Technical Specifications and Requirements for the Magellan 6.5-Meter Telescope Mount

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TABLE OF CONTENTS

1. General Information

The purpose of the work is to design, construct and test an astronomical telescope mount to utilize a 6.5 meter diameter primary mirror.

1.1 Introduction

The following specifications include those which the Carnegie Institution of Washington (CIW) and Contractor have established during the preliminary design phase. The preliminary design is summarized in Magellan Project Report No. 36, including L & F drawings E271066 sheets 1 through 9 and E271069.

In some cases a best effort is specified. A "best effort" is defined here to be a purposeful attempt by Contractor to apply the best existing and imagined design and fabrication practices to a problem in order to achieve the best possible subject feature within existing constraints of function, budget, and schedule. The spirit of this effort shall include an attempt to advance the state of the art for optical telescopes whenever an opportunity permits.

During the final design phase CIW and the Contractor will collaborate to:

- find higher performance and more cost effective solutions for the telescope mount.
- define and complete the Specifications and Requirements for all final design details not contained and/or deviating from the preliminary design described in Magellan Report No. 36.

1.2 Preliminary Design

CIW and Contractor have developed a partially engineered design for a 6.5 meter alt-azimuth telescope shown on L & F drawings E271066 and E271069. Engineering studies have been performed to determine the layout of the telescope and associated subassemblies, size bearings for the azimuth and altitude axes and instrument rotators, and optimize the structure for modal performance. The results of these studies are summarized in Magellan Report No. 36, "Summary of the Preliminary Design of the 6.5 Meter Telescope", which includes drawing E271066. Subsequent sheet number callouts in this specification will be references to this drawing.

Some changes have been incorporated into the design since Report No. 36 and drawing E271066 were issued. Unless otherwise stated, these changes shall be considered a part of the baseline design and this specification. The changes are:

- The (previous) f12 Gregorian secondary has become an f11 Gregorian secondary, extending the secondary end of the OSS and its clearance radius from 30'- 0" to 30'- 6".
- The (previous) f17.5 Gregorian secondary has become an f15 conventional secondary, mounted at the lower end of the secondary central support structure.
- Addition of azimuth plane bearing ring beam (discussed in detail in section 4.1A below), in lieu of grouting a shallow ring directly to the top of the pier.
- The primary mirror cell structure has been made deeper with an open back for improved access to the actuators and ventilation system. Removable sheet metal covers will be used to enclose the ventilation air during operation of the telescope. The perimeter of the primary mirror removal cart will be shallower to accept the deeper cell.
- The tertiary assembly will be redesigned to eliminate the second (small) tertiary mirror. The remaining tertiary mirror will be on bearings mounted to the (already) pivoting assembly so that, when it is folded clear of the Cassegrain light, it can reside on the side of the tertiary assembly opposite the corrector. This will result in greater clearance of the f15 infrared light cone. Due to lack of detailed information on the new design, the previous two-tertiary design described herein is to be considered a temporary baseline design for contractual purposes.
- The folded port mounts shown on sheet 2 will be made nearly flush with the perimeter of the center section.
- The mirror cover will include a central hole approximately 40 in. in diameter (a semi-circular hole on the edge of each biparting assembly) with a manually installed sheet metal cover.

1.3 Exact Dimensions

Except as otherwise provided in these specifications, exact dimensions are to be determined by Contractor to the extent that they represent reasonable cost/performance optimizations and are consistent with the functionality and performance requirements of the telescope.

1.4 Operating Conditions

Under operating conditions the telescope can be in any position with mirror covers open and the telescope acquiring or tracking objects. Unless otherwise stated, the telescope is to meet all functional and performance requirements under the conditions listed below.

Wind speed	50 mph (22 m/s) peak, outside free air 15 mph (6.6 m/s) on any part of telescope
Air temperature	isothermal, 15 to 80 °F (-9 to 27 °C)
Humidity	95%, non-precipitating
Altitude	8,000 ft. (2400 m)
Earthquake	0.4 g horizontal, any direction (performance n/a; no damage to telescope)

1.5 Survival Conditions

The system shall maintain functional integrity under the following survival conditions. Unless otherwise stated these will apply with the mirror covers open or closed and the telescope parked with OSS lockpin engaged.

Wind speed	50 mph (22 m/s) on telescope
Air temperature	0 to 100 °F (-18 to 38 °C)
Humidity	Up to 100%
Earthquake	0.4 g horizontal, any direction

1.6 Coordinate System, Reference Position, and Instrument Ports

A global coordinate system and earth-referenced position for the mount are useful for interface purposes. These are defined as follows:

In the reference position the optics support structure (OSS) is in the zenith position with the azimuth system positioned such that, if the OSS were rotated to horizon, it would point South. With North at 0° azimuth angle (increasing azimuthal angle clockwise looking down), and up as 0° zenith angle, the mount reference position is therefore 0° zenith, 180° azimuth.

The origin of the global coordinate system is at the intersection of the altitude and azimuth axes. Positive X is East, positive Y North, and positive Z up. Unless otherwise stated, coordinate system and telescope position references below will use this nomenclature.

Contractor may define additional coordinate systems referenced to this global system as required during the detail design.

The West Nasmyth port is hereby defined as "Nasmyth 1" (NAS1), the East Nasmyth port "Nasmyth 2" (NAS2).

The folded instrument port just West of North in the reference position is designated as Folded Port 1 (FP1), North as Folded Port 2 (FP2), and just East of North as Folded Port 3 (FP3).

1.7 Applicable Standards and Codes

The Standards and Codes listed below shall form an integral part of these Technical Specifications and Requirements:

American Institute of Steel Construction (AISC), Manual of Steel Construction
American National Standards Institute (ANSI), Reference Y14 and in particular Y14.6.
American Welding Society (AWS), Code D1.1-92
American Society for the Testing of Materials (ASTM), A6-91B
National Electrical Code (NEC), NFPA 70-1990
Electrical Standards for Industrial Machinery NFPA 79-1987

These Standards and Codes shall, where applicable, apply to the engineering and the manufacturing of the telescope mount or any portion thereof.

2. Interfaces

This section sets forth dimensions and properties of items not included in this contract which place constraints on the dimensions and configuration of the final telescope design.

2.1 Primary Mirror, Support and Ventilation Systems

The primary mirror and its support and ventilation systems will be manufactured by others but will reside in the primary mirror cell, shown on sheets 1 and 3. The details of the interface between the cell and these systems will be developed during the detail design. Finished parameters for the primary mirror are:

Overall diameter	256.40 in. (6512 mm)
Center hole diameter	35.00 in.
Outer edge thickness	28.00 in.
Inner edge thickness	15.40 in.
Focal length (f1.25 parabola)	320.00 in.
Weight	17,017 lbs (7,735 kg)

It will be supported by an array of axial and lateral actuators and hardpoints mounted to stiffening elements integral to the front plate of the cell. It will be ventilated by thermally conditioned air. A portion of the ventilation system will be mounted in the cell.

In addition, clearance shall be provided between the perimeter of the primary mirror and the mirror cell, and the central hole and the Tertiary Assembly.

The exact configuration of actuators, hard points, and ventilation devices will be provided by CIW as required by Contractor during the detail design phase.

2.2 Secondary Mirror Cell Assemblies

The telescope is being designed to accommodate four secondary mirror configurations. The mirror/cell assemblies are not part of this contract. Detailed interfaces will be developed during the detail design phase.

2.2.1 f11 Optical Gregorian

The f11 will be a Gregorian (concave) secondary mirror and cell assembly which will focus at either of the (2) Nasmyth or (3) Folded Ports. The f11 is shown schematically on sheets 3 and 6. The assembly will weigh approximately 900 lbs (410 kg) and mount to the top end of the secondary central support structure using approximately six bolts, one dowel pin and one diamond pin.

Detailed interface data will be developed jointly by CIW and Contractor when such information is required by Contractor. Contractor will prepare an interface drawing which shall include mounting dimensions and weight and c.g. limits for f11 secondary assembly.

Interface features provided by Contractor shall include:

- Mechanical mounting provisions of the cell assembly to the structure.
- Routing provisions for hoses and control cables to supply cell assembly.
- Balance compensation of OSS horizon gravity moments about the altitude axis (caused by removal or installation of cell assembly) by powered counterweight system.

Contractor shall simulate the mass of the secondary assembly during shop testing.

2.2.2 f15 Infrared Cassegrain

The f15 will be a conventional (convex) secondary mirror and cell assembly which will focus at the Cassegrain instrument port. It will be used in lieu of the f17.5 Gregorian infrared secondary shown schematically on sheets 3 and 6. The assembly will mount to a mechanism located near the lower end of the central support structure which pivots the cell assembly into or out of the light path.

Detailed interface data will be developed jointly by CIW and Contractor when such information is required by Contractor. Contractor will prepare an interface drawing which shall include mounting dimensions and weight and c.g. limits f15 secondary assembly.

