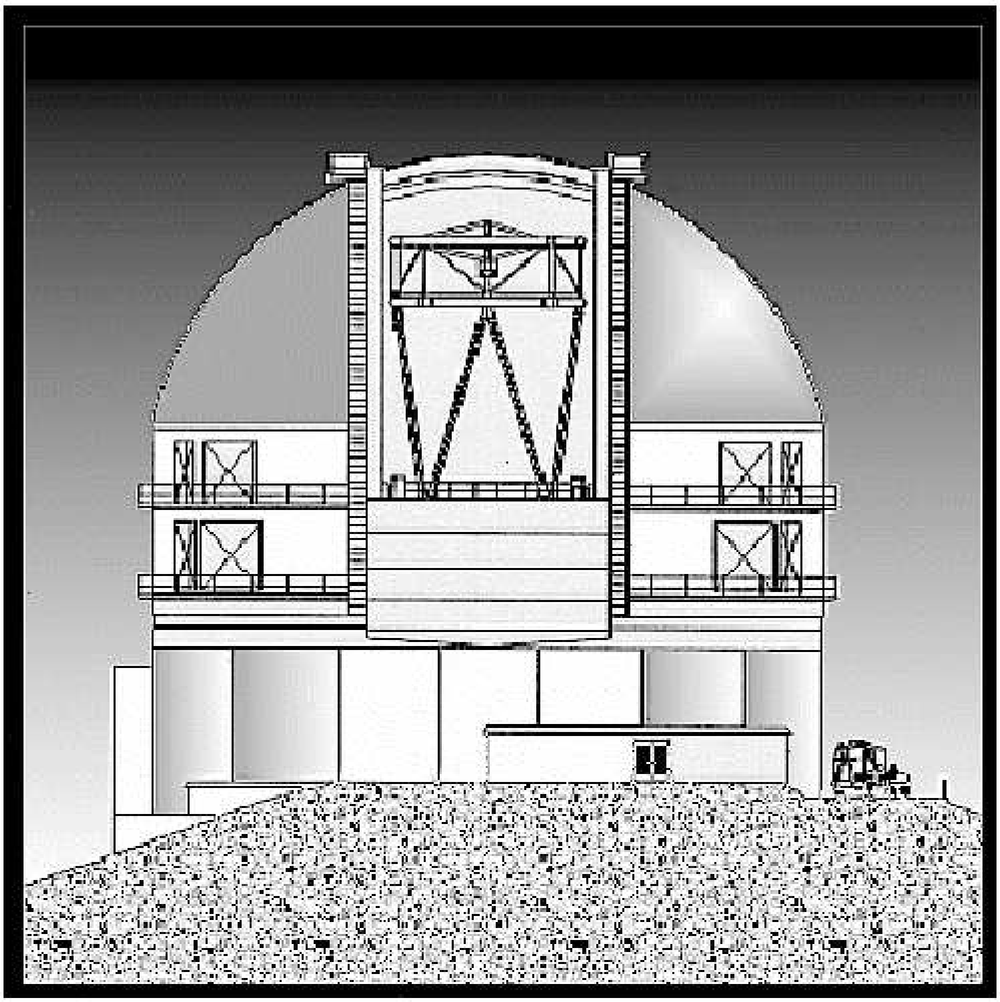
GEMINI
8-M Telescopes
Project

SPE-O-G0006

Specifications for Primary Mirror Polishing



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December 31, 1992

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1. Definitions and Term.

1.1. Conic Constant ("K"). $K = -e^2$, where e equals the eccentricity of any conic section.

1.2. Figuring. "Figuring" is the process whereby the shape of an optical surface is altered by polishing.

1.3. Generating; Generation. "Generating," or "Generation," is the process used for the rapid removal of glass using a high-speed fixed-abrasive tool.

