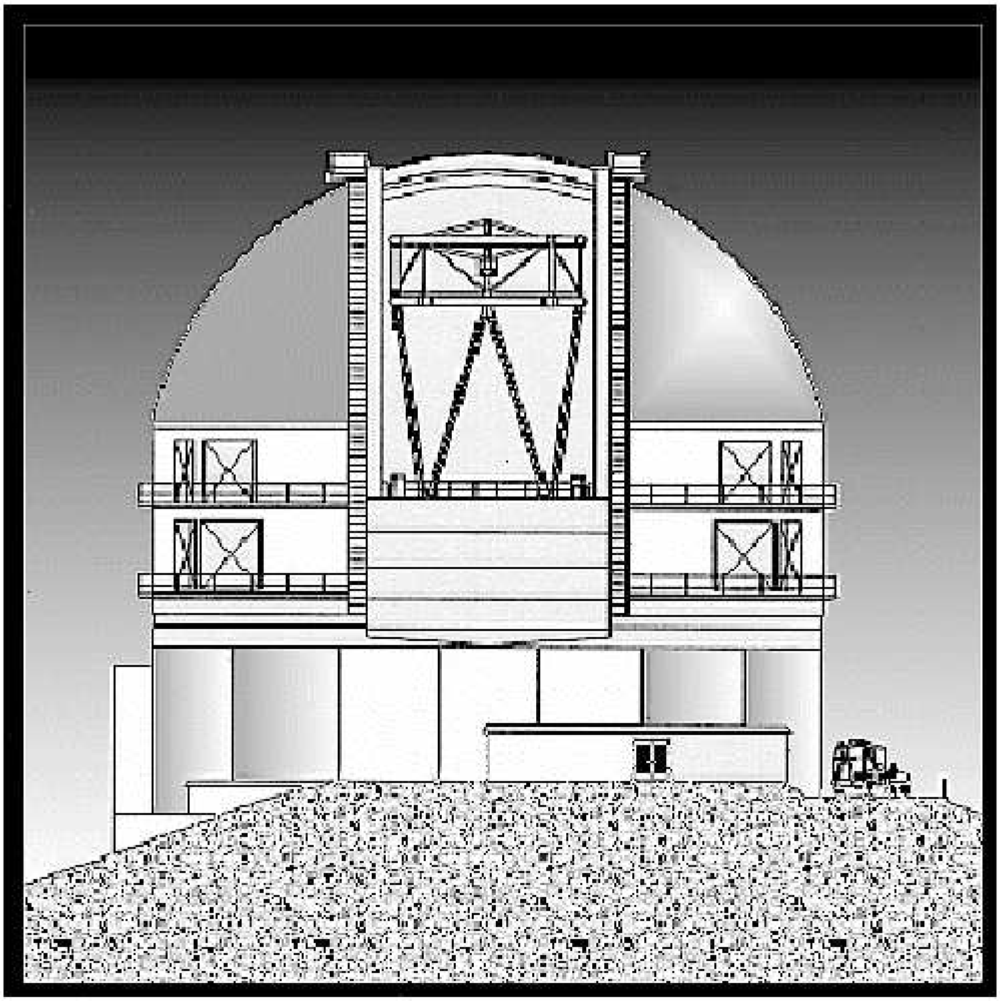
**GEMINI**
**8-M Telescopes Project**

**SPE-O-G0059**

# Functional Requirements for the f/16 Secondary Assembly



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# Section 1
# INTRODUCTION

## 1.1 Introduction

This document contains the functional requirements for the f/16 Secondary Assembly. Only top level requirements for the f/16 Secondary Assembly will be discussed in this document. For information on the subassemblies and subsystems of the f/16 Secondary Assembly see the drawings and design requirements documents for the particular subassembly or subsystem.

## 1.2 Description

The f/16 Secondary Assembly consists of the f/16 Secondary Mirror, the M2 Tilt System, the M2 Positioning System, the M2 Deployable Baffle, the M2 Central Baffle and their associated cabling. The f/16 Secondary Module consists of the f/16 Secondary Mirror, the M2 Tilt Mechanism, the M2 Positioning Mechanism and the M2 Central Baffle. The M2 Deployable Baffle remains on the Telescope Secondary Support Structure when the f/16 Secondary Module is removed for maintenance operations. The f/16 Secondary Mirror is attached to the M2 Tilt Mechanism. The M2 Tilt Mechanism is in turn suspended from the M2 Positioning Mechanism, which is mounted to the M2 Deployable Baffle. The M2 Deployable Baffle serves as the mechanical interface between the f/16 Secondary Module and the Secondary Support Structure of the Telescope top ring.

The M2 Tilt System consists of the M2 Tilt Mechanism, the M2 Tilt Sensor Electronics Module, the M2 Tilt control Electronics Module, a fiber optic link with interface to the Secondary Control System, and associated cabling. The M2 Tilt System is used to tilt and translate the f/16 Secondary Mirror in the focus direction. The M2 Tilt System operates in fast modes and in slow modes. Corrections in f/16 Secondary Mirror Position are continuously input to the M2 Tilt System. The M2 Tilt System changes f/16 Secondary Mirror Position following this input in tilt and focus. The slow mode of operation is determined internally to the M2 Tilt System. Slow actuators are used to reduce bias in the fast actuators. The fast tilt mode is used to tilt the f/16 Secondary Mirror for Chopping, and fast correction for wavefront tilt errors and Telescope vibration oscillations. There is also a fast focus mode. The slow tilt mode may be used for correction of f/16 Secondary Mirror tilt for such causes as telescope temperature gradients or gravity induced tilt. In the slow focus mode, the M2 Tilt System will be used to correct focus for causes such as temperature changes in the Telescope or gravity induced corrections.

The M2 Positioning System consists of the M2 Positioning Mechanism, the M2 Positioning Sensor Electronics Module, the M2 Positioning Drive Amplifier Module and associated cabling. The M2 Tilt Control Electronics Module will perform the local control functions for the M2 Positioning System. The M2 Positioning System is used to translate the f/16 Secondary Mirror in directions perpendicular to the Telescope optical axis. This capability will be used to correct the alignment errors of the f/16 Secondary Mirror for causes such as gravity deflection in the Telescope.

## 1.3 Definitions

The following terms are defined and their usage throughout this document will be consistent with these definitions.

(a) Actuator - An "Actuator" is a device used to produce motion of the f/16 Secondary Mirror.

(b) c.g. - The term "c.g." means center of gravity.

(c) Chopping - "Chopping" is the act of moving the f/16 Secondary Mirror in tilt between field positions in a regular, repeated manner.

(d) Dummy Mirror - The "Dummy Mirror" is a device used to simulate the f/16 Secondary Mirror for testing without the f/16 Secondary Mirror.

(e) f/16 Secondary Mirror - The "f/16 Secondary Mirror" is defined by drawing 85-GP-3200-0004 and design requirements document SPE-0-GO040.

(f) f/16 Secondary Assembly - The "f/16 Secondary Assembly" consists of the f/16 Secondary Mirror, the M2 Tilt System, the M2 Positioning System and the M2 Deployable Baffle.

(g) f/16 Secondary Mirror Mounting Features - The "f/16 Secondary Mirror Mounting Features" are shown on drawing 85-GP-3100-0004. They are the mechanical interface between the f/16 Secondary Mirror and the M2 Tilt Mechanism.

(h) f/16 Secondary Mirror Mounting Hardware - The "f/16 Secondary Mirror Mounting Hardware" are the parts used to mount the f/16 Secondary Mirror to the M2 Tilt Mechanism. The "f/16 Secondary Mirror Mounting Hardware" are part of the f/16 Secondary Mirror.

(i) f/16 Secondary Mirror Position - The "f/16 Secondary Mirror Position" is the combination of the location of the f/16 Secondary Mirror c.g., and tilt of the f/16 Secondary Mirror about its c.g. relative to the M2 Tilt Mechanism Mounting Features.

(j) f/16 Secondary Module - The "f/16 Secondary Module" consists of the f/16 Secondary Mirror, the M2 Tilt Mechanism, the M2 Positioning Mechanism and the M2 Deployable Baffle.

(k) Focus - "Focus" is linear motion of the f/16 Secondary Mirror c.g. in the Z direction. There is no tilt of the f/16 Secondary Mirror associated with focus motion.

(1) Horizon pointing - "Horizon pointing" is defined as the mechanical axes, as defined in section 1.5, below, oriented with the X and Z axes in the horizontal direction and the Y axis oriented vertically up.

(m) Lifting Points - The "Lifting Points", of the M2 Tilt Mechanism, are shown and identified on drawing 85-GP-3100-0004.

(n) M2 Central Baffle - the "M2 Central Baffle" is a baffle used to obscure the central hole through the f/16 Secondary Assembly. It is remotely deployed to one of two positions, either covering and obscuring the central hole through the f/16 Secondary Assembly or moved to a position where it is completely obscured by the f/16 Secondary Mirror.

(o) M2 Deployable Baffle - The "M2 Deployable Baffle" is a baffle that is part of the f/16 Secondary Assembly. The M2 Deployable Baffle may be stowed behind the f/16 Secondary Mirror or remotely deployed to its full extent. Its size, mounting details and interfaces are specified on drawing 85-GP-3300-0001.

(p) M2 Positioning Drive Amplifier Module - The "M2 Positioning Drive Amplifier Module" is a single enclosure containing the electronics of the M2 Positioning System that are not necessary to be in close proximity to the M2 Positioning Mechanism, the M2 Deployable Baffle or the M2 Central Baffle. Its size, location, mounting details and interfaces are specified on drawing 85-GP-3400-0001.

(q) M2 Positioning Mechanism - The "M2 Positioning Mechanism" contains Actuators and Sensors of the M2 Positioning System, and is the structural support for the M2 Tilt Mechanism and the f/16 Secondary Mirror and is used to articulate the f/16 Secondary Mirror and the M2 Tilt Mechanism in directions perpendicular to the Telescope optical axis. Its size, mounting details and interfaces are specified on drawing 85-GP-3400-0001.

(r) M2 Positioning Sensor Electronics Module - The "M2 Positioning Sensor Electronics Module" contains the electronics that must be located in close proximity to the M2 Positioning Mechanism in order for the M2 Positioning System to meet its requirements. Its size, location, mounting details and interfaces are specified on drawing 85-GP-3400-0001.

(s) M2 Positioning System - The "M2 Positioning System" is the system used to translate the f/16 Secondary Mirror and the M2 Tilt Mechanism in directions perpendicular to the Telescope optical axis. It contains the M2 Positioning Mechanism, the M2 Positioning Sensor Electronics Module, the M2 Positioning Control Electronics Module and their associated cabling. The M2 Positioning System envelope is specified on drawing 85-GP-3400-000 1.

(t) M2 Tilt Control Electronics Module - The "M2 Tilt Control Electronics Module" is a single enclosure containing the electronics of the M2 Tilt System that are not necessary to be in close proximity to the M2 Tilt Mechanism. Its size, location, mounting details and interfaces are specified on drawing 85-GP-3100-0004.

(u) M2 Tilt Mechanism - The "M2 Tilt Mechanism" contains the Actuators and Sensors used to produce the required motion of the f/16 Secondary Mirror. It is contained in the envelope specified by drawing 85-GP-3100-0004. The f/16 Secondary Mirror is attached to the M2 Tilt Mechanism with the parts and in the manner specified on drawing 85-GP-3000-0002. The M2 Tilt Mechanism is mounted in the manner specified in section 4.1 below.

(v) M2 Tilt Sensor Electronics Module - The "M2 Tilt Sensor Electronics Module" contains the electronics of the M2 Tilt System that must be located in close proximity to the M2 Tilt Mechanism in order for the M2 Tilt System to meet its requirements. Its size, location, mounting details and interfaces are specified on drawing 85-GP-3100-0004.

(w) M2 Tilt System - The "M2 Tilt System" is the system used to tilt and focus the f/16 Secondary Mirror. It contains the M2 Tilt Mechanism, the M2 Tilt Sensor Electronics Module, M2 Tilt Control Electronics Module, a fiber optic link with interface to the Secondary Control System, and associated cabling. The M2 Tilt System envelope is specified on drawing 85-GP-3100-0004.

(x) Non-repeatability - Use of the term "non-repeatability" in this document is defined as the event being between ±3 standard deviations, six (6) standard deviations total, of a Gaussian frequency distribution. The value stated is the full six (6) standard deviation range.

(y) Safety Stop Mounting Points - The "Safety Stop Mounting Points" are three tapped holes on the M2 Tilt Mechanism used to support the safety stops to contain the f/16 Secondary Mirror in the event the f/16 Secondary Mirror Mounting Hardware fails. They are shown and identified on drawing 85-GP-3100-0004.

(z) Secondary Control System - The "Secondary Control System" is the portion of the Telescope Control System that the M2 Tilt System must interface with electronically.

(aa) Set Position - The "Set Position" is the f/16 Secondary Mirror Position in decenter, tilt and focus set by the slow modes of operation. Fast tilt, focus and Chopping occur about and are relative to the Set Position.

(ab) Telescope - The "Telescope" is the Gemini 8-meter telescope.

(ac) Telescope Control System - The "Telescope Control System" is the electronic control system for the Telescope.

(ad) Zenith pointing - "Zenith pointing" is defined as the mechanical axes, as defined in section 1.5, below, oriented with the X and Y axes in the horizontal direction and the Z axis oriented vertically up.

## 1.4 Applicable Documents

The following documents form a part of this Functional Requirements Document to the extent referenced herein. Any other document referenced in any of these documents also forms a part of this Functional Requirements Document to the extent referenced therein.

### *1.4.1 Drawings*

85-GP-3000-0002, Assembly, Module, F/16 secondary mirror

85-GP-3100-0004, Envelope, Tip-Tilt System, f/16 Secondary Mirror
85-GP-3200-0004, Assembly, f/16 Secondary Mirror
85-GP-3300-0001, Assembly, M2 Deployable Baffle
85-GP-3400-0001, Assembly, M2 Positioning System
90-GP-0003-0001, ICD, f/16 Secondary Mirror Assembly to M2 Tilt System
90-GP-0003-0002, Secondary Mirror Module/Top End Interface
90-GP-0003-0004, ICD, M2 Assembly to Top End Structure

### *1.4.2 Requirements Documents*

SPE-PS-G0001, Gemini Science Requirements
SPE-O-G0039, M2 Tilt System Design Requirements Document
SPE-O-G0040, Secondary Mirror Design Requirements Document
SPE-S-G0041, Gemini System Error Budget Plan
SPE-O-G0057 M2 Positioning System Design Requirements Document
SPE-O-G0058 M2 Deployable Baffle Design Requirements Document

## 1.5 Coordinate Axes

Coordinate axes and directions will be referenced in this document. The coordinate system used is a right-handed Cartesian coordinate system. The Z-axis is the optical axis of the Telescope positive from the primary mirror towards the f/16 Secondary Mirror. The X-axis is parallel to the Telescope elevation axis. The Y-axis forms the third axis of the right-handed Cartesian coordinate system and is pointed vertically up with the Telescope in the horizon pointing orientation.