Interface features provided by Contractor shall include:

- Mechanical mounting provisions of the cell assembly to the pivot mechanism.
- Routing provisions for hoses and control cables to supply cell assembly.
- Balance compensation of OSS horizon gravity moments about the altitude axis (caused by rotation of the assembly into the light path) by powered counterweight system.

Contractor shall simulate the mass of the secondary assembly during shop testing.

2.2.3 f15 (future) Auxiliary Cassegrain

The auxiliary Cassegrain secondary, if implemented in the future, would pivot into the light beam on a similar mechanism as that used for the infrared Cassegrain secondary. The secondary central support structure shall be made symmetrical about the YZ plane and include mounting and register provisions for a future mechanism to be a mirror image of the infrared Cassegrain secondary mechanism.

Utilities routing and powered counterweight balance compensation interfaces shall be provided by Contractor.

2.2.4 f5 (future) Optical Wide Field

The optical wide field secondary, if implemented in the future, would focus at the Cassegrain instrument port. It is shown schematically on sheets 3 and 6. The mirror, cell, and mounting frame assembly would attach to the lower end of the secondary central support structure using approximately six bolts, one dowel pin and one diamond pin. The assembly would weigh approximately 1,100 lbs (500 kg).

Interface data will consist only of mounting provision dimensions, which will be provided by CIW to Contractor as available but no later than one month prior to the first major design review. Balance compensation by the powered counterweight system will not be required.

2.3 Tertiary Mirror Cells and Corrector Assembly

The tertiary assembly, less optics assemblies, is part of this contract. An earlier design is shown conceptually on sheet 3. The tertiary assembly will be redesigned to eliminate the second (small) tertiary mirror. The remaining tertiary mirror will be on bearings mounted to the (already) pivoting assembly so that, when it is folded clear of the Cassegrain light, it can reside on the side of the tertiary assembly opposite the corrector. This will result in greater clearance of the f15 infrared light cone.

Due to lack of detailed information on the new design the previous two-tertiary design, described in Report 36, is to be considered a temporary baseline design for contractual purposes.

Detailed interface data will be developed jointly by CIW and Contractor when such information is required by Contractor. Contractor shall prepare an interface drawing which shall include mounting dimensions and weight and c.g. limits for the tertiary mirror and corrector assemblies.

2.4 Instruments

Scientific instruments will be mounted at any or all of the NAS1, NAS2, FP1, FP2, FP3, and Cassegrain instrument ports as shown on sheet 3.

Detailed mounting dimensions and utilities requirements for all instruments will be developed jointly by CIW and Contractor when such information is required by Contractor. Mass and envelope dimensional data for the Nasmyth and Cassegrain instruments are provided in section 4.6 below. Envelope dimensional data for the folded port instruments will be supplied by CIW when required by Contractor. Contractor shall prepare interface drawings which shall include mounting dimensions and weight and c.g. limits for the instruments.

Interface requirements include:

- Mechanical mounting provisions of the instruments to the mounting flanges of the instrument rotators or telescope structure.
- Routing provisions for hoses and control cables to supply instruments.
- Balance compensation of OSS zenith gravity moments about the altitude axis (caused by installation/removal of one folded port instrument) by powered counterweight system.

2.5 Enclosure and Pier

CIW will monitor the telescope design and approve all features and dimensions which will drive enclosure and pier design. Enclosure and pier specifications that may be particularly affected by telescope design include but are not limited to:

- Observing floor clearance around the telescope.
- Clearance between the telescope and the enclosure structure.
- Height of the elevation axis above grade and above the observing floor.
- Shutter width requirements to accommodate telescope installation.
- Concrete foundation (pier)/telescope interfaces.
- Observing floor/telescope interfaces.
- Ventilation system design.
- Cable routing.

- Coude beam.

The basic geometrical relations determined in the preliminary design are shown on the system layout, L & F drawing number E271066. Contractor shall make a best effort to limit the clearance radius from the origin of the reference coordinate system to any part of the telescope, including the f11 secondary mirror cell to no more than 30' - 6" (9.3 m). Changes to dimensions that may affect the design of other systems (enclosure, pier, equipment lift, etc.) shall require the written approval of the CIW project manager.

2.6 Primary Mirror Removal

The primary mirror will be removed in its cell with the OSS at zenith. A preliminary design has been developed for a mirror removal cart, part of this contract and shown on sheet 7. The cart will be driven under the telescope, raised to mate with the cell, and the assembly lowered back to floor level. The self-powered unit will then be driven on rails to the aluminizing facility adjacent to the telescope enclosure.

Detailed interface data including wheel loads, envelope dimensions, rail data and electrical requirements shall be provided to CIW by Contractor as available but no later than two months after acceptance of contract.

Interface requirements are:

- Rail system mounted in observing floor of stationary enclosure building to mate with rails in the telescope floor.
- Hole in wall of stationary building for passage of mirror cart/cell assembly.
- Jacking points under cart in aluminizing facility.
- Guides to support and position assembly as it is mated to upper vacuum chamber in aluminizing facility.
- Final positioning and bolting provisions of upper vacuum chamber.
- Utilities (power and control) while operating vertically or horizontally.

Installation of the primary mirror is the reverse procedure to that of its removal.

2.7 Control System

The Telescope Control System provides the signals for driving motors, brakes, stow pins, lamps, etc. and reads encoders, limit switches, index marks, temperature sensors, etc. Power sources which are not supplied as an integral part of a component will also be provided by the control system. The control system will also provide the high-level control functions associated with observing such as pointing and tracking the telescope, master control over the various telescope subsystems, and the user interface.

Interface of actuators and transducers to their controller electronics is via electrical connectors. Connector types and locations are to be determined by Contractor and approved by CIW. Cabling from component connectors to controllers and off-telescope cabling will be provided by others. A full description of telescope cabling and control functions will be developed by CIW and made available when required by Contractor.

Interface requirements are:

- Contractor shall coordinate with CIW in the selection of motors, encoders, transducers, connectors, etc.
- Contractor shall coordinate with CIW in designing utilities routing and locating electronics boxes.
- Contractor shall provide mounts for controller boxes as required.
- Contractor shall provide ports into the mount ventilation plenum for electronics boxes mounted on the telescope.
- Contractor shall provide conduits, cableways, drapes, wraps, etc, for control system cabling.

3. General Specifications

3.1 Pointing and Tracking

The two most important features for the telescope mount system are the repeatable pointing and smooth tracking of the altitude and azimuth axes. The goal for pointing shall be to achieve 0.1 arcsecond RMS pointing accuracy for offsets up to 1 degree, 1 arcsecond RMS accuracy for offsets greater than that up to 10 degrees and 2 arcseconds RMS accuracy over the full range of motion of each axis.

The goal for tracking shall be to achieve less than 0.03 arcseconds RMS jitter during open loop tracking for one minute of time.

These goals apply to the operation of the complete telescope system during pointing and tracking in the absence of wind. Performance requirements under wind loading are included in section 3.9 below.

3.2 Resonant Frequencies

Contractor shall make a best effort during design and fabrication to produce a telescope with all primary mode resonant frequencies above 10 Hz. Primary modes are hereby defined as those whose modeshapes involve motion of over 50% of the mass of the telescope.

Contractor shall also make a best effort to produce a telescope with all local resonances of structural members above 8 hz. Exceptions to this for members remote from actively controlled devices will be considered on a case by case basis during the detail design.

3.3 Maximum Design Stresses, Safety Factor

For structural members not stability critical, calculated stresses under their maximum design load shall not exceed one-third of their material yield strength. Maximum design loads in stability critical members shall not exceed two-thirds (2/3) of that allowed by the requirements of the American Institute of Steel Construction (AISC) Manual of Steel Construction.

Exceptions to the above will be considered where other authoritative design specifications are applicable.

The above shall not be construed to limit Contractor from using higher factors of safety in cases where Contractor's experience and expertise suggest the prudence of doing so.

3.4 Axis Motion Ranges

As a minimum, the OSS shall be mechanically capable of pointing to zenith angles of +0.5° to +90° (horizon) with free travel unencumbered by force effects from the altitude axis shock absorbers. The observing range for the telescope shall be $+0.5° \leq Z \leq +80°$.

The telescope shall be capable of continuous azimuth rotation of 540°. The utilities wrap will exert its minimum torque on the telescope at the central position of this range of motion, which shall be at 90° true azimuth.

3.5 Axis Motion Rates

The system shall be capable of slew rates of 2°/sec in azimuth and 1°/sec about the altitude axis. Maximum slew accelerations shall be $0.2°/sec^2$ in azimuth and $0.1°/sec^2$ about the altitude axis. The system shall function reliably in this range. Tracking rates shall be 0.4°/sec in azimuth and 15 arcseconds/sec about the altitude axis. The system shall perform within specifications in this range. The system shall be capable of rates of 10°/sec during an overspeed event without damage to any component.

3.6 Hysteresis and Backlash

Contractor shall make a best effort in the design and fabrication of the telescope system to minimize hysteresis and backlash. No theoretical backlash shall exist in the main axis drives of the telescope.

