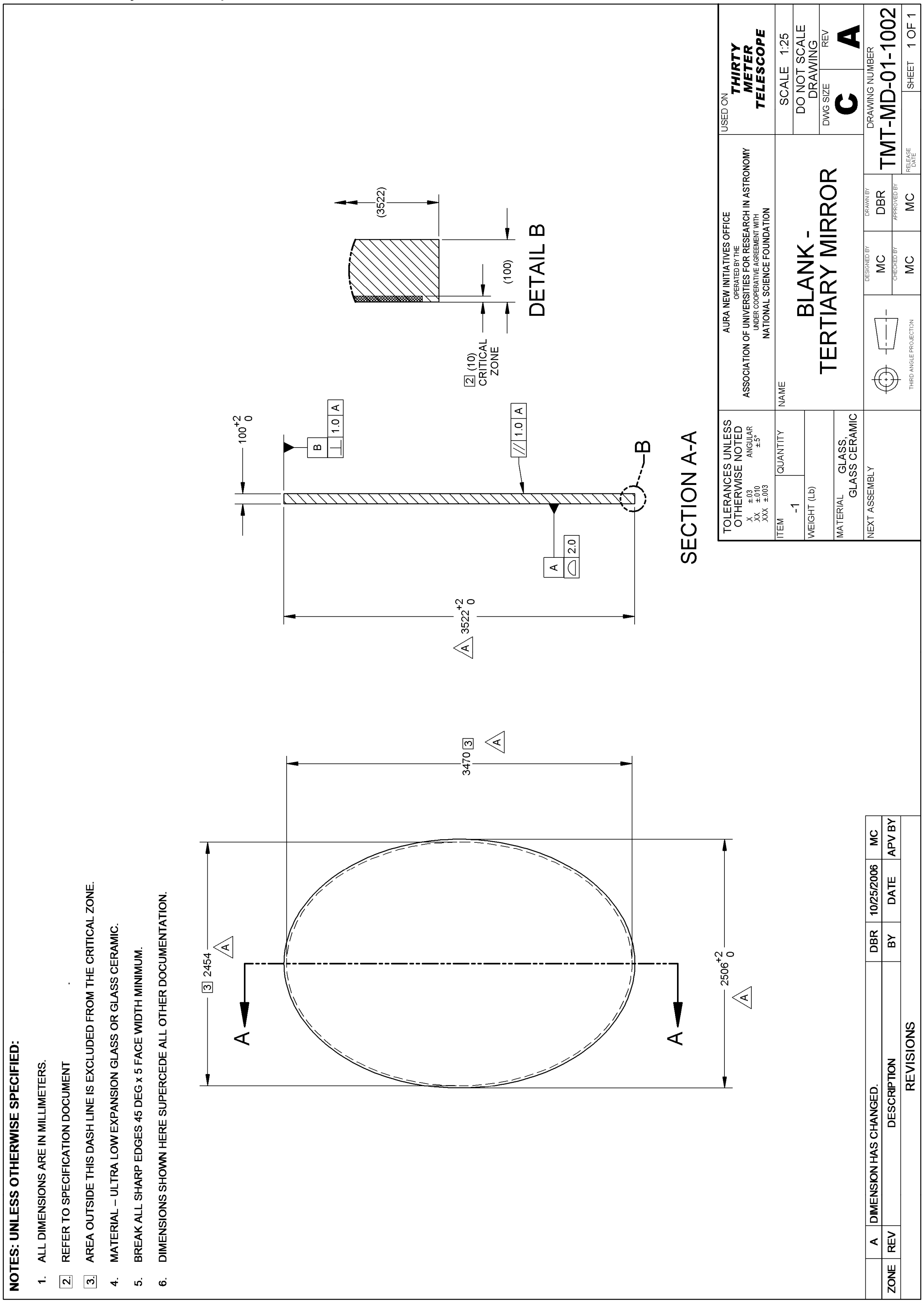
Table 7: Level 1 requirements in the ORD pertaining to the M3S.

