STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY (SOFIA)

TELESCOPE ASSEMBLY (TA) REQUIREMENTS

SOF-1011

June 24, 2013
Date: Revision: 8.2

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TELESCOPE ASSEMBLY (TA) REQUIREMENTS

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REVISIONS

Revisions to the document from the previous issue are denoted by vertical bars in the margin of the page. This page supersedes the original revision history contained in the document.

REVISION HISTORY
(CHANGE RECORD)

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY

DOCUMENT TITLE: SOFIA Telescope Assembly (TA) Requirements

DOCUMENT NO.: SOF-1011 **CONTROL NO.:**

REV. NO.	DOCUMENT CHANGE REQUEST NUMBER	REVISION DATE	DESCRIPTION
1		Sept. 1988	
2		Feb. 1989	
3		Oct. 1990	
4		Dec. 1990	
5	DCR-5	Nov. 1995	This revision represents an extensive reformatting of this document with all paragraphs being affected. Therefore, all pages within the text are annotated with "Revision 5" and each individual change is not recorded hereon.
6	DCR-6	May 1996	Revision 6 reflects a refinement of changes made in Revision 5. Text changes between the two revisions are indicated.
7	SCN-1011-001 (DCRs 0001.R1, 0002, 0003, 0004, 0005, 0009, 0011, 0018, 0019, 0020, 0021, 0023, 0028, 0030, 0033, 0036). SCN-1011-002 (DCRs 0008.R2, 0014.R1, 0015.R2, 0017.R1, 0041, 0043, 0045.	Jan. 2000	Changes per noted DCRs

REVISION HISTORY
(CHANGE RECORD)

STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY

DOCUMENT TITLE: SOFIA Telescope Assembly (TA) Requirements

DOCUMENT NO.: SOF-1011 **CONTROL NO.:**

REV. NO.	DOCUMENT CHANGE REQUEST NUMBER	REVISION DATE	DESCRIPTION
7 (cont.)	SCN-1011-003 (DCRs 0010.R1, 0024.R1, 0025.R2, 0027.R1, R1, 0047, 0055R1.	Jan. 2000	Changes per noted DCRs.

DEVIATION / WAIVER CHANGE RECORD

REV. NO.	DEVIATION / WAIVER NO.	DATE	DESCRIPTION
7	SOF-RFW-MT-001	94/11/97	3.12.8 Castings
7	SOF-RFW-MT-005	04/27/98	3.3.8 Optical Materials and Coatings

REV	DATE	DESCRIPTION	APPROVAL
8	Nov-08	Changes per noted DCRs. Reflects clarification in the pointing stability requirement. Reflects changes for the WFI, FFI, and FPI tracking stability. Reflects changes from MCS to MCCS implementation for Flight Test Segment 2. Incorporates the following list of approved DCRs: SCN-1011-004 (SOF-DCR 0013.R2, 0022.R3, 0026.R2, 0060, 0064, 0066, 0106.R1, 0124) SCN-1011-005 (SOF-DCR-0058.R2, 0145, 0148, 0165, 0166, 0167)	PMB 11/2008
8.1	Apr-2012	Delete requirement 3.3.14.3.7.13 for a “>15 kHz” clock, pg. 31	PMB 4/16/2012 PRG-CCR-109
8.2	June 24, 2013	Refine and restore requirement 3.3.14.3.7.13 for a 40 kHz chopper control clock. Clarify ambiguous, TA-centric and context-sensitive usage of “internally furnished” and “externally furnished” by adding annotation to define whether the synchronization signals is furnished by the TA (SCS) or SI.	PMB 6/24/2013 PRG-CCR-134

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1.0 SCOPE

1.1 PURPOSE

This document defines the performance and development requirements for the SOFIA Telescope Assembly (TA), including design, fabrication, test, product assurance, shipping, handling and storage.

1.2 OBJECTIVE

The SOFIA development program objective is to develop, integrate, and successfully test an airborne astronomical observatory which meets all of its performance requirements and is designed for an operational lifetime of at least 20 years.

1.3 OBSERVATORY DESCRIPTION

The following description provides a defined orientation of the SOFIA Observatory (Figures 1 and 2).

The SOFIA airborne observatory will be a high sensitivity, high resolution optical/ infrared/submillimeter TA mounted in a high-performance wide body aircraft, to be used for many basic astronomical observations performed at stratospheric altitudes. This facility will accommodate installation of different focal plane instruments with in-flight accessibility, provided by investigators selected from the international science community. The Telescope Assembly (TA), the Aircraft System (AS), and the Mission Controls and Communications System (MCCS) together will constitute the airborne observatory which will allow celestial observations to be made at or above 41,000 feet (12.5 km) for periods of at least 6 hours and for periods up to 13 hours using a combination of altitudes. Observations will be made in the spectral range of 0.3 to 1600 micrometers through an open full aperture door on the port side of the aircraft.

1.3.1 Telescope Assembly

The SOFIA TA will be a 2.5-meter clear aperture telescope of generic Cassegrain design, with provisions for Nasmyth focal plane mounting of science instruments, and will include supporting control, monitor, and communications equipment. The TA will consist of the following elements:

(a) The Telescope Optical Assembly, including: the Primary Mirror and Mount, Secondary Mirror Assembly (including chop/scan, center and focus mechanisms), Tertiary Mirrors and Assembly, Spiders, Baffles/stops,

Metering Structure, Wide Field Imager (WFI), Fine Field Imager (FFI), and associated wiring provisions.

(b) The Telescope Flange Assembly, including: Pressure Window Assembly, Science Instrument Interface Provisions (e.g., mounting, access, pneumatic line/cable interfaces), Focal Plane Imager (FPI), Torquer/Gyro Assembly, TA Balancing subsystem (coarse and fine), and associated wiring provisions.

(c) The Suspension Assembly including: Rotation Isolation Subsystem (RIS), Vibration Isolation Subsystem (VIS), Nasmyth Tube, Pressure Equalization/Sealing Subsystem, Braking and Caging Subsystem, Coarse Elevation Drive, Cable/Hose Load Alleviation Subsystem, Interfaces, and all associated wiring, tubing, and connectors.

(d) The Stabilization, Tracking and Monitoring Subsystem including: controls electronics for all TA functions associated with TA operation (start up sequences, shutdown, safety interlocks, stabilization, tracking, monitoring, electronics packaging, communications, system wiring, parts and sensor selection, TA temperature control provisions, power distribution, software development, etc.).

(e) Integration and Testing of the TA including: Planning, Integration, Checkout and Test, Data Analysis, Reporting and Documentation.

Figure 1. Telescope Assembly Reference Concept

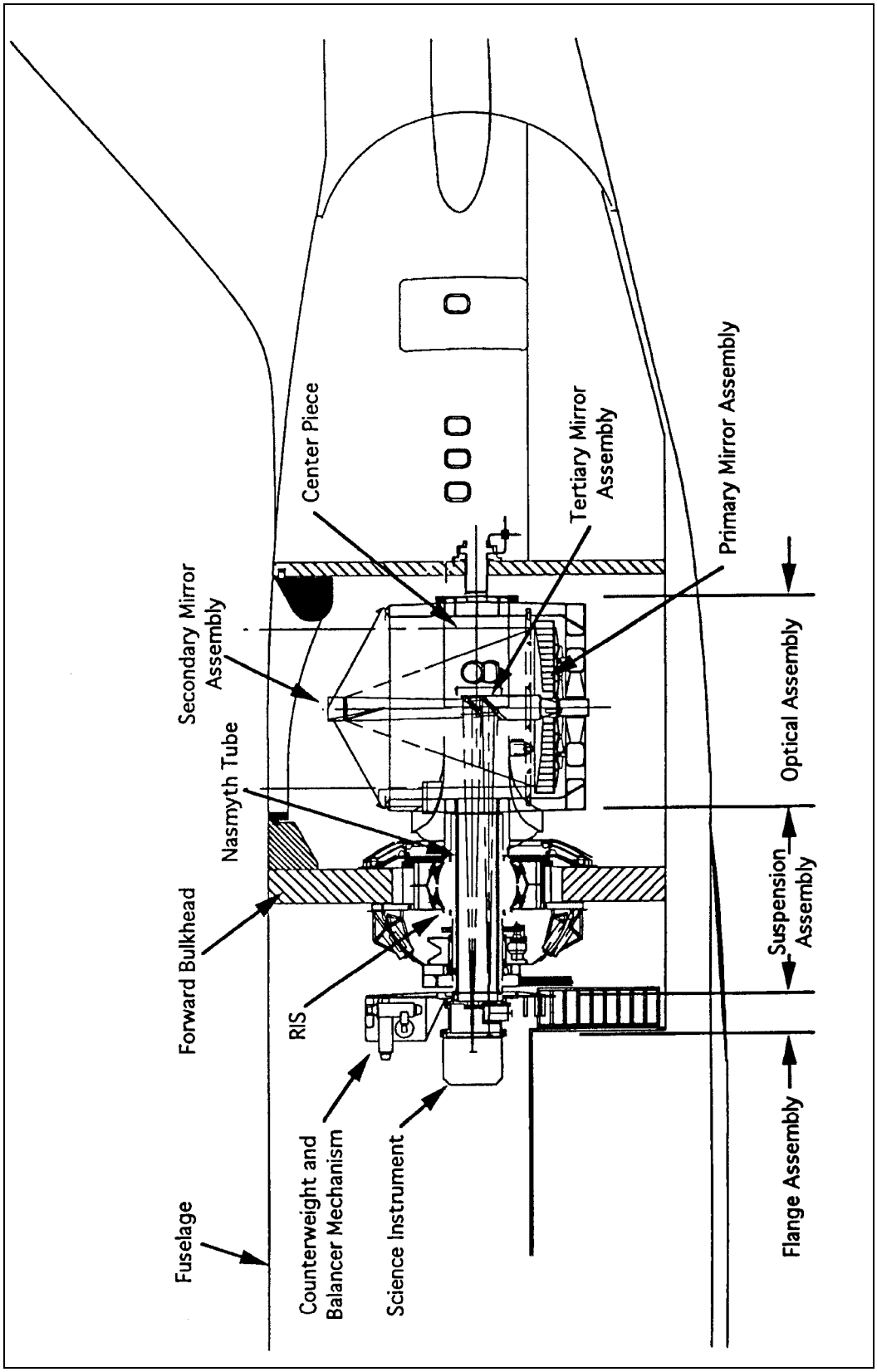
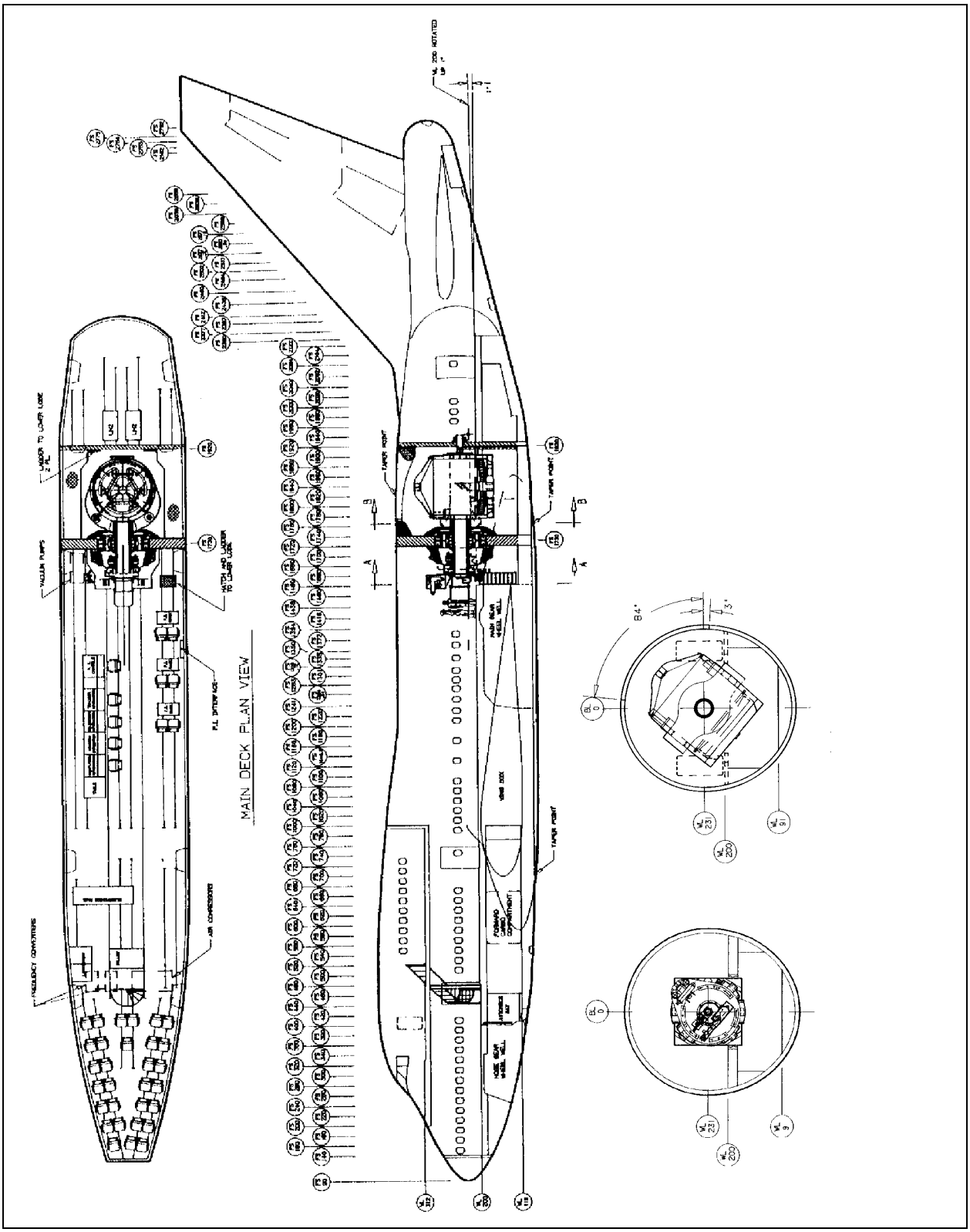