Stress-relieved welds are preferred over bolted joints. When separable joints are necessary, they shall be designed to minimize hysteresis and equipped with dowels where appropriate.

3.7 Materials and Fasteners

All major components shall be fabricated from suitable grades of high quality steel capable of being welded, stress-relieved and machined as appropriate. No materials shall be used that become brittle or otherwise deteriorate over the range of specified operating and survival conditions. Contractor shall make a best effort to thermally stress relieve all weldments.

Components that wear and are expected to require replacement over the life of the telescope shall be accessible for inspection and replacement and designed for ease of maintenance.

All fasteners shall be zinc-plated, cadmium-plated, or stainless steel.

CIW will have the right of review and approval of all materials, components, connectors and fasteners.

3.8 Thermal Control

Contractor shall make a best effort to optimize the thermal performance of the telescope system. In general, this will involve:

- Minimizing the mass of the structure.
- Minimizing plate thicknesses to promote rapid cooling of the structure above the observing floor. As a rule-of-thumb, steel plate up to 0.5 inch thickness ventilated from one side is acceptable. Plates ventilated from both sides may be up to twice as thick.
- Establishment of the structure internal air volume as a plenum for self-ventilation and as a vacuum source to aid in exhausting heat from local sources on the telescope.
- Providing enclosures and ducts to connect local heat sources on the telescope to the telescope plenum.
- Providing surfaces, where applicable, which will accommodate aluminum tape to be applied later by CIW, to minimize super cooling of the structure due to radiation to the night sky.

The goal shall be that the telescope will track the ambient air temperature to within 0.5°C when the air temperature is changing at 0.5°C/hour.

3.9 Wind Performance

The performance goals for the telescope under a 15 mph wind acting directly on the structure shall be not to exceed:

- 0.2 arcseconds primary pointing error.
- 0.15 arcseconds relative tilt of secondary and primary.
- 10 microns relative off-axis motion (decenter) of secondary and primary.
- 3 microns defocus of secondary with respect to primary.

4. Detailed Specifications and Requirements

This section sets forth detailed technical features and performance requirements for major components or subassemblies of the telescope mount.

4.1 Pier-interface Assemblies

4.1.1 Azimuth Plane Bearing Ring Beam

The Azimuth Plane Bearing Ring Beam, hereafter referred to as "ring beam" is a circular box beam which conveys load from the telescope vertically-acting hydrostatic pads to the concrete pier. Its preliminary design is shown on L & F drawing E271069.

During the detail design phase the number of bolted sections, the method and number of pier attachments, and structural cross-section shall be optimized for considerations of structural performance, shipping and handling, on-site assembly and adjustment, and cost. The overall depth of the basic section of the ring beam shall not exceed 48 inches. Its mean diameter shall be 31 feet (9.45 meters).

The top hydrostatic bearing running surface can be adjusted to be flat and level over the scale of the adjustable anchor bolt spacing. The oil drain gutters can be made in sections, mechanically sealed to each other and attached to the ring beam in a manner that will preclude leakage. Alternatively, the sections can be welded together on-site by others and then attached mechanically to the ring beam in a manner that will preclude leakage. There shall be no welding of the gutter to the ring beam on-site.

The three main structural effects of the ring beam, listed in order of importance, are:

- Vertical distortion caused by any difference in the hydrostatic oil temperature and the temperature of the ring beam. This will cause a largely non-repeatable pointing error which will be a function of the temperature difference, the structural section of the ring beam, and the spacing of supports at the pier. The goal for the ring beam design shall be that the pointing error about either main axis not exceed 0.3 arcseconds per °C (delta-T) due to this effect alone.
- Adequate vertical stiffness, in combination with the mass and stiffness of the rest of the telescope system, to meet or exceed the 10 Hz primary mode resonance requirement.
- Vertical distortion caused by gravity as telescope rotates about azimuth. This will cause a largely repeatable pointing error which will be a function of the structural section of the ring beam and the spacing of supports at the pier. The goal for the ring beam design shall be that the pointing error about either main axis not exceed 1.0 arcsecond due to this effect alone.

The two main mechanical effects of the ring beam are:

- A possible ledge in the top running surface at each bolted joint due to manufacturing tolerances associated with the end of each beam section. This can cause failure of a hydrostatic pad (loss of oil film) as it passes over the joint. Contractor shall demonstrate in his shop that each ledge does not exceed .001 in. or provide labor and materials to weld and grind the joints on-site in Chile.
- The degree to which the top running surface is not flat and level. This will cause a largely repeatable pointing error as the telescope rotates about azimuth. The goal for the ring beam manufacturing shall be that it can be adjusted on-site so that all points on the running surface lie within two hypothetical horizontal planes .030 in. distant from each other. In addition, local discontinuities in the surface, after on-site adjustment, shall not exceed a slope of .004 in. in 20" nor preclude proper function of the hydrostatic pads. In addition, the top machined surface shall be as flat as Contractor is capable of providing under normal constraints of cost and schedule.

4.1.2 Azimuth Pintle/Drive Disk

The azimuth pintle/drive disk (hereafter referred to as "pintle") is shown on sheets 1, 2, 4 and 5. It serves to define the X and Y translations and Z rotation for the telescope to the pier. It interfaces to the pier via a 120" diameter flange which is grouted and attached with anchor bolts. It interfaces to the telescope via four hydrostatic pads and the two azimuth friction drive units.

It shall include an integral or bolted oil collection gutter which, in combination with dams on the hydrostatic pads, shall permit no oil leakage to the pier area under normal operating conditions.

The pintle shall also include a machined cylindrical surface, at least 1" wide, suitable for mounting of a J. Alan Schier Co. Line-Scan Encoder scale. The mounting area shall be sufficiently remote from the hydrostatic bearing area to assure that no oil gets on the scale under normal telescope operation.

The pintle shall also include a machined cylindrical surface in the area of the drive surface which has suitable hardness and surface finish to accommodate a friction-driven incremental encoder, should one be added at some future time.

In addition, the azimuth utilities distribution system will pass through a large central hole in the pintle.

The critical structural features for the pintle are:

- Adequate horizontal stiffness, in combination with the mass and stiffness of the rest of the telescope system, to meet or exceed the 10 Hz primary mode resonance requirement.
- Adequate strength to transfer horizontal load from any one hydrostatic pad to the pier, under rated earthquake loading.

The critical mechanical features for the pintle are:

- Adequate precision in the cylindrical hydrostatic bearing area to assure proper function of the four hydrostatic pads.
- Adequate precision and material hardness in the drive disk area to assure proper function of the two azimuth drive units.
- Feasibility of drive surface replacement. The pintle shall be designed in such a way that the azimuth drive disk can be taken out and remachined or replaced without extensive disassembly of the telescope system. This can be accomplished by the inclusion of a bolted and dowelled joint between the pintle and a separate drive disk or between the entire pintle/drive disk and a separate grouted ring at the pier interface.

In addition, the machined areas for the drive disk, hydrostatic bearing, and friction driven encoder mounting shall be as precise as Contractor is capable of providing under normal constraints of cost and schedule. For purposes of this component, "precise" shall be considered a reference to surface finish and runout with respect to mean center. High spatial frequency runout is considerably more critical than low frequency runout. High spatial frequency shall be considered that with a period of less than 50 inches along the perimeter of the part. Contractor shall make a best effort in the machining of the drive disk surface and (possible future) friction driven encoder running surface to see that no visible signs of tool chatter exist after machining.

The design of the telescope shall accommodate up to 1" of non-concentricity between the inner and outer concrete pier walls.

4.1.3 Azimuth Utilities Distribution

A possible concept for the azimuth utilities distribution system is indicated on sheets 2 and 4. It consists of an annular double-wall tube (hereafter referred to as the "maypole") mounted rigidly at its top end to the center removable floor panel of the azimuth disk. Utilities are routed from each of the four cable trays in the removable floor panel to bulkhead connectors mounted near the top end of the maypole. Flexible drapes convey the utilities from the bulkhead connector level on the maypole to cable trays mounted in the pier in such a way that, as the telescope rotates, the utilities wrap on to, or off of, the maypole outer surface.

The annular tubes of the maypole will serve to convey conditioned air for the primary mirror ventilation system, while providing a clear hole on-axis for a future Coude light beam. A sealed rotating joint and sheet metal transition to a stationary ventilation duct, although not shown, will reside at the lower or upper end of the maypole. The maypole and utilities drape are likely to be somewhat longer than indicated on sheet 2 of drawing E271066.

The concept shown and described here shall be considered the baseline design. When details of number, size and type of utilities required become available, Contractor shall construct a scaled physical model (approximately 1/10 scale) to verify the feasibility of this concept.

The azimuth utilities distribution system shall accommodate possible future removal of the azimuth drive disk including provisions for disconnection of utilities.

