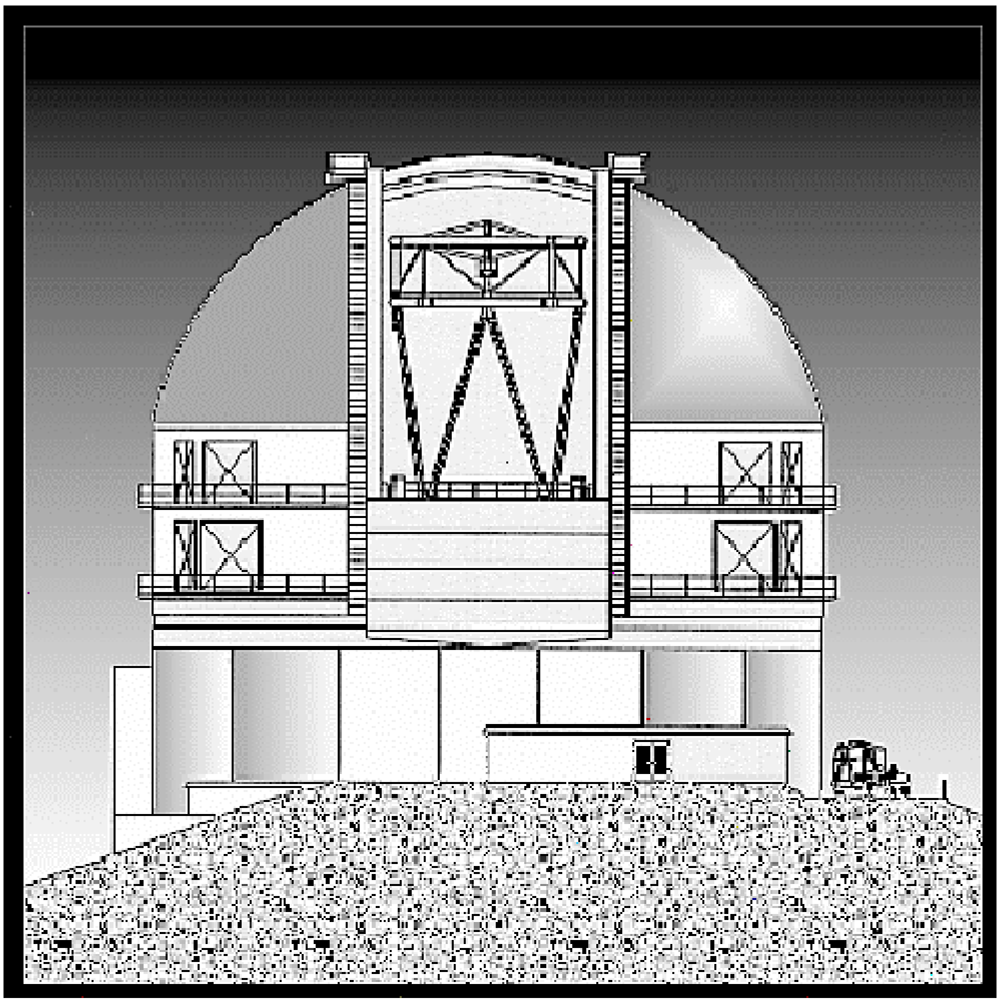
GEMINI
8-M Telescopes
Project

SPE-O-G0019
Revision 1

Design Requirements Document for the Gemini M1 Cell Assemblies



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1.0 General.

1.1 Scope of the Design Requirements Document. (a) This document (the "Design Requirements Document") contains the design requirements for the M1 Cell Assemblies for the Gemini 8M Telescopes.

1.2. Applicable Documents. (a) The M1 Cell Assembly interfaces with other component parts of the Telescope. The following documents contain information applicable to the design of the M1 Cell Assembly:

(1) Gemini Science Requirements Document;
(2) Gemini System Error Budget Plan;
(3) Primary Mirror Assembly Preliminary Design Review Package, Revision 1;
(4) Response to the Final Report of the Gemini Project Primary Mirror Assembly Preliminary Design Review Committee;
(5) Gemini System Interface Control Documents;
(6) Telescope Critical Design Review Package;
(7) Enclosure Critical Design Review Package;
(8) Cassegrain Assembly Design Requirements;
(9) Cassegrain Assembly Preliminary Design Review Report;
(10) Primary Mirror Support Control System Work Package Description.
(11) Gemini System Reliability Plan

1.3. Definitions.

1.3.1 General Definitions. (a) Where references to the main body of the Gemini Telescope M1 Support System Design Work Scope are intended herein, such references are to the "M1 Support System Work Scope."

(b) Capitalized terms defined in the M1 Support System Work Scope, or in the Statement of Work (Exhibit A to the M1 Support System Work Scope), have the same respective meanings in this Design Requirements Document, unless otherwise defined herein or unless the context requires otherwise.

1.3.2. Technical Definitions. In this Design Requirements Document, the following capitalized terms shall have the corresponding meanings given such terms in this Sections 1.3.2.

(a) AtmDC Deployment Mechanism. It is anticipated that an Atmospheric Dispersion Compensator ("AtmDC") will be required for use with some of the Cassegrain Instruments. The mechanism that moves the AtmDC into the center of the light beam, or moves it to the side to completely remove it from the light beam, is called the "AtmDC Deployment Mechanism".

(b) Ancillary Equipment. The term "Ancillary Equipment" is defined in Section 4.4.1., below.

(c) Aperture Plates. The term "Aperture Plates" is defined in Section 4.4.4., below.

(d) Axial Direction. A direction parallel to the optical axis of the Primary Mirror

(e) Axial Support Unit. The term "Axial Support Unit" is defined in Section 4.2.2.3.1., below.

(f) Cassegrain Cable Wrap. The "Cassegrain Cable Wrap" is the mechanism that carries cables, hoses, helium lines and other services required by the Cassegrain Rotator and Cassegrain Instruments, along with the associated cables, hoses, helium lines and other service lines.

(g) Cassegrain Rotator. The "Cassegrain Rotator" is the mechanism that supports, and rotates under computer control, the Cassegrain Instruments.

(h) Cassegrain Cluster. The term "Cassegrain Cluster" as used in this Work Scope, describes the instrumentation at the Cassegrain focus of the Telescopes, including the Cassegrain Rotator, the Cassegrain Cable Wrap, Cassegrain instruments, the instrument support structure, acquisition and guiding systems, calibration equipment, adaptive optics systems, and associated auxiliary equipment including control and cooling systems.

(i) Dust Removing System. The term "Dust Removing System" is defined in Section 4.4.5., below.

(j) Instrument Cover. The term "Instrument Cover" is defined in Section 4.4.3., below.

(k) Lateral Direction. A direction perpendicular to the optical axis of the Primary Mirror. In this Work Scope, the term "Lateral Direction" refers to a direction parallel to the Y axis as defined in Section 1.7 of this Design Requirements Document, unless the context requires otherwise.

(1) Lateral Support Unit. The term "Lateral Support Unit" is defined in Section 4.2.3.3.1., below.

(m) M1. "M1" is the Gemini Primary Mirror. The term can refer to the Primary Mirrors for either Site, or both Sites, as the context requires.

(n) M1 Air Pressure Support System. The term "M1 Air Pressure Support System" is defined in Section 4.2.1.1., below.

(o) M1 Assembly. The "M1 Assembly" is the assembly comprised of the Primary Mirror and the M1 Cell Assembly.

(p) M1 Axial Support System. The term "M1 Axial Support System" is defined in Section 4.2.2.1., below.

(q) M1 Baffle. The "M1 Baffle" is the large optical baffle that extends upwards from the center of the Primary Mirror. Unless otherwise stated, the term "M1 Baffle", as used in this work scope, refers to the baffle used with the F/16 optical configuration.

(r) M1 Baffle Support Mechanism. The term "M1 Baffle Support Mechanism" is defined in Section 3.2.4, below.

(s) M1 Cell Assembly. The term "M1 Cell Assembly" is defined in Section 3.1.1., below. The term, as used in this Work Scope, is limited to those portions of the M1 Cell Assembly that are covered by this Work Scope, as defined in paragraph 1. I.(b), above.

(t) M1 Cell Sensing System. The term "M1 Cell Sensing System" is defined in Section 4.2.6., below.

(u) M I Cell Structure. The term "M I Cell Structure" is defined in Section 4.1.1., below.

(v) M1 Lateral Support System. The term "M1 Lateral Support System" is defined in Section 4.2.3.1., below.

(w) M1 Safety Restraint System. The term "M1 Safety Restraint System" is defined in Section 4.2.5.1., below.

(x) M1 Support System. The term "M1 Support System" is defined in Section 4.2., below.

(y) M1 Support Cooling System. The term "M1 Support Cooling System" is defined in Section 4.2.7.1., below.

(z) M1 Thermal Management System. The term "M1 Thermal Management System" is defined in Section 4.3.1., below.

(aa) M1 X-Direction Defining System. The term "M1 X-Direction Defining System" is defined in Section 4.2.4.1., below.

(ab) Master Cylinder Unit. The "Master Cylinder Units" are the mechanisms that control the volume of hydraulic fluid in the mirror support hydraulic systems. Further descriptions are contained in Sections 4.2.2.4.1., 4.2.3.4. I., and 4.2.4.4. I., below.

(ac) Mirror Cell Support Frame. The " Mirror Cell Support Frame" is the part of the Telescope structure that supports the weight of the Ml Cell Assembly.

(ad) Nodding. "Nodding" is a controlled angular movement of the telescope used to compare the infrared signal from the science object with the background signal from a nearby portion of the sky.

(ae) Precision Elastic Limit. The "Precision Elastic Limit" is the stress that produces a permanent strain of one part in 10^6 in a material tension test.

(af) Primary Mirror. The "Primary Mirror" is the largest mirror in the Gemini Telescopes; it is described by drawing 85-GP-2000-0003.

(ag) Primary Mirror Assembly. The term "Primary Mirror Assembly" has the same meaning as the term "Ml Assembly".