Fuselage
Forward Bulkhead
Nasmyth Tube
Secondary Mirror Assembly
Center Piece
Counterweight and Balancer Mechanism
RIS
Science Instrument
Tertiary Mirror Assembly
Primary Mirror Assembly
Flange Assembly
Suspension Assembly
Optical Assembly

Figure 2. Aircraft System Layout Reference Concept



1.3.2 Aircraft System

The Aircraft System (AS) will be a Boeing 747 type aircraft modified for the SOFIA mission. The AS modifications will include a reinforced fuselage cutout to accommodate the full TA aperture and its range of motions, installation of a fuselage cutout, installation of a movable aperture door mechanism, incorporation of a shear layer control subsystem, incorporation of structural support members to carry the telescope on the pressure bulkhead, re-routing of control cables and other aircraft subsystems, modification of the aircraft electrical power distribution system, addition of mission control equipment, removal of unnecessary airline service type equipment where appropriate, and other changes to the basic aircraft to provide a reliable, efficient, and stable observatory. SOF-1010 provides the detailed Aircraft System requirements. The Aircraft System will provide the airborne cavity cooling, purging and heating system as well as the ground-based cavity precool system and cavity interior ducting provisions.

1.3.3 Mission Control and Communication System Software Description

The MCCS has been described as being the nerve center of the Observatory platform. This system provides inputs, and monitors the status of the Telescope Assembly (TA), Cavity Door Drive System (CDDS), Cavity Environmental Control System (CECS), and autopilot. Subsystems found in the MCCS provide for mission communication, power distribution, data acquisition, data archival, network services, and observatory crew interface. Without the MCCS, the observatory would fail to function as an integrated unit. A more detailed description of the subsystems found in the MCCS are described in greater detail below.

(a) <u>Platform Interface Subsystem (PIS)</u>

This subsystem provides the control and monitoring functions between the MCCS and the TA, CDDS, and autopilot. It also provides the mission management (coordinate transforms etc.) as well as the MCCS session manager functions. The computer software configuration items associated with the PIS include:

- Session Manager
- CDDS Proxy
- TA Proxy
- Coordinate Transforms
- Flight Management System (FMS)/Autopilot proxy
- Avionics ARINC 429 data collection Task (Internal Data)
- Built-In-Test (BIT)
- PIS configuration/redundancy management
- SOFIA Command Language (SCL) Interpreter
- Common Object Request Broker Architecture (CORBA) configuration

VxWorks Kernel Configuration
Help Utility

(b) Data Acquisition Subsystem (DAS)

This subsystem gathers a combination of analog sensor data and aircraft avionics data provided via the aircraft ARINC 429 data buses and provides the data to the archive subsystem, mission workstations, and science team computers. This subsystem also provides the user defined audio alert interface between the MADS and the MCCS. The computer software configuration items associated with the DAS include:

Avionics/aircraft data collection proxies
Power Distribution System (PDS) data collection proxy
Temperature Sensor Proxy
Pressure Sensor Proxy
CECS Proxy
MADS Alerts/Alarms
Data Archiving
BIT
Data Acquisition Subsystem configuration/redundancy management
CORBA configuration
VxWorks Kernel Configuration

(c) Archive Subsystem (ARS)

This subsystem collects and archives information transmitted by the DAS, PIS, VDS, IRIG B distribution system, and science team computers (if provided). It retrieves data from the Archive and transmits the resulting data to the Mission workstations and/or science team computers upon request. The computer software configuration items associated with the Archive Subsystem includes:

Archive Manager
Naming Service
Session Daemon
RAID services
BIT
CORBA configuration
VxWorks Kernel Configuration

(d) Video Distribution Subsystem (VDS)

This subsystem collects imager data provided by the TA, archives, and distributes the data to the mission workstations. It also provides an overlay capability from the workstations.

Telescope Assembly Imager Processor
Graphics Overlays
Imager Data Archiver
Housekeeping Data Archiver
Imager Frame Archiver

Image Distribution – Network
Video Playback
Video Input control
Audio recording and playback
BIT
Video Distribution Subsystem configuration/redundancy management
CORBA Configuration
VxWorks Kernel Configuration

(e) Mission Workstations (WS) and Displays

This subsystem provides user defined displays and control interfaces between the observatory observation team and other MCCS platform subsystems. The workstations also provide basic office automation applications including email, web browsing, document creation/editing, and the generation of presentation slides.

Workstation Graphical User Interfaces (GUIs)
- Mission Director
- Telescope Assembly Operator
- Alternate Telescope Assembly Operator
- Principal Investigator
- Computer Operator Workstation
- Education and Public Outreach
- Alternate Telescope Assembly Operator

PIXY
Observation Queue
Tweaker paddle control
Flight Planner
Interface to Help Utility
GUI Generation/Modification Tools
Workstation/MCCS Integration
Networking Services
File/Office Productivity Application
TA Image Data Display/Overlay generation Utilities
BIT(s)
CORBA Configuration
JAVA Configuration
SOLARIS Operating System Configuration

(f) Mission Audio Distribution Subsystem (MADS)

The Mission Audio Distribution System (MADS) is a fiber optic multiple channel communication system that allows crew members and operators to communicate with each other. The system is a proprietary system being developed in house by L-3 Communications and contains embedded software.

MADS Software Configuration
SOFIA/MADS Interface Software Configuration

MADS SOFIA Configuration

(g) Network (NW) Connectivity and Operations

This subsystem provides the network connectivity and firewall provisions needed to support the observatory mission and web connectivity while the aircraft is on the ground.

Network Firmware Configuration
Network Internet Protocol Address Configuration
Network Firewall Configuration

(h) Water Vapor Monitor (WVM)

This software controls the hardware that measures the amount of water vapor remaining in the atmosphere above the aircraft. The software that controls and monitors the Water Vapor Monitor is a standalone subsystem of the MCCS, but communicates with the MCCS via ethernet to provide column density of water vapor along the TA line of sight.

(i) Power Distribution Subsystem (PDS)

This subsystem provides the power/uninterruptible power supply capabilities for selected observatory components. The current PDS system design does not include provisions for software. Potential design changes include the requirement for load shedding. Implementation of the load shedding design may generate the requirement to include software in this subsystem design.

(j) NTP/IRIG Time Distribution System

This subsystem provides the IRIG-B distribution to MCCS components via either a Pulse Code Modulated data stream or via a Network Time Protocol Server (NTP). The most likely implementation of this subsystem is a commercial off the shelf based product.

(k) Common Architecture Items

This configuration items handles the generic systems that exist across multiple platforms. These items include the Adaptive Communication Environment (ACE)/Common Object Request Broker Architecture (CORBA) infrastructure is pervasive throughout the MCCS. It provides for the communication between subsystems associated with the MCCS. The second common architecture item are the MCCS XML configuration files. Since these infrastructures cross subsystem boundaries within the MCCS it is critical that they be correctly and consistently configured in order to make the system operate correctly.

1.3.4 Mission Support System and Operations

The SOFIA Mission Support System and Operations (MSSO) will be comprised of three major elements: The Ground Support Facility (GSF), the Mission

Support Equipment, and Operations Planning. The GSF includes a hangar for a 747 aircraft, mirror stripping/coating facility, storage for Ground Support Equipment, and laboratories and offices for scientists and support personnel. The Mission Support Equipment will contain airborne and ground support equipment to maintain and support the basic aircraft and telescope. Operations Planning will consist of flight, ground, science, and administrative support planning for SOFIA's operational phase. SOF-1051 will provide a detailed description of the MSSO.

1.4 CONTENT STATUS

This document may contain requirements with unspecified or preliminary values. In such cases, a "TBS" denotes a requirement to be supplied through DLR by the NASA SOFIA Project Office. A "TBD" denotes a requirement to be determined by the TA Contractor with DLR approval. Where a TBS or a TBD is followed by a value in parentheses, this denotes a preliminary value.

The following TBS/TBD items are in effect in this revision:

Paragraph	Type	Description
None		

1.5 REQUIREMENTS CHANGE PROCEDURE/APPROVAL

Changes to specifications and TBD/TBS values contained herein may only be accomplished by the NASA SOFIA Project Office following DLR approval. Upon DLR acceptance of a proposed change, a change notice or document revision will be generated.

2.0 APPLICABLE DOCUMENTS

The following documents of the latest issue at date of contract (unless otherwise specified) form a part of this specification to the extent specified herein. The documents are applicable to the extent they apply to the TA design as developed by the Contractor. The Contractor may propose an equivalent document (subject to DLR approval) for any or all of the documents. Requirement documents are annotated with an (R), guideline documents are annotated with a (G), and reference documents are annotated with (Ref.). The Contractor is encouraged to utilize the Guideline documents to the fullest extent practicable since they provide useful technical criteria.