1.4. Null Corrector. A "Null Corrector" is an optical system used in the optical testing of an aspheric surface. It converts a spherical wavefront into one that precisely matches the surface under test

1.5. Paraxial Radius of Curvature. The "Paraxial Radius of Curvature" is the radius of curvature of a region of the Mirror surface immediately surrounding the optical axis.

1.6. Polishing. "Polishing" is the optical fabrication process that puts a highly finished, smooth and apparently amorphous surface on the Mirror.

1.7. Theoretical Telescope Optical System. The term "Theoretical Telescope Optical System" is defined in Section 3.5. below.

2. General Requirements.

2.1. Introduction. This specification details the requirements for the generating, polishing and figuring of the Blanks.

2.2. Configuration. Contractor shall grind and-polish the Blanks, converting them into finished Mirrors, which shall conform in all respects to the requirements specified in Drawing No. 85-GP-2000-0003, Revision A. Such drawing is attached to, and is hereby made a part of, this document.

3. Polished Surface Specifications.

3.1. Definition. The polished surface of the Mirrors is defined as "Surface A" on Drawing No. 85-GP-2000-0003, Revision A.

3.2. Test Regions. Surface A, as defined in Section 3.1, above, is divided into three zones as defined below:

Zone 1: The annular section on Surface **A** having an outer diameter of at least 8080 mm and an inner diameter of 8000 mm.

Zone 2: The annular section on Surface A having an outer diameter of 8000 mm and an inner diameter of 1220 mm.

Zone 3: The annular section on Surface A having an outer diameter of 1220 mm and an inner diameter of no greater than 1190 mm.

3.3. Surface Figure of Revolution.

3.3.1. Equation for the Polished Surface A. Surface A shall be a conic surface of revolution described by the following equation:

$$Z = \frac{Y^2 / R}{1 + \sqrt{1 - (1 + K)(Y / R)^2}}$$

where:

Z = sagitta of the optical surface
R = Paraxial Radius of Curvature
K = conic constant
Y = distance from the optical axis

3.3.2. Conic Constant. The value of the conic constant, K, used in the above equation shall be:

K = -1.00376 ± 0.0005.

3.3.3. Paraxial Radius of Curvature. The Paraxial Radius of Curvature of Surface A shall be:

R = 28,800 ± 30 mm.

3.3.4. Vertex Location and Tilt of Optical Axis. The axis of revolution of Surface A shall be coincident with the geometrical axis of the Mirror, Datum Axis A on Drawing No. 85-GP-2000-0003, Revision A, to within the following tolerances:

(a) Axis Tilt - The axis of revolution of Surface A shall be parallel to the geometrical axis of the Mirror, Datum Axis A, to within 5 arc minutes; and

(b) Vertex Decenter - The vertex of Surface A shall be located on the geometrical axis of the Mirror, Datum Axis A, within a cylindrical tolerance zone of 2 mm diameter.

3.4. Surface Quality.

3.4.1. Surface Roughness. Surface A shall be pitch polished to a 20 A rms or better surface roughness.

3.4.2. Surface Imperfections. Contractor shall use its best efforts to minimize the number of imperfections in Surface A. Within Zone 2 of Surface A no surface imperfections of surface area larger than 1.0 square millimeter shall be allowed, and a maximum of two (2) defects of surface area 1.0 square millimeter or less, including scratches less than or equal to 5 mm in length, are allowed within any 70 mm by 70 mm square area of Surface A. Bubbles present in the Blanks upon their delivery to Contractor are not included in this requirement. Within Zone 2, no more than 5 scratches of length greater than 5 mm are allowed within any 3000 mm by 3000 mm square area of Surface A.

3.5. Theoretical Telescope Optical System. The optical performance of the Mirrors is to be calculated by Contractor as though the Mirror were incorporated into a theoretical optical system as described below and illustrated in Figure 1 (Theoretical Telescope Optical System), attached to and made a part of this Exhibit C. All point spread function and encircled energy calculations required by this Exhibit C shall be based on the Theoretical Telescope Optical System.