# Section 2
# SCIENCE REQUIREMENTS

## 2.1 Introduction

The top-level requirements for the Gemini telescopes are contained in document SPE-PS-G0001 *Gemini Science Requirements document.* All functional requirements and tolerances flow down from this document. In this section areas from the *Gemini Science Requirements* document are excerpted that pertain to the functioning and operational requirements for the Telescopes in the f/16 configuration. The requirements appearing here are for the complete Telescopes but have implications for the performance of the f/16 Secondary Mirror Assemblies.

## 2.2 First Order Characteristics

The primary mirrors will have clear apertures 8 meters in diameter with primary focal ratios of f/1.8. The Telescope focal ratio will be f/16. The Cassegrain focal surface will be located 4 meters behind the primary mirror vertex. The Telescopes are of a Ritchey-Chretien design.

The f/16 Secondary Mirror will be the aperture stop for the optical system and provide an unvignetted field of view of 3 arcminute diameter. During Chopping operation the image will be translated up to ±15 arcseconds on the sky, in any direction during which the field of view shall remain unvignetted. The f/16 Secondary Mirror will be sized, inside and outside diameters, such that the 3 arcminute diameter field of view will remain unvignetted at the extremes of Chopping.

In some optical modes of operation a field of view of 6 to 10 arcminutes in diameter will be required.

## 2.3 Image Quality

With any imaging system, image quality is of prime importance. The Gemini Telescopes have very stringent image quality specification requirements. The Telescopes are to deliver image quality of better than 0.1 arcsecond over a 1-arcminute diameter field in the near infrared.

The IR configuration, including tracking and enclosure effects, will produce images at a wavelength of 2.2 µm with 50% of point source energy within 0.1 arcsecond diameter and 85% within 0.25 arcsecond diameter over a 1.0 arcminute diameter field of view and time intervals of up to 3600 seconds with "fast guiding" capability and while pointing near the zenith. The above requirement will be met at the 70 percentile wind speed and image diameters will increase with zenith angle no more than proportional to $\sec^{0.6}(z)$.

At wavelengths other than 2.2µm image quality is stated in terms of goals. They are:

| | diameter, arcsecond | | |
|---|---|---|---|
| wavelength | 0.31 µm | 0.55 µm | 10 µm |
| 50% | 0.13 | 0.12 | 0.33 |

| | | | |
|---|---|---|---|
| 85% | 0.27 | 0.24 | 1.00 |

The primary mirror and the f/16 Secondary Mirrors must have optical quality which allows the tilt-correcting and adaptive optics systems to reach Strehl ratios of 0.5 at a wavelength of 1.6µm and 0.2 at a wavelength of 0.7µm. This particularly requires that the mirrors must be smooth on the spatial scales which cannot be corrected by the primary mirror active optics. A suitable criterion is that the mirror contribution to the wavefront error on all spatial scales must be less than the wavefront error introduced by the atmosphere when the seeing is at the best 10 percentile level. In other words, any 1.0-1.5 meter diameter area of pupil must be of the optical quality required to produce near diffraction limited performance at a wavelength of 0.7µm for an 8 meter diameter aperture, $w_{diff}$=0.02 arcsecond.

### 2.4 Wavelength Coverage and Throughput

Minimum reflectivity values are specified for fresh coatings for the mirrors as a function of wavelength. In addition to the values listed, a usable image is required for wavelengths to 1000µm. The requirements and goals for freshly coated mirrors are

| wavelength band | reflectivity | |
|---|---|---|
| micron | requirement | goal |
| 0.33-0.40 | 0.88 | 0.92 |
| 0.40-0.70 | 0.88 | 0.98 |
| 0.70-1.10 | 0.84 | 0.98 |

Telescope throughput is specified for wavelengths longer than 2.2µm. The throughput is calculated as the fraction of photons transmitted by the IR configuration compared to that transmitted by an 8.00-meter diameter telescope with no obscuration and with perfectly reflecting optical surfaces. The f/16 Secondary Mirror is the aperture stop for the f/16 infrared configuration. This has the effect of reducing the collecting area of the primary mirror to a 7.90-meter diameter. The central hole in the f/16 Secondary Mirror effectively increases the size of the central hole in the primary mirror to a 1.3-meter diameter. The emissivity, ε, requirement is 4% with a goal of 2%. The losses other than those due to the loss of collecting area above may be estimated as being equal to telescope emissivity. With this assumption the throughput of the telescope may be given by

$$Throughput = (1-\varepsilon)\frac{7.90^2 - 1.30^2}{8.00^2} = 0.91 \qquad (0.93\,goal)$$

This requirement is with fresh coatings on the primary and f/16 Secondary Mirrors. The maximum allowable degradation during operation is 0.5%. This has implications not only for mirror coating, but also for cleanliness of mirror optical surfaces. Nothing within the instruments' field of view shall cause the Telescopes to fail this requirement.

## 2.5 f/16 Secondary Mirror Articulation

The f/16 Secondary Mirror will be articulated for Chopping and rapid image motion compensation. It will also be articulated in slow modes to compensate for other movements of the Telescope.

The IR configuration will incorporate "fast guiding" consistent with the imaging performance, including differential refraction. The IR configuration win have acquisition capability adequate to identify the science target and place it on a spectrograph slit with a precision of 0.05 arcsecond or less. The instrument and/or the facility may provide this capability. The facility will be capable of offsetting over the infrared science field of view, using a guide star, with an error not to exceed 0.05 arcsecond. The Telescope will be capable of blind offsetting at least 10 arcminutes with an accuracy of at least 0.1 arcsecond rms under median wind conditions.

The f/16 Secondary Mirror Assembly will be capable of two axis square wave Chopping. The f/16 Secondary Mirror Assembly will be capable of Chopping between two points on the sky 15 arcsecond apart with an 80% viewing duty cycle at 10 Hz. It will be capable of Chopping between two points on the sky 30 arcsecond apart at a frequency of 5 Hz with an 80% viewing duty cycle. The image quality during the viewing cycle will be 50% of the energy within a circle 0.4 arcsecond in diameter for a wavelength of 10μm. These Chopping requirements should be considered as goals for the f/16 Secondary Mirror articulation systems, with the option of lowering the Chopping frequency requirements from 5 Hz to 3 Hz and from 10 Hz to 6 Hz if a substantial savings in cost and/or complexity could be obtained. A chopping amplitude of up to 15 arcsecond total on the sky is a requirement.

The f/16 Secondary Mirror Assembly will be capable of two axis tilting for image motion compensation. The intent is to remove the dynamic image motion due to wind buffeting and enclosure vibrations as well as to reduce the tilt power in the incoming wavefront by at least 90% rendering this component of the "seeing" to negligible levels compared to higher orders. This may require motions in the focal plane of ±1 arcsecond with a 3 dB bandwidth of 8 Hz. The goal is to reduce tilt-error to a negligible level for fifth order correction, requiring an estimated response bandwidth of 25 Hz. The f/16 Secondary Mirror Assembly will be capable of simultaneous Chopping and image motion compensation so that during the Chopping dwell time the residual image motion from wind buffeting and dome vibrations as well as the tilt power in the incoming wavefront are consistent with the 10μm image quality requirement.

The initial scientific requirement for the Gemini Telescopes is for low order adaptive optics system to be capable of delivering Strehl ratios greater than 0.5 at a wavelength of 1.6μm in median seeing conditions and greater than 0.2 at a wavelength of 0.7 pm for the best 10% of conditions using only natural guide stars.

## 2.6 Reliability and Maintainability

The Telescopes' useful lifetimes are likely to exceed fifty years.

Routine maintenance shall cause minimal loss of observing time. Routine maintenance, including mirror cleaning, shall be accomplished during the daytime. Overall downtime for the entire Telescope shall not cause the loss of more than 2% of the scheduled observing time. The goal for downtime is 1 % or less.

## 2.7 Other Considerations

In addition to the requirements already stated, there are other requirements for the Telescopes that the f/16 Secondary Mirror Assembly must accommodate. The Telescopes must meet their performance requirements over a range of environmental conditions present on both sites.

The tracking requirement is specified for the complete Telescope:

| condition | requirement |
|---|---|
| openloop | consistent with pointing performance, stability sufficient for acquisition of guide star |
| closed loop | 0.1 arcsecond rms in 10 minutes, 0.25 arcsecond rms in 1 hour |
| goal | 0.02 arcsecond rms in 10 minutes, 0.05 arcsecond rms in 1 hour |
| with image motion compensation | 0.01 arcsecond rms for 3600 seconds |

After slewing the Telescope, the Telescopes shall produce an image meeting the image quality requirements within a specified period of time. The total time for slewing the Telescope and settling of all systems are:

| condition | time to traverse and meet image quality specification |
|---|---|
| offsets or IR nods up to 5 arcseconds or less | 1 second |
| offsets up to 1 arcminute | 5 seconds |
| traverse up to 10 degrees | 30 seconds |
| traverse between any two allowed positions | 300 seconds |

System information pertinent to the scientific observations shall be recorded as part of the scientific data.

The f/16 Secondary Mirror Assembly will contain a remotely deployable stray light baffle. The M2 Deployable Baffle shall deploy within 5 minutes time.

The f/16 Secondary Mirror Assemblies for both sites shall be physically and functionally interchangeable. They shall be identical to the extent possible.

# Section 3
# ERROR BUDGET

## 3.1 Introduction

The error budget for the complete Telescopes is contained in the document *Gemini System Error Budget Plan.* This section repeats the requirements that apply to the f/16 Secondary Assembly. The error budget, as it applies to the f/16 Secondary Assembly, is divided into static image quality, dynamic image quality, image smear, and tracking and pointing. There is also a separate image quality error budget that applies when the f/16 Secondary Mirror Assembly is operated in the Chopping mode. In this case the error budget is given for a wavelength of 10µm, and, in some instances, will be treated separately. The error budget is constructed such that the effects of the errors add in quadrature.

## 3.2 Static Image Quality

Encircled energy is used as the criteria for image quality. Diffraction based calculations are used whenever possible. The Telescope optical system was optimized over the full field of view. In the process, some sacrifice in the on-axis image quality was made to produce acceptable image quality elsewhere. As a result, any error that produces a small shift in field position will not give an accurate evaluation of the change in image quality when using the diffraction based calculations. In these cases, geometric encircled energy is used. Table 3-1 contains the diffraction-based values for diameters for encircled energy for the nominal Telescope. The values in the Table are for the on-axis field position of the nominal Telescope.

**Table 3-1: Encircled Energy for the Nominal Telescope**

| diameters for encircled energy, arcsecond | | | |
|---|---|---|---|
| 2.2µm | | 0.55µm | 10µm |
| 50% | 85% | 85% | 50% |
| 0.065 | 0.197 | 0.049 | 0.296* |

*nominal, on-axis image quality, see text

The entry for a wavelength of 10µm is for the on-axis image. The on-axis image, when moved fifteen arcseconds off-axis during Chopping, becomes 0.319-arcsecond diameter for fifty percent encircled energy. The image quality degradation for a quadrature subtraction is 0.119 arcsecond on diameter. For an image initially fifteen arcseconds off-axis, the diameter encircling fifty percent of the energy is 0.296 arcsecond. When this image is brought to the on-axis position by tilting the f/16 Secondary mirror about its center of gravity the diameter encircling fifty percent of the energy goes to 0.319 arcsecond.

The static image quality requirements are given for two categories that effect the design of the f/16 Secondary Assembly. The first is surface errors of the f/16 Secondary Mirror. The second category is for static optical alignment.

### *3.2.1 f/16 Secondary Mirror Surface Quality*

The surface quality requirement for the f/16 Secondary Mirror is given in terms of image degradation. The image degradation is specified by allowable increases in encircled energy diameters. Requirements are given for three wavelengths, 2.2µm, 0.55µm and 10µm. The requirements are summarized in Table 3-2.

**Table 3-2: Requirements for f/16 Secondary Mirror Surface Quality**

| | image degradation, encircled energy, diameter arcsecond | | | |
|---|---|---|---|---|
| wavelength | 2.2µm | | 0.55µm | 10µm |
| percentage | 50% | 85% | 85% | 50% |
| polishing residuals | 0.015 | 0.067 | 0.110 | 0.015 |
| support residuals | 0.010 | 0.022 | 0.033 | 0.030 |
| thermal distortion | 0.005 | 0.009 | 0.013 | 0.005 |
| wind buffeting | 0.010 | 0.018 | 0.020 | 0.010 |
| coating thickness | 0.003 | 0.005 | 0.010 | 0.003 |
| total, rss | 0.021 | 0.074 | 0.118 | 0.035 |

### *3.2.2 Static Optical Alignment*

The three categories of static optical alignment are decenter, tilt and defocus. The tilt of the f/16 Secondary Mirror is about its center of gravity. The allowance for each case is summarized in Table 3-3.

**Table 3-3: Error Budget for Static Optical Alignment**

| | image degradation, encircled energy, diameter arcsecond | | | |
|---|---|---|---|---|
| wavelength | 2.2µm | | 0.55µm | 10µm |
| percentage | 50% | 85% | 85% | 50% |
| f/16 Secondary Mirror decenter | 0.010 | 0.020 | 0.020 | 0.010 |
| f/16 Secondary Mirror tilt | 0.010 | 0.020 | 0.20 | 0.010 |
| f/16 Secondary Mirror defocus | 0.010 | 0.020 | 0.029 | 0.010 |
| total, rss | 0.017 | 0.035 | 0.041 | 0.017 |

The mechanical alignment tolerances that result from these allowances are tabulated in Table 3-4.

**Table 3-4: Mechanical Tolerances for Static Optical Alignment**

| | mechanical tolerances for static alignment | | | |
|---|---|---|---|---|
| wavelength | 2.2µm | | 0.55µm | 10µm |
| percentage | 50% | 85% | 85% | 50% |
| f/16 Secondary Mirror decenter, ±pm | 35.3 | 33.8 | 36.1 | 20.7 |
| f/16 Secondary Mirror tilt, ±arcsecond | 3.64 | 3.73 | 4.32 | 2.51 |
| f/16 Secondary Mirror defocus, µm total | 7.76 | 5.48 | 7.39 | 8.18 |

These values represent alignment of the Telescope. Initial alignment will be for 0°C and for zenith pointing. Corrections for any deviation from these conditions will be made by translating and tilting the f/16 Secondary Mirror.

## 3.3 Dynamic Alignment Errors

This class of errors applies to image quality degradation during operation of the Telescope with all articulation systems operating. The error budget is organized along chopping and non-chopping operations.