4.1.4 Moat Seal

The moat seal is shown on sheet 2. It provides a frictionless seal of the large diameter joint between the rotating telescope and the stationary pier and observing floor structure. The moat will be have a "U" cross-section approximately 4" wide by 8" deep with a diameter of approximately 35' - 0". It can be fabricated from steel and seal welded or formed and rolled.

The stationary moat will be partially filled with ethylene glycol (antifreeze) or other suitable liquid. A continuous circular fin, attached to the rotating telescope, will have its lower edge submerged in the liquid and thus provide the seal between the rotating telescope and the stationary pier. The moat will be supported by the pier and observing floor structure using mounting brackets and sheet metal covers to isolate the moat from external dust and dirt.

The moat shall be made in sections suitable for handling and shipping. The joints between section ends shall be mechanically sealed and bolted or can be welded on-site by others. If welded joints are chosen, a small amount of excess length shall be provided on one end of each section for fitting and welding on-site. Provisions shall be made for periodic draining and cleaning of the moat. The sheet metal covers connecting between the moat and the observing floor structure shall be easily removable for inspection and maintenance access.

In addition, during the detail design phase Contractor shall consider the use of an alternate low-clearance noncontact type of seal to reduce cost and maintenance. However, the moat seal shall be considered the baseline design for contractual purposes.

4.2 Azimuth Assembly

The azimuth assembly is defined here as all parts of the mount system which rotate only about the azimuth axis. Its major components include the azimuth disk structure, tripods, pillow blocks, flooring system, and Nasmyth platforms, described below. Although presented below with a separate description, the tripods may be structurally integral with the azimuth disk.

4.2.1 Azimuth Disk Structure

The azimuth disk structure, hereafter referred to as "azimuth disk", is shown on sheets 1, 2, 4 and 5. The 35' - 0" (10.7 m) diameter structure consists of two horizontal plates separated by a dimension of approximately 23", and connected to each other by vertical gusset plates. The azimuth disk is part of the azimuth assembly, as distinguished from the azimuth pintle/drive disk, the stationary device described above.

The azimuth disk shall be designed with bolted joints the number and placement of which define reasonable structural subassemblies for manufacturing, shipping and installation purposes. Although described separately (section 4.2.2 below), each tripod can be an integral part of an azimuth disk sub-weldment, at the option of Contractor.

The important structural features of the azimuth disk are:

- Adequately high in-plane stiffness and low self mass, in combination with the mass and stiffness of the rest of the telescope system, to meet or exceed the 10 Hz primary mode resonance requirement. Also critical here are the local stiffness at hydrostatic pad and drive tangent arm supports.

- Adequate bracing and plate thickness to define local plate out-of-plane bending modes exceeding 8 Hz.
- Adequate bracing and plate thickness, in combination with the flooring system, to support personnel loading of 100 psf over any 5 ft square area and equipment loading of two 1,750 lb wheel loads at any two points 5 ft distant from each other.

The important mechanical features of the azimuth disk are:

- Provisions for mounting (6) vertically-acting hydrostatic pads on the bottom side, and (4) horizontally-acting hydrostatic pads around the large central hole.
- Provisions for mounting the azimuth drive tangent arms and radial preload units.
- Large bolted joints for mounting of tripods, should Contractor elect to not make them integral with the azimuth disk.
- Inclusion of mounting provisions for removable handrails to be installed when a large Cassegrain instrument is installed. The purpose of the handrails will be to preclude personnel from inadvertently walking to a position where they might be trapped between the instrument and the floor.
- Other miscellaneous features such as incorporation of mirror cart rails, accommodation of flooring system, utilities cable trays to be routed on the underside, mounting provisions for (2) J. Alan Schier Co. Line-Scan Encoder cameras, insulated primary mirror ventilation ducts, and bolted joints as described above.

4.2.2 Tripods

The tripods, shown on sheets 1 and 2, are structural elements each of which transfers support loads from one edge of the optics support structure (OSS) to three points on the azimuth plane bearing ring beam below. They may be integral parts of sections of the azimuth disk weldment.

The two tripods shall include machined mounting surfaces for the OSS hydrostatic pad pillow blocks, a horizontal clearance hole and mounting provisions for a future Coude light beam and flat mirror, insulated primary mirror ventilation ducts plus mounting provisions for flexible ducts for both primary mirror and OSS structure ventilation, and hydrostatic oil collection dams. The dams shall be designed to minimize ponding of oil. No oil leakage shall occur under normal telescope operation.

Each tripod shall also include mounting provisions for a J. Alan Schier Co. Line-Scan Encoder camera. The mounting shall be designed to be rigid and thermally stable.

4.2.3 Pillow Blocks

The "pillow blocks" are defined here as those small plate weldments which bolt and dowel to the top machined surface of the tripods and which in turn support hydrostatic oil pads that interface with the OSS. They are shown on sheets 1 and 2. There are two radial pad pillow blocks (those pads whose support forces point to the OSS rotation axis) and two lateral pad pillow blocks (those pads whose support forces act parallel to the OSS rotation axis) on each tripod.

The pillow blocks shall include self-mounting provisions and mounting provisions for each of their hydrostatic pads. In addition, one or more of the lateral pad pillow blocks shall include machining for the OSS position lockpin assembly (section 4.10 below).

It is evident that numerous manufacturing tolerances accumulate between the azimuth plane bearing ring beam and the altitude axis. Among them are the azimuth disk hydrostatic pad and tripod pillow block machined surfaces, the pillow block mounting and hydrostatic pad mounting machined surfaces, the hydrostatic pad machined surfaces, and the diameter of the altitude disks. Contractor shall use means to circumvent these tolerance accumulations, such as "Y" position adjustability of the pillow blocks, shims and/or final machining of one element to compensate for others.

The altitude axis (as defined at two points by the mean center of the two altitude disks) shall be perpendicular to the azimuth axis (defined as a line through the mean center of the pintle which is perpendicular to the mean plane of the top running surface of the ring beam) within 1 arcminute.

4.2.4 Flooring System

The flooring system is shown on sheets 2, 4, and 5. It serves to provide a flat working surface on the top side of the azimuth disk structure flush with the observing floor level of the stationary building. The modular system consists of two types of panels.

The "fixed" panels directly cover the top horizontal surface of the azimuth disk, and consist of 1 1/8" linoleum covered tongue-and-groove plywood attached to 3" steel decking. They shall be semi-permanently attached to the azimuth disk such as through the use of bolts or screws.

The three "removable" panels, shown in detail on sheet 4, are recessed into, and span the large central hole in the azimuth disk. The removable floor panels consist of shallow plate weldments covered with linoleum-covered plywood. The center panel shall additionally include a removable top section for access to the azimuth utilities cableways, the annular-tube maypole described in section 4.1.3, and a recessed machined mounting area and cover plate for the possible future mounting of a Coude flat.

The baseline flooring system shall be as described above. During the detail design phase consideration will be given to an insulated variation of the baseline design.

4.2.5 Nasmyth Platforms

The two Nasmyth platforms mount to the tripods of the azimuth assembly. They are shown on sheet 1. Their purpose is to provide personnel access to the OSS-mounted Nasmyth instruments as well as temporary support of the instruments during installation and removal. Although not shown, their access shall be from the azimuth disk via stairs at the back and a ladder at the front.

Each platform shall have a working area that is approximately 120" square and handrails on three sides as shown. The end handrail sections (those in planes parallel to the YZ plane) shall be removable to allow clear access to the platform when the equipment lift is positioned at the platform level.

The platform bracing and stairways shall be foldable or removable to facilitate platform removal and storage.

Each platform shall be designed for a live load of 6,000 lbs, meaning that it is capable of safely supporting its self weight plus:

- Personnel/light equipment loading of 100 psf over any 5 ft square area and:
- A capacity instrument (plus cart) load of 3,500 lbs, consisting of two 1,750 lb point wheel loads at any two points 5 ft distant from each other.

The Nasmyth platforms shall have low self-weight as limited by the need for robustness and functionality and shall be equipped with handrails and stairs.

4.3 Optics Support Structure

The optics support structure (OSS) is defined here as all parts of the mount system which rotate about the altitude axis. Its major components include the primary mirror cell, center section, altitude disks, main truss, secondary end ring, secondary vanes and secondary central support structure.

4.3.1 Mirror Cell

The primary mirror cell appears conceptually on sheets 1, 3, and 7. Since the preliminary design report and drawings were made its construction has been changed to improve the access to the support and ventilation systems. The changes include replacing the solid back plate with stiffened ribs and increasing the depth of the structure by 7 1/2". The open back structure will now be enclosed with stiffened sheet metal covers during normal operation.

Important structural features of the mirror cell include:

- Adequate global and local stiffness to limit mirror figure errors under wind loading should a stiff, passive mirror support system be used.
- Adequate global stiffness to limit pointing and focus errors to negligible values under wind load. The focus error due to a 5 mph wind acting evenly across the mirror due to cell deflection alone shall be less than 0.20 microns. The pointing error due to the same load condition shall be less than 0.003 arcseconds.
- Adequately high global and local stiffness and low self mass, in combination with the mass and stiffness of the rest of the telescope structure, to meet or exceed the 10 Hz primary mode requirement.
- Adequate bracing and plate thickness to define local out-of-plane bending modes exceeding 8 hz.
- Adequate stiffness to limit deflection of tertiary assembly optics and Cassegrain instrument to acceptable levels under gravity loading.