3.5.1. Aperture Stop. For purposes of optical performance calculations, the aperture stop of the system shall be 8,000 mm outside diameter and 1220 mm inside diameter, and shall be located 280 mm above the vertex of the Mirror.

3.5.2. Secondary Mirror. (a) The surface of the theoretical secondary mirror is defined by the following radius of curvature and conic constant:

Radius of Curvature = -4193.0685 mm;

Conic Constant = - 1.612898.

(b) The nominal distance between the vertices of the Mirror and secondary mirror shall be 12,539.326 mm; except that such distance can be adjusted slightly by Contractor during computer analysis to maintain the required focal surface position.

3.5.3. Focal Surface Position. The focal surface of the Theoretical Telescope Optical System shall be located 4,000 mm behind the primary Mirror vertex, as illustrated in Figure 1.

3.6. Surface Figure Accuracy - Required Level.

3.6.1. Accuracy for Zone 2. (a) Contractor shall use its best efforts to make Surface A as smooth as possible, free of ripple, zones and local bumps.

(b) The. figure of Surface A within Zone 2 shall be such that the encircled energy concentration of the calculated point spread function of the Theoretical Telescope Optical System, including diffraction effects at a wavelength of 2200 m, meets the following requirements:

Encircled Energy	Maximum Angular Diameter
50%	0.067 arc second
85%	0.207 arc second

(c) The figure of polished Surface A within Zone 2 shall be such that the encircled energy concentration of the calculated point spread function of the Theoretical Telescope Optical

System, including diffraction effects at a wavelength of 550 nm, meets the following requirements:

Encircled Energy	Maximum Angular Diameter
80%	0.10 arc second

(d) The calculation of encircled energy shall take into account the effects of all surface figure errors that significantly affect (as determined by AURA) the encircled energy distribution. therefore, the optical test information which describes the Mirror figure that is used in the encircled energy calculation shall include all spatial frequencies that will significantly affect (as determined by AURA) the calculated results, as discussed further in section 5.1.2, below. Active force adjustments shall be permitted, as provided in Section 4.3, below, in determination of the encircled energy calculation. The detailed aspects of such active force adjustments shall be specified in the Acceptance Test Plan.

(e) Measurement uncertainty in the calculation of encircled energy shall be considered, and shall be included in the calculation of encircled energy, as described in Section 5.2, below.

3.6.2. Accuracy for Zones 1 and 3. The surface figure of the polished surface A shall extend smoothly into Zone I and Zone 3 with no abrupt changes or discontinuities.

3.6.3. Intensity of Satellite Images. If regular patterns of repeating surface features exist in polished Surface A, such features will act as a diffraction grating to preferentially diffract energy from the point spread function into satellite images outside the central core of the point spread function. The maximum intensity of any such satellite image between 0.25 and 2 arc seconds radial distance from the center of the point spread function, at any wavelength between 500 nm and 3000 nm, shall not exceed:

$$I_s \leq I_c r^{-3}(5x10^{-4})$$

where I_s is the intensity of the satellite image, I_c is the central intensity in the point spread function, and r is the radial distance of the satellite image from the center of the point spread function in arc seconds.

3.7. Surface Figure Accuracy - Goal Level.

3.7.1. Application. The requirements set forth in this Section 3.7 shall apply, and shall only apply, in the event that AURA exercises the option, as provided in Section 7.3 of the Contract, to proceed with additional polishing, as provided in such Section 7.3.

3.7.2. Accuracy for Zone 2. (a) To meet the goal level of accuracy, the figure of Surface A within Zone 2 shall be such that the encircled energy concentration of the calculated point spread function of the Theoretical Telescope Optical System, including diffraction effects at a wavelength of 550 nm, meets the following requirements:

Encircled Energy	Maximum Angular Diameter
85%	0.08 arc second

(b) The calculation of encircled energy shall take into account the effects of all surface figure errors that significantly affect (as determined by AURA) the encircled energy distribution. Therefore, the optical test information which describes the Mirror figure that is used in the encircled energy calculation shall include all spatial frequencies that win significantly affect (as determined by AURA) the calculated results, as discussed further in section 5.1.2, below.