### *3.3.1 Chopping Operation*

The image degradation allowances during chopping operation are summarized in Table 3-5. They apply to fifty percent encircled energy for a wavelength of 10µm.

**Table 3-5: Dynamic Alignment Error Budget**

| | image degradation, 50% encircled energy, diameter arcsecond |
|---|---|
| wavelength | 10µm |
| percentage | 50% |
| pointing | 0.040 |
| primary/f/16 Secondary Mirror decenter | 0.040 |
| primary/f/16 Secondary Mirror tilt | 0.150 |
| primary/f/16 Secondary Mirror defocus | 0.040 |
| total, rss | 0.165 |

The optical alignments that produce the image degradations of Table 3-5 are summarized in Table 3-6.

**Table 3-6: Mechanical Tolerances for Dynamic Alignment Errors**

| | optical alignment | f/16 Secondary Mirror tilt* arcsecond |
|---|---|---|
| pointing | ±2.453 arcsecond | ±9.763 |
| primary/f/16 Secondary Mirror decenter | ±148µm | ±7.34 |
| primary/f/16 Secondary Mirror tilt | ±22.9 arcsecond | --- |
| primary/f/16 Secondary Mirror defocus | 32.7µm total | --- |

*f/16 Secondary Mirror tilted about its center of gravity to recenter image

### *3.3.2 Non-Chopping Operations*

The image quality degradation allowances for operations other than Chopping are summarized in Table 3-7.

| **Table 3-7: Dynamic Alignment Error Budget Allowances** | | | |
|---|---|---|---|
| | image degradation, encircled energy, diameter, arcsecond | | |
| wavelength | 2.2μm | | 0.55μm |
| percentage | 50% | 85% | 85% |
| tilt correction errors | 0.012 | 0.021 | --- |
| primary/f/16 Secondary Mirror defocus | 0.010 | 0.018 | 0.018 |
| pointing | --- | --- | 0.021 |
| total, rss | 0.016 | 0.028 | 0.028 |

The tilt correction errors are not items specific to the f/16 Secondary Assembly, but, rather, apply to the operation of the Telescope as a system. The misalignments of the f/16 Secondary mirror that produce these image degradations are summarized in Table 3-8.

| **Table 3-8: Mechanical Tolerances for Non-Chopping Dynamic Alignment** | | | |
|---|---|---|---|
| | mechanical tolerance | | |
| wavelength | 2.2μm | | 0.5μm |
| percent energy | 50% | 85% | 85% |
| primary/f/16 Secondary Mirror defocus | 7.76μm total | 4.93μm total | 4.63μm total |
| pointing | --- | --- | ±1.110 arcsecond |

If the f/16 Secondary Mirror is decentered, the image would shift on the detector. The f/16 Secondary Mirror will be tilted to bring the image back to the same point on the detector.

The entry in Table 3-9 is the maximum decenter that may be corrected with f/16 Secondary Mirror tilt before the image quality allowance is exceeded.

| **Table 3-9: Primary/f/16 Secondary Mirror Dynamic Alignment Decenter** | | | |
|---|---|---|---|
| wavelength (μm) | 0.55 | 2.2 | |
| encircled energy | 85% | 50% | 85% |
| image degradation, increase in diameter, arcsecond | 0.01 | 0.01 | 0.01 |
| primary/f/16 Secondary Mirror decenter, gm | ±34.61 | ±22.48 | ±19.63 |
| f/16 Secondary Mirror tilt to compensate, arcsecond | ±1.72 | ±1.12 | ±0.97 |

## 3.4 Image Smear

Image smear is the result of motion of the image, and of any time varying change in image size or quality, over the integration time of the detector. Motion of the image will "smear" the energy over an area larger than the instantaneous image itself and result in an effectively larger image. Motion of the image is the result of f/16 Secondary Mirror motion in tilt and decenter. Motion of the f/16 Secondary Mirror in focus will cause the size of the image to vary during the integration time. This motion may be caused by mechanical oscillations of the f/16 Secondary Mirror or by mechanical non-repeatability of f/16 Secondary Mirror Position when articulated in the fast modes of operation. The error budget, however, makes no distinction between oscillations and non-repeatability, nor into the various other causes of image smear, such as time-varying deformation of the f/16 Secondary Mirror optical surface as the result of forces applied to the f/16 Secondary Mirror for articulation A discussion of the image degradation, or smearing, that results from mechanical oscillation and non-repeatability of the f/16 Secondary Mirror appears in Appendix A. Appendix A also discusses some of the causes of mechanical oscillations. The error budget is divided into allowances while operating in the Chopping mode (10µm wavelength) and for operation in all other modes (0.55 and 2.2µm wavelengths).

### *3.4.1 Chopping Operation*

The error budget specifies image degradation allowances for Chopping operation as the increase in the diameter encircling 50% of the energy at a wavelength of 10µm. The image smear allowances for Chopping operation are summarized in Table 3-10. The entries in Table 3-10 are for motion of the f/16 Secondary Mirror over the integration time of the detector.

**Table 3-10: Image Smear Allowances, Chopping Operation**

| | image degradation, diameter, arcsecond, 10µm wavelength, 50% encircled energy |
|---|---|
| residual top end tilt | 0.100 |
| residual articulation systems tilt | 0.050 |
| residual f/16 Secondary Mirror tilt | 0.050 |
| other | 0.047 |
| total, rss | 0.131 |
| wind shake | 0.140 |
| measurement error | 0.003 |
| total of all, rss | 0.192 |

The residual top end oscillation in tilt is due to the reaction forces and moments that are not completely canceled by the M2 Tilt System while operating in the Chopping mode. Maximum values for moment, axial force and lateral force have been developed. They are 0.5 N-m peak moment, 1.5 N peak axial force and 0.10 N peak in the lateral direction. The predicted image degradations due to these forces and moments from the M2 Tilt System are summarized in Table 3-11. Details of the calculation of image quality degradation due to these forces and moments from the M2 Tilt System are contained in appendix A.

**Table 3-11: Image Degradation Due to M2 Tilt System Unbalance**

| source | image degradation, 50% encircled energy diameter increase, arcsecond |
|---|---|
| Telescope top ring structural response | 0.042 |
| articulation systems structural response | 0.004 |
| total, rss | 0.044 |

In addition to the oscillations of the M2 Positioning Mechanism and the Telescope Top Ring due to the dynamic output of the M2 Tilt System, the f/16 Secondary Mirror is allowed motion on the M2 Tilt Mechanism. The total motion allowed is

| | |
|---|---|
| tilt | 0.100 arcsecond total |
| decenter | 2.000μm total |
| focus | 10μm total |

This motion may include, without limitation, harmonic oscillation and non-repeatability. The effects of mechanical oscillation and non-repeatability are discussed in Appendix A.

### *3.4.2 Other Operations*

The error budget specifies image degradation allowances for any combination of modes of operation other than Chopping as increases in the diameters encircling 50% and 85% of the energy for a wavelength of 2.2μm and in the diameter encircling 85% of the energy for a wavelength of 0.55μm. The image smear allowances for operations other than Chopping are summarized in Table 3-12. The entries in Table 3-12 are for motion of the f/16 Secondary Mirror over the integration time of the detector.

**Table 3-12: Image Smear Allowances, Non-Chopping Operation**

| | image degradation, diameter, arcsecond | | |
|---|---|---|---|
| wavelength | 2.2μm | | 0.55μm |
| percent energy | 50% | 85% | 85% |
| wind shake | 0.043 | 0.043 | 0.043 |
| measurement error | 0.003 | 0.003 | 0.003 |
| other errors | 0.011 | 0.011 | 0.011 |
| total, rss | 0.044 | 0.044 | 0.044 |

The residual top end oscillation in tilt is due to the reaction forces and moments not completely canceled by the M2 Tilt System while operating in any combination of modes other than Chopping. Maximum values for axial force, lateral force and moment are limited to 0.1 N-m moment, 0.3 N peak axial force and 0.1 N peak lateral force while operating in any combination of modes other than Chopping. The predicted image degradations due to these forces and moments from the M2 Tilt System are summarized in Table 3-13. Details of the calculation of image quality degradations due to these inputs are contained in appendix A.

**Table 3-13: Image Degradation Due to M2 Tilt System Unbalance**

| | image degradation, diameter, arcsecond | | |
|---|---|---|---|
| wavelength | 2.2μm | | 0.55μm |
| percent energy | 50% | 85% | 85% |
| telescope top rms structural response | 0.017 | 0.018 | 0.024 |
| articulation systems structural response | 0.004 | 0.005 | 0.006 |

| | | | |
|---|---|---|---|
| total, rss | 0.017 | 0.019 | 0.024 |

In addition to the oscillations of the M2 Positioning Mechanism and the Telescope Top Ring, the f/16 Secondary Mirror is allowed motion on the M2 Tilt Mechanism. The total motion allowed is

| | |
|---|---|
| tilt | 0.025 arcsecond total |
| decenter | 0.30µm total |
| focus | 2.00µm total |

This motion may include, without limitation, harmonic oscillation and non-repeatability. Effects of mechanical oscillation and non-repeatability are discussed in Appendix A.

# Section 4
# OVERALL REQUIREMENTS

## 4.1 Introduction

This section summarizes the requirements the f/16 Secondary Assembly must meet. The requirements are the flow down of the requirements of section 2. The requirements of this section are consistent with the *Gemini System Error Budget Plan*, reference section 3. Other requirements follow from other considerations.

## 4.2 Physical Requirements

The requirements of this paragraph are necessary for the Telescope to meet its performance requirements.

### *4.2.1 Physical Envelope*

The f/16 Secondary Mirror is the aperture stop for the Telescope optical system. In the infrared mode of operation, none of the subassemblies or subsystems of the f/16 Secondary Module, other than the f/16 Secondary Mirror or M2 Deployable Baffle, when deployed, may be in the instrument field of view.

### *4.2.2 Mass Properties*

The f/16 Secondary Assembly is installed on the Telescope Top Ring. Part of the f/16 Secondary Assembly is installed on the outer ring of the Telescope Top Ring and the rest installed on the Secondary Support Structure of the Telescope Top Ring. The Secondary Support Structure supports the f/16 Secondary Module, the intermediate plate, the M2 Tilt Sensor Electronics Module and the M2 Positioning Sensor Electronics Module. The f/16 Secondary Module mass allocation is 450 kg. While there presently is no mass allocation for the other parts of the f/16 Secondary Assembly, their masses should be kept as low as possible, consistent with meeting their requirements. The masses of the f/16 Secondary Assembly components are summarized in Table 4-1.

**Table 4-1: f/16 Secondary Assembly Mass Estimate**

| item | mass, kg | | |
|---|---|---|---|
| | outer ring | inner ring | |
| | | f/16 Secondary Module | other |
| f/16 Secondary Mirror | | 45[1] | |
| M2 Tilt Mechanism | | 100[1] | |
| M2 Tilt Sensor Electronics Module | | | 30[1] |
| M2 Tilt Control Electronics Module | TBD | | |
| M2 Positioning Mechanism | | 200[2] | |
| M2 Positioning Sensor Electronics Module | | | 30[2] |
| M2 Positioning Drive Amplifier Module | 27[2] | | |
| M2 Deployable Baffle | | 74[2] | |
| total | TBD | 419 | 60 |

[1]controlled by Design Requirements Document
[2]estimate

### *4.2.3 Power Dissipation*

The maximum power dissipated to the atmosphere from the f/16 Secondary Assembly shall be 170 watts rms while operating the M2 Tilt System in Chopping and 120 watts rms for other operations. The total heat transmitted from the f/16 Secondary Assembly to the f/16 Secondary Mirror by a combination of conduction and radiation shall not exceed 5 watts rms. AD heat sources that may be removed from the area immediately behind the f/16 Secondary Mirror without adversely impacting the performance of the f/16 Secondary Assembly shall be placed on the outer ring of the Telescope Top Ring. Active cooling will be available on the outer ring of the Telescope Top Ring in the form of coolant of a water/ethylene glycol mixture at ambient temperature and flow rate of 4 liter/minute.

## 4.3 Functional Requirements, f/16 Secondary Mirror Articulation

The M2 Tilt System and the M2 Positioning System articulate the f/16 Secondary Mirror in five degrees of freedom, two in tilt and three in translation. Rotation about the Telescope optical axis is fixed. The M2 Positioning System translates the f/16 Secondary Mirror and the M2 Tilt Mechanism in directions normal to the Telescope optical axis (lateral axes). The M2 Tilt System translates the f/16 Secondary Mirror along the Telescope optical axis (focus) and tilts the f/16 Secondary Mirror about the lateral axes.

### *4.3.1 Tilt*

The f/16 Secondary Mirror will be tilted about the two lateral axes in fast and slow modes. The slow mode will maintain f/16 Secondary Mirror alignment in tilt for slowly varying events, such as changing gravity orientation and temperature gradients in the Telescope structure and f/16

Secondary Module. There will also be a component of tilt error in the initial alignment of the Telescope and a component of tilt error due to non-repeatabilities when the f/16 Secondary Module is removed from the Telescope, disassembled into its major components, re-assembled and re-installed on the Telescope, and when the Telescope Top Ring is removed and re-installed, that will be taken out in this mode of operation. The fast modes will be used for Chopping, wavefront tilt correction and correction for Telescope structural vibration.

#### 4.3.1.1 Slow Tilt

Tilt in the slow mode is used to set the Set Position of the f/16 Secondary Mirror. The M2 Tilt System will be used for articulation in the slow tilt mode. Appendix B details sources of slow tilt corrections required. Appendix B determines a required range of tilt in the slow mode of 1903 arcsecond total. There will be additional errors that are not yet determined. The total slow tilt range will be increased to 2° total to accommodate these undetermined errors.

#### 4.3.1.2 Fast Tilt

Fast tilt will be used for Chopping and for fast guiding/wavefront tilt correction. The requirements for each mode are sufficiently different that they will be dealt with separately.

##### 4.3.1.2.1 Chopping

Articulation of the f/16 Secondary Mirror for Chopping shall be between two or three tilt positions centered on the Set Position. The movement will be in a regular, repeated pattern. The motion shall be oscillatory in form. The total viewing duty cycle shall be 80% of the total cycle period for two or three point Chopping.

The f/16 Secondary Mirror Position waveform for two point Chopping is shown in figure 4-1. The maximum amplitude at frequency is given in figure 4-2. The maximum range to a frequency of 5 Hz is 132 arcseconds total. The maximum range decreases linearly to 60 arcseconds total at 10 Hz. These values should be treated as the goal. The area marked "mandatory requirement" is the minimum amplitude versus frequency range that is acceptable. The M2 Tilt System shall meet all performance requirements when operated within this envelope of amplitudes and frequencies, and when subjected to the performance environment of section 4.5.2, below.