2.1 NASA DOCUMENTS

(Ref.) SE01-005	SOFIA Mission Control and Communications System and Related Requirements
(R) SOF-1030	SOFIA Systems Interface Requirements
(G) AHB 5333.1	Establishment of Software Assurance Program
(G) NHB 6000.1	Requirements for Packaging, Handling and Transportation

2.2 SPECIFICATIONS

(G) MIL-W-5088	Wiring Aerospace Vehicle
(G) MIL-H-83282	Hydraulic Fluid, Fire Resistant, Synthetic Hydrocarbon Base, Aircraft
(G) MIL-P-87210	Pneumatic Power Systems, High Pressure
(G) MIL-SP-130	Identification and Marking of Property

2.3 STANDARDS

(R) MIL-STD-461	Electromagnetic Emission and Susceptibility Requirements for Control of Electromagnetic Interference
(R) MIL-STD-462	Electromagnetic Interference Characteristics, Measurement of
(R) MIL-STD-704	Aircraft Electric Power

(G) MIL-STD-810	Environmental Test Methods and Engineering Guidelines
(G) MIL-STD-882	System Safety Program Requirements
(R) MIL-STD-1515	Fastener Systems for Aerospace Applications

2.4 HANDBOOKS

(R) MIL-HDBK-5	Metallic Materials and Elements for Aerospace Vehicle Structures
(R) MIL-HDBK-17	Plastics for Flight Vehicles
(G) MIL-HDBK-454	Standard General Requirements for Electronic Equipment
(G) MIL-HDBK-791	Maintainability Design Techniques
(G) MIL-HDBK-1472	Human Engineering Design Criteria
(G) MIL-HDBK-5400	Airborne Electronic Equipment, General Requirements for

2.5 OTHER DOCUMENTS

(R) FAR PART 25	Airworthiness Standards: Transport Category Airplanes
(G) AC 25-10	FAA Aircraft Circular on Compliance with FAR Part 25
(R) ISO 9001	Quality Systems - Model for Quality Assurance in Design, Development, Production, Installation, and Servicing
(R) ISO 9000-3	Software Quality Assurance
(G) RATC-160	Environmental Conditions and Test Procedures for Airborne Equipment
(R) ANSI C-X3-J11	Programming Language C
(R) CFR Title 29	Chapter XVII, Part 1910 Code of Federal Regulation, Subpart Z, Toxic and Hazardous Substances

(R) FEDERAL STD No. 595 Colors

3.0 TELESCOPE ASSEMBLY PERFORMANCE/DESIGN REQUIREMENTS

3.1 TELESCOPE ASSEMBLY GENERAL REQUIREMENTS

The TA shall be designed and built to be installed in an unpressurized cavity located in the aft fuselage section of a Boeing 747 aircraft. The TA shall be configured and sized such that, when installed, the Telescope Optical Assembly nominal line-of-sight is normal to the aircraft longitudinal centerline, its required full elevation range is achieved, and its required operating unvignetted dynamic range is met. A vibration isolation subsystem shall be included with the TA to attenuate the effects of aircraft structure borne vibrations. The articulating portion of the Telescope Assembly shall be designed to be supported by a rotational isolation system mounted in the bulkhead separating the cabin from the unpressurized cavity. It shall be counter-balanced on the pressurized cabin side of the bulkhead by balance weights, Science Instrument (SI) assemblies, and other structural members necessary to support components and assemblages required for proper operation. The rotational isolation system (e.g., spherical air bearing or other suitable design) and its interfaces to the pressure barrier bulkhead shall form the necessary seal between the pressurized aircraft cabin and the cavity, which will be allowed to follow outside ambient pressure and temperature at observational altitudes. The TA shall be operable within specifications at prevailing environmental conditions from sea level to 45,000 ft (13.7 km), and shall remain operable after exposure to 4000 altitude cycles over a 20-year period.

Detailed TA interface and environmental requirements are described in document SOF-1030, “SOFIA Systems Interface Requirements,” and its associated Interface Control Documents (ICDs) and references.

The TA shall be calibrated and in condition to perform all intended functions to full capability and accuracy when it is delivered for integration with the SOFIA AS and MCCS. The TA shall be designed with minimal need for calibration or servicing after each flight. Where calibration or servicing is necessary, design and packaging shall provide means for re-calibration or servicing with minimum disassembly, removal, or replacement of subsystems or parts, or modifications which would necessitate any substantial re-testing before reintegration with the SOFIA AS and MCCS. Any subsystems which may require such routine servicing shall be located within the pressurized aircraft cabin, insofar as possible.

The TA shall be designed so that integrated assembly and test operations can be accomplished at the Contractor's facility prior to shipment, with it being subsequently disassembled as necessary for shipment and reassembled and installed in the AS with minimal effort.

3.2 MECHANICAL SUBSYSTEM

3.2.1 Telescope Assembly Mechanical Subsystem Description

The TA mechanical subsystem described in this section includes all mechanical, optical and structural elements of the Telescope and all of its integrated or distributed parts which are mounted on the AS bulkheads (i.e., not supporting elements such as control electronics, pumps, or other auxiliary support subsystems). Primary elements include the mirrors/mounts, metering structure/ centerpiece, Nasmyth tube, RIS, VIS, torquers, imagers, gyro assemblies, counterweights, brakes, and instrument mount.

3.2.2 General Requirements

The TA shall be designed to be compatible with the system loads, disturbances and limits described in SOF-1030. Proper materials, sizes, attachment schemes, and configurations of assemblies shall be used in the TA with emphasis placed on the following attributes:

a) Highest structural stiffness-to-inertia ratio practicable to reduce vibration and aero-torque disturbance effects and to reduce control system complexity and risks to acceptable levels.
b) Thermally stable design with materials selected to be exposed to the expected aerodynamic environment and to operate at pressures from sea level to 45,000 feet altitude and at temperatures between 310 and 210 Kelvin, including operation under clear-weather ground ambient conditions.
c) Minimal stiction and coulomb friction effects on the control system.
d) Maximized viscous damping coefficient for structural modes by judicious selection of materials and attachment schemes, while staying within constraints imposed by other critical requirements.
e) Minimized coupling of the TA to the aircraft by wires, tubes, seals, etc.
f) Operation over a 20 year period, at a level of 960 hours of research flights per year, with specified safety factors for operating and emergency loads (loads given in SOF-1030).
h) Ease of installation/disassembly with the AS to allow for periodic maintenance and primary mirror recoating.
i) The TA should be designed to operate continuously in flight for the maximum 15-hour flight duration. Time required for routine servicing of the telescope during normal flight operations should be minimized. Routine servicing time for the telescope should not be the limiting factor that determines time spent on the ground between flights. The telescope should be capable of operating for testing, maintenance, and other activities (with cavity door closed if necessary), within no more than two hours, with a goal of one hour, after landing.

3.2.3 Telescope Mounting

The TA will be mounted on the forward AS pressure bulkhead. The bulkhead and the TA will serve as the pressure and thermal barrier between the pressurized aircraft cabin and the outside ambient conditions in the TA cavity at altitude. The TA shall include all sealing provisions inside the pressure seal/bulkhead attachment interface (e.g., Rotation Isolation Subsystem (RIS), flexible seals, etc.), including the instrument mount pressure seal and the pressure window mechanism seals. Emphasis shall be placed in designing the TA mounts and seals to maximize personnel and equipment safety and to minimize seeing degradations. Air leakage through the TA pressure barrier shall be limited to no more than 50 lb/hr (22.68 kg/hr) of cabin air, or equivalent, with a goal of zero leakage into the cavity.

The aft bulkhead will serve as the aft cavity wall and may be used to mount a TA braking/caging mechanism. Any TA part mounted on the aft bulkhead and penetrating it shall be designed to seal against the expected pressures and be thermally insulated to permit cooling of the cavity on the ground. (Refer to SOF-1030 for interface details).

3.2.4 Vibration Isolation Subsystem

The TA support structure shall be isolated from the AS forward bulkhead through a Vibration Isolation Subsystem (VIS) designed to attenuate the structure-borne AS vibrations to levels tolerable to the TA structure, pointing system, and science instruments. The vibration transmissibility characteristics for each axis shall be attenuated to reduce the random disturbances caused by the AS, and to reduce the resonance effects caused by TA structural modes to levels commensurate with the TA tracking and stabilization system capabilities. Special attention shall be given in designing the VIS to prevent drive torque disturbances which cause unacceptable displacements of the TA support structure. AS input vibration levels, other TA loads environments, and vibration levels acceptable to SIs are given in SOF-1030. In addition, the TA shall provide any load alleviation device(s) required to minimize TA and SI cable load inputs into the TA structure; such devices, if used, shall interface with the AS structure and SI cables in accordance with SOF-1030.

3.2.5 Telescope Assembly Brakes

A failsafe braking mechanism (applied with no active power) subsystem shall be incorporated to provide a positive means for automatic stopping and holding of the TA at any position in all 3 axes of rotation. The mechanism (or a separate caging unit) shall be capable of safely holding the TA in place during taxi, takeoff, turns between observing legs, descent and landing maneuvers, and during TA maintenance/set-up activities. SOF-1030 provides the brake subsystem interfaces with the AS.

3.2.6 Telescope Assembly Balance

To accommodate varying science instruments, depletion of cryogens, changing TA elevation angles, or other factors affecting the TA center of gravity location, a TA balancing system shall be provided. Automated fine balance shall be furnished. A manually processed coarse balance scheme may be implemented.

3.2.7 Science Instruments Accommodations

The TA shall function as required with any SI within the limits given below mounted at the instrument mounting flange. Attenuation of aircraft vibrations shall be as required in Paragraph 3.2.4. (Science instruments and other SI installation equipment will conform to the volume defined by the aircraft floor, walls, and ceiling and the TA range of motions).

For design and testing purposes the following conditions shall be assumed relative to SIs:

SI mass range:	0-600 kg
SI volumetric envelope:	(Deleted - refer to ICD)
SI c.g. location:	longitudinal: 1.0 m forward to 50 cm aft of the SI mounting flange Radial: within a cone shaped moment envelope defined by connecting adjacent points with straight lines in Figures 3.2.7-1 and 3.2.7-2. The shape of the envelope is influenced by the mass of the SI electronic rack located on the balancing subassembly of the TA. Two envelopes are given: – considering a mass of the SI-rack of 150 kg (normal condition) – considering a mass of the SI-rack of 100 kg (heavy Science Instruments, that will not fit within the normal envelope) Figure 3.2.7-1 shows the maximum moments caused by cg-variation in V-direction. Figure 3.2.7-2 shows the maximum moments caused by cg-variation in W-direction.

The SI envelope is defined by a cone shaped by these axes.

SI aperture location: (Deleted - refer to ICD)

SI mass change: (Deleted)