(c) Measurement uncertainty in the calculation of encircled energy shall be considered, and shall be included in the calculation of encircled energy, as described in Section 5.2, below.

4. Mirror Support

4.1. Polishing. Contractor shall support the Mirrors during polishing in a manner that prevents the formation of high spatial frequency surface features or defects.

4.2. Testing. (a) The Mirror shall be supported during Plant Inspection testing by the Metrology Mount, the Optional Geometry Metrology Mount, the Air Pressure Support System, and/or the Optional Edge Actuators, as provided in Section 8.2.2 of the Contract.

(b) If the Metrology Mount does not provide support identical to that of the Mirror Cell, as provided in Section 8.2.2.3 of the Contract, any errors produced by such deviation shall be treated as described in Section 5.2, below. Any such deviations shall be approved by AURA. If Contractor can demonstrate that the errors produced by the deviation can be calculated with sufficient accuracy, AURA may permit subtraction of the errors from the interferometry data, and only the uncertainty in the calculations shall be treated as a measurement error.

4.3. Active Force Adjustment (a) The support mechanisms of the Metrology Mount or the Optional Geometry Metrology Mount, as appropriate, may have active force control to remove low order (as mutually determined by AURA and Contractor) aberration terms in Surface A. AURA will provide Contractor with a list of nominal mechanism support forces. During testing, Contractor may change each mechanism support force specified by AURA by up to ± 100 newtons from the nominal forces. Contractor shall determine the optimum force set to correct errors in Surface A. Once the optimum force set is determined, all tests evaluating the figure of Surface A, the Paraxial Radius of Curvature, and the Conic Constant shall be performed by Contractor with such optimum force set. Support mechanism forces shall not vary from the optimum force set by more than ±1 newton during Plant Inspection testing.

(b) If the force sensors incorporated into the Metrology Mount or the Optional Geometry Metrology Mount, as appropriate, do not have sufficient resolution in adjusting the Mirror figure, AURA may permit Contractor to analytically adjust the measured surface figure of the Mirror by adding a calculated theoretical correction to the measured Mirror figure as supported on the Metrology Mount or the Optional Geometry Metrology Mount, as appropriate; provided, however, that the theoretical correcting force at any support location must be within the range of ± 3 newtons.

5. Optical Testing.

5.1. Required Tests.

5.1.1. Full Aperture Interferometry. (a) Contractor shall test the entire Surface A (all zones of Surface A) of the Mirror by interferometry at a wavelength of 632.8 nm using a Null Corrector. The Null Corrector shall be used during such test in the manner specified in the Acceptance Test Plan, and to the extent not inconsistent with the provisions of this Contract, as specified in the Proposal. The projected size of the detector pixels on Surface of A of the Mirror shall be no larger than 35 mm. Contractor shall calculate the point spread function from the surface figure information derived during the interferometric test .

(b) No spatial "smoothing" of the surface map of Surface A (including an zones of Surface A) shall be allowed, other than that provided by averaging of multiple measurements. At least 99.7% of the data points contained within all zones of Surface A shall be included in the calculations. Any data points to be excluded from the map of Surface A, plus data dropouts, shall not exceed 0.3%.

5.1.2. Sub-aperture Interferometry. (a) Contractor shall verify the surface smoothness of the polished Surface A by sub-aperture interferometry, which shall be capable of measuring all surface errors that significantly (as determined by AURA) affect the encircled energy calculation, but were not adequately measured by the full aperture interferometry. The aperture size and resolution of the sub-aperture interferometry shall allow measurement of surface errors having spatial frequencies ranging from the upper limit of frequencies measured by the full aperture interferometry, up to the highest spatial frequency having an amplitude large enough to significantly (as determined by AURA) affect the encircled energy calculation; provided, however, that the projected size of the detector pixels on Surface A of the Mirror shall be no larger than 4 mm.