(ah) Radiating Plate System. The term "Radiating Plate System" is defined in Section 4.3.1., below.

(ai) Recovery Time. - The term "Recovery Time" refers to the length of time required for a system to return to its specified level of performance or accuracy after a significant external disturbance.

(aj) Response Time. The term "Response Time" refers to the allowable length of time between sending a signal commanding a system to execute an action and completion of the action, including the settling time required for the system to return to its specified level of performance or accuracy.

(ak) Surface Heating System. The term "Surface Heating System" is defined in Section 4.3.1., below.

(al) TBD. TBD stands for "to be determined". It signifies requirements or data that is not known or has not been defined at the time this document was written.

(am) Telescope. The "Telescope" is the optical/mechanical system comprised of the telescope structure, the Ml Assembly, the telescope top end (which contains the secondary mirror assembly and related systems) and the telescope mount assembly.

(an) Utility Services. The term "Utility Services" is defined in Section 4.4.6.1., below.

(ao) X-Direction Defining Unit. The term "X-Direction Defining Unit" is defined in Section 4.2.4.1., below.

1.4 Applicable Codes and Requirements. (a) All aspects of the design and fabrication of the M1 Cell Assembly shall comply with the following codes and regulations, to the extent that such codes and regulations apply. The current edition of such codes and regulations utilized by the local building officials shall be used.

- Uniform Building Code, or equivalent.
- Uniform Mechanical Code, or equivalent.
- Uniform Plumbing Code, or equivalent.
- Uniform Fire Code, or equivalent.
- National Electrical Code, or equivalent.
- ASCE 7-88 (for wind load and load combination determination), or equivalent.
- "Recommended Lateral Force Requirements and Commentary," Seismology Committee of the Structural Engineers Association of California.
- OSHA Health Regulations.
- Americans with Disabilities Act of 1990.
- Hawaii Department of Health - Air Pollution Ordinance.
- Other applicable codes and requirements with specific application to the Mauna Kea Site and the Cerro Pachon Site.

(b) In addition to the above codes and regulations, all aspects of the design and fabrication of the M1 Cell Assembly shall comply with the requirements of SPE-ASA-G0008 Gemini Electronic Design Specification, to the extent reasonably practicable.

1.5 Coordinate Axes. (a) The coordinate axes used in this document form a right-handed system. The X-axis is parallel to the Telescope elevation axis, positive from left to right looking at the Primary Mirror optical surface with the Telescope horizon pointing. The Z-axis is parallel with the optical axis, positive from the Primary Mirror towards the secondary mirror. The origin of this coordinate system is at the center of the mounting surface for the Cassegrain Rotator bearing.

(b) The position angle θ_x is specified in relation to the y and z coordinates of the positive end of a line whose other end is at the origin, $\theta_x = \arctan(z/y)$. The position angle θ_y is specified in relation to the x and z coordinates of the positive end of a line whose other end is at the origin, $\theta_y = \arctan(x/z)$. The position angle θ_z is specified in relation to the x and y coordinates of the positive end of a line whose other end is at the origin, $\theta_z = \arctan(y/x)$.

(c) Small angular rotations about the X, Y and Z axes are defined as Rx, Ry and Rz, respectively.

(d) The Zenith Angle is defined as the angle between vertical and the optical axis of the Telescope.

(e) The term "normal" direction, when used in regard to the Primary Mirror, indicates a direction through the center of curvature of the mirror, or perpendicular to the optical surface.

(f) "Piston" motion is defined as a movement in the ± Z direction.

(g) "Tip-tilt" motion is defined as a rotation about the X or Y axes, or a simultaneous combination of rotation about the X and Y axes..

2.0 Environmental Conditions. (a) The Gemini 8-meter telescopes will be subjected to various environmental conditions, These conditions include the operating in-specification conditions, operating off-specification conditions, nonoperating conditions, survival conditions, and transportation and handling conditions. The M1 Cell Assembly and its component subsystems shall be designed and tested over environments that will ensure their performance in the Telescopes will meet all requirements of this Design Requirements Document.

(b) Other operations will impose further environmental requirements that the M1 Cell Assembly and its subassemblies shall be designed to withstand. These operations include, but are not limited to, storage conditions, twilight instrument calibration, and movement of the M1 Assembly for recoating the Primary Mirror. If necessary, special equipment shall be designed to protect the M1 Cell Assembly and its subassemblies from the environments specified and during any special operations necessary for installation, alignment, calibration, operation or maintenance.

2.1 General Environments

2.1.1 Operating In-specification Conditions. The M1 Cell Assembly and its subassemblies or subsystems shall meet all the performance requirements under the following environmental conditions:

Condition	Requirement
gravity orientation	0.5° to 75° zenith angle
altitude	2700 to 4300 meters
ambient air temperature	-5° to +20°C
relative humidity	0% to 90%
wind velocity over Primary Mirror	0 to 5 meters/second
tracking velocity - alt	0.004 degrees/second max.
tracking velocity - az.	0.5 degrees/second maximum
tracking acceleration - alt.	0.02 degrees/second^2 maximum
tracking acceleration - az.	0.05 degrees/second^2 maximum

2.1.2 Operating Off-specification Conditions. The M1 Cell Assembly and its subassemblies or subsystems shall operate under the following environmental conditions:

Condition	Requirement
gravity orientation	0° to 75° zenith angle
altitude	sea level to 4300 meters
ambient air temperature	-10° to +25°C
relative humidity	0% to 95%
wind velocity over Primary Mirror	0 to 11 meters/second
tracking velocity - alt	0.004 degrees/second max.
tracking velocity - az.	0.5 degrees/second maximum

tracking acceleration - alt.	0.02 degrees/second^2 maximum
tracking acceleration - az	0.05 degrees/second^2 maximum

2.1.3 Nonoperating Conditions. The M1 Cell Assembly and its subassemblies or subsystems shall meet all the performance requirements under operating environment conditions after being subject to the following nonoperating environment conditions:

Condition	Requirement
gravity orientation	-3° to 90° zenith angle
altitude	sea level to 4300 meters
ambient air temperature	-15° to +35°C
relative humidity	0 to 100 %
wind velocity over Primary Mirror	0 to 20 meters/second
shock and vibration	0.4 g in all axes
slewing velocity - alt	0.75 degrees/second max.
slewing velocity - az	2.0 degrees/second max
slewing acceleration - alt	0.05 degrees/second^2 max.
slewing acceleration - az	0.1 degrees/second^2 max.
braking deceleration - alt.	0.3 degrees/second^2 max.
braking deceleration - az.	1.0 degrees/second^2 max.

2.1.4 Survival Conditions. The M1 Cell Assembly, subassemblies or subsystems shall meet all the performance requirements under the operating environment conditions after being subject to the following survival environment conditions. Minor repair and realignment are allowed to bring the system back to operating condition.

Condition	**Requirement**
gravity orientation	-5° to 90° zenith angle
altitude	sea level to 4300 meters
ambient air temperature	-20° to +40°C
relative humidity	0 to 100 % condensing
wind velocity over Primary Mirror	0 to 30 m/sec
earthquake loads at Primary Mirror	2.7g in X, 1.5g in Y and 1.4g in Z, simultaneously. Specific data to be supplied

2.1.5. Transportation and Handling Conditions. The M1 Cell Assembly, subassemblies or subsystems shall meet all the performance requirements under the operating environment conditions after being subject to the following transportation and handling environment conditions.

Condition	**Requirement**
gravity orientation	-45° to 90° zenith angle
altitude	sea level to 4300 meters

Condition	Requirement
ambient air temperature	-20° to +50°C
relative humidity	0 to 100 % condensing
wind velocity over Primary Mirror	0 to 30 m/sec
shock and vibration loads at any location on M1 Cell Assembly	5g (shock, any axis)

2.2 Specific Environments.

2.2.1 Storage Conditions. The M1 Cell Assembly shall be designed to withstand all anticipated storage environments with no damage.

2.2.2 Twilight Instrument Calibration. It will sometimes be necessary to open the Primary Mirror cover and open the dome slit one hour before the end of twilight to allow flat fielding using the twilight sky. This procedure will expose the M1 Cell Assembly to ambient air that is warmer than the night time air temperature.

2.2.3 Movement of M1 Assembly for Recoating Operation. The M1 Assembly will periodically be removed from the Telescope to allow recoating the Primary Mirror. During the removal and transportation operations the M1 Assembly may be subject to accelerations and shock loads up to 1.0 g in the Z direction and up to 0.5 g in the X and Y directions.

3.0 Requirements for the Complete Assembly

3.1 Definition

3.1.1 M1 Cell Assembly. (a) The "M1 Cell Assembly" is the system that consists of all components, equipment and materials mounted on the Telescope Mirror Cell Support Frame that support, define, adjust, and thermally control the Primary Mirror. Each M1 Cell Assembly includes, without limitation, the M1 Cell Structure, the M1 Support System, the M1 Thermal Management System, and the Ancillary Equipment, The specific design requirements for these subassemblies are described in Section 4.

(b) The M1 Cell Assembly is subject to various Telescope operating modes and to the environments described in Section 2. The M1 Cell Assembly supports the Primary Mirror, the Cassegrain Cluster, the M1 Baffle, and potentially the AtmDC and AtmDC Deployment Mechanism. A preliminary design layout for the M1 Cell Assembly is shown in Drawing 85-GP-2000-0006. A list of subassemblies and their components is provided in Table 1 below.