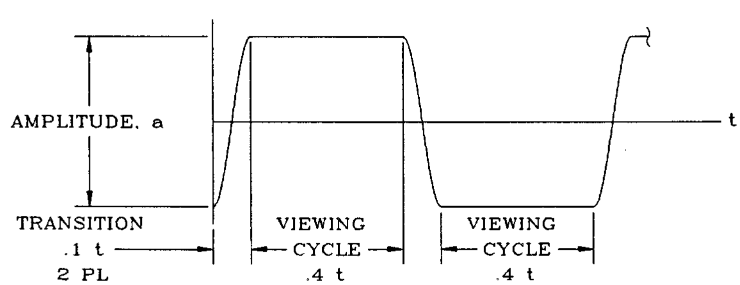

Figure 4- 1: Typical Chopping Motion Waveform

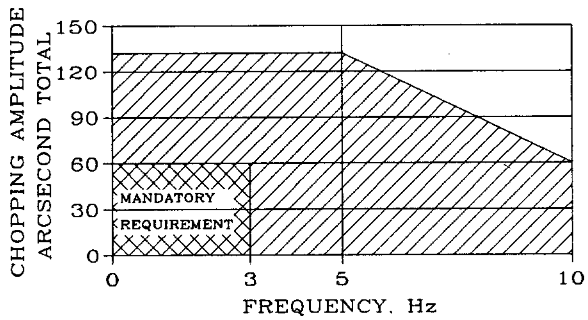


Figure 4-2: Maximum Chopping Amplitude and Frequency for Two Point Chopping

Tilt amplitudes are of the f/16 Secondary Mirror about its cg. A tilt of the f/16 Secondary Mirror of 1 arcsecond results in a displacement of the chief ray of 0.253395 arcseconds in the image surface. The centroid of the image is displaced a slightly lesser amount due to the aberrations induced and is dependent on wavelength.

The f/16 Secondary Mirror Position waveform for three point Chopping is shown in figure 4-3. The three points will be in line. The maximum range at frequency, where frequency is defined as in figure 4-3, is given in figure 4-4. The maximum range to a frequency of 2.5 Hz is 132 arcsecond total. The maximum range decreases linearly to 66 arcsecond total at 5 Hz. The M2 Tilt System shall meet all performance requirements when operated within this envelope of amplitudes and frequencies, and when subjected to the performance environment of section 4.5.2, below.

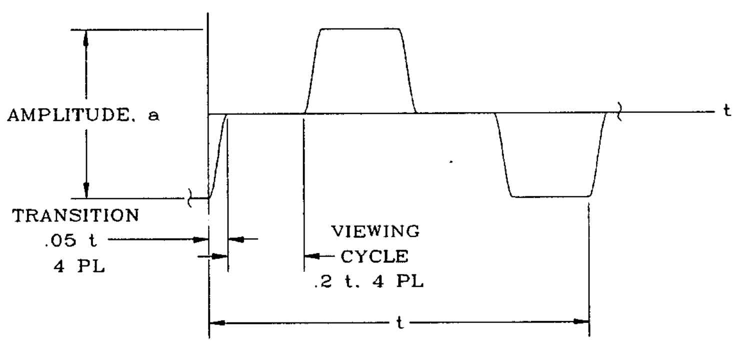


Figure 4-3: Three Point Chopping Waveform

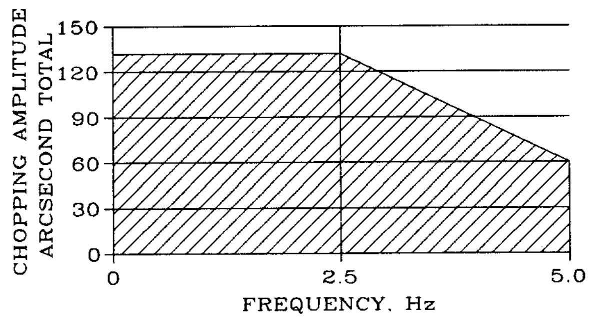


Figure 4-4: Maximum Chopping Amplitude and Frequency for Three Point Chopping

Chopping may also be performed using a saw tooth waveform. For a saw tooth Chopping waveform, the viewing duty cycle is 90%. The f/16 Secondary Mirror Position waveform is shown in figure 4-5. Amplitude a may be up to 40 arcsecond with frequencies up to 0.05 Hz.

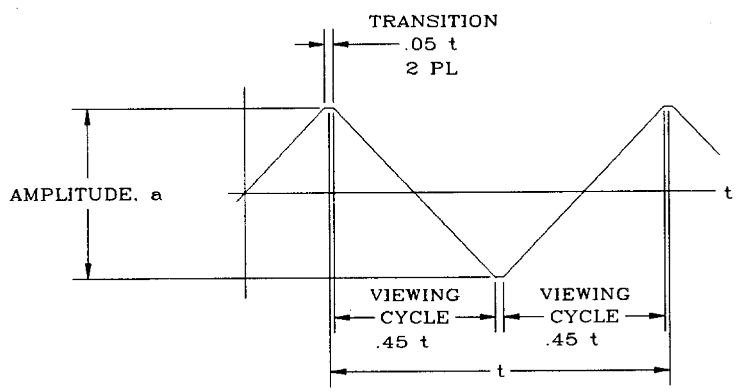


Figure 4-5: Mirror Position for Saw Tooth Chopping

### 4.3.1.2.2 Fast Guiding/Wavefront Tilt Correction

Wavefront tilt correction is used to correct for tilt in the incoming wavefront and for structural vibration of the Telescope structure and the f/16 Secondary Assembly articulation systems. The power spectral density (PSD) input to the M2 Tilt System is shown in figure 4-6. The sample rate may be to a frequency of 200 Hz. The M2 Tilt System must follow this input with a maximum RMS residual of 0.22 arcsecond tilt motion.

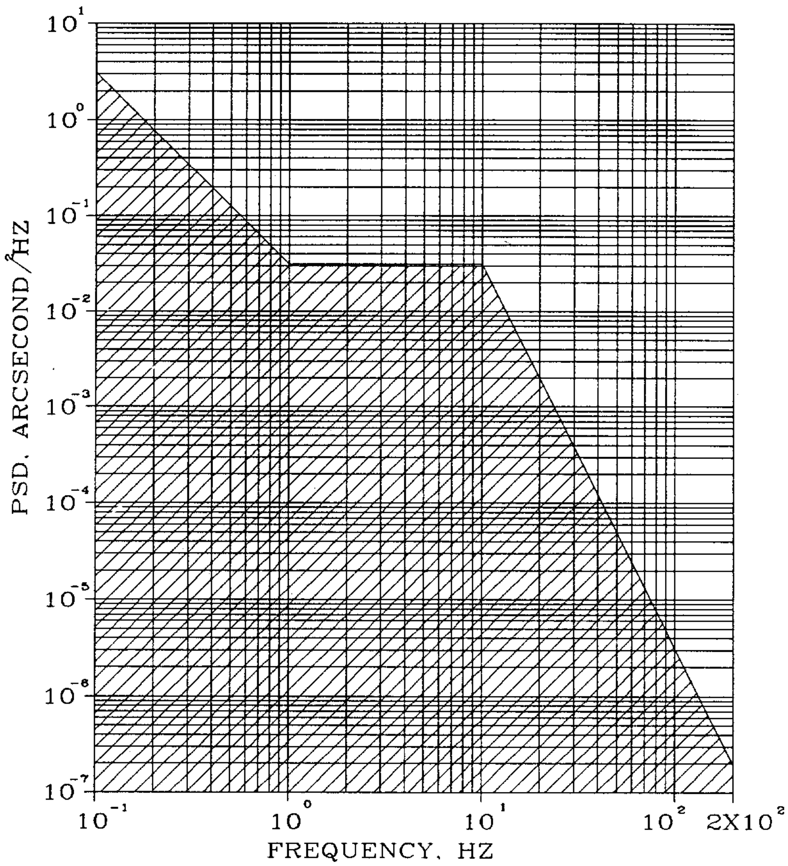


Figure 4-6: Fast Guiding and Wavefront Tilt Correction PSD

### *4.3.2 Translation*

The f/16 Secondary Mirror will be translated in three orthogonal directions. The f/16 Secondary Mirror will be translated in the axial, or focus, direction in both fast and slow modes and in the lateral directions in slow mode only.

#### 4.3.2.1 Fast Focus

Fast translation of the f/16 Secondary Mirror will be accomplished in the axial direction only. The fast focus PSD input to the M2 Tilt System is shown in figure 4-7. Sampling rate may be to a frequency of 200 Hz. With this input PSD and sample rate, the M2 Tilt System must remove this disturbance with a maximum residual RMS of 1.3μm focus motion.

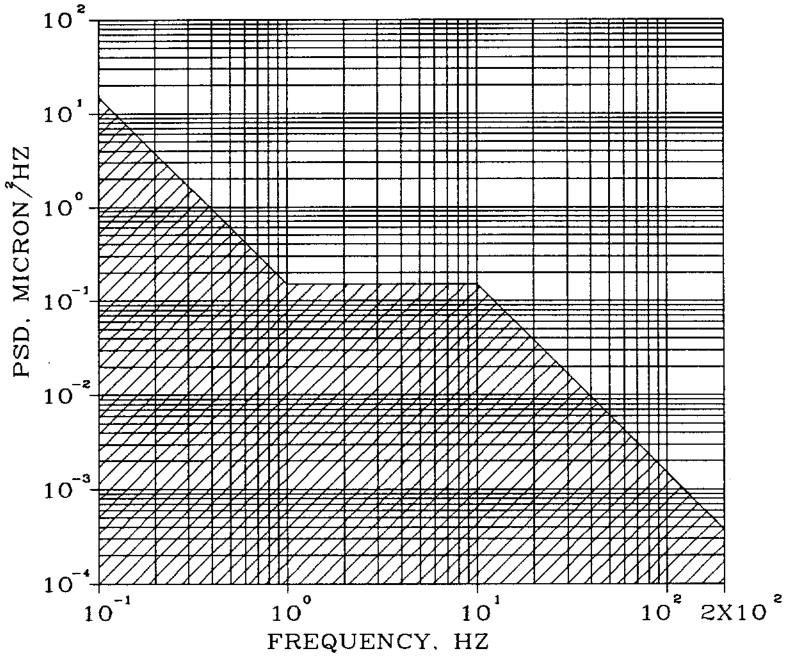


Figure 4-7: Fast Focus PSD

#### 4.3.2.2 Slow Translation

The requirements for slow translation are tabulated in Appendix B. The requirements determined in Appendix B will be increased to accommodate additional corrections that are as yet undetermined. The requirements from Appendix B are summarized in Table 4-2.

**Table 4-2: Slow Translation Requirements**

| direction | requirement from Appendix B |
|---|---|
| x | 4.75 mm total |
| y | 5.88 mm total |
| z | 10.31 mm total |

The ranges of Table 4-2 will be increased to accommodate additional corrections as yet undetermined. The increased requirements are tabulated in Table 4-3.

**Table 4-3: Slow Translation Requirements**

| direction | requirement for f/16 Secondary Assembly |
|---|---|
| x | 5 mm total |
| y | 10 mm total |
| z | 20 mm total |

The M2 Tilt System is not required to meet the full range of tilt of 2° total and Z direction translation of 20 mm total simultaneously. It will, however, more than meet the requirements of

Appendix B for tilt and focus simultaneously. The range of tilt and focus required in the M2 Tilt System Design Requirements Document, SPE-O-G0039, is shown in figure 4-8.

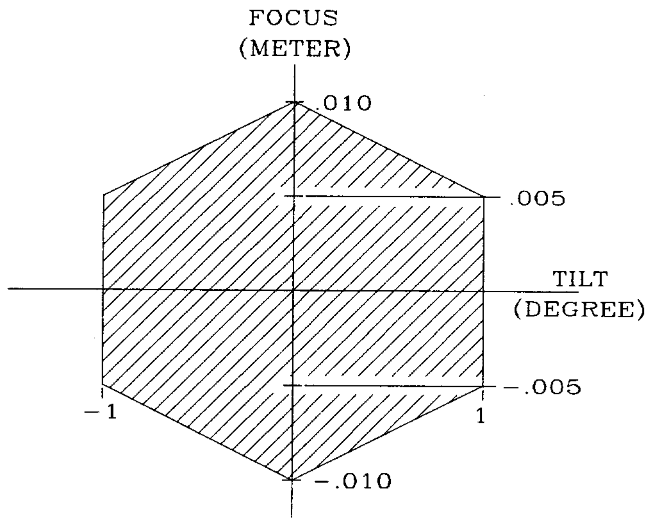


Figure 4-8: Range of Tilt and Focus Required

### 4.4 Functional Requirements, M2 Deployable Baffle and M2 Central Baffle

The f/16 Secondary Assembly is required to contain a remotely deployable baffle. When retracted, the M2 Deployable Baffle will be entirely concealed behind the f/16 Secondary Mirror. Also, in the retracted position the M2 Deployable Baffle shall not contact nor interfere with the M2 Tilt Mechanism and the M2 Positioning Mechanism. The M2 Deployable Baffle shall be deployable to 2 positions. Deployment shall take no more than five minutes time.

In the first deployed position, the M2 Deployable Baffle shall have a outside diameter of 1.125 in ±0.010 in. In the second deployed position the M2 Deployable Baffle shall have an outside diameter of 2.000 in ± 0.010m. The outer edge of the M2 Deployable Baffle shall be centered behind the f/16 Secondary Mirror to within ∅.010m.

The f/16 Secondary Assembly is required to contain a remotely deployable baffle to cover the central hole through the f/16 Secondary Assembly. When deployed, the M2 Central Baffle obscures any instrument's view of anything through the central hole in the f/16 Secondary Assembly, including stray radiation. When retracted, the M2 Central Baffle shall not be visible to any instrument over the required field of view, see section 2.

### 4.5 Environmental Requirements

The f/16 Secondary Assembly and all of its subassemblies and subsystems will be subjected to various environments. The entire f/16 Secondary Assembly must meet all of its functional requirements while experiencing the performance environment. The f/16 Secondary Assembly must operate, but not necessarily meet the performance requirements, when subjected to the operating environment. The f/16 Secondary Assembly must experience survival environment conditions with no permanent damage and be fully capable of resuming operation when the conditions are removed. The survival conditions may also be applied to the f/16 Secondary Assembly, its subassemblies and subsystems and component parts, when in the Telescope, on any handling equipment or in the shipping containers. The subassemblies and subsystems and their shipping containers must survive transportation environmental conditions with no damage.

### 4.5.1 Operating Environment

The conditions that the f/16 Secondary Assembly must operate under are in Table 4-4.