(b) The size and number of test areas for the sub-aperture interferometry will be chosen by AURA to provide coverage of all radial zones of Surface A, and to provide 100% coverage of Zone 2 of Surface A. Test area locations for each radial zone of Surface A will be specified by AURA at the time of the Pre-final Inspection test by AURA.

5.1.3. Second Test Method. An additional and completely independent test method, not requiring a null corrector, shall be used by Contractor to verify the Paraxial Radius of Curvature and Conic Constant of Surface A. Such test shall provide for Paraxial Radius of Curvature measurements to an accuracy of ± 10 mm, and Conic Constant measurements to an accuracy of ± 0.0005.

5.1.4. Satellite Image Test. Contractor shall develop a test method that is capable of verifying compliance with the requirements of Section 2.6.3. of this document.

5.2. Testing Accuracy. (a) For each test required to verify compliance with this specification, expected errors that might occur because of test equipment inaccuracies, test parameter uncertainty, air refraction and vibration effects during testing, calculation approximations, or other error sources, shall be predicted by Contractor. The predicted errors shall be evaluated by Contractor in terms of relative probability of occurrence, and shall be set at a level such that there shall be a 90% probability that the actual errors will be less than the predicted errors. These predicted errors shall be added to the measured or calculated test values as appropriate, and the combination of the measured or calculated test values, plus the predicted errors, shall meet the requirements of this document.

(b) In evaluating the expected errors, Contractor may remove any errors that can be shown by appropriate calculations to be correctable by the active optics system, provided that the total correction for all removed errors can be accomplished without extending the range of active force magnitude at any one actuator by more than 50 newtons. A summary of the error evaluation for each testing procedure shall be included in the Acceptance Test Plan.

5.3. **Detailed Aspects of Optical Testing.** The detailed aspects of the optical testing, as provided in this Article 5, shall be specified in the Acceptance Test Plan.