TABLE 1 - Ml Cell Assembly Component List

1. M1 Cell Assembly
- **A. M1 Cell Structure**
- **B. M1 Support System**

1. M1 Air Pressure Support System
    a. inner and outer seals
    b. pressure sensors
    c. air pressure regulator
    d. control electronics
2. M1 Axial Support System
    a. Axial Support Units
    b. Master Cylinder Units
    c. position sensors
    d. hydraulic system
        (i) differential pressure sensors
        (ii) computer control valves
        (iii) pressure sensors
        (iv) air accumulating tanks
        (v) pressure relief valves
        (vi) piping
    e. pneumatic system
        (i) pressure regulators
        (ii) pressure sensors
        (iii) pressure relief valves
        (iv) tubing
        (v) f ilter
    f. control electronics
3. M1 Lateral Support System
    a. Lateral Support Units
    b. Master Cylinder Units
    c. position sensors
    d. hydraulic system
        (i) pressure sensors
        (ii) air accumulating tanks
        (iii) pressure relief valves
        (iv) piping
    e. control electronics
4. M1 X-Direction Defining System
    a. X-Direction Defining Units
    b. Master Cylinder Units
    c. position sensors
    d. hydraulic system
        (i) pressure sensors
        (ii) air accumulating tanks
        (iii) pressure relief valves
        (iv) piping
    e. control electronics
5. M1 Safety Restraint System
    a. Axial Safety Restraint System

b. Lateral Safety Restraint System

6. M1 Cell Sensing System
   a. accelerometers
   b. temperature transducers
   c. strain gages
   d. associated electronics
7. M1 Support Cooling System
   a. heat exchangers
   b. insulated enclosures

C. M1 Thermal Management System

1. Radiating Plate System
   a. radiating panels and supports
   b. modular chiller
   c. circulation pump
   d. pressure sensor
   e. piping
   f. insulation
   g. coolant
   h. temperature sensors
   i. control electronics
2. Surface Heating System (the equipment that makes up the Surface Heating System is not to be provided as part of this Work Scope)
   a. electrodes
   b. power supplies
   c. temperature sensors
   d. control electronics

D. Ancillary Equipment

1. M1 Baffle Support Mechanism
2. Instrument Cover
3. Aperture Plates
4. Dust Removing System
5. Utility Services

3.2 Interfaces

3.2.1 Primary Mirror Interface. The Primary Mirror substrate is a meniscus shaped piece of Coming ULE' titanium-doped ftised silica. The dimensions and configuration of the Primary Mirror are specified in Drawing 85-GP-2000-0003. The Primary Mirror interfaces with the M1 Support System as follows:

(a) Axial Support Unit / Primary Mirror. Each Axial Support Unit bears against the convex surface of the Primary Mirror through a 75 mm diameter pad.

(b) Lateral Support Unit / Primary Mirror. Each Lateral Support Unit is attached through a linkage to an Invar pad approximately 100 mm in diameter that will be bonded to the outer edge of the Primary Mirror by REOSC Optique. The distance between the line of action of the linkage and the edge surface of the Primary Mirror is 30 mm.

(c) M1 Air Pressure Support System seal / Primary Mirror. The seals shall be located at the inner and outer edges of the Primary Mirror, and shall satisfy the requirements of Section 4.2. 1, below.

3.2.2 Mirror Cell Support Frame Interface. The M1 Cell Assembly is mounted on the Mirror Cell Support Frame with four bipods. The location and size of the bolt holes connecting the eight bipod feet to the Mirror Cell Support Frame are specified in the system interface control Drawing 90-GP-000 1 -0020.

3.2.3 Cassegrain Cluster Interface. (a) The Cassegrain Rotator bearing is mounted on the bottom surface of the M1 Cell Structure. The location and size of the mounting bolt holes are specified in the system interface control Drawing 90-GP-0002-0002. Clearance may be required for the motors of the Cassegrain Rotator to extend into the M1 Cell Assembly. The motors may also require cooling water, to be provided by piping in the M1 Cell Assembly, connected to the Telescope cooling water system.

(b) The Cassegrain Cable Wrap is mounted to the bottom surface of the M1 Cell Structure. Two breakout panels from the Cassegrain Cable Wrap will extend into the M1 Cell Assembly. The location and size of the mounting bolt holes, and the locations and dimensions of the breakout panels, are specified in the interface control Drawing 90-GP-0002-0002.

(c) The total weight of the Cassegrain Cluster is 13,000 Kg and the C.G. is centered on the Z-axis, 1.37 meter below the interface plane between the M1 Cell Structure and the Cassegrain Rotator bearing, which is shown on Drawing 90-GP-0002-0002. The interface plane shall not rotate more than 7 arc-second under this weight at the horizon pointing.

3.2.4 M1 Support System Interface. The mounting locations, force orientations, attachment details, allowable masses, and clearances required for the components of the M1 Support System shall be defined in interface control Drawing TBD.

3.2.5 Ml Baffle Interface. The M1 Baffle is mounted on the inner top surface of the M1 Cell Structure with a controlled locking / release mechanism (the "M1 Baffle Support Mechanism"), as described in Section 4.4.2., below. The location and size of the M1 Baffle Support Mechanism are specified in the system interface control Drawing 90-GP-0002-0005.

3.2.6 AtmDC Deployment Mechanism Interface. The AtmDC Deployment Mechanism may be required to deploy the AtmDC inside or outside the light path within the center hole of the M1 Cell Structure. The location and size of the mounting bolt holes on the M1 Cell Structure shall be specified in the system interface control Drawing TBD.

3.2.7 Control System Interface. The interface between the Ml Cell Assembly and the control system will be that point where a set point signal is received to change the configuration of the operational component. This interface shall be defined in the interface control Drawing TBD, which shall include the interface to diagnostic features built into the M1 Cell Assembly.

3.2.8 Power Supply Interface. The facilities at each Site will have three phase power available in three voltages: 480 V, 208 V, and 120 V. The Mauna Kea Site will use a frequency of 60 Hz, and the Cerro Pachon Site will use a frequency of 50 Hz. There will be a power panel on the Telescope Center Section adjacent to the M1 Cell Assembly, as shown in the system interface control Drawing TBD.

3.2.9 Compressed Air Supply Interface. There will be a 1.0 inch (25.4 mm) air supply line in the Telescope Center Section adjacent to the M1 Cell Assembly, as shown in the system interface control Drawing TBD. This air line is connected to the facility compressed air system, which is nominally capable of delivering 210 s.c.fm. (100 liters/sec) at 110 p.s.i.g (0.76 MP) at the altitude of Mauna Kea. The air leaving the compressor first enters a 400 gallon (1.5 cubic meter) receiver, then enters the facility compressed air piping network, which is composed of 2" (50.8 mm), 1" (25.4 mm), 3/4" (19 mm), and 1/2" (12.7 mm) diameter steel pipe. Adapters to convert to metric pipe sizes, air filtering equipment, and air drying equipment are to be provided at or near the point of entry to the M1 Cell Assembly.

3.2.10 Coolant Supply Interface. (a) There will be a 1.5 inch (38.1 mm) coolant line in the Telescope Center Section adjacent to the M1 Cell Assembly, as shown in the system interface control Drawing TBD. This coolant line is nominally capable of supplying 0.02 cubic meter coolant per minute at TBD degree C (nominally 0° ± 1.0° C) for the electronic cooling.

(b) The coolant supply system shall be considered part of the M1 Cell Assembly, and will not be supplied by the facility. The modular chiller, circulation pump, connecting piping and coolant shall be designed and supplied as part of the M1 Cell Assembly work. The interface of these components with the facility depends on the detailed design of the M1 Cell Assembly.

3.2.11 Alignment Feature Interface. The alignment feature Interface depends on the detailed design of the Ml Cell Assembly. The details of the aligm-nent features shall be shown in interface control Drawing TBD.

3.2.12 Ml Lifting Fixture Interface. The M1 Lifting Fixture Interface shall be defined by interface control Drawing TBD.

3.2.13 Mass Balance Interface. The mass balance for the M1 Cell Assembly is defined in interface control Drawing TBD.

3.3 Requirements

3.3.1 Error Budget Requirements. The preliminary design of the M1 Cell Assembly, which is the basis of this Design Requirements Document, has been designed to meet the error budget specified in the Gemini System Error Budget Plan. The error budget shall be considered when making any design tradeoffs of the M1 Cell Assembly.

3.3.2 Stresses. Stresses in all members shall be maintained within safe working values for all possible combinations of fabrication, erection, operation, and survival conditions. Unless specified otherwise, all stresses shall remain below the Precision Elastic Limit of the material under any combination of operational and environmental loading.

3.3.3 Deflection. The operational requirements of the mirror cell demand that the structure have minimal deformation on change in gravity vector and that any deformations or deflections due to the effects of gravity or other causes be free of discontinuities or hysteresis effects. Particular care is needed in the detailed design of connections to eliminate any possibility of joint movement and to minimize compliance.

3.3.4 Resonance Frequency. (a) The M1 Cell Assembly and its subassemblies or subsystems shall meet the following frequency requirements:

System Mode	Minimum Frequency (Hz)
rigid body motion of the Primary Mirror on its supports	
decenter in X	18
decenter in Y	22
tip-tilt	30
rigid body motion of the M1 Assembly on its bipod supports	14

3.3.5 Mirror Defining. (a) The mirror defining capabilities of the M1 Cell Assembly shall be able to define and adjust the primary mirror with the ranges and tolerances specified below:

X decenter motion	Range:	± 500 µm
	Resolution:	2 µm
	Repeatability:	± 2 µm
Y decenter motion	Range:	± 500 µm
	Resolution:	2 µm
	Repeatability:	± 2 µm
Piston (Z) motion	Range:	± 500 µm
	Resolution:	2 µm
	Repeatability:	± 2 µm
Tip-tilt motion	Range:	± 40 arcsec
	Resolution:	0.2 arcsec
	Repeatability:	± 0.2 arcsec
Recovery Time	< 5 seconds	
Response Time	< 5 seconds	
Defining stability over 5 minutes (under all Operating Conditions)	X decenter motion:	<± 2 µm
	Y decenter motion:	< ± 2 µm
	Z (Piston) motion:	< ± 2 µm

	Tip-tilt:	< ± 0.2 arcsec

All motions shall be smooth, free of vibration and precisely controlled.

These specifications include the effects of the M1 Cell Structure and the M1 Support System.

(b) Additional range of motion up to ±5 mm for X-, Y- and Z-direction translation, and up to ± 4 arc minutes for Tip-tilt may be required for the initial alignment.