**Table 4-4: Operating Environment**

| Condition | Requirement |
|---|---|
| altitude | sea level to 4300 m |
| air temperature | -15° to +25° C |
| relative humidity | 0% to 95% |
| wind speed | 0 to 5 m/sec |
| gravity orientation | Z axis vertical up to vertical down |

### 4.5.2 Performance Environment

The f/16 Secondary Assembly and all of its subassemblies and subsystems shall meet all performance requirements when subjected to any combination of the conditions in Table 4-5.

**Table 4-5: Performance Environment**

| Condition | Requirement |
|---|---|
| altitude | sea level to 4300 m |
| air temperature | -15° to +25° C |
| relative humidity | 0% to 90% |
| wind speed | 0 to 5 m/sec |
| gravity orientation | Z axis vertical up to vertical down |

### 4.5.3 Survival Environment

The f/16 Secondary Assembly, subassemblies, subsystems and component parts and their shipping, storage and handling equipment shall be designed so the f/16 Secondary Assembly and subassemblies shall survive any combination of the conditions of Table 4-6.

| Table 4-6: Survival Environment | |
|---|---|
| Condition | Requirement |
| altitude | 0 to 4300 m |
| air temperature | -20° to +40° C |
| relative humidity | 0% to 100% with condensation |
| wind speed | 0 to 35 m/sec in +Z direction |
| | 0 to 18 m/sec in -Z direction |
| seismic | 12g, 0.5Hz to 100Hz, all axes |

### *4.5.4 Transportation Environment*

The subassemblies of the f/16 Secondary Assembly and their shipping containers shall be designed to withstand the environmental conditions of Table 4-7 with no damage to the container or the subassembly.

| Table 4-7: Transportation Environment | |
|---|---|
| Condition | Requirement |
| altitude | sea level to 15,500 m |
| air temperature | -200° to +400° C |
| relative humidity | 0% to 100% with condensation |
| wind speed | 0 to 67 m/sec |
| vibration | IAW MIL-STD-810E, July ‘89, section 514.4 |
| shock | IAW MIL-STD-810E, July ‘89, section 516.4 |
| seismic | see figure TBD |

### *4.5.5 Handling Environment*

The f/16 Secondary Assembly, all subassemblies and subsystems shall survive any combination of the environmental conditions of Table 4-8 without permanent damage when suspended by lifting points or mounting features, and with or without the f/16 Secondary Mirror installed.

| Table 4-8: Handling Environment | |
|---|---|
| Condition | Requirement |
| altitude | 0 to 4300 m |
| air temperature | -20° to +40° C |
| relative humidity | 0% to 100% with condensation |
| wind speed | 0 to 67 m/sec |
| shock and vibration | 10g, 0.5Hz to 100Hz, any axes |

# Section 5
# f/16 SECONDARY MODULE ALIGNMENT

## 5.1 Introduction

This section concerns itself with mechanical alignment of the f/16 Secondary Mirror to the Telescope optical system at initial installation, and when the f/16 Secondary Module and Telescope Top Ring are removed, disassembled, re-assembled and reinstalled on the Telescope. Both topics have an impact on the articulation ranges required of the components of the f/16 Secondary Assembly and adjustment range required at the Telescope interface at initial alignment. Initial alignment of the Telescope will set various indexing features such that f/16 Secondary Mirror alignment is within the range of the mechanisms used to position the f/16 Secondary Mirror. Features at the interfaces between the f/16 Secondary Module subassemblies assure that alignment of the f/16 Secondary Mirror is within the range of the mechanisms used to position the f/16 Secondary Mirror following removal, disassembly, reassembly and reinstallation of the f/16 Secondary Module.

## 5.2 Initial Alignment

Initial alignment of the f/16 Secondary Module will consist of setting the position of the M2 Deployable Baffle. An alignment target will be inserted into and index on the central hole of the f/16 Secondary Mirror. This target will have a flat mirror and a cross hair target aligned to the central hole and rest against the optical surface of the f/16 Secondary Mirror for measuring decenter and tilt of the f/16 Secondary Mirror.

At initial alignment, the total tilt and decenter of the f/16 Secondary Module will be measured using this alignment target. The decenter, tilt and Z direction position for best focus and image quality will then be measured using the entire optical system of the Telescope. A ring at the M2 Positioning MechanisnVM2 Deployable Baffle interface win be reground to the thickness and wedge required to align the f/16 Secondary Module in tilt and focus. The f/16 Secondary Module will be re-installed with the modified ring and the M2 Deployable Baffle adjusted to reduce the decenter of the f/16 Secondary Module to put the alignment of the f/16 Secondary Mirror to the Telescope optical system within the articulation ranges of the components of the f/16 Secondary Assembly.

The tolerances are summarized in tables 5-1 and 5-2. The invariant misalignments, those that will be removed at initial alignment, are summarized in Table 5-1. The non-repeatable misalignments are summarized in Table 5-2. These will be removed at initial alignment for the condition within these limits the f/16 Secondary Module is in at that time. All or a portion of these will have to be removed each time the f/16 Secondary Module is removed, disassembled into its major components, re-assembled and reinstalled on the Telescope. Also included is the non-repeatability experienced when the Telescope Top Ring is removed from and re-installed on the Telescope. The tables also include clocking errors. These will not be removed during alignment, but represent the correction to the coordinate systems of the M2 Tilt system and the M2 Positioning System that must be applied to the articulation commands.

## 5.3 Component Indexing

Positional tolerances locate the optical surface of the f/16 Secondary Mirror relative to its mounting features. Other positional tolerances locate the indexing features of the other components of the f/16 Secondary Module. These are invariant and only need be adjusted out once. These, along with the non-repeatabilities, contribute to the range of adjustment needed at initial alignment of the f/16 Secondary Mirror to the Telescope optical system.

The subassemblies of the f/16 Secondary Module have indexing features that allow the removal, disassembly, re-assembly and re-installation of the f/16 Secondary Module with minimal non-repeatability. These, along with the initial alignment tolerance, determine the range of articulation required of the f/16 Secondary Assembly.

### *5.3.1 f/16 Secondary Mirror*

The position of the optical surface of the f/16 Secondary Mirror is specified relative to a mechanical axis defined from the surface of the Mirror Mounting Hardware that mates with the M2 Tilt Mechanism and the central hole. Figure 5-1 shows the datums used to establish the mechanical axis from which the f/16 Secondary Mirror optical surface and center of gravity locations are toleranced.

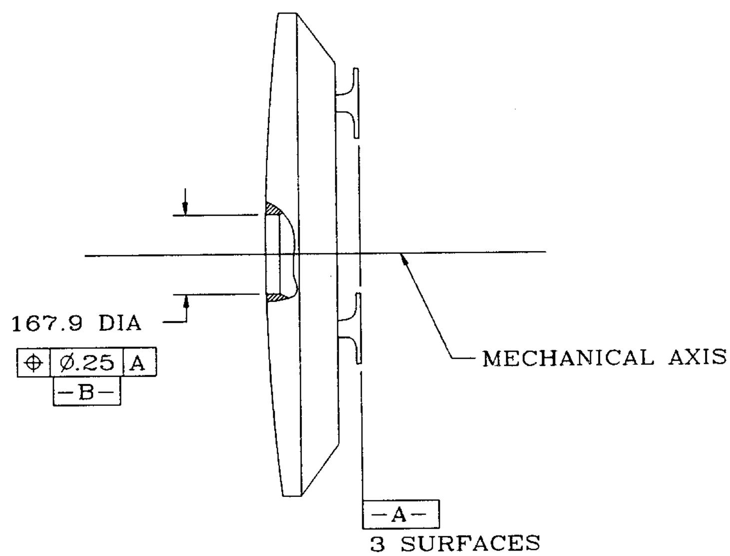


Figure 5-1: Features Used in Establishing the f/16 Secondary Mirror Mechanical Axis

The optical axis of the f/16 Secondary Mirror shall be parallel to the mechanical axis within ±5 arcminutes. The tilt is invariant and will be a component of the total tilt and decenter that will be removed at initial alignment of the f/16 Secondary Module. The plane in which the rotational articulation axes of the f/16 Secondary Mirror lies is defined by the flexures on which it is supported. The plane in which the rotational articulation axes of the f/16 Secondary Mirror lies is located approximately 50 mm behind the vertex. The decenter of the vertex that results from tilting the f/16 Secondary Mirror around its rotational articulation axis is ∅.145 mm. The vertex of the f/16 Secondary Mirror shall be located on the mechanical axis within a tolerance zone of 1mm diameter. The center of gravity of the f/16 Secondary Mirror shall be located within 1 mm, 2mm total, of any rotational articulation axis of the f/16 Secondary Mirror.

### *5.3.2 VI 6 Secondary Mirror/M2 Tilt Mechanism*

Decenter of the f/16 Secondary Mirror relative to the M2 Tilt Mechanism will be set by the fasteners used to secure the f/16 Secondary Mirror to the M2 Tilt Mechanism. The f/16 Secondary Mirror will be tilted to bring the optical axis into alignment with the optical axis of the Telescope. The clearance holes in the three studs of the f/16 Secondary Mirror are ∅6.43 +0.15/0.03 mm. Their locations are toleranced within 0.20 at maximum material condition to datums -A- and -B- at maximum material condition.

Six M6 x 1.0 set screws will be installed in the tapped holes on each Mirror Mounting Feature of the M2 Tilt Mechanism. The major diameter limits for an M6 x 1.0 male thread are ∅5.794-5.974. The median clearance is ∅1.396. Size tolerances on both features win also be accounted for.

### *5.3.3 M2 Tilt Mechanism*

The M2 Tilt Mechanism datums are one flat surface, datum -C-, and two precision holes (12.729+0.010/-0.000 diameter). The datums and the Mirror Mounting Features are shown in figure 5-2.

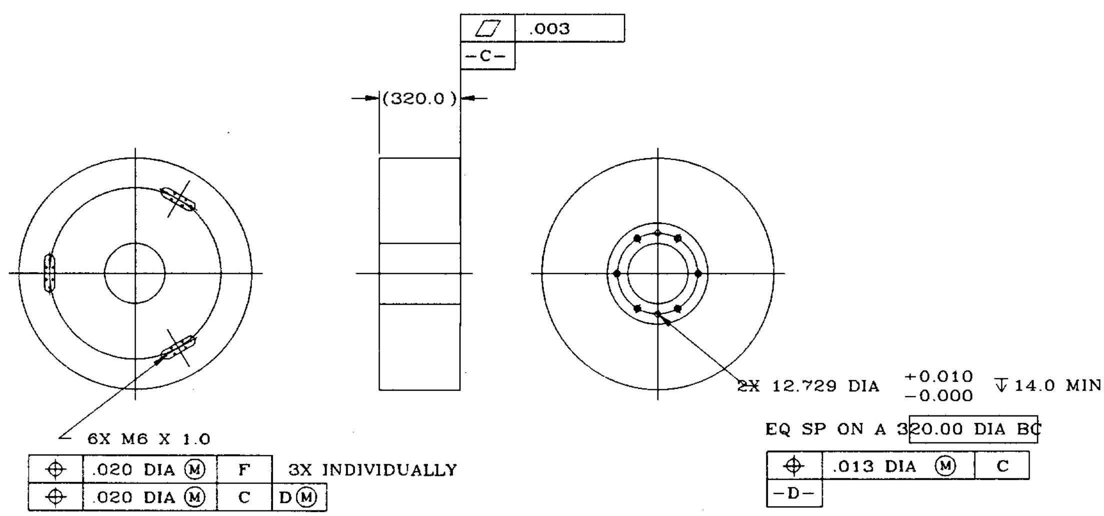


Figure 5-2: M2 Tilt Mechanism

The tapped holes in the Mirror Mounting Features have a positional tolerance of ∅.20 at maximum material condition to datums -C- and -D- at maximum material condition. The tolerance on an M6 x 1.0 pitch diameter is ∅.18 (total). The Mirror Mounting Features are on a 636 mm diameter bolt circle and will introduce clocking efforts. The mounting surface flatness tolerance may introduce a tilt of 3.2 arcsecond and a decenter of ∅.008 mm.

### *5.3.4 M2 Tilt Mechanism/M2 Positioning Mechanism*

The M2 Tilt Mechanism mounts to the M2 Positioning Mechanism on one flat surface. Two tooling balls on the M2 Positioning Mechanism index two precision holes (drill bushings) on the M2 Tilt Mechanism. One of the tooling balls is ground into a diamond shape. The fit between the tooling balls and the precision holes set decenter and clocking between the M2 Tilt Mechanism and the M2 Positioning Mechanism. The positional tolerances for the two bushings are shown in figure 5-2. The positional tolerances for the two tooling balls are shown in figure 5-3.

### *5.3.5 M2 Positioning Mechanism*

The M2 Positioning Mechanism has a "zero" position where the indexing features on the M2 Tilt Mechanism interface are related to the indexing features on the M2 Deployable Baffle interface. It should be noted that in operation one surface moves relative to the other and the “zero" position is only used to define the travel ranges of the M2 Positioning Mechanism, and has little meaning when discussing the alignments in this section. The M2 Positioning Mechanism envelope and the positional tolerances relating the alignment features are shown in figure 5-3.

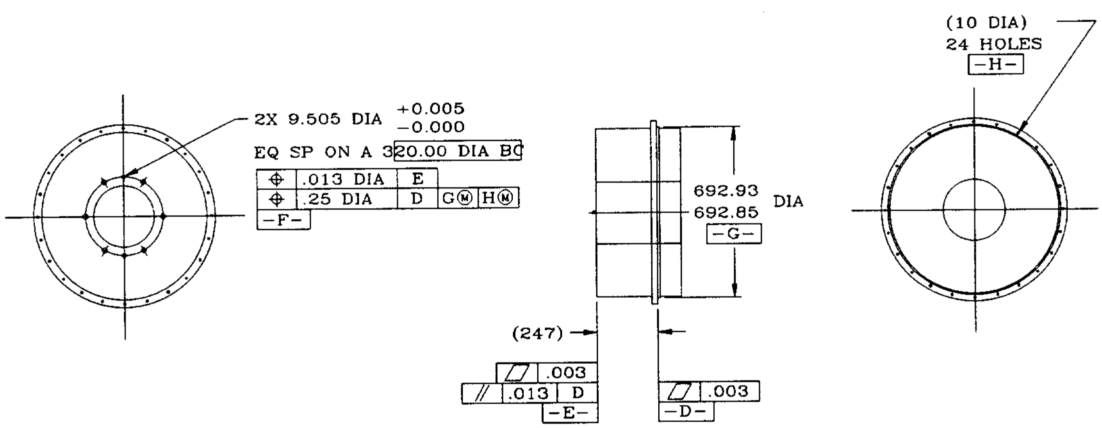


Figure 5-3: M2 Positioning Mechanism

### *5.3.6 M2 Positioning Mechanisni/M2 Deployable Baffle*

The M2 Positioning Mechanism mates with a flat surface and a pilot diameter on the M2 Deployable Baffle. Clocking alignment is held by the mounting screws in their clearance holes. The indexing features on the M2 Positioning Mechanism are shown in figure 5-3. The indexing features of the M2 Deployable Baffle are shown in figure 5-4.