Important mechanical features of the mirror cell include:

- Accommodation of mirror support and ventilation systems.
- Mounting provisions of the tertiary assembly on a pair of approximately 34" diameter precision angular contact ball bearings. See section 4.12 below for tertiary precision requirements.
- Mounting of the Cassegrain instrument rotator on a pair of approximately 41" diameter precision angular contact ball bearings. The axis of the Cassegrain instrument rotator bearing shall pass within $\pm$.027 in. of the altitude axis. The altitude axis is defined here as a theoretical line between the mean center of the outside bearing running surface of the two altitude disks. The bearing rotation axis shall be perpendicular to the master reference plane of the mirror cell to within ± 2 arcminutes. See section 4.6 below for additional rotator requirements.
- Provisions for mounting to the OSS center section around the top flange. This flange shall also serve as the vacuum flange for the upper aluminizing chamber.
- Provisions for attachment to the altitude disk bracing at both lateral edges.
- Provisions for mounting to the primary mirror cart around the bottom flange. This flange shall also serve as the vacuum flange during aluminizing. It shall be protected during shipping and while in use in the telescope by a separate bolted-on device.
- Mounting provisions for a seal between the cell structure and primary mirror to isolate the clean and dirty vacuums.
- Mounting provisions for flexible ducts for the primary mirror and OSS structure ventilation. These shall consists of two approximately 20" diameter ducts near each edge at the back of the mirror cell.

The mirror cell shall be a one-piece weldment with no manufacturing or shipping joints.

4.3.2 Center Section

The center section, shown on sheets 1 and 3, is a plate weldment approximately 26 ft by 27 ft by 38" in size. It can be made in sections with bolted machined joints if necessary for manufacturing and shipping. Its weight will be approximately 18,000 lbs.

Important structural features of the center section include:

- Adequately high stiffness and low self mass, in combination with the mass and stiffness of the rest of the telescope system, to meet or exceed the 10 Hz primary mode resonance requirement.
- Adequately high local stiffness of the folded port instrument mounts to limit instrument deflection to acceptable levels under gravity loading.

Important mechanical features of the center section include:

- Bolted joints for mounting to the altitude disks.
- Provisions for mounting to the mirror cell around the bottom inside corner.
- Mounting provisions for the (3) folded port instruments as shown on sheet 2 and modified in the change description in section 1.2.
- Mounting provisions for the Y and Z powered counterweights (see section 4.9 below).
- Mounting provisions for the Y fixed counterweights.
- Clearance holes for the two Nasmyth light beams and three folded port light beams.
- Mounting provisions for the primary mirror cover assembly.
- Eight standard commercial ventilation fans around the perimeter of the center section. Each approximately 15" dia. fan will be mounted in a hole in the structure which shall be lined with a thinwall tube or pipe. Each fan shall include a remotely-controlled louver to close off the mirror cell cavity when not in use.

4.3.3 Altitude Disks

The two altitude disks, shown on sheets 1 through 3, serve to define the altitude axis, provide the altitude friction drive surfaces and support the OSS via their 20 ft diameter hydrostatic bearings. Each altitude disk will be approximately 20 ft by 17 ft by 5 ft in size and weigh about 26,000 lbs.

Although not shown on the preliminary design drawings, the baseline design shall include separate altitude drive segments to be bolted to the altitude disk structures.

Important structural features of the altitude disks include:

- Adequately high stiffness and low self mass, in combination with the mass and stiffness of the rest of the telescope system, to meet or exceed the 10 Hz primary mode resonance requirement.
- Adequate bracing and plate thickness to define local out-of-plane bending modes exceeding 8 hz.
- Adequately high stiffness of the Nasmyth instrument rotator and supporting structure to limit instrument tilt to less than 30 arcseconds under gravity loading.

Important mechanical features of each altitude disk include:

- The large bolted joint for mounting to the center section.
- Mounting of the Nasmyth instrument rotator on a pair of approximately 40" diameter precision angular contact ball bearings. The mechanical center of the bearing pair shall be coincident with the mean center of its altitude disk's radial hydrostatic pad running surface within .027 in. (.054 in. dia). The rotation axis of the bearing pair shall be parallel to the altitude axis within ± 2 arcminutes. The altitude axis is defined by the mean center of the two altitude disk running surfaces. See section 4.6 below for additional rotator requirements.
- Clearance hole for the Nasmyth light beam.
- Mounting provisions for the secondary main truss.
- The perimeter machined area to act as the hydrostatic bearing runner surface and provide mounting provisions for the altitude drive segments.
- Adequate precision in the hydrostatic bearing area to assure proper function of the hydrostatic pads.
- Adequate precision and material hardness in the drive segments to assure proper function of the two altitude drive units.
- Inclusion of a circular flanged device to act both as a drip lip (to prevent oil from running down the face of the altitude disks) and to provide a mounting surface for a J. Alan Schier Co. Line-Scan Encoder scale. Alternatively, the Line-Scan encoder scale may require a separate cylindrical mounting surface.
- Each altitude drive segment shall also include a machined cylindrical surface in the area of the drive surface which has suitable hardness and surface finish to accommodate a friction-driven incremental

encoder, should one be added at some future time.

In addition, the machined areas for the hydrostatic bearing, drive and friction encoder surfaces and Nasmyth instrument rotator mounting shall be as precise as Contractor is capable of providing under normal constraints of cost and schedule. For purposes of the perimeter machining area, drive segments, and scale mounting surface, "precise" shall be considered a reference to surface finish and runout with respect to mean center. High spatial frequency runout is considerably more critical than low frequency runout. High spatial frequency shall be considered that with a period of less than 50 inches along the perimeter of the part. Contractor shall make a best effort to see that the drive segment and encoder scale mounting areas show no visible sign of tool chatter after machining. For purposes of the instrument rotator, "precise" shall be considered a reference to parallelism and concentricity of the rotator local axis with the altitude axis of the telescope.

4.3.4 Main Truss

The eight-member main truss is shown on sheet 1. It serves to define and support the secondary end ring assembly and provide a flow path for ventilation air for the secondary end of the telescope. The structural section used for the main truss in the preliminary design was 7" outside diameter by 3/8" wall round steel tubing.

During the detail design Contractor shall optimize the truss members to minimize misalignments of the secondary optics with the primary mirror due to rotation through the gravity field. For thermal reasons, the wall thickness of the tubes shall not exceed 3/4". The exterior surface shall be suitable for the subsequent application of aluminum tape by CIW.

4.3.5 Secondary End Ring

The secondary end ring, shown on sheets 2 and 9, supports the secondary vanes and central support structure and transfers wind and gravity loads from them to the main truss. The 320" outside diameter circular ring used in the preliminary design had a 12" by 20" cross section made from 3/8" steel plate.

During the detail design Contractor shall optimize the secondary end ring to minimize misalignment of the secondary optics with the primary mirror due to rotation through the gravity field and to balance OSS due to horizon gravity. The secondary end ring shall include four bolted and dowelled joints for shipping purposes and to facilitate machining for the vane end-node actuators. In addition, the end ring shall include machined mounting pads for the main truss and holes for ventilation air entry. The ventilation holes shall include screens.

4.3.6 Secondary Vanes and Central Support Structure

The secondary vanes and central support structure are shown on sheets 1, 6, and 9. The central support structure serves as a platform for mounting any of the four secondary mirror assemblies for which the system is being designed. The vanes in turn support the central support structure, and the assembly is supported by the secondary end ring via the vane end actuators described in section 4.8 below.

Interfaces are described in section 2.2 above. The central support structure shall include one f15 pivot mechanism and mounting provisions for a second (future) mechanism to be symmetrical about the YZ plane.

During detail design Contractor shall optimize the design of the complete assembly to have high stiffness, low mass, and minimal wind profile to decrease deflection due to gravity and wind loading and to reduce telescope seeing.

Important mechanical features for this assembly are:

- Design for ease of removal; assembly may require occasional removal and replacement with an alternate assembly in the future. This may require the use of pinned or bolted joints between the vanes and central support structure and/or providing for the addition of braces to take the assembly out as a unit.
- Contractor shall design the f15 pivot mechanism with preloaded bearings and preloaded position stop

to eliminate all theoretical backlash in defining the working position for the f15 mirror assembly. Contractor shall consider the use of a flexured stop to isolate the secondary cell assembly against strain from the central support structure.

- The mounting provisions for the f11 secondary assembly shall include features to accommodate quick removal and installation.

4.4 Drives and Encoders

4.4.1 Azimuth and Altitude Drives

The azimuth and altitude drives are shown on sheets 1 and 5. Two drive units will be used on each axis. Each drive unit consists of a hardened traction roller directly driven by an Inland QT-12505 frameless torque motor and an idler roller adjacent to the drive roller. The assembly is preloaded against the drive surface by a hydraulic actuator and defined stiffly to the supporting structure by a large rod flexure.