3.3.6 Removal from Telescope. For periodic coating, the M1 Assembly shall be capable of being easily removed from the telescope structure, and the primary mirror shall be easily removed from the M1 Cell Assembly. The M1 Assembly, with the Mirror Cell Support Frame, will be removed from the telescope while in a zenith pointing attitude, and be lowered on to a mirror cell cart. The cassegrain instruments will have been removed beforehand, but the instrument support structure will remain attached to the assembly. Assembly control cabling shall be disconnected at the VME crate located on the center section. The instrumentation cabling shall also be disconnected at a location near the cell / Cassegrain. rotator interface. The mirror will be lifted off from the M1 Cell Assembly using a lifting fixture and overhead crane.

3.3.7. Shift of Cassegrain Cluster Weight. (a) The M1 Assembly must meet required levels of performance, including image quality and pointing accuracy, under the following conditions of Cassegrain Cluster variability:

(1) Change of mass moment of Cassegrain Cluster, about telescope elevation axis, of 100 Kg-m.
(2) Change of location of center of mass of Cassegrain Cluster, in X or Y direction of 0.03 meter.

3.3.8. Versatility. To aid versatility and decrease the time required to switch between observing modes, the Ml Baffle and AtmDC must be capable of being installed or removed easily. A goal for the proposed f /16 AtmDC is that it be deployable under operator control and be stored in the mirror cell structure.

3.3.9. Instrument Cover. In order to protect optical correctors and instruments when not in use, an operator-controlled deployable cover over the central hole is required. The design requirement is specified in Section 4.4., below.

3.3.10. Aperture Plates. Aperture plates of 8.0 meters outside diameter and 1.2 meters inside diameter shall be provided at the front surface of the primary mirror. The design requirement is specified in Section 4.4., below.

3.3.11. Alignment Features. For ease of installation and alignment, the following provisions will be made:

- Installation of lifting features for any removable subassembly having a mass over 15 Kg

- Installation of mounting points for alignment telescopes at locations TBD
- Use of datum surfaces and reference holes where appropriate

3.3.12. Diagnostic Features. (a) The Systems in the M1 Assembly shall be monitored by computer to ensure proper operation. Special attention shall be given to any problem that could in any way threaten the security or safety of the telescope or personnel. In the event of asystem malfunction, the system should provide sufficient information to allow Telescope operators to diagnose the problem.

(b) System status information pertinent to the scientific observations shall be recorded as part of the scientific data. This information includes: whether an optical corrector is in the beam, continuous monitoring of the position of AtmDC elements, the deployment of the Instrument Cover, etc. It also includes information on the performance of mirror cell systems, for example air-to-glass temperature differences,, mirror position relative to the cell, mirror support load cell readings, etc. As a goal any calibration or initialization procedures required by the mirror cell systems shall be automated.

(c) The M1 Assembly shall have provisions for diagnostic instrumentation to include but not be limited to the following;

- Vibration accelerometers at 3 or more locations
- Thermal sensors at 16 or more locations
- Pressure sensors in all hydraulic and pneumatic systems
- Strain gages at highly stressed structural locations, with the minimum requirement being 4 strain gages on each leg of the bipod supports

These requirements are described further in Section 4.2.6., below.

3.3.13. Symmetry. All conditions of loading and support of the M1 Cell Assembly shall maintain symmetry about the Y axis to the maximum extent possible. Where possible, rotational symmetry about the Z axis shall also be maintained.

3.3.14. Total Mass. The overall mass of the M1 Cell Assembly shall be 46,500 ± 2000 Kg.

3.3.15. Center of Mass. The center of mass of the M1 Cell Assembly shall be 985 ± 45mm above the interface plane between the M1 Cell Structure and the Cassegrain Rotator bearing.

3.3.16. Mass Moment of Inertia. The mass moments of inertia of the M1 Cell Assembly with respect to its C.G. shall be:

About the X-axis	243,000 ± 10,000 Kg-m^2
About the Y-axis	243,000 ± 10,000 Kg-m^2
About the Z-axis	403,000 ± 20,000 Kg-m^2

3.3.17. Operational Degradation. No equipment operating within the M1 Cell Assembly shall degrade performance of the telescope. Such equipment might include encoders using laser diodes operating at IR wavelengths, vibration sources, heat sources, etc.

3.3.18. Reliability. The M1 Cell Assembly shall be designed for at least 50 years of service. It is a project goal that any failures of the M1 Cell Assembly shall not cause more than 1% loss of observing time. Estimates shall be developed of the mean time between failures and mean time to repair for the complete M1 Assembly, and for its subsystem and subassemblies including, at minimum, the following:

- M1 Air Pressure Support System
- M1 Axial Support System
- M1 Lateral Support System
- M1 X-Direction Defining System
- Radiating Plate System
- Instrument Cover
- Utility Services
- M1 Support Cooling System

The estimates of mean time between failures and mean time to repair shall follow the guidelines in the Gemini System Reliability Plan.

3.3.19. Maintenance. (a) The M1 Cell Assembly design shall ensure that maintenance requirements shall be-minimal and all necessary maintenance operations can be effectively carried out without risk to personnel or to the telescope.

(b) The M1 Cell Assembly, including all its subassemblies and subsystems, shall be designed with standard components to the extent possible. Wherever possible, items shall be designed so routine maintenance shall require no special tooling.

3.3.20. Manuals. (a) Manuals shall be prepared, containing all information related to maintenance and operation of the pertinent M1 Cell Assembly, so that the information in the Manuals will be adequate to enable Gemini Project personnel to perform the full range of expected operating and regular maintenance functions related to the M1 Cell Assembly without the need to seek information from a source other than the Manuals.

(b) The Manuals shall have the maintenance and operating infon-nation organized into suitable sets of manageable size, which shall be bound into individual binders properly identified on both the front and spine of each binder. Each Manual binder shall be a heavy-duty 2 inch, 3-ring vinyl-covered binder, which is indexed (thumb-tabbed) and includes pocket folders for folded sheet information. It is anticipated that the Manuals will be extensively revised during commissioning, therefore the Manuals shall also be supplied in electronic form, in a medium TBD.

(c) Such information shall include, but not be limited to, all information related to normal operations and procedures, emergency operations and procedures, normal maintenance and procedures, emergency maintenance and procedures, spare parts, warranties, wiring diagrams, inspection procedures, performance curves, shop drawings, product data, and similar applicable information. The maintenance tasks to be covered in the Manuals include, but are not limited to;

- Recoating the primary mirror at 6 month to I year intervals
- Cleaning the primary mirror at weekly intervals
- Replacing Axial Support Units or Lateral Support Units
- Replacing Master Cylinder Units
- Replacing the M1 Air Pressure Support System seals
- Calibration or replacement of position, pressure. or temperature sensors

(d) Each major component and item of equipment comprising the M1 Cell Assembly shall have a separate section in the Manuals devoted specifically to such component or item of equipment describing the operation and maintenance thereof. The Manuals shall also include pertinent information for future maintenance, including the name, address, and telephone number of the installer and maintenance contractor.

3.3.21. Plating and Coatings. (a) Surface finishes are to be approved by the project office as suiting the location and function of each member, so as not to adversely affect the functioning of the telescope, and to require minimum maintenance during the life of the telescope.

(b) All parts of the M1 Cell Assembly shall be finished so as to promote cleanliness of the telescope and to avoid contamination of any optical surface. It is of prime importance that all protective coatings be of high quality and long life due to the high cost of recoating.

(c) The reflectivity and emissivity properties of all exposed surface coatings must be considered in their selection to preclude interference with telescope operation.

(d) All metallic surfaces, other than mating machined surfaces, shall be painted or otherwise protected against atmospheric corrosion.

3.3.22. Interchangeability The M1 Cell Assemblies fabricated for the Mauna Kea site and the Cerro Pachon site shall be identical and functionally interchangeable.

3.3.23. Primary Mirror Cleaning. The primary mirror is planned to be cleaned weekly with laser or $C0_2$. During cleaning the M1 Cell Assembly will be at horizon pointing with the mirror cover open. A dust removing system is needed at the lower edge of the mirror to collect and remove the dust. The M1 Cell Assembly shall incorporate this dust removing system into the design. The design requirement is specified in Section 4.4.5., below.

3.3.24. Atmospheric Pressure. Air pressures will be influenced by the site altitude of approximately 4250m (14000 ft.) and by exposure of the observatory to local weather conditions.

All subsystems shall be designed so that changes in pressure when transporting from sea level to the observatory site shall not cause damage or failure. Any equipment designed to operate at normal atmospheric air pressures and incorporating air cooling shall be de-rated for the reduced air density.

3.3.25. Heat Sources. It is essential to avoid heat sources on or near the telescope which could thermally disturb the primary mirror or the air in the optical path. All heat sources located on or near the M1 Assembly shall be insulated in an enclosure and capable of being actively cooled. The residual heat dissipation after cooling of the M1 Support System shall be as specified in Section 4.2.7., below. A maximum coolant flow rate of 0.02 cubic meter per minute at nominally 0 degree C will be available for this purpose.

3.3.26. Safety. The design of the M1 Cell Assembly and its handling equipment shall comply with OSHA safety requirements. During normal operations or when subjected to the environments of Section 2.0, there shall be minimum risk to the hardware and no risk to personnel.

3.3.27. Envelope and Clearance. The outside envelope of the M1 Cell Assembly, and the clearance from other telescope structures, shall be as specified in the interface control drawing 90-GP-0002-0003.

3.3.28. Cell Flexure Effect. The effect of cell flexure on the primary mirror figure due to gravity, thermal, and other loads shall be less than 4 nm r.m.s. per minute under the operating in-specification condition as specified in Section 2. 1. 1.

4.0. Subassembly Requirements

4.1 M1 Cell Structure

4.1.1. Definition. The "M1 Cell Structure" is the main structure of the M1 Cell Assembly, which provides mounting surfaces for the M1 Support System, the M1 Thermal Management System, the Ancillary Equipment, and the Cassegrain Cluster. The M1 Cell Structure is a single piece welded steel structure. The M1 Cell Structure is mounted on the Mirror Cell Support Frame of the telescope structure through four pairs of bipod struts. A preliminary design layout is shown in Drawing 85-GP-2000-0022.