### *5.3.7 M2 Deployable Baffle/Telescope Secondary Support*

The M2 Deployable Baffle will be installed on the Telescope Secondary Support Structure. It will be adjusted in decenter during initial alignment of the Telescope optical system. Clearance holes in the Secondary Support Structure win allow the M2 Deployable Baffle to be adjusted in decenter. A ring that is part of the M2 Deployable Baffle may be removed and wedge may be ground into the ring to correct for tilt errors if necessary. Regrinding the ring will also decrease the thickness of the ring to achieve correction in focus, if necessary. Four screws will hold the ring to the M2 Deployable Baffle to maintain its position when the f/16 Secondary Module is removed.

The ring may be reground to an accuracy of 21 arcsecond in angle. If the direction of wedge is held within I degree, the additional decenter that would require removal is ∅.073 mm. The M2 Deployable Baffle will be recentered following regrinding of the ring as part of the initial alignment. The additional tilt error would be 0.37 arcsecond. These inaccuracies are not part of the total error that is to be corrected, but represent the residual error just due to grinding inaccuracies. The ring will be reground to adjust focus.

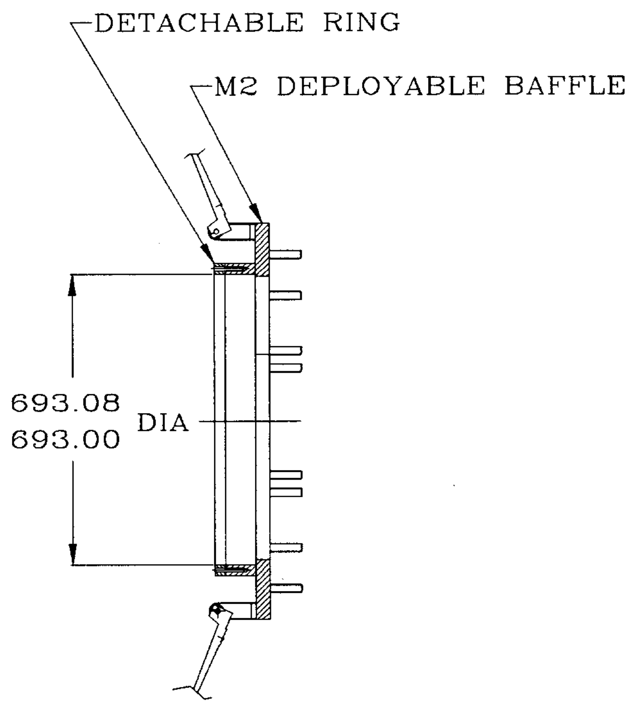


Figure 5-4: M2 Deployable Baffle

### 5.3.8 *Telescope Top Ring*

The surface the f/16 Secondary Module mounts to on the Telescope Top Ring is normal to the Telescope optical axis within 0.017 mm. The mounting hardware features have a positional tolerance relative to the Telescope optical axis of ∅1.0 at maximum material condition. The Telescope top ring non-repeatability at each mounting point is ∅.500. The mounting points are on a 9350 mm diameter. This non-repeatability introduces decenter, tilt and clocking errors.

### *5.3.9 Overall V16 Secondary Mirror Alignment*

The total alignment of the f/16 Secondary Mirror to the Telescope optical axis is divided into invariant tolerances and alignment non-repeatability after the f/16 Secondary Module is removed, disassembled into the major subassemblies and then reassembled and reinstalled.

Invariant tolerances are tabulated in Table 5-1. These errors win be removed to the extent specified in 5.2. They are given to assess the amount of adjustment required at initial alignment of the Telescope optical system.

**Table 5-1: Invariant Tolerances, f/16 Secondary Module Alignment**

| tolerance | decenter | tilt | clocking | |
|---|---|---|---|---|
| | | | M2 Tilt Mechanism | M2 Positioning Mechanism |
| | mm total | arcsecond total | arcsecond total | arcsecond total |
| f/16 Secondary Mirror | --- | --- | --- | --- |
| decenter relative to mechanical axis | ∅1 | --- | --- | --- |
| tilt relative to mechanical axis | ∅.145 | 600 | --- | --- |
| clearance hole location at MMC | ∅.20 | --- | --- | --- |
| bonus, size, clearance holes | ∅.18 | --- | --- | --- |
| additional, size, datum -B- | ∅.20 | --- | --- | --- |
| M2 Tilt Mechanism | --- | --- | --- | --- |
| tapped hole location at MMC | ∅.20 | --- | --- | --- |
| bonus, size, tapped holes | ∅.18 | --- | --- | --- |
| additional, size, datum -D- | ∅.010 | --- | --- | --- |
| M2 Positioning Mechanism | --- | --- | --- | --- |
| tooling baus, location at MMC | ∅.25 | --- | 322 | --- |
| bonus, size, tooling balls | ∅.005 | --- | 6.4 | --- |
| additional, size, datum -G- | ∅.08 | --- | --- | --- |
| parallelism, datum -E- | ∅.004 | 1.5 | --- | --- |
| M2 Deployable Baffle | --- | --- | --- | --- |
| M2 Positioning Mechanism pilot diameter, location at MMC | ∅.25 | --- | --- | --- |
| bonus, size, pilot diameter | ∅.008 | --- | --- | --- |
| additional, size, datum -X- | ∅.335 | --- | --- | --- |
| Telescope Top Ring | --- | --- | --- | --- |
| clearance holes, location at MMC | ∅1.0 | --- | 517.60 | 517.60 |
| bonus, size, clearance holes | ∅.33 | --- | 170.81 | 170.81 |
| f/16 Secondary Module mounting surface tilt relative to optical axis | ∅.016 | 3.71 | --- | --- |

| | | | | |
|---|---|---|---|---|
| total | ∅4.393 | 605.21 | 1,016.81 | 688.41 |

Tolerances that will effect alignment non-repeatability after the f/16 Secondary Module and the Telescope Top Ring are removed, disassembled into subassemblies, then reassembled and reinstalled. This is a component of misalignment that will be removed at initial alignment This range of misalignment non-repeatability is part of what must be removed using the articulation systems and is a portion of the articulation ranges required of the f/16 Secondary Assembly.

**Table 5-2: Tolerances that Contribute to Non-repeatability**

| tolerance | decenter | tilt | clocking | |
|---|---|---|---|---|
| | mm total | arcsecond total | M2 Tilt Mechanism arcsecond total | M2 Positioning Mechanism arcsecond total |
| f/16 Secondary Mirror/M2 Tilt Mechanism | --- | --- | --- | --- |
| median fit, studs to clearance holes | ∅.606 | --- | --- | --- |
| tolerance, size, stud major diameter | ∅.090 | --- | --- | --- |
| tolerance, size, clearance holes | ∅.09 | --- | --- | --- |
| M2 Tilt Mechanism, flatness, datum -C- | ∅.008 | 3.2 | --- | --- |
| M2 Tilt Mechanism/M2 Positioning Mechanism | --- | --- | --- | --- |
| fit, tooling balls to indexing holes, median fit | ∅.039 | --- | 0.01 | --- |
| tolerance, size, indexing holes | ∅.005 | --- | 6.4 | --- |
| tolerance, size, tooling balls | ∅.005 | --- | 6.4 | --- |
| M2 Positioning Mechanism, flatness, datum -D- | ∅.006 | 0.83 | --- | --- |
| M2 Positioning Mechanism/M2 Deployable Baffle | --- | --- | --- | --- |
| pilot diameter, median fit | ∅.15 | --- | --- | --- |
| tolerance, size, M2 Deployable diameter | ∅.04 | --- | --- | --- |
| tolerance, size, M2 Positioning Mechanism | ∅.04 | --- | --- | --- |
| mounting hardware, median fit | --- | --- | 522.12 | 522.12 |
| tolerance, size, clearance holes | --- | --- | 51.64 | 51.64 |
| tolerance, size, major diameter | --- | --- | 135.41 | 135.41 |
| M2 Deployable Baffle/Telescope Top Ring | --- | --- | --- | --- |
| median fit, studs to clearance holes | --- | --- | 522.12 | 22.12 |
| tolerance, size, studs | --- | --- | 51.64 | 51.64 |
| tolerance, size clearance holes | --- | --- | 135.41 | 135.41 |

| | | | | |
|---|---|---|---|---|
| Telescope Top Ring non-repeatability | ∅.500 | 15.60 | 11.03 | 11.03 |
| total | ∅1.579 | 19.63 | 1,442.18 | 1,429.37 |

# Appendix A: MECHANICAL OSCILLATION

## A.1 Introduction

The derivation of the mechanical oscillation tolerances for the f/16 Secondary Mirror Assembly subassemblies is presented here. There are two cases, Chopping and other operations. Each has a different requirement.

The oscillations are caused by f/16 Secondary Mirror articulation. One form is the structural response of the Telescope, the M2 Positioning Mechanism and the M2 Tilt Mechanism when the M2 Tilt System is operated in the fast modes, Chopping, fast tilt and fast focus. A second form is inaccuracies within the f/16 Secondary Mirror/M2 Tilt System.

## A.2 Chopping Operation

The Telescope Group has evaluated the Telescope Top Ring's response to dynamic force and moment inputs from the M2 Tilt System. This forms the basis for estimating the image degradation due to the first category above (structural response). From these inputs and responses, coefficients will be calculated relating input and response. It is assumed that the responses are linear and independent. Table A-1 lists the inputs, the structural responses and the coefficients that are calculated from them. The inputs are peak values. The responses are total, or peak to peak, values. The coefficients are, therefore, displacement total/input peak.

**Table A-1: Input Forces and Moments, and the Telescope Top Ring Response, 45 Hz**

| input mode | response | |
|---|---|---|
| | mode | coefficient |
| moment | decenter | 0.840μm/N-m |
| | tilt | 0. 1731 sec/N-m |
| piston force | piston | 2.39μn/N |
| lateral force | decenter | 5.12μm/N |
| | tilt | 0. 1747 sec/N |

Additional displacements were assumed for structural resonances of 20 and 100 Hz. The coefficients are then combined for a total displacement for inputs of the same magnitude. The total coefficient for decenter due to a moment input is found from

$$k_{dM} = k_{dM45}\sqrt{1+\left(\frac{45}{20}\right)^2+\left(\frac{45}{100}\right)^2}$$
$$= 2.503k_{dM45}$$

The other coefficients are treated in the same manner. These coefficients are used to describe the response of the Telescope structure only. Coefficients will be derived from and combined with these describing the response of the M2 Positioning System. The coefficients describing the Telescope response appear in Table A-2.

**Table A-2: Input Forces and Moments, Response Modes and Coefficients**

| input mode | response | |
|---|---|---|
| | mode | coefficient |
| moment | decenter | 2.103µm/N-m |
| | tilt | 0.433 arcsecond/N-m |
| piston | focus | 5.98 µm/N |
| lateral force | decenter | 12.81µm/N |
| | tilt | 0.437 arcsecond/N |

The M2 Positioning Mechanism and the M2 Tilt Mechanism/f/16 Secondary Mirror combination will be assumed to follow the "octave" rule. The octave rule means that the lowest natural frequency of the M2 Positioning Mechanism with the M2 Tilt Mechanism and f/16 Secondary Mirror installed is twice that of the Telescope Top Ring. In this case, the M2 Positioning Mechanism is mounted to a rigid structure. The lowest natural frequency of the M2 Tilt Mechanism with the f/16 Secondary Mirror installed is twice that of the M2 Positioning Mechanism. The M2 Positioning Mechanism and M2 Tilt System Design Requirements Documents specifies the natural frequencies of these two systems in accordance with this assumption. This assumption will be modified to reflect that tilt and piston of the f/16 Secondary Mirror is controlled by the M2 Tilt system. These values will be controlled to limit oscillation to one-tenth the value that would be expected if they were not controlled. The coefficients derived for the Telescope structure will be modified by the addition of factors that follow. For decenter, the coefficient for the f/16 Secondary Assembly is

$$k_{d\sec} = k_{dstruct}\sqrt{\left(\frac{1}{4}\right)^2+\left(\frac{1}{16}\right)^2}$$

The total decenter coefficients are calculated from $k_{dtotal} = k_{dstruct}\sqrt{1+\left(\frac{1}{4}\right)^2+\left(\frac{1}{16}\right)^2}$

The tilt and piston coefficients for the f/16 Secondary Assembly are calculated from $k_{t,p\sec} = k_{t,pstruct}\sqrt{\left(\frac{1}{4}\right)^2+\left(.1\cdot\frac{1}{16}\right)^2}$

The total tilt and piston coefficients are then $k_{t,ptotal} = k_{t,pstruct}\sqrt{1+\left(\frac{1}{4}\right)^2+\left(.1\cdot\frac{1}{16}\right)^2}$

The total calculated coefficients are given in Table A-3.

| **Table A-3: Input Forces and Moments, Response Modes and Coefficients** | | |
|---|---|---|
| input mode | response | |
| | mode | coefficient |
| moment | decenter | 2.172 μm/N-m |
| | tilt | 0.477 arcsecond/N-m |
| piston | focus | 6.161 μm/N |
| lateral force | decenter | 13.23μm/N |
| | tilt | 0.450 arcsecond/N |

The M2 Tilt System Design Requirements Document limits the vibratory output of the M2 Tilt System during Chopping operation to:

| <u>mode</u> | <u>maximum amplitude</u> |
|---|---|
| moment | 0.5 N-m |
| piston force | 1.5 N |
| lateral force | 0.10 N |

The image smear resulting from these moments and forces for Chopping operation are given in Table A-4.

| **Table A-4: Image Degradation Due to Telescope Response** | | | |
|---|---|---|---|
| input mode | response | | image degradation |
| | mode | coefficient | arcsecond dia |
| moment | decenter | 1.052 μm/N-m | 0.0089 |
| | tilt | 0.217 arcsecond/N-m | 0.0368 |
| piston | focus | 8.97 μm/N | 0.0108 |
| lateral force | decenter | 1.281 μm/N | 0.0108 |
| | tilt | 0.0437 arcsecond/N | 0.0074 |
| total, rss | | | 0.0415 |

In addition to these limits, the M2 Tilt System DRD allows inaccuracy in f/16 Secondary Mirror Position due to, but not limited to, oscillation, non-repeatability and settling band. The maximum inaccuracies are

| <u>mode</u> | <u>maximum amplitude</u> |
|---|---|
| decenter | 2.000μm total |
| tilt | 0. 100 arcsecond total |
| piston | 10μm total |

The image degradation due to these inaccuracies of the f/16 Secondary Mirror on the M2 Tilt Mechanism will depend on the nature of the inaccuracies. Plots of image degradation due to various combinations of oscillation and non-repeatability are presented here as figures A-1 through A-3 for Chopping operation.