A detail design has been developed for the direct friction drives, which are described in detail in Magellan Report No. 18. The existing detail design shall be considered the baseline design for the drives for both axes.

In addition a test of a prototype drive unit is ongoing. Should any changes to the design become appropriate as a result of the test, they shall be incorporated in the production telescope units.

The altitude and azimuth drives shall be identical to the maximum extent feasible. The total torque capacity of the two azimuth drives shall meet or exceed 9,400 lb-ft referenced to the axis. The total torque capacity of the two altitude drives shall meet or exceed 6,200 lb-ft referenced to the axis.

The drive assemblies shall include rod flexures, preload mechanisms, side guide rollers, and motor ventilation shroud with flexible duct connected to the telescope plenum.

4.4.2 Azimuth and Altitude Encoders

J. Alan Schier Co. Line-Scan Encoders shall be used for both axes. The encoders have a resolution of 0.1 micron, providing a resolution of .01 arcsecond or better on each axis.

The azimuth axis will use two cameras mounted on the azimuth disk structure at 180° with respect to each other about the azimuth axis. The mounting and support structure for the cameras shall be designed to be structurally and thermally stable. One Line-Scan encoder scale shall be mounted to the azimuth pintle/drive disk as described in section 4.1.2.

The altitude axis will use two cameras, each mounted on a structure supported from its adjacent tripod, and one Line-Scan encoder scale mounted on each altitude disk as described in section 4.3.3. The two camera mounting positions and support structures shall be symmetrical with each other about the YZ plane. They shall be designed to be structurally and thermally stable. Light shrouds which closely fit the profile of the scale mounting structure shall be provided.

4.5 Hydrostatic Bearings

Hydrostatic bearings will be used to define the azimuth and altitude axes. Requirements for the bearing running surfaces are stated in sections 4.1.1, 4.1.2, and 4.3.3 above.

4.5.1 Hydrostatic Pads

Four hydrostatic pads bearing on runners on each altitude disk will define five degrees of freedom of the OSS to the azimuth structure. Six pads bearing on the azimuth plane bearing ring beam and four pads bearing on the azimuth pintle will define five degrees of freedom for the complete telescope to ground.

Therefore, a total of (18) hydrostatic pads will be used to define (10) degrees of freedom for the system. The overconstraint will be accommodated by two methods:

- Twisting of the azimuth disk structure, which has purposefully been made thin. This allows the six vertically-acting pads to maintain their individual loads (and therefore stiffness) even though the running surface is not perfectly flat.
- "Floating" of pads in two areas of the system. Three of the four pads which define the OSS laterally to the azimuth structure will act as preload pads, as follows:

The pad immediately opposite the one pad which is rigidly mounted to a tripod will be mounted on a hydraulic actuator and preloaded against the altitude disk and therefore the rigid pad. The two pads at the other altitude disk will each be mounted on their own hydraulic actuator and preloaded against their altitude disk with nominally equal forces. Therefore the first preload pad holds the OSS against the rigid pad while the other two preload pads "squeeze" through the thickness of their altitude disk. All three preload pads will receive their supply of pressurized oil via small orifices which will result in their having high frequency stiffness but negligible stiffness for low frequency effects such as machining imperfections of the bearing running surfaces. This effect is defined here as "high frequency overconstraint" (HFOC).

In a similar manner, two of the four horizontally-acting pads at the azimuth pintle will be rigidly mounted to the azimuth disk and their opposite pads preloaded with high frequency overconstraint.

The approximate pad loads are:

- (4) OSS radial pads - 50,000 lbs working load each.
- (4) OSS lateral pads - 30,000 lbs preload each (three with HFOC).
- (2) of (6) azimuth vertical pads - 73,000 lbs working load each.
- (4) of (6) azimuth vertical pads - 31,000 lbs working load each.
- (4) azimuth horizontal pads - 50,000 lbs preload each (two with HFOC).

The above hydrostatic pads (not including preload actuators) can be supplied as commercially available units, such as SKF 325 x 420 and SKF 225 x 290 or be custom designed units. All pads shall be self-aligning to compensate for manufacturing tolerances of the running surfaces, or Contractor shall accept responsibility for their proper function under the full range of motion and operation of the telescope.

Of the eighteen pads, five shall be equipped with preload actuators with HFOC. The preload actuators shall be designed to be very stiff so that their hydrostatic pads' stiffness can be effective in achieving the 10 Hz primary mode resonances. They shall also be designed to have very low axial friction so that the frictional forces don't cause unacceptable distortion of the structure.

4.5.2 Oil System

Contractor shall design the hydrostatic oil system complete including pumping unit with filtration, valves and plumbing required and oil collection system. Also included shall be an oil temperature control system. The goal for the oil temperature control system will be to supply oil to all pads at a temperature such that the average oil temperature, as it expands across the hydrostatic pad film lands, is at the ambient air temperature. Contractor shall thermally condition the reservoir oil temperature to be within $\pm 0.5°C$ (or less) of a temperature commanded by the control system to be supplied by CIW. The reservoir oil temperature shall be maintained whenever power to the pumping unit is on, irrespective of flow to the hydrostatic pads.

The hydrostatic oil system shall be equipped with an oil temperature sensor mounted in or just upstream from a piping manifold mounted on the azimuth disk assembly. The sensor shall electronically indicate the temperature of oil that flows to all hydrostatic pads at a point just prior to the point where flow is split to distinct groups of pads.

The hydrostatic oil system shall include solenoid-operated valve(s) to selectively direct flow to all OSS and/or Azimuth hydrostatic pads during system testing. In addition, a solenoid-operated valve shall be included which vents the pressure to all hydrostatic pads. This feature shall be suitable for use as a system emergency stop. If necessary, the release of the hydraulic pressure shall be done through fixed flow control(s) or orifice(s) to help in decelerating the system in a runaway condition. Applicable test requirements are outlined in section 5.13.

An oil pad instrumentation system, such as individual gap and temperature sensors, will be required for each pad and needs to be defined.

4.6 Instrument Rotators

The Cassegrain Instrument rotator and two Nasmyth instrument rotators are indicated on sheet 3. Each consists of a turntable mounted on a large diameter precision angular contact bearing pair. The Cassegrain rotator mounts on the bottom of the primary mirror cell with its axis nominally coincident with the OSS optical axis. The two Nasmyth rotators mount to the outboard surface of the altitude disks with their axes nominally coincident with the altitude axis.

A hole through the adjacent structures provides clearance for the light cone coming from the secondary or tertiary mirrors.

The three rotators shall be designed to have as much commonality as is feasible and unless otherwise stated, descriptions below will apply to all three.

The turntable is rotated by a single motor and friction drive running against the perimeter of the disk. The motor type will be either DC servomotor or stepper motor as determined during the detail design. The rotator position is encoded by an incremental encoder friction coupled to the drive surface. Absolute position is referenced to an electronically readable position sensor that provides a fiducial position at one rotation angle.

A caliper, disk type, failsafe brake is used to prevent rotator motion when the motor drive is off. The braking force is applied by springs and pneumatically released. A manually operated locking pin will also be provided at the rotator stow position to prevent rotation during instrument changes. Removable hard stops and limit switches can restrict rotation to $\pm 179.5°$ when engaged.

Data below specific to the Cass instrument will be designated [Cass], to the Nasmyth instruments, [Nas]. Each rotator shall perform within specifications as outlined below:

Instrument weight	3000 lb
Maximum instrument length from rotator	140 in. (Nas); 110 in. (Cass)
C.G. from mounting plane	50 in.
Maximum radius from axis	50 in.
Radius of homogeneous mass	30 in.
Operating rotation range	360°
Positioning accuracy	± 5 arcsec max
Tracking nonrepeatability, less than	± 5 arcsec max
Bearing nonrepeatable runout, less than	.00068 in. TIR
Rotation rate	-5°/sec to +5°/sec
Tracking rate	-0.5°/sec to +0.5°/sec
Acceleration	$-1°/sec^2$ to $+1°/sec^2$
Brake capacity	1000 lb-ft
Lockpin capacity	5000 lb-ft

Each instrument rotator shall have adequately high stiffness, in combination with its supporting structure, to limit instrument tilt to less than 30 arcseconds under gravity loading. In addition, the unloaded instrument mounting surface for each rotator shall be perpendicular to its bearing rotation axis within ± 30 arcseconds.

Location and alignment precision requirements for the Cassegrain rotator are included in section 4.3.1. Location and alignment precision requirements for the Nasmyth rotators are included in section 4.3.3.

4.7 Mirror Cover

The primary mirror cover is shown on sheets 1 and 8. A circular hole has been added on the optical axis which is described in section 1.2. The purpose of the mirror cover is to keep dust and dirt off the mirror and protect it from falling objects when the telescope is not in use.