4.1.2. Requirements

4.1.2.1. Axial Support Unit Mount. The M1 Cell Structure shall provide 120 supporting mounts for the Axial Support Units at the locations and with the tolerances specified in Section 4.2.2.2.1., below.

4.1.2.2. Lateral Support Unit Mount. The M1 Cell Structure shall provide 60 supporting mounts for the Lateral Support Units at the locations and with the tolerances specified in Section 4.2.3.2.1., below.

4.1.2.3. X-Direction Defining Unit Mount. The M1 Cell Structure shall provide 24 supporting mounts for the X-Direction Defining Units at the locations and with the tolerances specified in Section 4.2.4.2.1., below.

4.1.2.4. Air Pressure Seal Mount. The M1 Cell Structure shall provide mounting surfaces for the inner and outer seals of the M1 Air Pressure Support System at the locations and with the tolerances specified in Section 4.2.1., below.

4.1.2.5. Safety Restraint Mount. The M1 Cell Structure shall provide supporting mounts for the M1 Safety Restraint System.

4.1.2.6. Radiating Plate Mount. The M1 Cell Structure shall provide supporting mounts for the radiating panels of the M1 Thermal Management System..

4.1.2.7. Mirror Cell Support Frame Mount. The M1 Cell Structure shall mount to the Mirror Cell Support Frame at the location and with the tolerances specified in Section 3.2.2., above.

4.1.2.8. Cassegrain Cluster Mount. The M1 Cell Structure shall provide a supporting mount for the Cassegrain Cluster at the locations and with the tolerances as specified in Section 3.2.3., above.

4.1.2.9. M1 Baffle Mount. The M1 Cell Structure shall provide a supporting mount for the M1 Baffle mount at the location and with the tolerances specified in Section 3.2.4., above.

4.1.2.10. AtmDC Deployment Mechanism Mount. The M1 Cell Structure shall provide a supporting mount for the AtmDC Deployment Mechanism at the location and with the tolerances specified in Section 3.2.5., above.

4.1.2.11. Instrument Cover Mount. The M1 Cell Structure shall provide a supporting mount for the Instrument Cover within the center hole of the M1 Cell Structure.

4.1.2.12. Utility Service Line Mounts. The M1 Cell Structure shall provide supporting mounts for the Utility Service lines, including the Utility Services to the M1 Cell Assembly, as well as the Utility Services to the Cassegrain Cluster.

4.1.2.13. Dimensional Stability. The M1 Cell Structure shall be dimensionally stable. All welded parts and assemblies shall be fully stress relieved prior to final machining operations. Stress relieving shall be accomplished by heat treatment method in a chamber with sufficient volume and temperature capacity to fully stress relieve the welded parts and subassemblies.

4.1.2.14. Resonance Frequency. The M1 Cell Assembly shall be designed so that the first bending frequency of the M1 Assembly, including the primary mirror, shall be larger than 40

Hertz. It shall be the responsibility of AURA to ensure the structural design of the M1 Cell Structure allows this requirement to be met.

4.1.2.15. Support Mount Stiffness. The local stiffness of the M1 Cell Assembly at each Axial and Lateral Support Unit mount shall be higher than 100,000 N/mm along the support orientation,

4.1.2.16. Stress. The stress in the M1 Cell Structure shall be less than the precision elastic limit of the material under all the environments specified in Section 2., above.

4.1.2.17. Weld. For dimensional stability the M1 Cell Structure shall be fabricated from steel plates connected with full penetration welds. A complete stress relief process shall be conducted upon the completion of the entire structure, as described in Section 4.1.2.13., above.

4.1.2.18. Envelope and Clearance. The dimensions of the M1 Cell Structure shall be as specified in the system interface control Drawings 90-GP-0001-0019.

4.1.2.19 Maintainability. The M1 Cell Structure shall be designed to provide access to all major subassemblies and subsystems. The Axial Support Units, the Lateral Support Units, the X-Direction Defining Units, and the Master Cylinder Units shall be mounted in such a way that they can be serviced or replaced without removing the primary mirror or other major component of the M1 Assembly. As a goal this maintainability should be possible at all zenith angles.

4.1.2.20. Transportability. The M1 Cell Structure shall be designed with provisions for the attachment of tiedown straps for shipment and assembly.

4.1.2.21. Machined Surfaces. All machined surfaces, unless specified or approved otherwise by AURA in writing, shall have a surface finish no worse than 125 micro-inches RMS.

4.2 M1 Support System. The "M1 Support System" is the system that provides support, position definition and position adjustment for the Primary Mirror. The M1 Support System consists of the M1 Air Pressure Support System, the M1 Axial Support System, the M1 Lateral Support System, the M1 X-Direction Defining System, the M1 Safety Restraint System, the M1 Cell Sensing System, and the M1 Support Cooling System. The definitions and the requirements for each subsystem are specified below.

4.2.1 M1 Air Pressure Support System

4.2.1.1 Definition. (a) The "M1 Air Pressure Support System" is the system that supports a portion of the weight of the Primary Mirror on an air pressure support, and includes, without limitation, the inner and outer seals, pressure sensors, air pressure regulator(s), and control electronics.

(b) The support of the mirror in the axial direction is accomplished by floating approximately 80 % of the mirror weight on a uniform air pressure and the remainder of the weight on the M1 Axial Support System. The air pressure inside the M1 Air Pressure Support System shall be varied as a function of zenith angle in such a way that the force exerted by the M1 Axial Support System remains constant up to a zenith angle of 78 degree. Flexible seals around the outside diameter and the central hole of the mirror contain the air pressure. The air pressure variation shall be controlled by a closed servo loop with feedback from the total force measured on the Axial Support Unit load cells. A preliminary design layout is shown in Drawing 85-RGO-2000-5060.

4.2.1.2 Requirement

4.2.1.2.1 Pressure Variation

Pressure:	= 0.432 (cos Z - 0.2) N/cM2, Z = 0 to 75 degree
Repeatability:	< 0.02 N/cM2
Stability:	< 0.004 N/CM2 over 5 minutes, under all Operating Conditions
Recovery time:	< 5 seconds
Response time:	< 5 seconds

4.2.1.2.2 Air Leak Rate

Leak rate (goal): < 0.01 cubicmeter/minute

4.2.1.2.3 Seal Force on Mirror. The seal force acting normal to the mirror shall vary with the zenith angle, Z, as follows:

Inner seal force per unit length (N/m) = 4320 (CosZ - 0.2) d^i
Outer seal force per unit length (N/m) = 4320 (CosZ - 0.2) d^o + F^1CosZ

Here d^i and d^o are the inner and outer seal location distances in meters measured from the mirror edge respectively, and F^1 is the average force acting on the mirror per unit length (N/m) due to the weight of the lateral support at zenith pointing. The distance d shall be selected such that the seal force is larger than the minimum seal force for retaining the air pressure and satisfy the above equations from Z = 0 to 75 degrees.

For a given zenith angle the seal force shall be constant within a tolerance of ± 5 N/m for 1 mm mirror motion in any direction, and for the pressure and temperature variations. Also any frictional force acting tangent to the mirror shall be within ± 50 N/m.

4.2.1.2.4 Air Moisture Content. The air moisture content shall be controlled so that there is no condensation at -20 C.

4.2.2 Ml Axial Support System

4.2.2.1 Definition. (a) The Ml Axial Support System is the system that provides partial mechanical support for, and position definition and adjustment of, the Primary Mirror in the

Axial Direction. The Ml Axial Support System consists of components that include, but are not limited to: 120 Axial Support Units, 7 Master Cylinder Units, 7 pressure sensors, 4 position sensors, 6 differential pressure sensors, 6 air accumulating tanks, 7 pressure relief valves, 6 computer controlled valves, piping, 126 air pressure regulators, a cooling system, and control electronics.

(b) The 120 Axial Support Units are arranged to have the minimum optical surface error at zenith position. They are distributed in five concentric rings as shown in Drawing 85-GP-2000-0015. Each Axial Support Unit consists of a dual-chamber hydraulic cylinder with load cell and a pneumatic actuator with load cell.

(c) The hydraulic cylinders are divided into three groups and are hydraulically connected to each other within each group so that they form a statically determinate whiffletree support system. This is called the "three-zone" supporting mode. In order to couple the mirror with the stiffer mirror cell for reducing the mirror deformation under wind buffeting, each group is further divided into two subgroups with a Computer Controlled Valve as shown in Drawing 85-GP-2000-0018. In the three-zone supporting mode, three of the Computer Controlled Valves are closed and three are open. When all six Computer Controlled Valves are closed, this is called the "six-zone" supporting mode. When three Computer Controlled Valves are closed, and the other three are partially closed, this is called the "damped three-zone" supporting mode.

(d) For each group a Master Cylinder Unit is provided to control the volume / pressure of the fluid within the group. The mirror tip-tilt and piston motions are controlled with these master cylinder units and four position sensors. Also a Master Cylinder Unit is provided for the hydraulic system which connects all the gravity pressure head compensation chambers (120). A preliminary design layout is shown in Drawing 85-GP-2000-0029. In order to eliminate the air bubbles in the hydraulic system, each group is connected to an air accumulating tank with a bleed valve. This valve may also be used as the pressure relief valve for possible over-pressure in the system.

(e) A pneumatic actuator is provided in each axial support unit to correct the mirror figure distorted from various effects such as gravity, thermal distortions, air pressure, wind buffeting etc. The pneumatic actuators are controlled by a closed loop servo system with feedback from a wavefront sensor or look up table, however, the wavefront sensor and look up table are not part of the M1 Support System as defined in this document.

(f) Any mirror distortion caused by flexure of the M1 Cell Structure, when in the six-zone supporting mode, will be corrected first with the axial hydraulic cylinders under the control of the Master Cylinder Units and differential pressure sensors, and then the residue error will be corrected with the pneumatic actuator.

(g) The Axial Support System Shall be capable of supporting the full weight of the Primary Mirror during non-operating times, without damage and without degradation of its performance during subsequent operation.