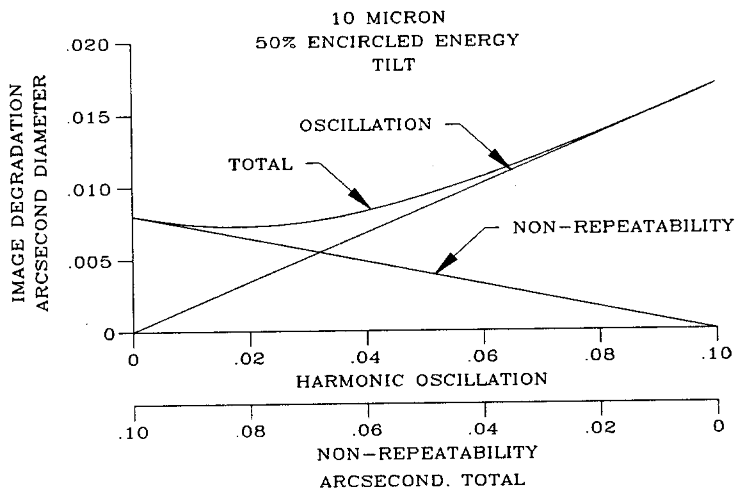


Figure A-1: Image Degradation for Inaccuracies in Tilt

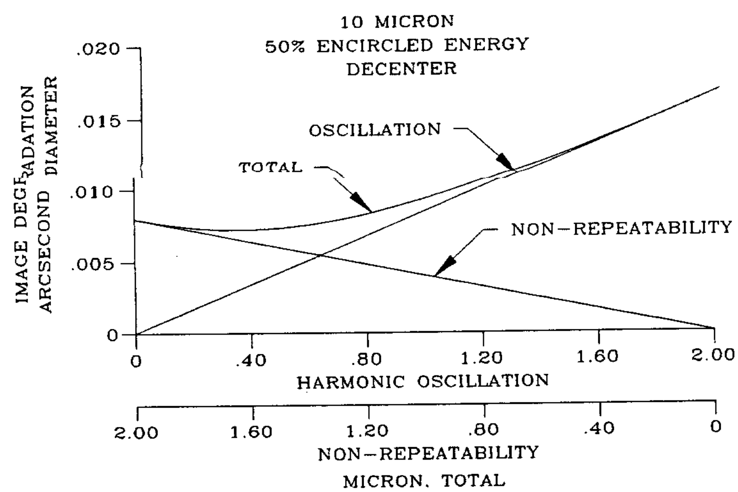


Figure A-2: Image Degradation for Inaccuracies in Decenter

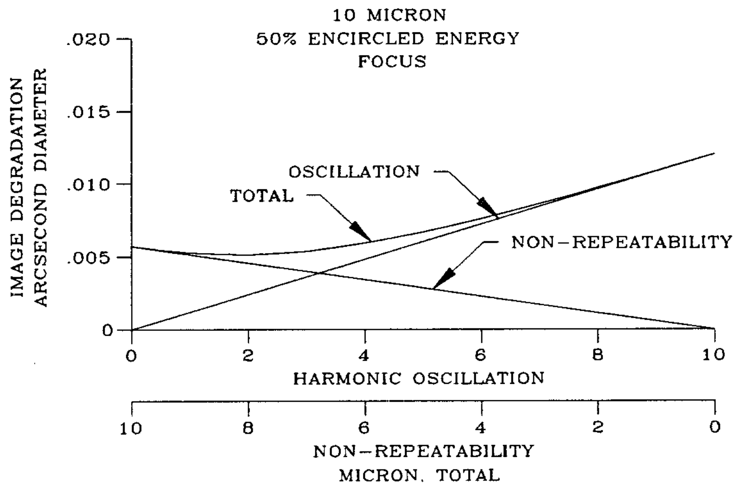


Figure A-3: Image Degradation for Inaccuracies in Focus

The image quality degradation allowances in the *Gemini System Error Budget* for image smear for 10µm wavelength are:

| cause | allowance, 50% EE 10µm |
|---|---|
| 1.3.3.1 Residual Top End Tilt | 0.100 |
| 1.3.3.2 Residual Articulation System Tilt | 0.050 |
| 1.3.3.3 Residual Mirror Tilt | 0.050 |
| 1.3.3.4 Other | 0.047 |
| combined | 0.113 |

## A.3 Other Operations

Oscillation of the f/16 Secondary Mirror with the M2 Tilt System operating in the fast tilt and focus modes produces the same effects, to a lesser degree, as those induced in the Chopping mode. The maximum vibratory output allowed the M2 Tilt System by the M2 Tilt System Design Requirements Document is:

| mode | maximum amplitude |
|---|---|
| moment | 0.10 N-m |
| piston force | 0.30 N |
| lateral force | 0.10 N |

The structural response of the Telescope structure and the f/16 Secondary Mirror Assembly components are summarized in Table A-5.

| **Table A-5: Image Degradation Due to Structural Response of Telescope and f/16 Secondary Module** | | | | | |
|---|---|---|---|---|---|
| | response | | image degradation, arcsecond diameter | | |
| | | | .55μm | 2.2μm | 2.2μm |
| input mode | mode | amplitude | 85% | 50% | 85% |
| moment | decenter | 0.2172μm total | 0.0028 | 0.0020 | 0.0022 |
| | tilt | 0.0447 sec total | 0.0117 | 0.0081 | 0.0090 |
| piston | focus | 1.848 pm total | 0.0041 | 0.0032 | 0.0044 |
| lateral force | decenter | 1.323 pm total | 0.0172 | 0.0120 | 0.0132 |
| | tilt | 0.0451 sec total | 0.0118 | 0.0082 | 0.0091 |
| total, rss | | | 0.0244 | 0.0171 | 0.0191 |

In addition to these limits, the M2 Tilt System DRD allows inaccuracy in f/16 Secondary Mirror Position due to, but not limited to, oscillation, non-repeatability and settling band. The maximum inaccuracies are

| mode | maximum amplitude |
|---|---|
| decenter | 0.300μm total |
| tilt | 0.025 arcsecond total |
| piston | 2.00μm total |

The image degradation due to these inaccuracies of the f/16 Secondary Mirror on the M2 Tilt Mechanism will depend on the nature of the inaccuracies. Plots of image degradation due to various combinations of harmonic oscillation and non-repeatability are presented here as figures A-4 through A-12.