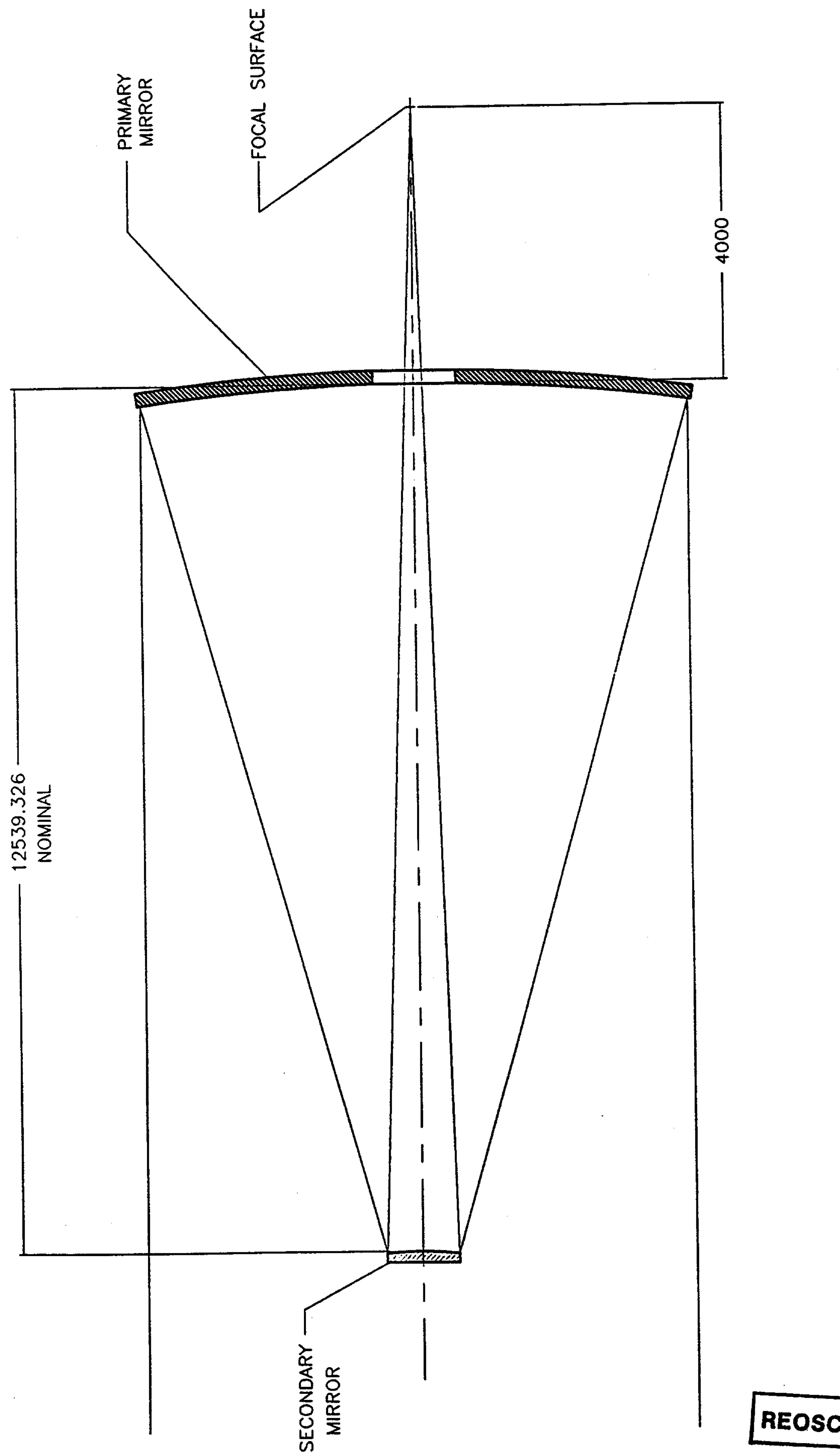
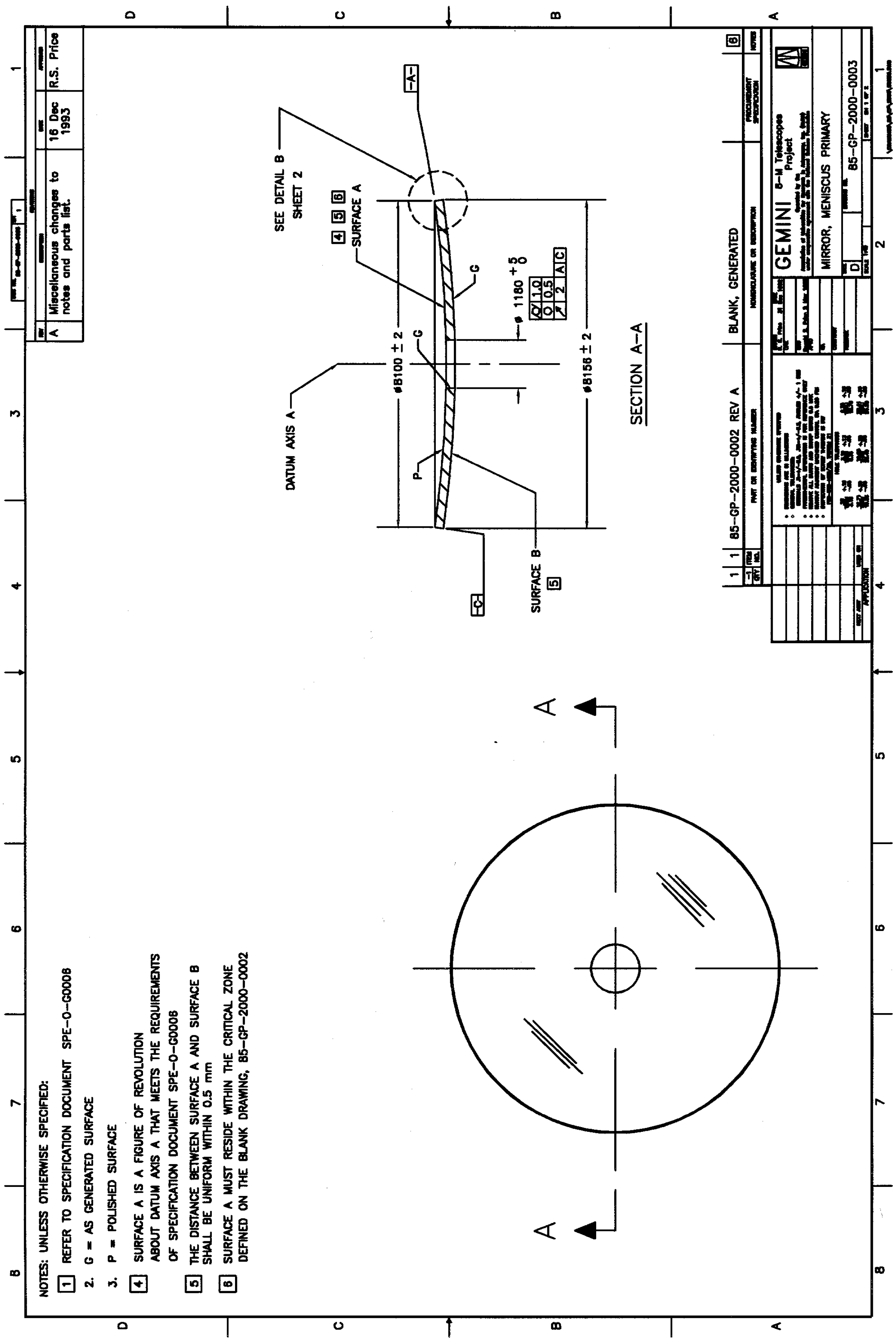