4.2.2.2 Requirements

4.2.2.2.1 Axial Support Unit Distribution. The 120 Axial Support Units shall be arranged so that the nominal forces acting on the back surface of the primary mirror have the following distribution, distributed in five concentric rings as shown in Drawing 85-GP-2000-0015 .

	Ring 1	*Ring 2*	*Ring 3*	*Ring 4*	*Ring 5*
Radius (mm)	903.6	1632.1	2363.5	3031.9	3776.3
No. of forces	12	18	24	30	36
Force magnitude (N)	285.6	386.6	386.6	386.6	386.6

The Axial Support Units shall be- equally spaced on each ring. The indicated radii are the straight-line distances of the centers of the support pads, at the back surface of the Primary Mirror, from the Z-axis. Note that, because the Axial Support Units are oriented normal to the curved mirror surface, the radii of Axial Support Unit mounting locations at the top surface of the M1 Cell Structure are slightly larger than the numbers in the table in this Section 4.2.2.2. 1.

The Axial Support Unit is attached to the M1 Cell Structure by means of an interface ring. The lower surface of the flange on the interface ring is defined as the Axial Support Mounting Surface. The location and orientation tolerances for the Axial Support Units are:

Location (mm)			Orientation (degree)		
X	Y	Z	Rx	Ry	Rz
1.5	1.5	0.5	0.5	0.5	--

To achieve these tolerances the axial support rod shall be perpendicular to the Axial Support Mounting Surface within ± 0. I degree, and shall be concentric with the mounting bolt circle on the Axial Support Mounting Surface within ± 0.5 mm. Also, a provision for a 5mm thick shim at the Axial Support Mounting Surface is required for piston and tip-tilt adjustment to a resolution of 0.2 mm and 0. I degree respectively. AURA will supply the required shims.

The tolerance for the force magnitude shall be less than ± 0.2 Newton. Note that a maximum of 15 N active force is allowed to achieve this force tolerance.

4.2.2.2.2 Active Optics Capability. The active optics system shall be able to change the forces applied by the 120 Axial Support Units by up to ± 400 N for each Axial Support Unit. The Response Time for making these changes shall be less than five seconds for changes over the full range; the goal for the Response Time when making changes of less than 50 N per Axial Support Unit shall be less than one second.

4.2.2.2.3 Mirror Defining. The M1 Axial Support System shall define and move the primary mirror in Piston and Tip-tilt to meet the following requirements:

Piston (Z) motion	Range:	± 500 μm

	Resolution:	1 μm
	Repeatability:	± 1 μm
Tip-tilt motion	Range:	± 40 arcsec
	Resolution:	0.1 arcsec
	Repeatability	0.1 arcsec
Recovery Time	< 5 seconds	
Response Time	< 5 seconds	
Defining stability over 5 minutes (under all Operating Conditions)	Z (Piston) motion:	< ± 1 μm
	Tip-tilt:	< ± 0.1 arcsec

4.2.2.2.4 Correctability for six-zone Cell Flexure Effect. In the six-zone supporting mode, the Master Cylinder Units with the differential pressure sensors shall be able to control the fluid volumes so that the average mirror deformation in each zone has the following repeatability and stability:

Repeatability	< ± 10nm
Stability	< ± 5 nm over 5 minutes
Response Time	< 5 second (goal of < 1 second)

4.2.2.3 Axial Support Unit

4.2.2.3.1 Definition. An "Axial Support Unit" is one of the mechanisms that is in contact with the convex surface of the Primary Mirror to provide mechanical support, position definition, and position adjustment of the Primary Mirror in the Axial Direction. Each Axial Support Unit includes, without limitation, a dual chamber hydraulic cylinder with load cell and a pneumatic actuator with load cell. A preliminary design layout is shown in Drawing 85-RGO-2000-5001

4.2.2.3.2 Requirements

4.2.2.3.2.1 Dual-chamber Hydraulic Cylinder with Load Cell. Each dual-chamber hydraulic cylinder with load cell shall meet the following requirements:

Force Resolution	< ± 0.2 N
Force Repeatability	< ± 0.4 N
Stroke	> 5 mm
Axial Stiffness	> 9000 N/mm (compression)
Cross-Direction Stiffness, measured at mirror	< 50 N/mm
Moment Applied to Mirror	<±l N-m
Damping	> 5 % of critical damping

The axial stiffness requirement relates to a condition in which the Axial Support Unit is tested with each hydraulic line valved off approximately one meter from the Axial Support Unit. and with the two hydraulic chambers preloaded against each other by a pressure of approximately 50,000 N/m^2.

The lateral stiffness requirement refers to the lateral stiffness of the entire Axial Support Unit measured at the contact point with the back of the mirror.

The damping requirement is for motion of approximately 5μm amplitude in the ± Z direction when the Axial Support Unit is loaded by a mass approximately equivalent to 0.2 % of the mass of the Primary Mirror.

4.2.2.3.2.2 Pneumatic Actuator with Load Cell. Each pneumatic actuator with load cell shall meet:

Force Range	± 400 N
Force Repeatability	< ± 0.2 N for periods up to 30 minutes
Stroke	> 5 mm
Axial Stiffness	< 50 N/mm

4.2.2.4 Master Cylinder Unit

4.2.2.4.1 General. There are 7 Master Cylinder Units in the M1 Axial Support System. Six of them are used to control the fluid pressure/volume for the six hydraulic groups, and one of them is used to control the pressure for the gravity pressure head compensation. Each Master Cylinder Unit consists of components that include, but are not limited to, a hydraulic cylinder and a linear drive. A conceptual design layout is shown in Drawing 85-GP-2000-0031.

4.2.2.4.2 Requirement. The Master Cylinder Units in the M1 Axial Support System shall be designed to meet the requirements specified in Sections 3.3.5., 4.2.2.2.3., and 4.2.2.2.4., above.

4.2.2.5 Computer Controlled Valve

4.2.2.5.1 General. There are 6 Computer Controlled Valves which are provided to allow three possible modes of operation of the M1 Axial Support System. A conceptual design layout is shown in Drawing 85-GP-2000-0029.

4.2.2.5.2 Requirement. (a) Each Computer Controlled Valve shall have three flow settings: fully open, partially open, and closed. The size of opening in the partially open position shall be adjustable. If necessary to accomplish the three flow settings, two or more valves can be incorporated into each Computer Controlled Valve.

(b) The Computer Controlled Valves shall be designed so that they will not change the fluid volume and pressure in any of the hydraulic systems during valve operation. The goal is for any such change to be within the level specified for mirror deformation repeatability in Section 4.2.2.2.4., above.

4.2.3 Ml Lateral Support System

4.2.3.1 Definition. (a) The "M1 Lateral Support System" is the system that provides mechanical support for, and position definition and adjustment of, the Primary Mirror in the Lateral Direction. The Ml Lateral Support System consists of components that include, but are not limited to, 60 Lateral Support Units attached to the surface of the outside diameter of the Primary Mirror, 3 Master Cylinder Units, 3 pressure sensors, air accumulating tanks, pressure relief valves, piping, 2 position sensors, and control electronics. Each lateral support unit includes a dual-chamber hydraulic cylinder and a load cell.

(b) The 60 Lateral Support Units are located at the periphery of the mirror as shown in Drawing 85-GP-2000-0017. For minimizing the local defon-nation of the mirror at each Lateral Support Unit, the Lateral Support Unit is located at the thickness center with an approximately I 00 mm diameter pad bonded on the mirror

(c) The 60 Lateral Support Units are divided into two groups and are hydraulically connected together within each group. Similar to the M1 Axial Support System, a Master Cylinder Unit is provided for each group to control the mirror clocking and the decenter in the Y direction with two position sensors. Also a Master Cylinder Unit is provided for the hydraulic system that connects all the gravity pressure head compensation chambers. A preliminary design layout is shown in Drawing 85-GP-2000-0030.

4.2.3.2 Requirement

4.2.3.2.1 Lateral Support Force Distribution. The Lateral Support Units shall be arranged so that the lateral support forces acting on the side surface of the mirror have the following distribution. The force distributions are symmetrical with respect to the Y axis. The locations, magnitudes and orientations for the forces in the +X side are:

Support	Location θ_Z (degree)	Force Magnitude F(N)	Orientation (degree) θ_Z	 θ_{XY}*	Force Components(N) F_X	 F_Y	 F_Z
L1	-85.28	-3708	-101.6	7.61	740	3600	-490.9
L2	-77.78	-3708	-114.4	5.93	1522	3359	-383.0
L3	-70.28	-3708	-120.5	4.84	1876	3183	-313.1
L4	-62.78	-3708	-122.1	3.85	1963	3135	-248.7
L5	-55.28	-4119	-120.8	3.17	2105	3533	-227.9
L6	-47.78	-4119	-119.4	2.79	2019	3585	-200.5
L7	-42.28	-4119	-117.7	2.10	1912	3645	-150.7
L8	-37.28	-4119	-116.5	1.20	1837	3685	-86.6
L9	-32.28	-4119	-114.5	1.33	1709	3746	-95.7
L10	-27.28	-4119	-111.2	0.60	1489	3840	-43.0
L11	-22.28	-4119	-107.2	0.69	1218	3934	-49.4
L12	-17.28	-4119	-103.7	0.42	978	4001	-30.1
L13	-12.28	-4119	-99.0	0.40	645	4067	-28.6
L14	-7.28	-4119	-94.0	0.42	287	4109	-30.5
L15	-2.28	-4119	-89.0	0.41	-72	4118	-29.4
L16	2.28	4119	89.0	0.41	72	4118	29.4
L17	7.28	4119	94.0	0.42	-287	4109	30.5
L18	12.28	4119	99.0	0.40	-645	4067	28.6
L19	17.28	4119	103.7	0.42	-978	4001	30.1
L20	22.28	4119	107.2	0.69	-1218	3934	49.4
L21	27.28	4119	111.2	0.60	-1489	3840	43.0
L22	32.28	4119	114.5	1.33	-1709	3746	95.7
L23	37.28	4119	116.5	1.20	-1837	3685	86.6
L24	42.28	4119	117.7	2.10	-1912	3645	150.7
L25	47.78	4119	119.4	2.79	-2019	3585	200.5
L26	55.28	4119	120.8	3.17	-2105	3533	227.9
L27	62.78	3708	122.1	3.85	-1963	3135	248.7
L28	70.28	3708	120.5	4.84	-1876	3183	313.1
L29	77.78	3708	114.4	5.93	-1522	3359	383.0
L30	85.28	3708	101.6	7.61	-740	3600	490.9

θ_{XY} = ArcSIN(F_Z/F)

The required accuracies of lateral support force locations and orientations are:

Location		Orientation (degree)	
θ_Z(degree)	Z (mm)	θ_Z	θ_{XY}
0.03	0.2	1.0	0.5

The tolerance for the force magnitude is ± 8 Newtons. The required adjustment resolution for the orientation of each lateral support force is 0.1 degree. Adjustable features shall be incorporated in the design to achieve these tolerances. These features shall be demonstrated during the acceptance testing, and the procedures for making these adjustments shall be included in the manuals, however, it is not required that the force orientations be adjusted to the specified accuracies in the factory assembly operation.