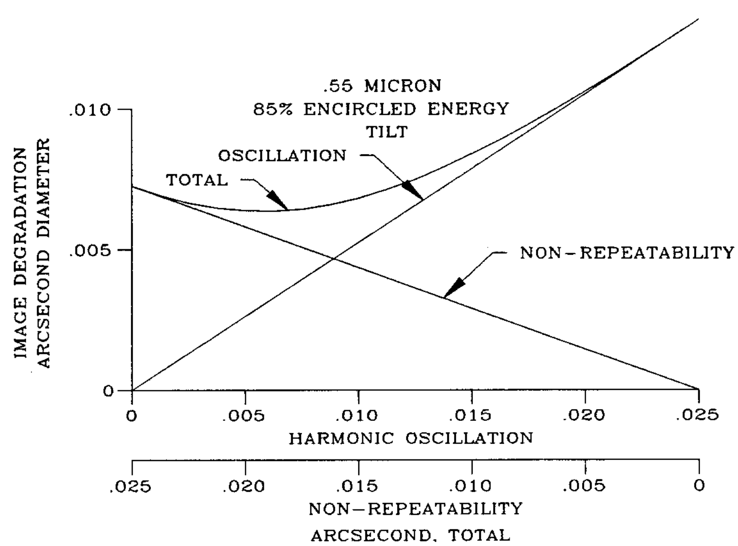


Figure A-4: Image Degradation for Inaccuracies in Tilt

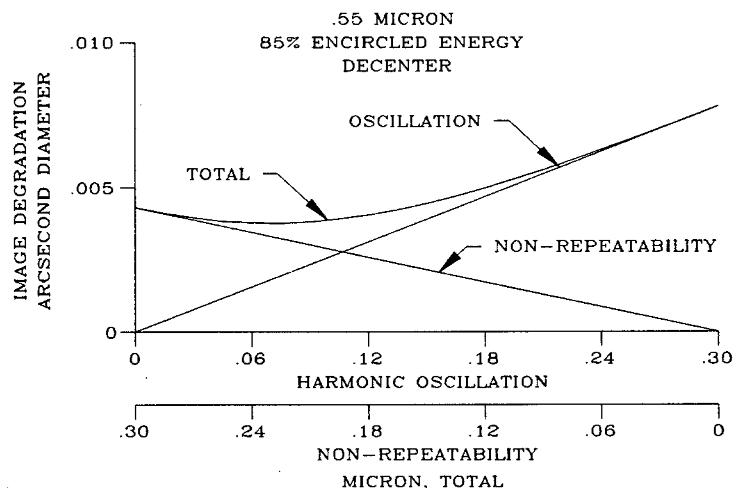


Figure A-5: Image Degradation for Inaccuracies in Decenter

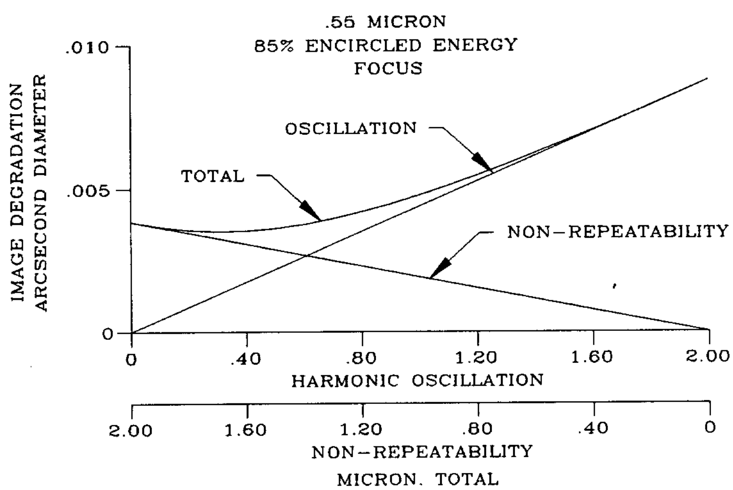


Figure A-6: Image Degradation for Inaccuracies in Focus

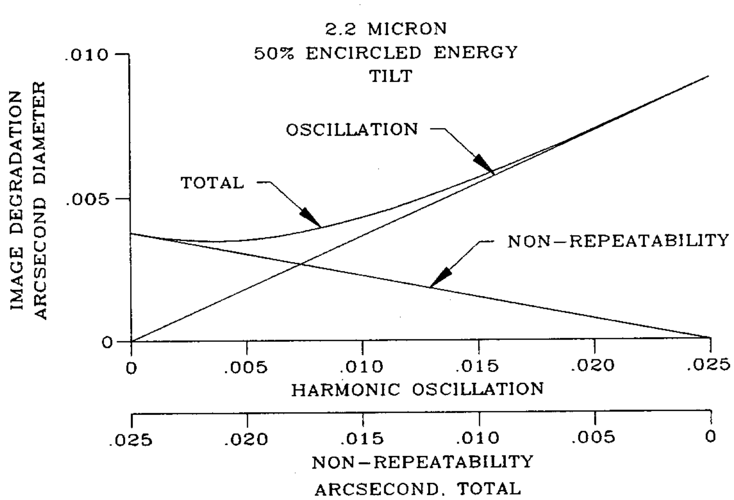


Figure A-7: Image Degradation for Inaccuracies in Tilt

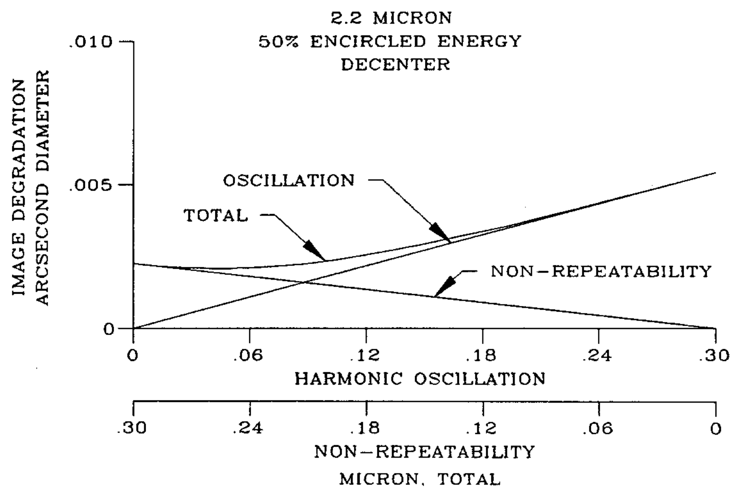


Figure A-8: Image Degradation for Inaccuracies in Decenter

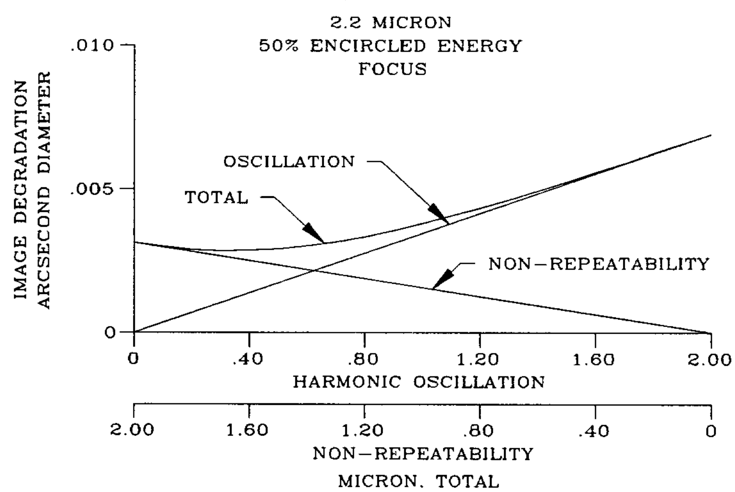


Figure A-9: Image Degradation for Inaccuracies in Focus

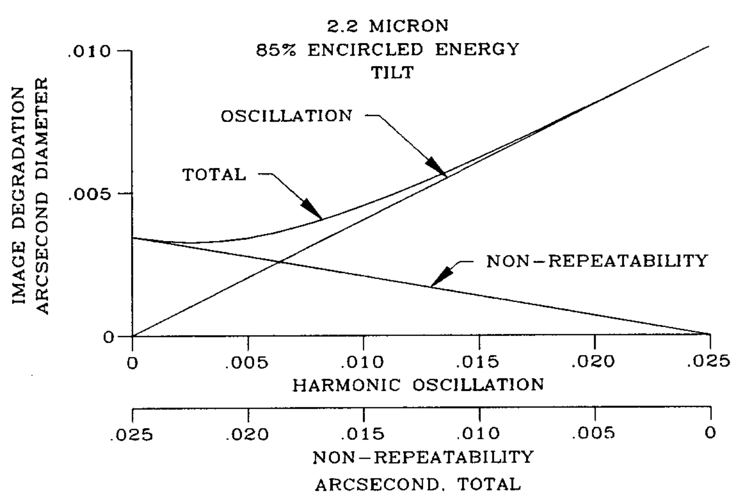


Figure A-10: Image Degradation for Inaccuracies in Tilt

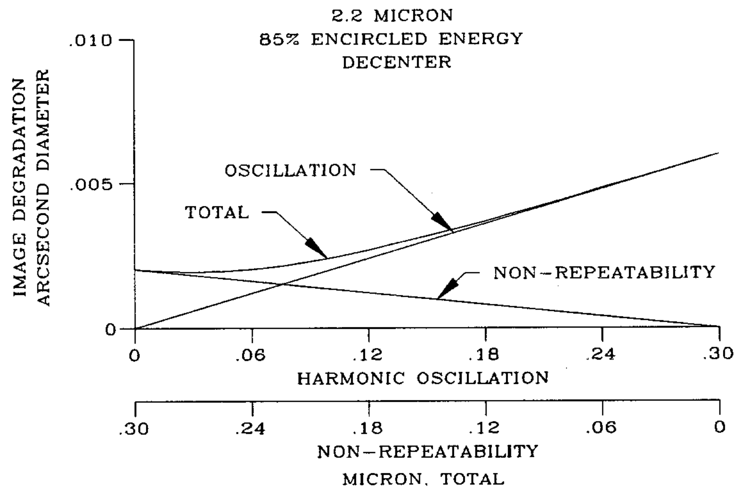


Figure A-11: Image Degradation for Inaccuracies in Decenter

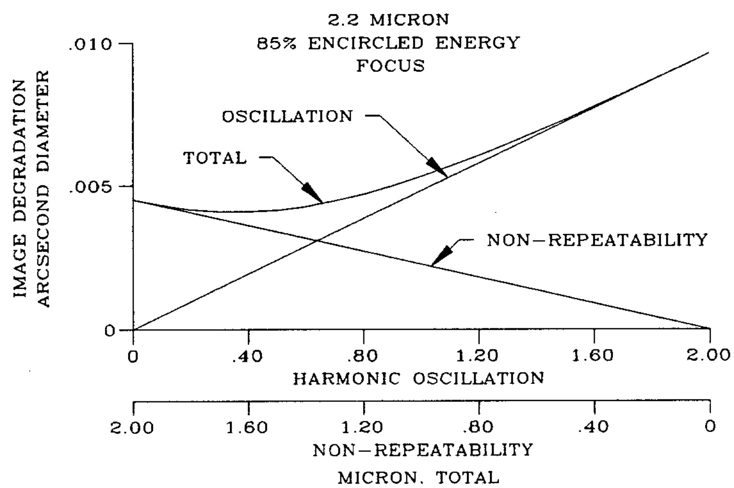


Figure A-12: Image Degradation for Inaccuracies in Focus

The Gemini System Error Budget Plan has allowances similar to those for Chopping for the other wavelengths listed. The allowances for the other wavelengths are shown in Table A-6.

**Table A-6: Error Budget Allowances for Image Smear**

| | image degradation, diameter increase, arcsecond | | |
|---|---|---|---|
| wavelength | .55µm | 2.2µm | |
| percent energy | 85% | 50% | 85% |
| 1.3.1 Wind Shake | 0.043 | 0.043 | 0.043 |
| 1.3.2 Measurement Error | 0.003 | 0.003 | 0.003 |
| 1. 3.3 Other | 0.011 | 0.011 | 0.011 |
| combined | 0.044 | 0.044 | 0.044 |

# Appendix B: ARTICULATION RANGES

## B.1 Introduction

This section presents the details for the total articulation ranges required of the f/16 Secondary Assembly. These ranges are for slowly varying events, such as gravity orientation or temperature variations, and do not include rapidly varying events, such as wind shake. The requirements will be given for each axis and for each mode of operation. All misalignments and corrections are referenced to the Cassegrain Rotator bearing axis, which is the primary datum for the Telescope optical system.

Tilt about the X and Y-axes is performed by the M2 Tilt System. Translation in the Z direction is performed by the M2 Tilt System. Translation in the X and Y directions is performed by the M2 Positioning System. Rotation about the Z-axis is fixed, no rotation is allowed once the f/16 Secondary Assembly is installed on the Top Ring of the Telescope.

## B.2 Translation in the X-Y Plane

Some requirements are in the X direction, some in the Y direction and others are circular in the X-Y plane. Those unique to one direction will appear in their respective paragraphs. Those that apply equally to X and Y directions are in B.2.3.

### *B.2.1 X Direction Requirements*

The decenter in the X direction of the f/16 Secondary Mirror due to a $1\sigma$ wind is $\pm 6.5\mu m$. For a $\pm 6\sigma$ case the total deflection is $39\mu m$.

### *B.2.2 Y Direction Requirements*

The maximum decenter of the f/16 Secondary Mirror in the Y direction due to changing gravity orientation is 0.940 mm. This is in one direction only. Initial alignment of the Telescope will take this into account by aligning the f/16 Secondary Assembly to the Telescope optical system at the midpoint of the excursion due to gravity orientation.

The maximum decenter in the Y direction of the f/16 Secondary Mirror due to wind is $\pm 34\mu m$. This is for the wind velocity of the operating environment of 4.5.1.

The M2 Tilt Mechanism may deflect $20\mu m$ due to changing gravity orientation. The M2 Positioning Mechanism may deflect $2\mu m$ total due to changing gravity orientation. The f/16 Secondary Mirror will translate $38\mu m$ total due to tilt within the M2 Positioning Mechanism Y direction due to changing gravity orientation.

### *B.2.3 Circular Requirements*

If one side of the Telescope tube is 0.5°C warmer than the other, the f/16 Secondary Mirror will translate 122µm to one side.

Alignment non-repeatabilities for removal, disassembly into major components, re-assembly and re-installation of the f/16 Secondary Module are presented in section 5. The total alignment non-repeatability in the X-Y plane is ∅1.579 mm. The f/16 Secondary Module may be aligned, at initial alignment, with the f/16 Secondary Mirror at one side of this zone and on subsequent reinstallation it may be at the other side of this zone. For this reason, the articulation range in the X-Y plane for this component is doubled.

### *B.2.4 Summary*

The translations required are summarized in Table B- 1.

**Table B-1: X and Y Direction Corrections**

| cause | X direction | Y direction |
|---|---|---|
| wind | 39µm total | 68µm total |
| gravity orientation, Telescope top ring | | 940µm total |
| gravity orientation, f/16 Secondary Module | --- | 100µm total |
| gravity orientation, M2 Tilt Mechanism (specification item) | --- | 20µm total |
| gravity orientation, M2 Positioning Mechanism (translation and translation due to tilt) | --- | 40µm total |
| temperature gradient, Telescope tube, .5℃ | 244µm total | 244µm total |
| initial alignment | 1000µm total | 1000µm total |
| alignment non-repeatability | 3158µm total | 3158µm total |
| f/16 Secondary Module non-repeatability | 310µm total | 310µm total |
| total | 4751µm total | 5880µm total |

A range of 5 mm total in X and 10 mm in Y is chosen to allow for other effects in Y that may be unknown at this time.

## B.3 Z-Axis Translation

The maximum Z direction motion of the f/16 Secondary Mirror due to gravity orientation is 1.3 mm. This is due to the Telescope structure and is in one direction only. There are also additional axial shifts due to the components of the f/16 Secondary Module due to changing gravity orientation. The M2 Tilt Mechanism may deflect 3µm total (one direction in operation) due to changing gravity orientation. The M2 Positioning Mechanism may deflect 10µm total due to changing gravity orientation.

The maximum Z direction motion of the f/16 Secondary Mirror due to wind flowing in the -Z direction is 54.6µm, for the wind velocity of the operating environment of 4.5.1. The wind velocity in the +Z direction is one half that in the -Z direction. The deflection in the +Z direction is 27.3μm. The total deflection is 81.9μm.

Instrument confocality should be within 1 mm from instrument to instrument, requiring a 0.01 mm shift in the f/16 Secondary Mirror Position.

The Telescope structure will change length 0.150mm/°F, 0.270mm/°C. The maximum temperature excursion expected from 0°C is ±15°C, producing an axial shift of the f/16 Secondary Mirror of 8.1 mm total.

The f/16 Secondary Mirror paraxial radius of curvature will change with changes in the temperature of the f/16 Secondary Mirror. The maximum expected correction required is 83.6 PM total over the temperature range of the operating environment of section 4.5.1.

At initial alignment, the detachable ring on the M2 Deployable Baffle will be reground with a maximum inaccuracy of 0.20 mm.

The Z direction translations required are summarized in Table B-2.

**Table B-2: Z Axis Corrections, Slow Mode Only**

| cause | requirement |
|---|---|
| gravity orientation, Telescope | 1.3 mm total |
| gravity orientation, f/16 Secondary Mirror Assembly | 0.020 mm total |
| gravity orientation, M2 Tilt Mechanism | 0.003 mm total |
| gravity orientation, M2 Positioning Mechanism | 0.010 mm total |
| Temperature, Telescope tube | 8.1 mm total |
| wind, three sigma | 0.082 mm total |
| instrument confocality | 0.01 mm total |
| temperature effects on f/16 Secondary Mirror | 0.084 mm total |
| initial alignment | 0.20 mm total |
| Telescope Top Ring | 0.500 mm total |
| Total | 10.31 mm total |

**B.4 Tilt**

Articulation in tilt includes Chopping, fast tilt and slow tilt. Chopping operation is well documented in the *Gemini Science Requirements* document and will not be dealt with here. The input PSD for fast tilt corrections is contained in section 4.3.1.2.2 and will not be dealt with here. Only slow tilt requirements are presented in this section.

The maximum tilt of the f/16 Secondary Mirror due to changing gravity orientation (zenith pointing to horizon pointing orientation) is 1 arcsecond total (in one direction only).

The maximum tilt of the f/16 Secondary Mirror due to wind (1σ) is ±0.4 arcsecond.

For a 0.5°C temperature difference from one side of the Telescope structure to the other, there will be a tilt of the f/16 Secondary Mirror of 1.719 arcsecond total.
Dynamic alignment is covered in sections 3.3.1 and 3.3.2. The entry in Table B-3 contains pointing errors and correction for f/16 Secondary mirror decenter.

Alignment non-repeatabilities for removal, disassembly into major components, re-assembly and reinstallation of the f/16 Secondary Module are presented in section 5. The total alignment non-repeatability in tilt is 19.63 arcsecond total. The f/16 Secondary Module may be aligned, at initial alignment, with the f/16 Secondary Mirror at one side of this zone and on subsequent reinstallation it may be at the other side of this zone. For this reason, the articulation range in tilt for this component is doubled to 39.26.

The slow tilt requirements are summarized in Table B-3.

**Table B-3: Slow Tilt Requirements**

| cause | tilt, arcsecond total |
|---|---|
| gravity orientation, Telescope | 1 |
| wind, three sigma | 2.4 |
| initial alignment | 1,800 |
| alignment non-repeatability, f/16 Secondary Module | 39.26 |
| temperature gradient, Telescope tube | 1,719 |
| dynamic alignment | 58.8 |
| total | 1,903 |

# Appendix C: SECONDARY ENVELOPE

## C.1 Introduction

This appendix presents diffraction calculations pertinent to the envelope of the f/16 Secondary Module. The method used in evaluating the diffraction effects around the f/16 Secondary Mirror outside diameter and the central hole are derived from the paper "Method for calculating diffraction effects in opto-mechanical systems of arbitrary geometry" by Alan W. Graynolds, proceedings SPIE volume 257, 1980. This paper presents a method of evaluating diffraction by integrating along the edge of the aperture rather than over the entire area of the aperture. It then reduces this to performing calculations at certain points on the aperture. This method only applies in some cases and it should be consulted before using the method for any arbitrary case.

## C.2 Geometry

The geometry and terminology used in these calculations are shown in figure C-1.

Figure C- 1: Geometry and Terminology for Calculations

The aperture is circular for our application. It has a radius of R. Vectors describing the distance from the plane of the aperture to the source and from the plane of the aperture to the observation point are shown. Unit vectors in these directions are defined from relations

and

Two more unit vectors are required for the calculations. One is the unit vector in the direction from the point of integration directed towards the local center of curvature of the aperture. This unit vector is denoted as . The other is a unit vector in the direction of the path of integration at the point being integrated. This unit vector is not shown in figure C- 1. This unit vector is

denoted by

**C.3 Calculation Method**

The total field at the observation point is the sum of the geometric field and the diffracted field.

The geometric field has a value of in the region directly illuminated by the source and a value

of zero in the shadow region. The field at the observation point for our case is found by evaluating the diffracted field only.
The equation for the diffracted field may be written as

Where , and I is the path of integration along the aperture edge. This integral can be approximated by

where

and

a(l) is the incident amplitude

The contribution from the end points of the integration win be zero. The last term's contribution will be negligible and will be neglected. The equation for the diffracted field is then approximated

Noting that this expression becomes

Expressing a diffracted field for each point as

The approximation for the diffracted field may be expressed as

The points at which this equation will be evaluated are determined from

There are two points at which this is true. They are at (O,-+R,O). The vectors for these two points
are

The unit vectors and are found by dividing the expressions for the vectors by their magnitudes. The terms in the expression for the diffracted field may now be calculated. Begin with point 1, (O,+R,O). Recalling that

Terms in the numerator include

Terms in the denominator include

Another term to be evaluated is

The first term in this expression is

The second term is

The third term is

The complete expression for is

The sign of this expression will have to be evaluated for each point under consideration. The contribution from point I to the diffracted field is now completely known in terms of the geometry of figure D- I and the source strength .
The expressions for the point 2 are evaluated in the same way. The results are

and

The energy incident on the observation point due to the diffracted field is equal to the field squared.

The energy that would be incident on the observation point from the source located as shown in figure D- I if no obstacle were present is equal to the geometric field squared

Where d is the distance from the source to the observation point.

This expression allows comparison between the energy diffracted onto the observation point from the source to the energy that would fall on the observation point if no obstacle were present.

### C.4 V16 Secondary Assembly Envelope