Figure 3.2.7-1. Maximum Moments Caused by cg-Variation in V-Direction

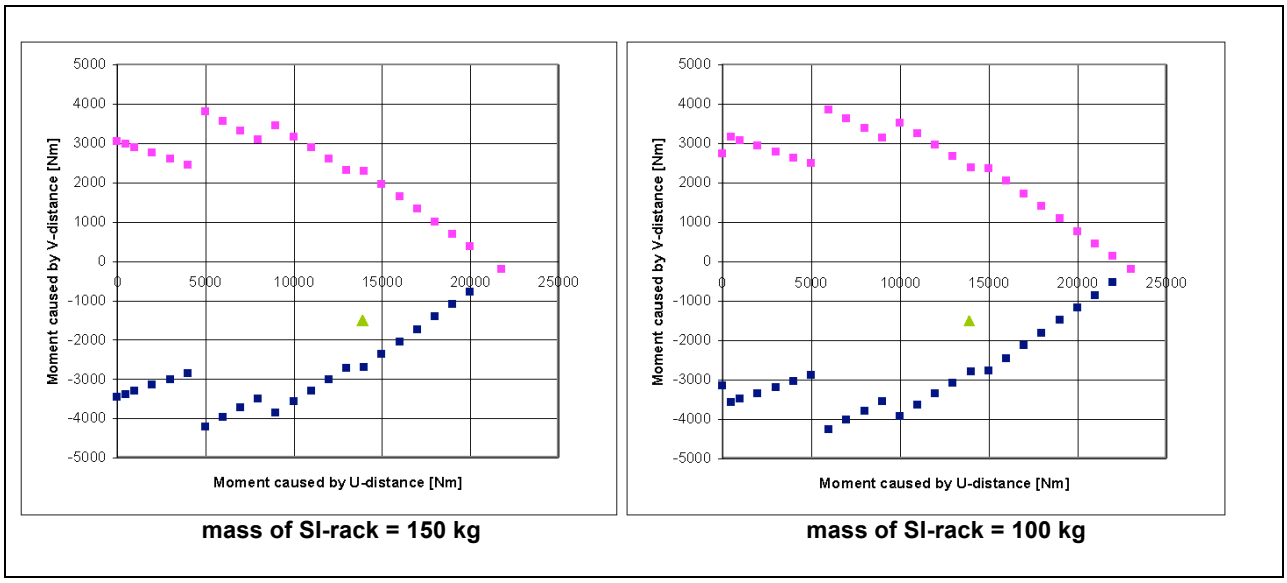
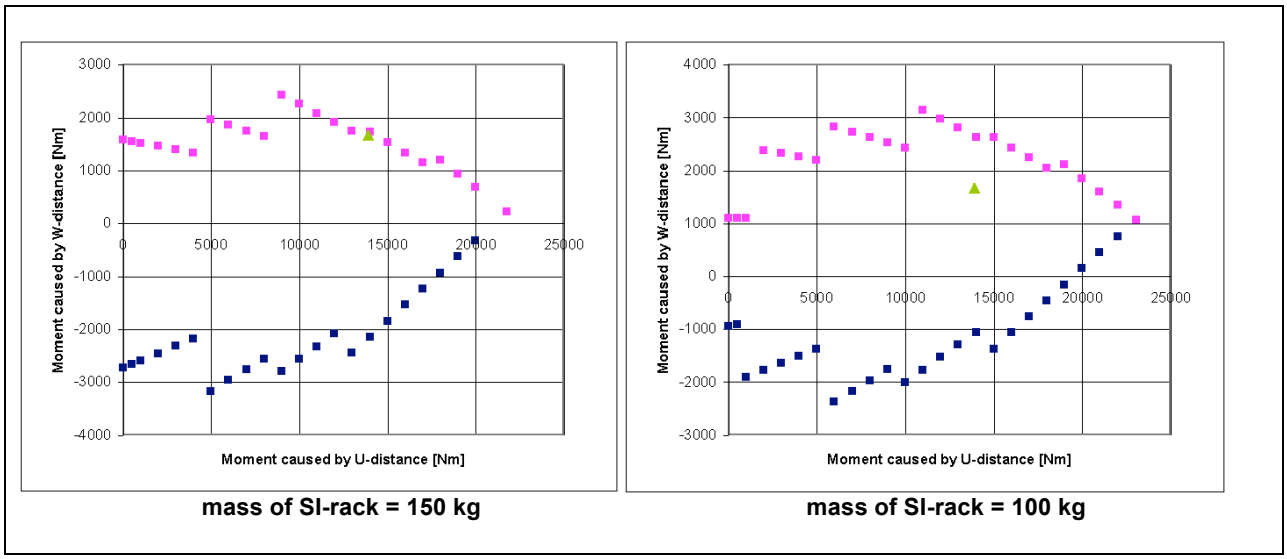


Figure 3.2.7-2. Maximum Moments Caused by cg-Variation in W-Direction



3.2.7.1 Science Instrument Mounting Flange

A flange for SI mounting with sealing provisions for open port use shall be provided 30 cm, ±40 mm, aft of the nominal Nasmyth focus. Figure 3 depicts the general mounting location on a representative TA configuration. Detailed TA/SI interface requirements on the TA are addressed in SOF-1030.

3.2.7.2 Changeout

The SI mounting flange shall be designed with clear access to the SI attachment fasteners, so as to allow attachment of an instrument to the flange, or removal of an instrument from the flange, in less than 2 hours, with a goal of 1 hour.

3.2.8 Telescope Assembly Mass Limit

3.2.8.1 Integral Telescope Assembly Subsystems Supported on AS Cavity Bulkheads

The portion of TA mass which is supported by the forward AS cavity bulkhead shall not exceed 16,800 kg (including the SI and balance weights). The limit for the TA mass on the aft bulkhead shall be 200 kg.

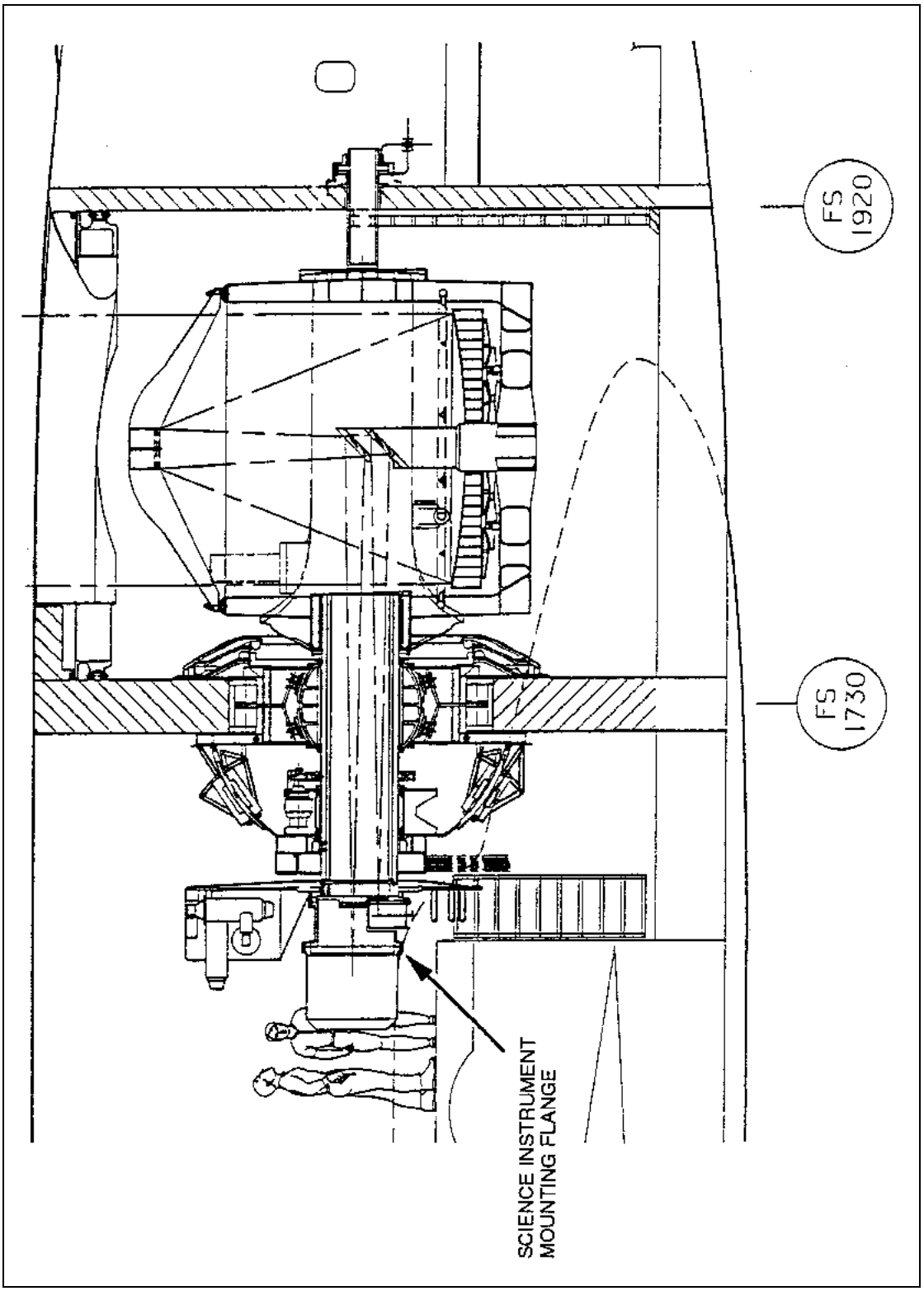
3.2.8.2 Other Subsystems

The mass of all TA subsystems not supported on the AS cavity bulkheads shall not exceed 3000 kg (for example controls/displays/electronics, compressors, cabling/ tubing, etc.).

3.2.9 Telescope Assembly Size Limit

The TA size shall be such that, with the SI size given in Para. 3.2.7, its dynamic envelope nowhere intrudes into the dynamic envelope of the AS in the cavity, cabin, and bulkhead(s), with the exception of the physical interface locations (reference SOF-1030 and associated ICDs).

Figure 3. Science Instrument Mounting Locations – Reference Concept



3.3 TELESCOPE OPTICAL ASSEMBLY

3.3.1 Telescope Assembly Optical Assembly Description and General Requirements

The TA shall be a generic Cassegrain with a Nasmyth focii arrangement, consisting of figured primary and secondary mirrors, and two flat tertiary mirrors, one of which shall be dichroic. It shall include a removable and remotely controlled articulating secondary mirror assembly, and removable (for recoating) primary and tertiary mirrors. The integrated total optical system shall consist of the main telescope and two auxiliary smaller telescopes, mounted to and boresighted with the main unit, used to furnish sky and target information to cameras associated with the target acquisition and tracking systems (unless a single auxiliary telescope and camera system can provide all of the required functions of two). Support apparatus and optical subsystems shall be provided for components protection, components maintenance, systems collimation and calibration, target acquisition and monitoring, and target tracking.

3.3.2 Thermal Requirements

3.3.2.1 Temperature Range Tolerance

The Telescope Assembly structure and optical elements shall be capable of being precooled from ambient local temperatures on the ground to temperatures between 220K and 250K. Temperatures shall be sensed at appropriate locations on the Telescope Assembly and provided to the MCCS for display at the workstation console (see SOF-1030 for interfaces).

3.3.2.2 Temperature Deviation

To limit seeing effects at observing altitudes, all sections of all TA surfaces within 50 cm of the IR beam path which are exposed to cavity air, including the mirror surfaces, shall operate (steady-state conditions) at temperatures within -10 and +2 degrees K of the mean recovery air temperature in the cavity. Active blowing or cooling may be used to minimize temperature and convective turbulence in the optical path. These surface temperature requirements do not apply to any TA surfaces on the cabin side of the pressure window assembly.

The interior of the Nasmyth tube, as far forward as the pressure window assembly, shall be insulated or cooled to avoid heating cavity air which will circulate in this volume. The entire inner surface of this insulation shall operate between -10 and +2 degrees K of the cavity recovery temperature, and shall present a rough-textured surface to minimize scattered radiation. (This inner surface shall have a total hemispheric reflectance ≤ 0.05 and a specular reflectance ≤ 0.001 at all wavelengths $\leq 70\ \mu$m.) Thermal control forward of the pressure window assembly is not required as part of the TA.

3.3.2.3 Temperature Distribution

The spatial variation of temperatures on and within the mirrors shall be made sufficiently small to meet the image quality requirements for the TA. In addition to the requirements on the temperature distribution needed to maintain the optical image quality, infrared background suppression shall require that the temperature differences across the reflecting primary mirror surface be less than 10 degrees K. This requirement shall be met after rapid changes in the steady state recovery air temperature in the cavity as detailed in SOF-1030.

3.3.2.4 Thermal Time Constant

The thermal time constant (time for response to step function change to reach 63.2% (1-1/e of final value) of the telescope structure and optics surfaces exposed to cavity air shall be less than 2 hours, as a goal. Time constant here shall be defined using a step change in cooling media temperature from 293K to 245K and media velocity of 5 m/sec over one side of all structural and optical elements at sea level ambient conditions. The primary purposes of this time constant goal are to minimize the time required for cooling the telescope prior to flight and to minimize effects of thermally driven cavity seeing. Active devices (e.g., fans) may be used on the TA as flow aids. Consideration shall be given to an "open" structural design which allows good air circulation to critical components.

3.3.2.5 Heat Transfer to Cavity Air

The total allowable heat input to cavity air due to all TA sources (e.g., conduction through TA subsystems at any location whether inside or outside the cavity, TA mechanism heat dissipation, plus any residual air leakage from the cabin) shall be ≤ 2000 Watts for the nominal cavity and cabin operating temperatures (245K and 293K, respectively). Appropriate design, materials and insulation shall be used as needed to meet this requirement.

3.3.3 Spectral Range

The TA operating spectral range shall be 0.3-1600 micrometers with no change of optics and using a purely reflecting tertiary.