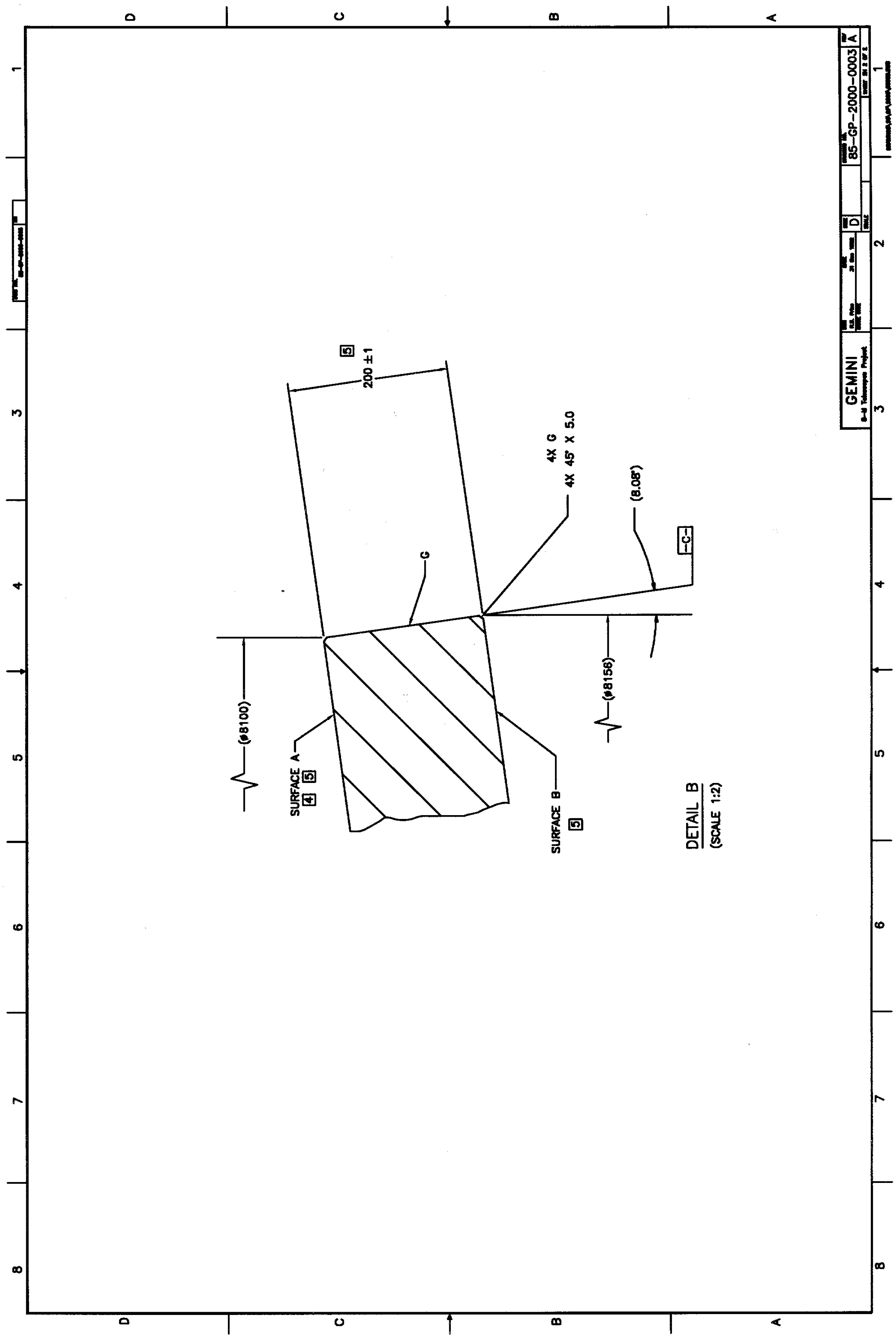