4.2.3.2.2 Mirror Defining. The M1 Lateral Support System shall define and move the primary mirror in the Y direction and in rotation about the Z axis to meet the following requirements:

Y decenter motion	Range:	± 500 μm
	Resolution:	1 μm
	Repeatability:	± 1 μm
Recovery Time	< 5 seconds	
Response Time	< 5 seconds	
Defining stability over 5 minutes	Y decenter motion:	< ± 1 μm
(under all Operating Conditions)	Rotation about Z axis	< ± 0.1 arcsec

4.2.3.2.3 Envelope. No part of the Ml Lateral Support System shall extend outside the outer diameter of the M1 Cell Structure, as defined in Section 4.1.2.1 8., above.

4.2.3.3 Lateral Support Unit

4.2.3.3.1 Definition. A Lateral Support Unit is one of the mechanisms that is attached to the outer edge of the Primary Mirror to provide mechanical support, position definition, and position adjustment of the Primary Mirror in the Lateral Direction. The M1 Lateral Support System has 60 Lateral Support Units. Each Lateral Support Unit consists of components that include, but are not limited to, a dual-chamber hydraulic cylinder a load cell, a linkage to connect to the mirror, a bracket for attachment to the M1 Cell Structure, and associated adjustment features. A preliminary design layout is shown in Drawing 85-RGO-2000-5020.

4.2.3.3.2 Requirements

4.2.3.3.2.1 Dual-chamber Hydraulic Cylinder with Load Cell. Each dual-chamber hydraulic cylinder with load cell shall meet the following requirements:

Force Repeatability	< ± 8 N
Stroke	> 5 mm
Axial Stiffness	> 9000 N/mm
Cross-Direction Stiffness, measured at mirror	< 50 N/mm
Moment Applied to Mirror by Linkage	<±l N-m

Damping > 5 % of critical damping

The axial stiffness requirement relates to a condition in which the Lateral Support Unit is tested with each hydraulic line valved off -approximately one meter from the Lateral Support Unit, and with the two hydraulic chambers preloaded against each other by a pressure of approximately 50,000 N/m’.

The damping requirement is for motion of approximately 5 Jim amplitude in the ± Y direction. when the Lateral Support Unit is loaded by a mass approximately equivalent to 1.6 % of the mass of the Primary Mirror.

4.2.3.3.2.2. Balance of Support Hardware Weight. Each Lateral Support Unit shall be designed so that the Z-direction force acting on the Primary Mirror due to its weight shall be balanced by the Z-direction force exerted on the Primary Mirror by the outer seal of the air pressure support. The goal is for the portion of Z-direction Lateral Support Unit weight that is not compensated in this manner to be less than ±2 N per Lateral Support Unit for all Zenith Angles between 0deg and 75deg.

4.2.3.4 Master Cylinder Unit

4.2.3.4.1 General. There are 3 Master Cylinder Units in the M1 Lateral Support System. Two of them are used to control the fluid pressure/volume for the two hydraulic groups, and one of them is used to control the pressure for the gravity pressure head compensation. Each Master Cylinder Unit consists of components that include, but are not limited to, a hydraulic cylinder and a linear drive. A conceptual design layout is shown in Drawing 85-GP-2000-0031.

4.2.3.4.2 Requirements. The Master Cylinder Units in the M1 Lateral Support System shall be designed to meet the requirements specified in Sections 3.3.5. and 4.2.3.2.2., above.

4.2.4 M1 X-Direction Defining System

4.2.4.1 Definition. (a) The "M1 X-Direction Defining System" is the system that controls the position of the Primary Mirror in the X direction. The M1 X-Direction Defining System consists of components that include, but are not limited to, 24 X-Direction Defining Units, 2 Master Cylinder Units, 2 pressure sensors, air accumulating tanks, pressure relief valves, 1 position sensor, and control electronics.

(b) Each "X-Direction Defining Unit" has a dual-chamber hydraulic cylinder, as described in Section 4.2.4.3., below. The right chambers of the 24 dual-chamber hydraulic cylinders are hydraulically connected to each other. Similarly the 24 left chambers are hydraulically connected. Each X-Direction Defining Unit is attached to the miffor at the miffor thickness center with an approximately 100 mm diameter pad bonded on the miffor.

(c) Two Master Cylinder Units are provided for the two hydraulic groups to control the miffor motion in X direction, using feedback from a position sensor. A preliminary design layout is shown in Drawing 85-GP-2000-0030.

4.2.4.2 Requirements

4.2.4.2.1 Location and orientation. The 24 X-Direction Defining Units shall be located at the periphery of the miffor as shown in Drawing 85-GP-2000-0017 . The orientations of all the units are parallel to the X direction. The location and orientation tolerances shall be less than:

Location		Orientation (degree)	
θ_Z(degree)	Z (mm)	θz	θ_Y
0.03	0.2	1.0	1.0

4.2.4.2.2 Mirror Defining. The M1 X-Direction Defining System shall define and move the primary miffor in the X direction to meet the following requirements:

X decenter motion	Range:	± 500 μm
	Resolution:	1 μm
	Repeatability:	± 1 μm
Recovery Time	< 5 seconds	
Response Time	< 5 seconds	
Defining stability over 5 minutes (under all Operating Conditions)	X decenter motion:	<± 1 μm

4.2.4.3 X-Direction Defining Unit

4.2.4.3.1 Definition. Each "X-Direction Defining Unit" consists of components that include. but are not limited to, a dual-chamber hydraulic cylinder, a linkage to connect to the mirror, a bracket for attachment to the M1 Cell Structure, and associated adjustment features.

4.2.4.3.2 Requirements

4.2.4.3.2.1 Dual-chamber Hydraulic Cylinder. Each dual-chamber hydraulic cylinder shall meet the following requirements:

Stroke	> 5 mm
Axial Stiffness	> 9000 N/mm (goal > 12,000 N/mm)
Cross-Direction Stiffness measured at mirror	< 50 N/mm
Moment Applied to Mirror by Linkage	< ±l N-m
Damping	> 5 % of critical damping

The axial stiffness requirement relates to a condition in which the X-Direction Defining Unit is tested with each hydraulic line valved off approximately one meter from the X-Direction

Defining Unit, and with the two hydraulic chambers preloaded against each other by a pressure of approximately 50,000 N/m^2.

The damping requirement is for motion of approximately 5μm amplitude in the ± X direction, when the X-Direction Defining Unit is loaded by a mass approximately equivalent to 4.2 % of the mass of the Primary Mirror.

4.2.4.4 Master Cylinder Unit

4.2.4.4.1 General. There are 2 Master Cylinder Units in the M1 X-Direction Defining System. Each Master Cylinder Unit consists of components that include, but are not limited to, a hydraulic cylinder and a linear drive. A conceptual design layout is shown in Drawing 85-GP-2000-0031.

4.2.4.4.2 Requirements. The Master Cylinder Units in the M1 X-Direction Defining System shall be designed to meet the requirements specified in Section 3.3.5. and 4.2.4.2.2., above.

4.2.5 M1 Safety Restraint System

4.2.5.1 Definition. (a) The "M1 Safety Restraint System" is the system that will protect the Primary Mirror in the event that excessive forces act on the Primary Mirror and M1 Cell Assembly (for example, loads occurring during an earthquake). . The M1 Safety Restraint System consists of the axial safety restraint system and the lateral safety restraint system. Each of these subsystems consists of components that include, but are not limited to:

- Axial safety restraint system - axial restraint mechanisms, sensors
- Lateral safety restraint system - lateral restraint mechanisms, sensors

(b) The M1 Safety Restraint System is provided to restrain and protect the Primary Mirror from motion both axially and laterally during an earthquake, a failure of the M1 Air Pressure Support System, installation or removal of the Primary Mirror, and Primary Mirror cleaning. The restraint pads shall not contact the primary mirror under the normal Operating Conditions.

4.2.5.2 Requirements. The M1 Safety Restraint System shall be designed to meet the following requirements:

Maximum stress in the mirror < 750 psi

4.2.6. Ml Cell Sensing System

4.2.6.1. Definition. The "M1 Cell Sensing System" consists of sensors and associated electronics for monitoring the conditions in the M1 Cell Assembly. These sensors include, at minimum, 3 accelerometers, 16 temperature transducers, and 32 strain gages.