3.3.4 Image Quality

Requirements for image quality are expressed in terms of contributions to the diameter of a circle enclosing 80% of the energy from a stellar image at a wavelength of 0.633 micrometers at the IR focus. This value is termed the "image diameter" and is referenced to astronomical object space. The total image diameter is defined to be the square root of the sum of the squares (RSS) of the individual contributions listed below.

3.3.4.1 On-Axis Image Quality

The TA optics and structure shall contribute no more than 1.5 arcseconds to the image diameter when the full aperture is used, for an image at the center of the field-of-view. This specification shall include: diffraction from the aperture, the central obstruction and the secondary support structure; aberrations inherent in the optical design, from imperfections in the mirror surfaces, from mirror and structural distortion due to gravity, wind-loading, aero-acoustics, and dynamical forces associated with the pointing system, and from thermal effects; and other tolerances of the actual telescope with respect to the design. These requirements apply in the specified operating environment. (Note that pointing stability and seeing contributions to image quality are discussed later.)

3.3.4.2 Off-Axis Image Quality

The off-axis image quality shall be consistent with the on-axis quality, f/ratio requirements, and use of a classical Cassegrain optical prescription.

3.3.4.3 Secondary Mirror Static Tilt

Static tilting of the secondary mirror shall not significantly increase the image diameter (goal: no more than 20% beyond the image size produced by an ideal Cassegrain telescope with the secondary tilted about its vertex).

3.3.4.4 Seeing

The Telescope Assembly shall minimize seeing due to telescope temperature imbalances by appropriate optics thermal control (as necessary), surfaces' temperature control, and minimization of heat generation from telescope active mechanisms in the cavity and from air leakage and heat conduction through the telescope from the cabin.

3.3.5 Field-of-View

The system unvignetted field-of-view diameter shall be ≥ 8.0 arcminutes at the nominal Nasmyth focus for chop amplitudes up to 5 arcmin off-axis (object space). See Figure 4a.

3.3.6 Nominal System Focus Location

The telescope system image and tracking (accuracy and stability) requirements apply to the nominal IR Nasmyth focus. The nominal IR focal plane shall be located on the SI side of the instrument mount flange (forward of mount flange) to allow convenient mounting of focal plane instruments. Allowable system focal ratio shall be between f/10 and f/24, inclusively.

3.3.7 Focusing System

Focusing shall be accomplished by movement of appropriate optics, controllable from the Workstation console, with capability for external control by the Science Investigator via the MCCS, and controllable by the OCDS ground support equipment. Data representing the relative focal position(s) shall be provided to the MCCS for display at the workstation console. Fine focusing will be optimized in-flight by viewing images from the focal plane imager, but may also be adjusted to optimize SI signals. The range of adjustment of the IR focal plane position shall be ± 60 cm referenced to the nominal Nasmyth focal plane location. Focusing adjustment and readout resolution (not including any contribution from MCCS provided devices) shall be 0.15 cm or better in the focal plane. Readout accuracy of the display relative to the actual TA focus position shall be ≤ 1 cm in the focal plane, on the ground. (Note that the total TA focus range capability will have to be greater than the "adjustment" range to account for focal length changes caused by the operating environments, including operation on the ground; that is, the TA shall be able to provide the specified focus range for all instruments in flight and also at ground ambient temperatures.)

An operator initiated automatic focus optimization design shall be provided for the entire system including the main IR optics and the optical train to the Focal Plane Imager (FPI). Separate focusing mechanisms for these may be used in which case a systematic focusing process must be developed and documented.

3.3.8 Optical Materials and Coatings

The main optical elements of the telescope shall be lightweight and thermally stable or compensated. The primary, secondary, and non-dichroic tertiary mirrors shall be delivered coated with bare aluminum. The dichroic tertiary shall be delivered coated with the required layer of gold to provide 50% transmission at 0.5 micron wavelength. The combined reflectivity of the primary, secondary, and dichroic tertiary mirror surfaces after coating shall be more than 75% (with a goal of 80%) for wavelengths greater than 2 microns, so that a total emissivity for the telescope equal to 25% or less (with a goal of 20% or less) may be achieved. For the system with the dichroic replaced by a fully reflecting tertiary, the combined reflectivity of the primary, secondary, and tertiary mirror surfaces after coating shall be more than 85% (with a goal of 90%) for wavelengths greater than 2 microns, so that a total emissivity for the telescope equal to 15% or less (with a goal of 10% or less) may be achieved. The total emissivity may be measured on the ground at 10-12 microns. All other TA elements which can be seen by the SI to any degree via diffraction effects on the normal FOV (see Para. 3.3.18) shall be delivered coated with high-emissivity, stray-radiation suppressing infrared black material. This material shall have a total hemispheric reflectance ≤0.05 and a specular reflectance ≤0.001 at all wavelengths ≤70 μm. However, if a TA component as seen by the SI can be designed so as to only reflect sky into the beam if polished to a low emissivity (high reflectivity), it should be constructed in

this way. The secondary support structure (spider legs) shall be coated with high emissivity, stray radiation suppressing infrared black paint, with provisions for mounting NASA-provided mirror deflectors on the edges facing the primary mirror. See SOF-1030 for interfaces.

3.3.9 Provisions for Cleaning and Recoating

The TA shall be designed so as to minimize contamination of the optics in the course of SOFIA operations. As a goal, the TA shall be designed to enable cleaning the primary mirror in place in the cavity. This goal includes a mount design that prevents leakage of liquid into the mirror support structure, but provides for liquid runoff paths (drains) for catching cleaning solutions below the primary support. Any paint or other surface treatment associated with the primary mount, centerpiece, or any other surface exposed to cleaning shall not deteriorate in mild solutions.

The TA mirror/mount system and associated handling Ground Support Equipment (GSE) shall be designed to provide a convenient and efficient means to remove the optical train for periodic cleaning and recoating such that:

a) The mirror/mount/tub assembly can be installed, removed and handled as a single unit on a routine basis. As a goal, removal and installation operations shall require less than 8 hours each, using a maximum of 2 technicians in the cavity.

b) The mirror can be cleaned in the cavity at 15° or 90° elevation (hard stops removed), or outside the cavity in a vertical orientation (i.e., elevation = 0°), while still attached to the mount/tub assembly.

c) The aluminum coating can be stripped from the mirror in a vertical orientation while attached to the mount/tub.

d) The mirror/mount/tub assembly can be rotated outside the cavity to an inverted position and remain in that orientation for up to 2 days every 6 months, for the coating operation.

For purposes of these operations, the primary mirror/mount system shall incorporate protection devices, or shall be designed to accommodate GSE devices to protect the system during such operations. For example, while the mirror/mount is inverted in the coating facility, a ring-shaped cover could be placed around the outer periphery of the mirror to protect the mount from the aluminum vapor and a cover could protect the central hole in the primary.

3.3.10 Full Aperture Cover/Sun Filter

Provisions shall be incorporated on the TA so that a lightweight (e.g., polyethylene) NASA-provided full aperture cover or Sun filter to be used in flight may be installed immediately in front of the primary. Interfaces shall be per SOF-1030.

3.3.11 System Effective Aperture Diameter

The system effective aperture diameter shall be ≥2.50 meters for any specified focus position.

3.3.12 Primary Mirror

3.3.12.1 Diameter

The primary mirror clear aperture diameter shall be larger than the system effective aperture diameter to account for the following: an unvignetted 8 arcminute field-of-view (FOV); tilt of the secondary mirror to shift the FOV by 5 arcminutes in any direction; margins for manufacturing tolerances with respect to the design; and for diffraction margin at the longest observing wavelength. The latter parameter is to be calculated by equating the required excess primary mirror diameter to twice the maximum wavelength (1.6 mm) multiplied by the ratio of the system effective aperture to the secondary mirror clear aperture. The hole in the center of the primary mirror shall be sufficiently small that no part of the hole shall be visible from any point in the FOV at any position of the Nasmyth focal plane even when chopping. All of the factors accounted for in determining the primary mirror clear aperture diameter shall also be considered in determining its inner diameter, which is the maximum diameter of the hole.

3.3.12.2 Focal Ratio

The primary focal ratio shall be as large as practicable, consistent with the overall system constraints (cavity geometry, secondary size), in order to provide the optimum chopped image quality. The focal ratio shall be at least f/1.10.

3.3.12.3 Material

The primary mirror material shall be such as to meet the image quality and thermal requirements over the range of operating environments specified in SOF-1030.

3.3.13 Secondary Mirror

3.3.13.1 Outer Diameter and Aperture Stop

The secondary mirror outer diameter shall be sized to be the system aperture stop but not the central aperture obscuration determining parameter.

The outer edge of the secondary mirror shall be tapered to ensure that the front surface of the mirror is always the aperture stop, commensurate with the above requirements. If any residual edge surface is visible from the focal plane, it shall be polished and aluminized to reflect only sky radiation at any point within the specified FOV.

The housing of the secondary mirror assembly (behind the mirror) shall be smaller than the mirror so that it is not visible from any point in a 16 arcminute FOV centered on the on-axis IR Nasmyth focus, even when the secondary is tilted to shift the FOV by up to 5 arcminutes from its centered position.

3.3.13.2 Central Obstruction and Central Obscuration Stop

The secondary mirror or its mount shall incorporate a tapped hole, bolt, or other suitable mounting provision, for attachment of NASA-provided central obscuration stops in the center of the secondary. The Contractor shall provide the first central obscuration stop. It shall be coated with high emissivity, low reflectance stray-radiation suppressing infrared black material as specified in Paragraph 3.3.8. The central obscuration stop shall produce an obstruction of the aperture area of no more than as defined by the size of the tertiary system and primary central hole (see Para. 3.3.15.2). An aperture obstruction of 4.0% shall be regarded as a goal and the secondary mirror surface shall be figured and polished in the center region to allow the use of a smaller central obscuration stop corresponding to 4.0% obscuration. The mount interface shall be as described in SOF-1030. The mount design shall be such that it allows central obscuration stop replacement in less than one hour by one technician as a goal.

3.3.13.3 Figure

The secondary mirror shall be figured to provide the specified image quality at the nominal Nasmyth focus.

3.3.13.4 Material

The secondary mirror material shall be selected to meet the TA image quality, thermal and chopper performance requirements, over the range of operating environments (ref. SOF-1030).

3.3.13.5 Secondary Mirror Support (Spider)

The secondary support spider shall present ≤3% obstruction of the aperture area to the effective system aperture. The spider arms shall be attached radially to the secondary assembly, as a goal; if attached tangentially, the ends shall be hidden behind the mirror as required above. The inside diameter of the spider support

structure shall be larger than the effective primary mirror diameter to assure that 1.6 mm wavelength radiation originating from an on-axis point source which is diffracted from the inner surface of the centerpiece/truss structure shall contribute at most 0.1% of the energy in the diffraction-limited image formed at the focal plane. The diffraction-limited image diameter is defined as 2.4 λ/D. This requirement shall be met throughout the range of focal plane positions.

3.3.14 Secondary Mirror Assembly

The secondary mirror assembly shall support the secondary mirror from the TA spider legs and provide the articulation functions described below.

3.3.14.1 General Requirements

The secondary mirror assembly shall provide mirror support of proper stiffness to meet the TA image quality and stability requirements under operating environments, and shall provide for fixed, scanned or chopped mirror operations, in addition to system focusing and alignment in flight and on the ground. Operating environments are defined in SOF-1030.

Exchange of the secondary mirror assembly with a spare assembly shall be possible in less than 6 hours by two technicians as a goal. Changing the secondary mirror on the secondary mirror assembly in place on the telescope shall require less than two hours by one technician. Alignment mechanisms, equipment and procedures for the TA after replacement of the secondary or secondary assembly shall be provided.

3.3.14.2 Functions

The secondary mirror assembly shall provide the following functions: Focus, alignment, two-axis ("x-y") chopping in any direction, offsetting of the center location of chop, three-point chopping (3 points in straight line), and stationary operation. See Figure 4, Chopping Parameters. For three-point chopping, the center of the line is at the offset point and the interior (between the ends) chop point shall be positionable to be anywhere on the line. All three points shall meet the requirements listed below.