FIGURE 1. THEORETICAL TELESCOPE OPTICAL SYSTEM


NOTES: UNLESS OTHERWISE SPECIFIED:
1 REFER TO SPECIFICATION DOCUMENT SPE-O-G0006
2. G = AS GENERATED SURFACE
3. P = POLISHED SURFACE
4 SURFACE A IS A FIGURE OF REVOLUTION ABOUT DATUM AXIS A THAT MEETS THE REQUIREMENTS OF SPECIFICATION DOCUMENT SPE-O-G0006
5 THE DISTANCE BETWEEN SURFACE A AND SURFACE B SHALL BE UNIFORM WITHIN 0.5 mm
6 SURFACE A MUST RESIDE WITHIN THE CRITICAL ZONE DEFINED ON THE BLANK DRAWING, 85-GP-2000-0002
A
A
SECTION A-A
SEE DETAIL B SHEET 2
4 5 6 SURFACE A
-A-
DATUM AXIS A
P
G
G
ø8100 ± 2
ø8156 ± 2
ø 1180 +5 0
SURFACE B 5
-C-
A Miscellaneous changes to notes and parts list. 16 Dec 1993 R.S. Price
1 1 85-GP-2000-0002 REV A BLANK, GENERATED 6
GEMINI 8-M Telescopes Project
MIRROR, MENISCUS PRIMARY
D 85-GP-2000-0003
2 1


200 ±1
4X G
4X 45° X 5.0
(8.08°)
-C-
G
(ø8100)
(ø8156)
SURFACE A
SURFACE B
DETAIL B
(SCALE 1:2)
GEMINI
85-GP-2000-0003