ORD Requirement Numbers	ORD Section is Bold Parameter Specified not in Bold	Referenced in DRD
	Constraints	
[REQ-1-ORD-1000] thru [REQ-1-ORD-1005]	General Constraints	3.1.4

	Environmental Constraints	
[REQ-1-ORD-1050]	Site location	
[REQ-1-ORD-1100] thru [REQ-1-ORD-1105]	Performance Conditions	
[REQ-1-ORD-1200] thru [REQ-1-ORD-1260]	Observing Operating Conditions	3.1, 3.2.1, 3.3.2
[REQ-1-ORD-1400] thru [REQ-1-ORD-1435]	Operational Basis Survival Conditions	
[REQ-1-ORD-1500] thru [REQ-1-ORD-1550]	Maximum Likely Earthquake Conditions	3.1.1, 3.1.6, 3.2.6
	3.3.2 Target Acquisition Requirements	
[REQ-1-ORD-1800]	Allowed time to switch between objects	3.1.1, 3.2.1
[REQ-1-ORD-1810]	Allowed time to switch between instruments	3.1.1
	3.3.7 Offsetting and Nodding	
[REQ-1-ORD-2750] thru [REQ-1-ORD-2757]	Acquisition Offsetting, Guider Offsetting and AO Guider Offsetting	3.1.1
	Image Quality	
[REQ-1-ORD-2850]	Plate Scale Uniformity	
	Environmental, Health and Safety Requirements	
[REQ-1-ORD-7000] thru [REQ-1-ORD-7015]	Safety	3.1.3
[REQ-1-ORD-7200]	Health	3.1.3
[REQ-1-ORD-7400] thru [REQ-1-ORD-7410]	Environmental	3.1.3
[REQ-1-ORD-7600] thru [REQ-1-ORD-7610]	Security	3.1.3

4.2 APPENDIX B: BLANK - TERTIARY MIRROR

This drawing of the TMT conceptual design of the M3 Mirror Blank is for illustration purposes only and does not constitute a requirement.


NOTES: UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2 REFER TO SPECIFICATION DOCUMENT
3 AREA OUTSIDE THIS DASH LINE IS EXCLUDED FROM THE CRITICAL ZONE.
4. MATERIAL – ULTRA LOW EXPANSION GLASS OR GLASS CERAMIC.
5. BREAK ALL SHARP EDGES 45 DEG x 5 FACE WIDTH MINIMUM.
6. DIMENSIONS SHOWN HERE SUPERCEDE ALL OTHER DOCUMENTATION.
3 2454 A
3470 3 A
2506 +2 0 A
A
A
3522 +2 0 A
100 +2 0
B
1.0 A
1.0 A
A 2.0
B
SECTION A-A
(3522)
(100)
2 (10) CRITICAL ZONE
DETAIL B
TOLERANCES UNLESS OTHERWISE NOTED
X ±.03
XX ±.010
XXX ±.003
ANGULAR ±.5°
ITEM -1
QUANTITY
WEIGHT (Lb)
MATERIAL GLASS, GLASS CERAMIC
NEXT ASSEMBLY
AURA NEW INITIATIVES OFFICE
OPERATED BY THE
ASSOCIATION OF UNIVERSITIES FOR RESEARCH IN ASTRONOMY
UNDER COOPERATIVE AGREEMENT WITH
NATIONAL SCIENCE FOUNDATION
NAME
BLANK -
TERTIARY MIRROR
THIRD ANGLE PROJECTION
DESIGNED BY MC
DRAWN BY DBR
CHECKED BY MC
APPROVED BY MC
USED ON
THIRTY METER TELESCOPE
SCALE 1:25
DO NOT SCALE DRAWING
DWG SIZE C
REV A
DRAWING NUMBER
TMT-MD-01-1002
RELEASE DATE
SHEET 1 OF 1
ZONE REV DESCRIPTION BY DATE APV BY
A DIMENSION HAS CHANGED. DBR 10/25/2006 MC
REVISIONS