It consists of aluminum honeycomb sandwich panels made in two bi-parting assemblies. Each assembly is shown with two hinged folding panels to reduce its side wind profile when open. The use of four hinged folding panels in each assembly can be considered during the detail design to further reduce the wind profile, reduce the opening torque (and therefore actuator size) and eliminate manufacturing splices required in the larger panels.

The mirror cover shall:

- Enclose the primary mirror cavity with nearly air and water-tight seals. It shall be designed to clear the tertiary assembly when closed and provide a clear aperture for the incoming light when open.
- Protect the mirror from impacts of 30 kg-m/s by blunt objects.
- Support a load of 500 lbs distributed over any 2 ft square area of either bi-parting assembly when at zenith.
- Open or close reliably at any altitude angle. Cycle time to open or close shall be between 10 and 30 seconds.
- Hold position without external power at any cover position and altitude angle.
- Have all mechanisms accessible from outside the mirror cavity. The cover shall be readily removable and be capable of being pivoted forward for cleaning when the OSS is at horizon.
- Be capable of manual closure or opening in the event of actuator failure. This procedure shall require no more than 15 minutes by a single maintenance person.

4.8 Vane End Actuator System

The vane end actuator system positions the secondary vane ends with respect to the secondary end ring. Each vane end node (the intersection of the upper and lower vane at either of the four vaneset locations) can be positioned axially (in the Z direction) and radially (in the XY plane). Synchronous or differential motions at the four vane ends can then be used to control the tip, tilt, focus, and X and Y position for any secondary mirror mounted on the central support structure.

The preliminary design is shown on sheet 9. The two levers amplify the effective force and precision of the two actuators. The radial lever pivots on bearings mounted at one end of the axial lever. With the radial actuator mounted to the axial lever, when the radial actuator moves only its lever moves, and the vane end node moves radially. The axial lever pivots in bearings inside the secondary end ring. With the axial actuator mounted to the secondary end ring, when the actuator moves the entire assembly pivots, moving the vane end node axially. The radial actuators are also used to establish and maintain tension in the vanes.

Critical system features are:

- The establishment and maintenance of 10,000 lbs, $\pm 10\%$, tension in each vaneset.
- Force feedback information for each radial and axial actuator.
- Open loop axial position control of each vane end node to an accuracy of 3 microns over a travel range of 20 mm.
- Open loop radial position control of each vane end node to an accuracy of 30 microns over a travel range of 25 mm.
- Ability to hold position with no power input.
- High axial and radial stiffness.

The design is currently being refined, and a prototype test is being developed, which will verify critical performance features for the design. The system as shown on sheet nine and described in Report 36 and herein shall be considered the baseline design.

4.9 Powered Counterweights

Powered counterweights will be required to balance the OSS about the altitude axis as described below.

4.9.1 Z counterweights

Powered counterweights with weights moving in the Z direction will be mounted to the center section immediately inboard of the altitude disks. They will occupy a cylindrical space requiring clearance holes through the center section and altitude disk bracing. (2) or (4) counterweights shall be used as determined by Contractor during the detail design.

The Z counterweights are required to balance the OSS due to the horizon-pointing gravity component. If the reference condition for the telescope includes the Cassegrain instrument (or substitute fixed counterweight) installed, the tertiary flipped "down", the mirror cover closed, the f15 in the light beam, and the f11 not installed, the moment due to the Z counterweights is to account for:

- Tertiary flip "up", 350 lbs @ 15"
- Mirror cover open, 1,200 lbs @ 37"
- f15 pivot out of beam, 150 lbs @ 28"
- f11 installation, 750 lbs @ 360"

The total differential moment about the altitude axis for the (2 or 4) Z counterweights, including 10% margin above those moments listed above, shall be 360,000 lb-in. The powered counterweights shall be designed to eliminate internal clearances so that no uncontrolled motion of the weights occurs as the telescope moves about either axis. The counterweight drives shall be capable of positioning their weights to an accuracy representing a total on-axis residual torque of 1000 lb-in. and hold position of the weights without the application of power.

4.9.2 Y Counterweights

(2) powered counterweights with the weights moving in the Y direction will be mounted to the telescope structure immediately inboard of the altitude disks and below the center section.

The Y counterweights are required to balance the OSS due to the zenith-pointing gravity component. The total variable design moment will be due to the installation or removal of one of the three folded port instruments, which will be 200 lbs on a moment arm of 192 in.

The total differential moment about the altitude axis for the two Y counterweights, including 10% margin above that moment described above, shall be 43,000 lb-in. The powered counterweights shall be designed to eliminate internal clearances so that no uncontrolled motion of the weights occurs as the telescope moves about either axis. The counterweight drives shall be capable of positioning their weights to an accuracy representing a total on-axis residual torque of 700 lb-in. and hold position of the weights without the application of power.

If necessary to install or remove more than one folded port instrument simultaneously, fixed counterweights mounted on the opposite side of the center section will be installed or removed.

4.10 OSS Position Lockpin Assembly

A possible location for the OSS position lockpin assembly is shown on sheet 2. The purpose of the device is two-fold:

- To prevent uncontrolled motion of the OSS due to a large imbalance about the altitude axis. For example, such an imbalance would result from removing the assembly of the secondary vanes and central support structure.
- To aid in verifying proper balance of the OSS prior to disengaging the lockpin, such as after installing the f11 assembly. With significant clearance in the lockpin mechanism, the OSS hydrostatic oil system can be brought up to pressure. The altitude drives can then be used to rotate the OSS through the range

of travel allowed by the lockpin clearance. The torquemotor current can then be measured to verify proper balance, and then the lockpin disengaged.

The use of only one lockpin mechanism shall be deemed adequate if Contractor can demonstrate by calculation that its capacity is adequate and that the OSS and azimuth structures can tolerate the asymmetric loading.

System shall have a capacity of 5E6 lb-in about the altitude axis and be capable of locking OSS at zenith angles of 0°, 30°, 60°, and 90°. System shall be remotely operable and shall not require power to hold lockpin in either the locked or unlocked positions.

4.11 OSS and Azimuth Travel Limits

Travel limits shall be provided at or near each end of travel of the OSS. The progressive limits shall include software limits (by CIW), and limit switches, shock absorbers and hard stops to be supplied by Contractor. The limit switches shall activate at zenith angles beyond -0.1° and +90.1° and shall stay activated as long as the condition exists. The shock absorbers shall be capable of decelerating the OSS from a travel rate of 5°/sec with a maximum allowable tangential acceleration rate of 0.4g anywhere in the system (see section 5.13). The hard stops shall engage just beyond that point at which the OSS comes to rest from a 5°/sec deceleration by the shock absorbers and shall be capable of resisting a total static torque of 13E6 lb-in. about the altitude axis. The shock absorbers may also serve the purpose of the hard stops if they meet all of the requirements of this section.

The mechanical rotation of the azimuth axis is limited only by cable wrap up. Electrical travel limits for the azimuth axis shall consist of software limits (by CIW) and limit switches. A unique limit switch signal shall be activated at each end of travel (azimuth angles of ±270° from the midrange position).

4.12 Tertiary Assembly

The baseline tertiary assembly, which shall be revised during the detail design phase, is described in section 2.3.

4.13 Utilities and Cabling

(THIS SECTION TO BE SUPPLIED BY CIW)

In addition, Contractor shall supply the four approximately 20" diameter flexible ducts that connect the tripods to the mirror cell. Two of the ducts will be used for primary mirror ventilation, and two for OSS structure ventilation.

4.14 Primary Mirror Cart

The primary mirror cart is shown on sheet 7, which is current except for the lowering of the perimeter wall to accommodate the deeper primary mirror cell. It serves two purposes:

- As a handling cart to remove the primary mirror cell assembly, move it to the aluminizing building, and to move it back to the telescope and reinstall it after realuminizing.
- As the lower portion of the vacuum chamber.

As shown, it consists of the lower vacuum chamber (an inverted vacuum vessel head integral with a conical support wall) mounted on wheels. Two of the four wheels are driven and all four run on rails in the floor of the buildings or azimuth disk structure (shown on sheet 5). The two non-driven wheels are mounted on an articulated support beam to assure kinematically defined loading of the wheels, rails and structure. Caliper brakes, although not shown, are included which will hold the assembly against uncontrolled motion in the event of an earthquake.

Also part of the cart are three machine screw jacks for raising and lowering the assembly at the telescope or upper aluminizing chamber. The inverted-mounting jacks use a rotating/translating nut, stationary screw mechanical arrangement. The lower end of the screws are supported by compact hydraulic jacks for precise control of the final 1" of vertical motion as the mirror cell is engaged by the cart.

Aluminum bronze guide blocks mounted to the cart run against guide rails temporarily mounted to the telescope during cell removal and installation.