3.3.14.3 Chopping

3.3.14.3.1 <u>Reaction Forces</u> – The chopping reaction forces shall be sufficiently low to enable the telescope system to meet its tracking stability requirements while chopping over its full range of chopping parameters.

3.3.14.3.2 <u>Amplitude</u> – The peak-to-peak chop amplitude shall be adjustable from 2 arcseconds to 10 arcminutes (object space), in increments of 0.5 arcsecond or less. Amplitude error shall be within ±10% of the commanded amplitude. Amplitude

error is defined as the absolute difference (measurement worst case) between the commanded peak-to-peak (p-p) amplitude setpoint and the actual attained p-p amplitude measured using the average (steady-state) end-point displacements during the periods following the end of settling time t_s in each half chop cycle. Referring to Figure 4, amplitude error is $|Ø_c - Ø_a|$.

Amplitude shall be repeatable, after "interruption" periods of up to five minutes of time, to within 1% of attained amplitudes or 0.2 arcsecond RMS in object space, whichever is greater. Amplitude repeatability error is defined as the RMS deviation from exact reappearance of the attained p-p chop amplitude for any set of command amplitude and frequency setpoints after periods of up to five minutes of interrupted operation. An "interruption" period shall be defined as a time period during an astronomical mission in which changes are made in chopper settings and operation (including chopping on a new astronomical target), and changes are experienced in TA attitude, but electrical power to the chopper subsystem is maintained. Note that drift of chop center point (chop offset point) is not included in this defined error.

Amplitude repeatability may be measured by taking the difference between the last chop cycle p-p amplitude in the time period before the "interrupted" interval, and the first chop cycle p-p amplitude in the period after the "interrupted" interval. Chopper settings in the latter period shall be reset to the command settings in the former period and the same astronomical target shall be used in both periods. Both "before" and "after" amplitudes shall be determined by using their averaged end-point displacements.

Note: For chopping requirements, "peak-to-peak amplitude" is meant whenever the term "amplitude" is used.

3.3.14.3.3 Waveforms – The chopper system shall provide a square waveform for image displacement. External inputs to the chopper control electronics shall be accommodated to synchronize the chopper with an external transistor to transistor logic (TTL) squarewave and to drive it with an analog waveform such as a sawtooth or sinewave. These external signal communication links shall be mainly between the TA and the SI electronics, but not necessarily only between them. The TA-SI analog and sync signal channels shall be comprised of the following, as a minimum:

a. Analog command for chopper axis parallel to the TA elevation axis (R axis).
b. Analog command for chopper axis parallel to the TA cross-elevation axis (S axis).
c. Analog waveform output of R axis displacement.
d. Analog waveform output of S axis displacement.
e. Analog waveform output of R axis displacement with no TA flexible motion compensation components included.

f. Analog waveform output of S axis displacement with no TA flexible motion compensation components included.
g. External sync-in TTL squarewave signal.
h. Sync-ref TTL squarewave signal representing the sync-in signal being used whether internally or externally provided.
i. Chop Phase Reference Output TTL squarewave signal which is referenced to, and phase adjusted against, the sync-ref signal.
j. Chopper control clock signal.

The external input interface is detailed in SOF-1030.

3.3.14.3.4 Offset – For two-point chopping, the chop center point shall be adjustable relative to the nominal center of the telescope FOV by up to 5 arcminutes (object space), with amplitude reduced correspondingly, as necessary. Offset for three-point chopping may be made with reference to the interior stop point.

3.3.14.3.5 Overall Stability – The overall chopping end-point (and stop-point for three-point chop) stability error circle radius shall be ≤1% of chop amplitude, or 0.2 arcsec, whichever is greater (object space), RMS, for periods of at least one hour. See Figure 4.

Measured over a period of multiple chop cycles spanning at least one hour, but measured at each half cycle only after the end of the 'specified' settling time, overall stability of chop end point (and stop point) is defined as the radius of a circle in object space representing the motion of the IR beam (worst end) over this period. (As defined, the measured motions for overall stability at each end point or stop point includes jitter, end point drift or stop point drift, cycle-to-cycle non-repeatability, and center point drift. They do not include the transients before the end of the 'specified' settling times at each end point or stop point).

Referring to the single axis time-base example representation in Figure 4, the overall chopping end point (and stop point) stability error ($\Delta Ø$) is the width of the band representing the RMS value of all single chop responses for the particular end point (or stop point) during the required period of at least one hour for one axis. This band may include all single chop stability error bands $\Delta Ø_i$. Note that the actual overall stability requirement specified above refers to an image motion circle radius in object space which must include at least two axes. An accepted equivalent peak definition of three times the RMS value may be substituted for the 1% and 0.2 arcsecond RMS values in establishing overall stability during verification and in formulating AITV plans (i.e., 3% peak and 0.6 arcsecond peak).

3.3.14.3.6 Settling Time – Chop settling time t_s is defined as the time elapsed between the instant of initiation of a throw to a new position and the instant when the end point (or stop point) stability is first achieved at the new position. Referring to Figure 4, $\Delta Ø_i$ is defined as the single half-chop cycle end point stability error

band (applies also to stop points). It is the error band which determines settling time for any single chop position response. The chop settling time shall be: ≤ 5 milliseconds for ≤ 1 arcminute amplitude (± 30 arcseconds); ≤ 7 milliseconds for 4 arcminute amplitude; and ≤ 10 milliseconds for 10 arcminute amplitude, with settling times for intermediate amplitudes as determined by linear interpolation between these values. An accepted equivalent peak definition of three times the RMS value may be substituted for the 1% and 0.2 arcsecond RMS values in establishing overall stability during verification and in formulating AITV plans (i.e., 3% peak and 0.6 arcsecond peak).

3.3.14.3.7 Frequency (chopping) – The chopper controller shall provide square wave mirror drive inputs at frequencies from 0 to 20 Hz in increments ≤0.5 Hz and at amplitudes up to 10 arcminutes p-p. However, the 1 percent end-point stability requirement above shall only be applicable for chops at 10 arcminutes amplitude for frequencies up to 10 Hz, and for chop amplitudes proportionately reduced from 10 arcminutes to 2 arcminutes for the range 10 to 20 Hz. The secondary mirror assembly surface temperature requirements shall only be applicable for static operation and for chopping up to 2 arcminutes p-p amplitude up to 10 Hz. Chop phase angle (θ) shall be defined as the time lag or lead (measured in equivalent angular degrees) between a synchronization-in signal state transition (sync-in provided by an external (SI generated) TTL source or equivalently, internally by the SMA itself) and the onset point of actual chop throw. An allowable option for testing purposes is the selection of any other suitable stable reference point on the mirror position waveform, for use as the chop phase "marker" (e.g., the chop throw midpoint). Polarity phasing between the sync-in TTL signal and the chop directions shall be provided.

A TTL synchronization-reference (sync-ref) signal shall be provided to represent the sync-in signal, whether or not it is externally or internally furnished. This sync-ref signal shall have no latency delay ≥50 micro-seconds. A TTL-based squarewave signal (named Chop Phase Reference Output) shall be provided for use by investigators as an adjustable chop phase reference for data-taking initiation. Both the TTL sync-ref signal and the TTL Chop Phase Reference Output shall be provided for use by observers as part of the direct interface connection between the SMA and the science investigators per SOF-1030. The Chop Phase Reference Output squarewave shall be phase adjustable with regard to the sync-ref signal and the phase angle difference between these two signals shall be defined as (θref). This phase angle (θref) shall be capable of being adjusted by the chopper electronics via commands from the MCCS, per SOF-1030. The chop phase adjustment requirement only applies to the internal-sync and external-sync modes of chopper operation. The adjustment range shall be ±180 degrees with resolution of better than or equal to one (1) degree. Any external sync frequency within the continuous range defined by ±0.5 Hz of the frequency setting sent to the chopper via the MCCS shall be allowed. A 40 kHz TTL signal representing the chopper control clock (i.e., with the same phase and

frequency as the 40 kHz Secondary Control system master clock) shall be provided to science investigators.

Chop phase angle (q), as defined above for the actual chop waveform, shall be fixed for any chop frequency. It's inherent value due to the chopper control system's phase lag shall not change by more than 10 degrees in the inclusive range of operation between 0.5 Hz and 20 Hz. For any given combination of chop amplitude, offset, chop angle, and frequency settings controlled by the chopper itself, stability of chop phase angle (θ) shall be such that $|\Delta\theta| \leq 0.5$ degree for frequencies up to 7 Hz, and increasing linearly from 0.5 degree to 1.5 degrees in correspondence with 7 Hz≤chop frequency≤20 Hz. Changes in chop offsets or chop direction angles controlled by an independent device (e.g., focus mechanism) shall not affect this requirement. The stability requirement shall be met over a time period of at least one hour of operation in flight. Given the same conditions described above for chop phase angle stability, and with power on for the entire period, chop phase angle shall be repeatable such that $|Dq| \leq 0.5$ degree over a six-hour flight duration.

For 3-point chopping, one full cycle corresponding to the TTL squarewave sync-in full cycle shall include the steps from one chop end to the other and back to the starting point. This will include four steps. See Figure 4b.

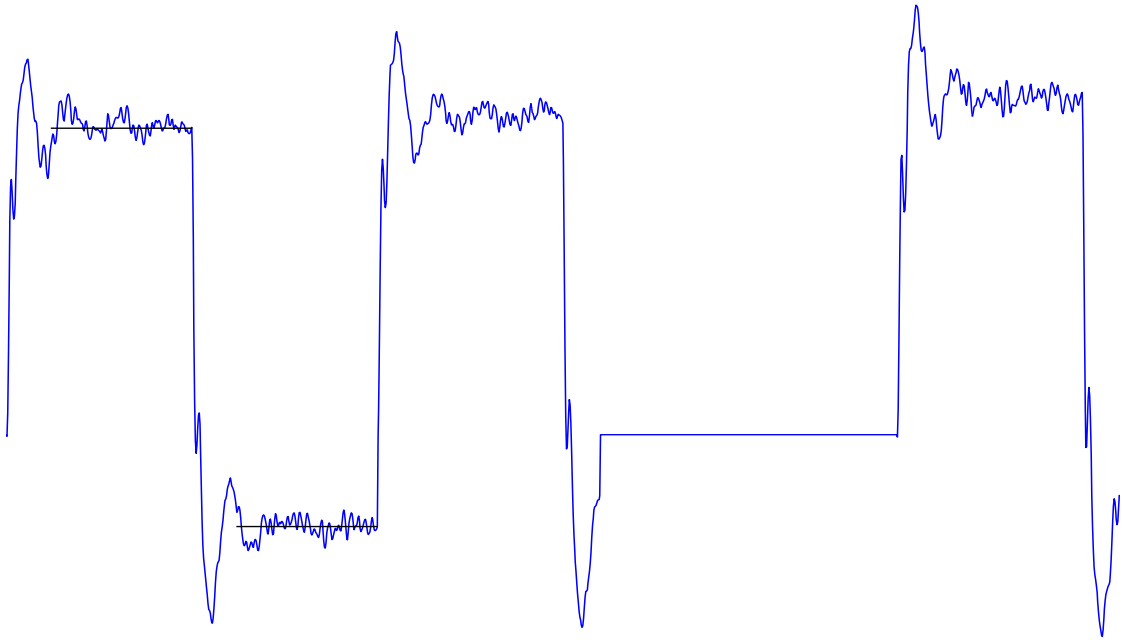
3.3.14.3.8 Chop Angle – The angle of chop shall be commandable with 0.2 degree resolution through 180 degrees total angle. The angle of chop shall be stable to within ±0.5°, maximum, for periods of at least one (1) hour.