4.2.6.2. Requirements. The M1 Cell Sensing System shall include the sensors, their associated mounting hardware, and all necessary signal conditioning electronics, and these electronics shall be designed to allow expansion of sensing capabilities in the future. The conditioned signals from these sensors shall be in a form that is readable by the Telescope Control System. The required range and resolution of these sensors is specified in the table below:

Type of sensor	Range	Resolution
Accelerometers	± 3g	± 0.01 g
Strain gages	70,000 N/cm^2	± 200 N/Cm^2
Temperature sensors	15° C to + 35° C	± 0.1° C

4.2.7. Ml Support Cooling System

4.2.7.1. Definition. The Ml Support Cooling System removes excess heat generated by the M1 Support System.

4.2.7.2. Requirements. The maximum heat, averaged over any five minute period, that can be dissipated to the M1 Cell Structure and to the surrounding air by each of the Axial Support Units, Lateral Support Units, and Master Cylinder Units, including their associated pneumatic valves and control electronics, shall be I watt. The maximum heat that can be dissipated to the M1 Cell Structure and to the surrounding air by the remainder of the M1 Support System is 50 watts. All other heat generated by the M1 Support System shall be removed by the M1 Support Cooling System. No part of the M1 Support Cooling System shall allow the formation of condensation either internal or external to the M1 Cell Assembly. During observing, the M1 Support Cooling System shall not cause vibration of the Primary Mirror that would significantly degrade the image quality of the Telescopes. This requirement shall be used in designing the coolant piping and the support clamps for the piping. The goal for maximum acceleration of the Primary Mirror caused by the M1 Support Cooling System shall be 0.0001g.

4.3 Ml Thermal Management System

4.3.1 Definition. (a) The "M1 Thermal Management System" is the system that will provide thermal control for the Primary Mirror. The M1 Thermal Management System consists of the Radiating Plate System and the Surface Heating System. These systems are described below.

(1) Radiating Plate System. The "Radiating Plate System is the system that will cool or heat the back surface of the Primary Mirror. This system consists of, without limitation, radiating panels and supports, modular chiller(s), circulation pump(s), pressure sensor(s), piping, insulation', coolant, sensors for temperatures at all radiating panels and at the back of the mirror, sensors to measure the temperature difference between the ambient air and the mirror surface, and control electronics.

(2) Surface Heating System. The Surface Heating System is the system that will provide electrical current to the coating on the front surface of the Primary Mirror to cause heating of the surface of the Primary Mirror. The Surface Heating System consists of, without limitation, electrodes, cables, power supplies, additional sensors to measure the temperature difference between the ambient air and the mirror surface, and control electronics

(b) The strategy for primary mirror thermal control involves subcooling the mirror during the day and night, and heating the surface just enough during observation to reach equilibrium with the air temperature. Heat transfer from a liquid cooled radiation plate behind the mirror substrate, supported on the cell structure. is planned to subcool the mirror during the day and night. Heating of the mirror surface will be done by passing a current through the mirror coating. A preliminary design layout is shown in Drawing 85-GP-2000-0033.

(c) It is expected that the primary mirror covers will be open a significant percentage of time during some days in order to clean the mirror, Therefore it must be possible to achieve an adequate level of preconditioning of the mirror with the mirror covers open.

(d) The detailed design, fabrication and assembly of the Surface Heating System are not included as part of this Work Scope, however, the detailed design of the M1 Cell Assembly shall be compatible with a later installation of a Surface Heating System that meets all the requirements of this Section 4.3.

4.3.2 Requirements

4.3.2.1 Primary Mirror Temperature. During observing, the optical surface temperature shall be maintained at a temperature no more than 0.6° C colder nor more than 0.2° warmer than the air temperature immediately above the Primary Mirror, provided, however, that the air temperature is not changing faster than 0.5° C per 15 minutes.

4.3.2.2 Optical Surface Temperature Variation. During observing, the goal for the variation in optical surface temperature, at any one time, across the mirror is ± 0.2 degree C.

4.3.2.3 Air-Mirror Temperature Difference. The temperature difference between the mirror surface and the air shall be measured at 12 or more points around the perimeter of the optical surface and at 4 or more points around the central hole, with an accuracy of ± 0.05 degree C.

4.3.2.4 Capacity. During the day, the M1 Thermal Control System shall be capable of changing the average mirror substrate temperature to the expected operating temperature by ±4 degrees C in 8 hours. Ten hours after the start of daytime thermal control, temperature nonuniformities in the mirror substrate shall be reduced to less than 0.5 degree C in any single layer parallel to the optical surface.

4.3.2.5 Coating Degradation. The Surface Heating System shall not adversely affect coating life or emissivity.

4.3.2.6 Surface Heating Envelope. The Surface Heating System shall not obscure or degrade the performance of any part of the optical surface within the clear aperture. The clear aperture includes the entire optical surface of the mirror except for a thin annular ring around the outside diameter beyond a radius of 4.0 meters, and a thin annular ring around the inside diameter inside of a radius of 0.6 meters.

4.3.2.7 Surface Heating Performance. The Surface Heating System shall be able to maintain the optical surface temperature equal to the air temperature when the average mirror blank temperature is up to 3.0° C cooler than the air.

4.3.2.8 Heat Sources. The M1 Thermal Management System shall not cause thermal problems anywhere else in the telescope or enclosure. For example, no pipes, heat exchangers, blowers, etc., shall be allowed to absorb or dissipate heat in a way that would upset seeing conditions within the enclosure.

4.3.2.9 Operational Degradation. During observing, the M1 Thermal Management System shall not cause vibration of the Primary Mirror that would significantly degrade the image quality of the Telescopes. This requirement shall be used in designing the radiating plate supports and in designing the coolant piping and flow rates. The goal for maximum acceleration of the Primary Mirror caused by the M1 Thermal Management System shall be 0.0001g.

4.3.2.10 Condensation. No part of the M1 Thermal Management System shall allow the formation of condensation either internal or external to the M1 Cell Assembly.

4.3.2.11 Reject Heat. The M1 Thermal Management System shall have one or more modular chillers that will transfer excess heat to the air in the heat exhaust duct of the Telescope enclosure.

4.3.2.12 Cell Temperature Uniformity. The M1 Thermal Management System shall not produce significant temperature nonuniformities in the M1 Cell Structure.

4.4 Ancillary Equipment

4.4.1 General. The Ancillary Equipment includes the M1 Baffle Support Mechanism, the Instrument Cover, the Aperture Plates, the Dust Removing System, and Utility Services. These are described in the following sections.

4.4.2. Ml Baffle Support Mechanism

4.4.2.1 General. Baffles reduce stray radiation at the focal plane from out-of-field sources. In both the f/6 and f/16 Telescope configurations, the M1 Baffles will extend upwards from the central hole of the Primary Mirror. The M1 Baffle Support Mechanism will locate and lock in place either of the M1 Baffles.

4.4.2.2. Requirements. The positional repeatability of the M1 Baffle location shall be within ± 5 mm, measured anywhere on the M1 Baffles up to 4 meters from the M1 Baffle Support Mechanism. The locking device shall be controllable by key switch, which shall be located at an appropriate place on the M1 Cell Assembly within sight of the M1 Baffle. A sensor readable by the Telescope Control System shall indicate the status of the M1 Baffle Support Mechanism, including which M1 Baffle, if any, is in place, and indicating whether the mechanism is locked or not. The M1 Baffle Support Mechanism shall be designed so that it is possible to install, remove, or exchange the f/6 and/or f/ 1 6 M1 Baffles in six hours or less.

4.4.3. Instrument Cover.

4.4.3.1. Definition. The "Instrument Cover" is a deployable cover that can close the opening in the center of the M1 Cell Assembly to protect the Cassegrain Instruments.

4.4.3.2. Requirements. The Instrument Cover shall be able to close and open the center hole of the M1 Cell Structure without releasing dust into the instrumentation below. In its open condition, the clear aperture through the Instrument Cover shall be at least 0.6 meter diameter. In its closed condition, the Instrument Cover shall be light tight and be able to withstand the impact of a small maintenance tool, at minimum, it shall withstand the impact of a 1 kg tool dropped from a height of 15 meters without damage to any equipment in the Cassegrain Cluster, and it shall still be able to function after such an impact. The Instrument Cover shall be operated under computer control from the Telescope Control System, and sensors shall be incorporated into the Instrument Cover to indicate its status, whether open or closed.

4.4.4. Aperture Plates

4.4.4.1. Definition. The "Aperture Plates" are two continuous, circular rings that define the outer and inner diameters of the clear aperture of the Primary Mirror.

4.4.4.2. Requirements. The Aperture Plates shall have a aperture sizes and position tolerances as follows:

Outer aperture	8000 -0 /+10 mm.
Inner aperture	1200 -5 /+0 mm

The outer and inner aperture plates shall be placed immediately in front of the Primary Mirror to control stray light. The precise configuration of the surfaces and edges of the Aperture Plates shall be determined by stray light analysis that is not part of this Work Scope, however, it is anticipated that the edges must be sharp, with an edge radius of less than 1 mm. The outer Aperture Plate may be mounted on the support brackets of the Lateral Support Units.

4.4.5. Dust Removing System.

4.4.5.1. Definition. The Dust Removing System is a system to collect and remove the dust that is released during primary mirror cleaning. It consists of a dust collecting duct located at the edge of the primary mirror, and a vacuum system to remove the dust.

4.4.5.2. Requirements. The Dust Removing System shall be designed to collect and remove the dust accumulated at the lower edge of the mirror, during the primary cleaning. The Dust Removing System shall be designed so that any dust that is collected but that is not removed by the vacuum system shall not be redeposited on the mirror at any operational Zenith Angle, with the goal that less than 1% of the dust accumulated in the dust collecting trough shall ever be redeposited on the mirror.

4.4.6. Utility Services.

4.4.6.1. Definition. The Utility Services are facilities in the M1 Cell Assembly to provide power. control signals, cooling water or compressed air to subsystems of the M1 Cell Assembly or to the Cassegrain Cluster. The Utility Services also includes lighting inside the M1 Cell Assembly for use by maintenance personnel.

4.4.6.2. Requirements. Electrical power, coolant, compressed air and computer interface cables will be required for the primary mirror active support actuators. All M1 cell Utility Services shall be routed through a junction box at the point of entry to the M1 Cell Assembly. The power, control signals, cooling water and compressed air to the instrumentation in the Cassegrain Cluster shall be routed from the telescope center section to the Cassegrain Cable Wrap through the M1 Cell Structure. A sensor shall indicate to the Telescope Control System when the maintenance lights are on inside the M1 Cell Assembly.