Additional descriptions are included in Section 2.11 of Report No. 36. Unless otherwise revised during the detail design, system shall meet or exceed the following performance requirements:

Horizontal travel speed	5 fpm ≤ S ≤ 15 fpm
Vertical travel	76 in.
Vertical travel speed	0.1 ips ≤ S ≤ 0.25 ips

The mirror cart system shall be designed to the requirements of section 3.3 under the 0.4 g earthquake acceleration under any operating condition. The vertical and horizontal drives shall be designed for full load but must be capable of meeting the test requirements of section 5.10 (one complete operating cycle under 125% of full load).

4.15 Finish

No sharp edges or corners shall exist unless necessary for their proper function. All exposed non-critical surfaces shall be sandblasted and properly prepared for painting, then painted with a high quality metal primer prior to shipping. Primed surfaces that are not to be covered with aluminum tape shall receive a high quality finish coat of paint. In addition, surfaces that are to be later covered with aluminum tape may be painted with the same high quality finish coat of paint, at Contractor's option. Colors will be specified by CIW during the detail design. Aluminum tape, where required, will be applied on-site by CIW.

4.16 Cassegrain Fixed Counterweights

Contractor shall furnish a set of (8) weights and provisions for mounting them near the lower end of the OSS. The fixed counterweights shall be progressively removed as larger Cassegrain instruments are progressively installed, with no counterweights installed when the capacity 3,000 lb Cassegrain instrument is mounted on its rotator. The counterweight increments shall represent increments of 12.5% of the capacity Cassegrain instrument moment.

5. Acceptance Tests and Procedures

This section sets forth specific criteria for tests that will be performed with the telescope assembled in Contractor's shop. Contractor is to provide substitute masses for the Cassegrain instrument, the primary mirror including its support and ventilation system, the f15 and f11 secondary assemblies, and the tertiary mirror and corrector. These shall be used to verify proper mechanical function of all systems under true gravity loading and to verify OSS balance. In lieu of the Cassegrain instrument mass, the actual Cassegrain fixed counterweights (section 4.16) may be used for testing of the complete telescope. The Cassegrain instrument mass may also be used at the Nasmyth instrument ports for separate verification of their proper function.

In some cases, Contractor shall devise test procedures which will be subject to CIW's approval, and supply required test equipment and fixtures.

Where applicable, tests shall be performed with the telescope structure and mechanical devices well thermalized; that is, with all elements at the same temperature to the maximum extent feasible. Unless otherwise stated, testing of the system will be done only at the ambient conditions that exist in Contractor's shop.

5.1 Fit and Function

Unless otherwise stated, all components of the telescope mount system being supplied as part of this specification shall be assembled to test for fit and function. Assembly to test for fit will be self-evident after telescope mount system is assembled. Therefore it will not be necessary for CIW to witness all assembly operations. Unless otherwise arranged, Contractor shall demonstrate all functional tests in presence of CIW. Functional tests are described in further detail below.

5.2 OSS Balance

Contractor shall demonstrate that OSS imbalance does not exceed 1100 lb-in. with mount completely assembled and in the horizon attitude. Condition of assembly shall be: (Cassegrain instrument, primary mirror system, f15, f11, tertiary and corrector) substitute masses in place, tertiary "up", mirror cover open, f15 out of light beam, f11 installed, and with Z counterweights at their 95% aft positions.

Contractor shall also demonstrate that OSS imbalance does not exceed 700 lb-in. in the zenith attitude. If Contractor is unable to demonstrate this with complete telescope mount assembled Contractor may do so with secondary end structure (including main truss, end ring, and vanes with central support structure) removed, or with a substitute secondary end mass symmetric about the XZ plane in place. Condition shall be folded ports bare and Y counterweights at their neutral positions.

Contractor shall demonstrate full altitude rotation either with OSS completely assembled or with secondary end removed and OSS balanced by other means.

5.3 Friction

With OSS balanced within limits specified herein, axis-referenced starting and running torques at any axis position shall not exceed:

Altitude axis	1,000 lb-ft
Azimuth axis	2,000 lb-ft

In addition, Contractor shall demonstrate that starting torques measured at 30° increments around each axis vary no more than 25%. Running torques measured continuously around each axis shall vary no more than 15%.

5.4 Structure Dimensions and Alignments

Contractor shall demonstrate compliance with the following dimensions and alignments. Measurements shall be taken with the OSS at horizon and all (8) vane end actuators close to their neutral (center) positions.

- Distance from primary mirror cell reference surface (12 machined pads) to altitude axis, 46.712 ±.050 in.
- Distance from primary mirror cell reference surface to f11 mounting bosses, 396.400 ±.10 in.
- Distance from primary mirror cell reference surface to f15 pivot axis, 310.900 ±.10 in.
- Distance from primary mirror cell reference surface to Cassegrain instrument rotator surface, 30.818 ±.050 in.
- X distance from Cassegrain rotator bearing axis to NAS1 and NAS2 rotator surfaces, 177.000 ±.10 in.
- Perpendicularity of altitude and azimuth axes within 1 arcminute.

5.5 Encoder Repeatability

The Contractor shall determine encoder repeatability as follows:

For each axis, a linear position feedback device will be mounted near the radius upon which the encoder scale is mounted. The feedback device can be mounted on either the rotating or stationary side of the axis, at Contractor's option. An actuating arm will be mounted on the opposing component (stationary or rotating). Under control of the axis drives, the moving assembly shall be positioned within the useful range of the position feedback device and the Line-Scan Encoder and feedback device initial positions noted. The telescope shall be rotated away from the initial position, then returned immediately to the Line-Scan Encoder initial position. The feedback device position shall be noted as compared to its initial position.

This shall be repeated for rotation increments of 30° around each axis.

Contractor shall provide the proper mounting of encoder scales and cameras. Beyond this, Contractor shall not be held responsible for encoder repeatability.

5.6 Instrument Rotators

The instrument rotators shall be installed on the telescope and a substitute mass mounted sequentially at the three instrument locations. The substitute mass shall simulate the maximum instrument load, c.g., and imbalance. Functional tests will be performed to verify the operation of motors, brakes, stow pins, encoders, sensors, limit switches, and mechanical stops. A shop test of the servo performance is not required. Testing of the entire telescope mount with Nasmyth instruments in place is not required.

Contractor shall demonstrate compliance to CIW's satisfaction the following:

- Coincidence of NAS1 and NAS2 bearing mechanical centers with altitude axis, .027 in. (.054 in. TIR).
- Parallelism of NAS1 and NAS2 rotation axes with altitude axis, ± 2 arcminutes.
- Perpendicular distance from Cassegrain rotation axis to altitude axis, 0.000 $\pm .027$ in.
- Perpendicularity of Cassegrain rotation axis to mirror cell reference plane within ± 2 arcminutes.
- Rotator angle repeatability ≤ 5 arcseconds.

Controls for the tests will be supplied by CIW.

5.7 Mirror Covers

Contractor shall demonstrate that the mirror covers will:

- Support a static proof load of 625 lbs over any 2 ft. square area of either bi-parting assembly when at zenith.
- Open or close reliably at any altitude angle in no more than 30 seconds and no less than 10 seconds.
- Hold position without external power at any cover position and altitude angle.

Other mirror cover requirements (except for the 30 kg-m/s blunt impact) outlined in section 4.7 will be visually verified. Compliance with the blunt impact requirement shall be demonstrated by calculation or actual impact test on a sacrificial section of panel representative of the production panel.

5.8 Counterweights

The Z and Y counterweights shall be driven with their motors between limits to verify the operation of drives, encoders and limit switches, if required. Tests will be performed with the counterweights vertical and horizontal. Controls for the test will be supplied by CIW. The total differential moment available from the counterweights shall be demonstrated by calculation.

5.9 Tertiary Assembly

A complete functional test of the tertiary assembly will be performed. Details of the acceptance test are to be determined during the detail design.

5.10 Mirror Cart

One complete removal and reinstallation cycle of the primary mirror cell shall be performed. The horizontal travel will be limited by the length of the rails on the azimuth disk. The moving assembly shall include the mirror cell (including substitute mass representing the primary mirror and its support and ventilation systems) and mirror cart plus 25% of the above total moving weight. Proper system function and travel speeds shall be verified.

5.11 Vane End Actuators

A complete functional test shall be performed which will verify that the vane end actuator system performs in a manner consistent with the results achieved by the vane end actuator prototype test or exceeds the requirements of section 4.8. All controls and instrumentation required for the test will be supplied by CIW.

5.12 OSS Position Lockpin Assembly

Contractor shall demonstrate proper function of the OSS position lockpin assembly and related interlock limit switches at each locking position.

5.13 Emergency Stops, OSS Travel Limits

Contractor shall demonstrate that the emergency stop feature of the hydrostatic bearing pressurized oil system functions properly for each axis. The test shall include accelerating either axis to 5°/sec then exhausting the oil pressure as designed. System shall come to rest in no less than 0.75 and no more than 1.25 seconds.

The test of each axis may be performed separately.

In addition, it shall be demonstrated that the OSS mechanical travel limits (shock absorbers) will bring the OSS to rest from a rate of 5°/sec with no damage to the system, and that the limit switches function properly. This shall be demonstrated at both ends of the altitude travel range.