3.3.14.3.9 Stationary Secondary – The chopping mechanism shall be capable of positioning the secondary mirror at any position within its amplitude range on demand, such that including its residual motion, the TA system provides ≤0.2 arcsec rms image stability (from all TA sources of instability) at the focal plane. During chopping operation, the chopper controller shall provide a functional capability for stopping the image in either beam location or at the midpoint with an accuracy of 1% of the throw, or 0.2 arcsec, whichever is greater (object space).

3.3.14.4 Command Sources

All Secondary Mirror Assembly (SMA) functions including chopping, focus, alignment, and chop phase adjustment shall be capable of being remotely commanded from the investigator station, and a workstation console. Communications interfaces with the external controllers shall be provided in the chopper control electronics/software to permit implementation of this capability. SOF-1030 provides interface details.

Figure 4. Chopping Parameters



Square Waveform

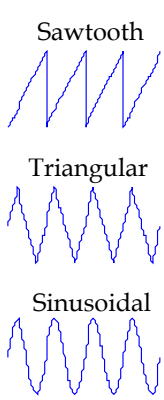
$Ø_c$ p-p chopping amplitude command.

$Ø_a$ actual attained p-p chopping amplitude measured during a single chop cycle using the average (steady state) values of the chop excursions at each half cycle "dwell".

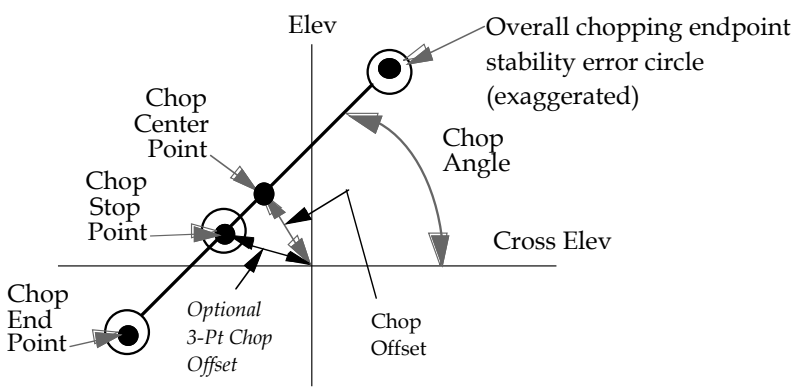
$\Delta Ø_i$ chopping end point (or stop point) stability for a single chop position during a half chop cycle.

$\Delta Ø$ overall chopping end point (or stop point) stability which includes end point stabilities of multiple chop cycles.

t_s settling time.



Other Employable Waveforms



View of Sky of Chopped Beam Motion

Figure 4a View of Sky with Chopped and Unvignetted Fields of View

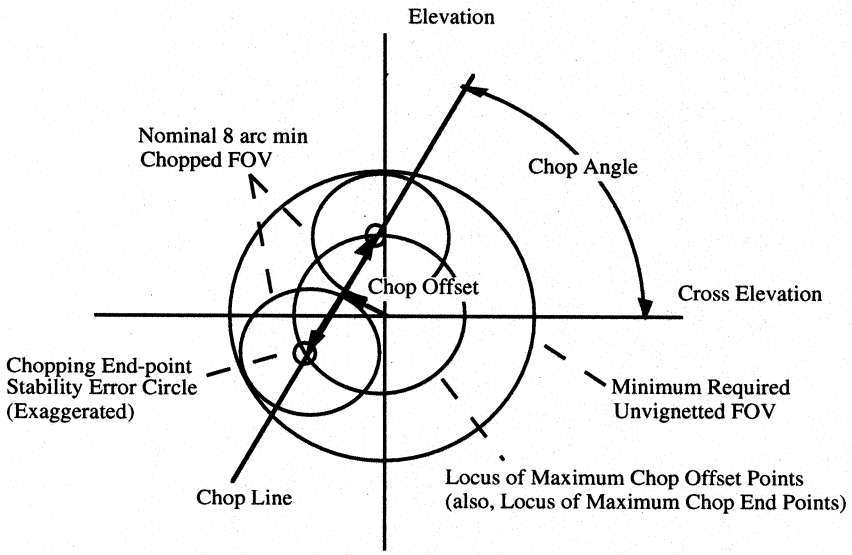
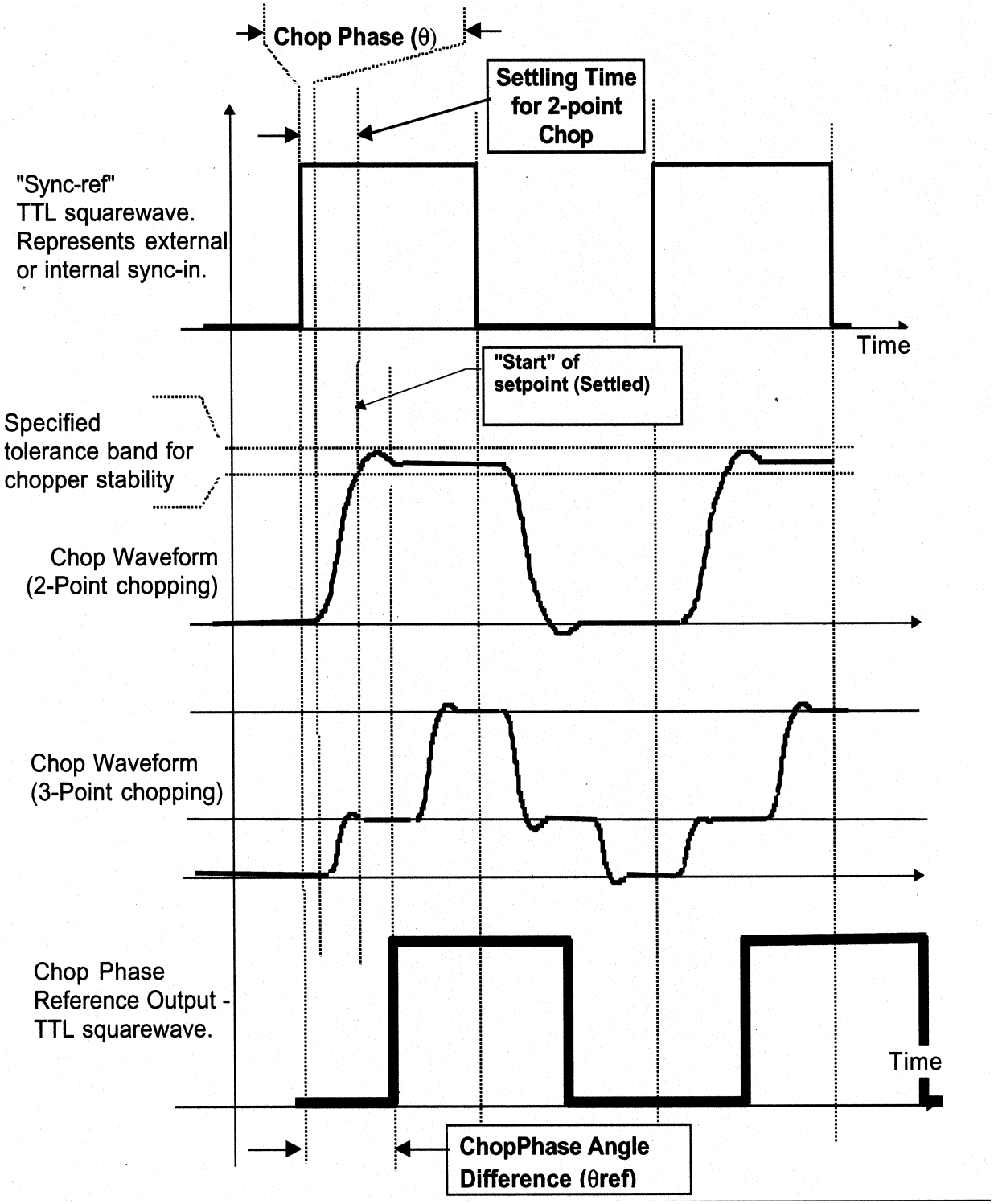


Figure 4b. Chop Phase Definitions



3.3.15 Tertiary Mirror

3.3.15.1 Configuration

The tertiary mirror system shall consist of 2 flat mirrors: a dichroic mirror ahead of a fully reflecting flat. The dichroic mirror shall reflect IR radiation ($\lambda \geq 2\ \mu$m) to the Nasmyth focus. The fully reflecting mirror shall reflect visible light transmitted by the dichroic to the vicinity of the Nasmyth focus for use by the Focal Plane Imager. Vignetting of the reflecting mirror by the dichroic is permitted if necessary, as long as the FPI meets its sensitivity and other requirements. The tertiary system shall be designed such that the reflecting mirror is entirely blocked by the dichroic mirror, as viewed from any part of the secondary mirror. The tertiary mirror system shall be designed for ease of installation, removal, and positional adjustment. Preference will be for both the dichroic and fully reflective mirrors to be replaceable without removal of the entire tertiary assembly. As a goal, replacement time for the dichroic mirror only, or the fully reflective mirror only, shall each be less than 2 hours by 1 technician, with post-replacement angular alignment error consistent with system boresight requirements. Whether or not the mirrors need to be removed and reinstalled separately, as a goal, replacement time for the entire tertiary assembly shall be less than 3 hours by 1 technician, with post-replacement angular alignment error consistent with system boresight requirements.

3.3.15.2 Dichroic Tertiary Mirror

The dichroic tertiary mirror shall be designed so that the visible beam transmitted to the focal plane imager via the reflecting tertiary mirror preserves the TA's visible image quality requirement. The size of the dichroic tertiary shall be larger than that of the optical beam of the FOV of the telescope at the tertiary in order to reduce dynamical IR noise to one-millionth of the thermal background power of the telescope (see also Para. 3.3.18). As an example, the tertiary would have to be 1.2 times the diameter of the optical beam for the FOV at the tertiary, for a telescope system f-ratio of 20 and a vibrational motion of the tertiary in the axes perpendicular to the Nasmyth axis equal to 0.01 mm peak-to-peak relative to the instrument mount. The edges of the dichroic tertiary shall be beveled so that only its front surface is visible from either the focal plane or the secondary. Insofar as practicable, the dichroic tertiary shall be rear mounted, or otherwise designed such that the mount is not visible from either the focal plane or the secondary mirror and such that the optical system meets straylight requirements. This requirement shall be met throughout the range of Nasmyth focal plane positions. Coating on the beveled surfaces shall be black as per Para. 3.3.8. The dichroic tertiary mirror shall be replaceable with a NASA-provided reflecting flat mirror for use in visible wavelength studies at the Nasmyth focus. (See SOF-1030)

3.3.15.3 Fully Reflective Tertiary Mirror

The fully reflective tertiary mirror shall be aluminized and mounted behind (in terms of incoming light rays) the dichroic mirror. It shall be designed to furnish the focal plane imager with visual target information, as necessary, to permit the system to meet specified pointing requirements.

3.3.16 Pressure Window Assembly

During observations the telescope and science instrument cavities will normally be at pressures corresponding to outside ambient conditions. To permit research instrumentation adjustments and/or real-time emergency fixes by the science investigator teams in flight, an articulating pressure window assembly "gate valve" with safety interlocks shall be incorporated within the Nasmyth tube near the cabin side of the spherical bearing, to provide pressure isolation when desired.

The pressure window assembly shall provide:

(a) Capability for "open-port" operation with pressure-sealed instruments.
(b) Manual and remote insertion, in-flight, of a pressure-sealed cover or plate into the IR beam. This plate shall be capable of being removed and replaced on the ground with a NASA-provided, pressure-sealed filter window.
(c) Deleted.
(d) Provisions on the IR pressure window opening to allow mounting a NASA-provided tube or bellows coupler which will connect to the SI (and subsequently to a small port on the aircraft fuselage to ensure movement of any stagnant air in the SI or the Nasmyth tube), usable in both open-port and closed modes. (Interface defined in SOF-1030.)
(e) Deleted.
(f) The "open port" clear optical path sized to conform to the requirements in Para. 3.3.18.
(g) A mounting interface for a NASA-provided pressure sealed filter window centered on the IR beam forward of the pressure window “gate valve.” The window shall not be part of the gate valve shutter mechanism. The interface shall be the same as for the bellows coupler.
(h) Rough paintable surface (roughness to be determined via ICD) on the SI side of “gate valve” oriented orthogonal to the IR beam (details per SOF-1030 related Interface Control Document).

3.3.17 Telescope Assembly Baffles/Stops

An infrared-black plate, with angular diameter roughly 3 times that of the dichroic tertiary, as viewed from the IR focus, shall be mounted on the TA truss/centerpiece (or other suitable structure) behind the dichroic tertiary as seen directly from the Nasmyth focus. This plate shall have a total hemispheric reflectance ≤0.05 and a specular reflectance ≤0.001 at all wavelengths ≤70 μm.

The plate and its mounting provisions shall be outside the incoming IR beam in accordance with the NASA-supplied disk of absorbing material for submillimeter observations. Provisions shall also be made in appropriate locations for mounting NASA-supplied removable baffles behind the secondary mirror and inside the Nasmyth tube, but any such provisions shall not intrude into the FOV of the telescope. The mounting provisions behind the secondary mirror may be on either the secondary mirror mechanism, or the support spiders, or both. The other mounting provisions shall allow installation of a sleeve structure into the aft end of the Nasmyth tube (NT). The sleeve structure would contain straylight vanes or a two-hole plate baffle, or both, and would be mounted by sandwiching it between the NT aft end and the NT cover (air exhaust manifold). To accommodate this mounting, the TA shall provide a threaded hole pattern in the NT aft steel flange. The NT sleeve structure, with both the straylight vanes and the baffle plate attached, will have a maximum weight of 20 kg. The Telescope Assembly shall be relieved of its performance requirements whenever any of these removable baffles is installed on the telescope.

3.3.18 Clear Optical Path

The TA shall provide a clear optical path for the infrared beam to the Nasmyth focal plane to accommodate at least an 8 arcminute science FOV, with a chop amplitude up to 10 arcminutes, plus a visible beam to the Focal Plane Imager.

The only objects that may intrude into the clear optical path of the IR beam are the secondary support spiders and the central obscuration stop, or “button mirror” mounted on the secondary.

In addition to these objects, the dichroic tertiary and the lower edge of the Nasmyth tube may intrude into the visible beam.

The visible beam will be permitted to cross the IR beam, if necessary.

These requirements must be met over the entire telescope operating range, for all points in the IR FOV at the nominal system focus.

3.3.18.1 Additional Clearance with the Nasmyth Tube

Additional clearance around the clear optical path must be provided to compensate for the effects of diffraction and instrument response patterns. The amount of clearance required can be calculated as follows: Define the IR beam as a truncated cone extending from the edge of the secondary mirror to the edge of the IR FOV at the nominal system focus. The axis of the truncated cone is the IR beam centerline joining the centers of the secondary and the system focus. Let **R** be the radius of that cone at any distance from the system focus.

No part of the TA more than 1.5 meters from the system focus shall be closer than 1.9**R** to the IR beam centerline.

For TA parts at or closer than 1.5 meters to the system focus, the minimum clearance shall be 1.5**R**.

This clearance shall be maintained despite the effects of structural bending and beam centering tolerance.

3.3.19 Straylight Goal

As a goal, during unchopping observations no part of the telescope assembly should cause dynamic changes in the telescope background power level larger than one-millionth of the background.

The telescope background power is described by the telescope's temperature (see Para. 3.3.2.2) and effective emissivity (see Para. 3.3.3).

This goal should be met over the entire telescope operating range, for all points in the IR FOV at the nominal system focus.

3.4 ALIGNMENT PROVISIONS

3.4.1 Telescope Assembly Alignment

This section addresses requirements on the TA for provision of sensors to measure optics alignment, and for provision of mechanisms, fixtures and tools to perform alignment adjustments.

3.4.2 General Requirements

Convenient sensing and adjustment of the TA alignment shall be provided to achieve the specified TA image quality and image positions at the SI focal plane and at the focal plane imager. Requirements shall include:

a) Provision of appropriate sensing and adjustment devices to ensure that the primary mirror system is properly positioned, for each installation, and provision of any special sensing and adjustment device that may be required for periodic adjustment of the primary mirror mount between flights.

b) Incorporation of provisions in the secondary mirror mechanism to enable secondary tilting and centering alignment, including in flight.

c) Placement of a fiducial mark at the center of the IR tertiary reflecting surface, with a maximum diameter of 2 mm, so as to permit alignment verification from the IR focus. The IR tertiary shall be capable of being

positioned on the ground such that the center of the mirror is located within ±1 mm, in any direction, of the intersection of the axes of the primary mirror and the SI boresight.

The TA shall be designed such that once the optics (primary/secondary/tertiary) are aligned, the alignment shall be sufficiently stable to assure meeting the specified image quality and tracking stability requirements under the full range of operating conditions. If necessary to accomplish this, the TA shall incorporate a pre-programmed automatic adjustment, which shall have the capability to be switched off (example: adjustment of the secondary mirror position), to eliminate misalignments caused by elevation or environmental (e.g., temperature) changes."

3.4.3 Science Instruments Mounting Flange

The SI mounting flange shall be orthogonal to the IR beam within 20 arcmin, with its center known and repeatable within 0.25 mm, after mounting the worst-case SI, and after optics alignment to achieve appropriate image quality. Refer to SOF-1030 for TA/SI mechanical interfaces.

3.4.4 Pre-Flight and In-Flight Adjustments

Provisions shall be made for all requisite pre-flight and in-flight adjustments, as follows.

3.4.4.1 Focus

Focusing shall be accomplished routinely in flight or on the ground as required for alignment, collimation, and boresight exercises as well as for science observations.

3.4.4.2 Boresight

In-flight and ground-based imager/SI reference boresighting, and verification of boresight setting accuracy of the imagers relative to the SI reference, shall be able to be accomplished routinely, for example, by using the imagers while observing a star or other appropriate source.

3.4.4.3 Collimation

Equipment integral to the TA and procedures for ground-based collimation/ alignment of the TA optics, with capability sufficient to meet the TA (on-axis) image quality requirements, shall be provided.

3.5 POINTING SUBSYSTEM

3.5.1 Subsystem Description

The Pointing Subsystem (PS) shall be capable of tracking, in the on-axis mode, point sources and features of extended bodies (e.g., Moon, comets, planets). The subsystem shall also be capable of offset tracking so that any part of an extended body, a dim star, or an invisible object may be centered as the telescope image (science target).

The main objectives of the PS are to coordinate, control and monitor all activities necessary to perform proper stabilization of the telescope system, effect efficient acquisition of selected celestial targets, maintain accurate tracking of those targets, provide required interfaces for mission control commands and displays, and maintain a safe and efficient telescope assembly.

3.5.2 General Requirements

The PS shall, as a minimum, provide the following major features and provisions (stand alone system):

(a) Three-axis Control
(b) Automated Inertial Reference Stabilization
(c) Automated Tracking
(d) Offset Tracking
(e) Focal Plane Imager Tracking (fixed or chopped image)
(f) Boresighted Imager Tracking
(g) Point Source, Extended Body and Limb Tracking
(h) Override Controls for System Fault Resets (e.g., travel limits)
(i) Target Identification & Acquisition (operator performed)
(j) Video Monitoring
(k) Sensor Protection (e.g., camera detectors)
(l) Coarse Elevation Positioning
(m) Telescope Attitude Measurement
(n) Preflight and Inflight Adjustments and Verifications
(o) Automatic and Manual Balancing
(p) Automatic Telescope Braking and Caging
(q) System Start-up Permissive Logic
(r) System Fault Sensing, Safety Interlocks (Inhibits), and Failsafe Logic
(s) System Fault Annunciation
(t) Operator Controls, Instrumentation, Status Indicators, and Monitors
(u) Telescope Slewing and Nodding
(v) Tracking Position Memory (object tagging)

3.5.3 PS Definitions

This section defines some PS terms commonly used herein.

a. <u>TA Elevation Axis</u>

The TA elevation axis is defined as that rotational axis of the telescope which is nominally parallel with the roll axis of the aircraft when the TA is installed.

b. TA Cross-elevation Axis
The TA cross-elevation axis is defined as that rotational axis of the telescope orthogonal to the elevation axis and nominally parallel to the yaw axis, when the TA is installed and theoretically set to 0° elevation.

c. TA Line-of-Sight (LOS) Axis
The TA LOS axis is defined as that rotational axis of the telescope orthogonal to both the elevation and cross-elevation axes and nominally parallel to the pitch axis, when the TA is installed and theoretically set to 0° elevation.

d. SI Reference
The SI reference is defined as the point in the TA plane of the SI mounting flange representing the center of the IR beam. SIs will be mounted and positioned relative to mounting guide indices on the TA SI mounting flange.

e. Imager/SI Boresight
The imager/SI boresight is defined as that location in the imager FOV that maps to the SI reference. This definition applies to the Focal Plane Imager (FPI)/SI boresight, the Fine Field Imager (FFI)/SI boresight, and the Wide Field Imager (WFI)/SI boresight.

f. Tracking
Tracking is defined as the automated feedback controlled process by which the telescope is pointed at a location in the sky by opto-electronic reference to a celestial body. Tracking commences the moment the tracker error signals are used to close the TA tracking feedback loop.

g. Target Acquisition
Target acquisition is defined as the process which culminates in the tracking opto-electronic sensor unit (tracker) locking onto and generating error signals relative to an identified and selected single target or set of targets.

h. On-Axis Tracking
On-axis tracking is that tracking mode where the tracker sensor and the experimenter's detector both derive information from the same celestial source. The line-of-sight to the source is controlled to be in alignment with the telescope main optical axis. (See Figure 5.)

i. Offset Tracking
Offset tracking is that tracking mode where the tracker sensor and the experiment's detector derive information from separate sources. In this mode, suitable bias coordinates are impressed on the tracked target(s) to position another object (the desired science object) on the SI reference. (See Figure 6.)

j. Telescope Pointing

Telescope pointing is defined as the act of causing the telescope assembly to be aimed or directed in a particular direction effecting the telescope optics to gather light within its field of view in that direction as observed at the IR focal plane. Pointing action is accomplished generally by any means of positioning the telescope (by hand, by motorized control, by moving the aircraft in which it is carried, etc.) and includes a number of specialized subset activities which achieve particular types of pointing (inertial stabilized control, tracking control, hand-moved, etc.).

k. Pointing Accuracy

Pointing accuracy is defined as the fidelity with which the PS, after acquiring a suitable target (or set of targets), initially positions the science object relative to the SI reference at the onset of observation.

Pointing accuracy (under both on-axis tracking and offset tracking) will be quantified by establishing the average value of the set of measured angular displacements between the SI reference and 10 "instantaneous" science object location samples taken immediately following a 5-second settling time upon initiation of track. (See Figures 5 and 6.)

l. Pointing Stability

Pointing stability is defined as the measure of relative motion of a science object of interest in the IR focal plane, over the observation period of time during which TA attitude is controlled. Specifically, under both on-axis and offset tracking operations, it is defined as the image deviation from the centroid of the image imprint in the focal plane, measured as the RMS value of the deviation over any period from 5 milliseconds up to an hour of continuous pointing at the same object. (See Figures 5 and 6.)

m. Telescope Slewing

Slewing is defined as a smooth, controlled angular movement of the telescope.

n. Telescope Nodding

Telescope nodding is defined as a low frequency periodic switching of telescope pointing direction between observed beams during chopping operations (squarewave displacement response).

o. Blind Pointing

Blind pointing is defined as the automated process of initially aiming the telescope closely in the neighborhood of the target of interest prior to target identification, acquisition, and tracking, by simply commanding celestial coordinates of the target of interest.

p. Inertial Stabilization

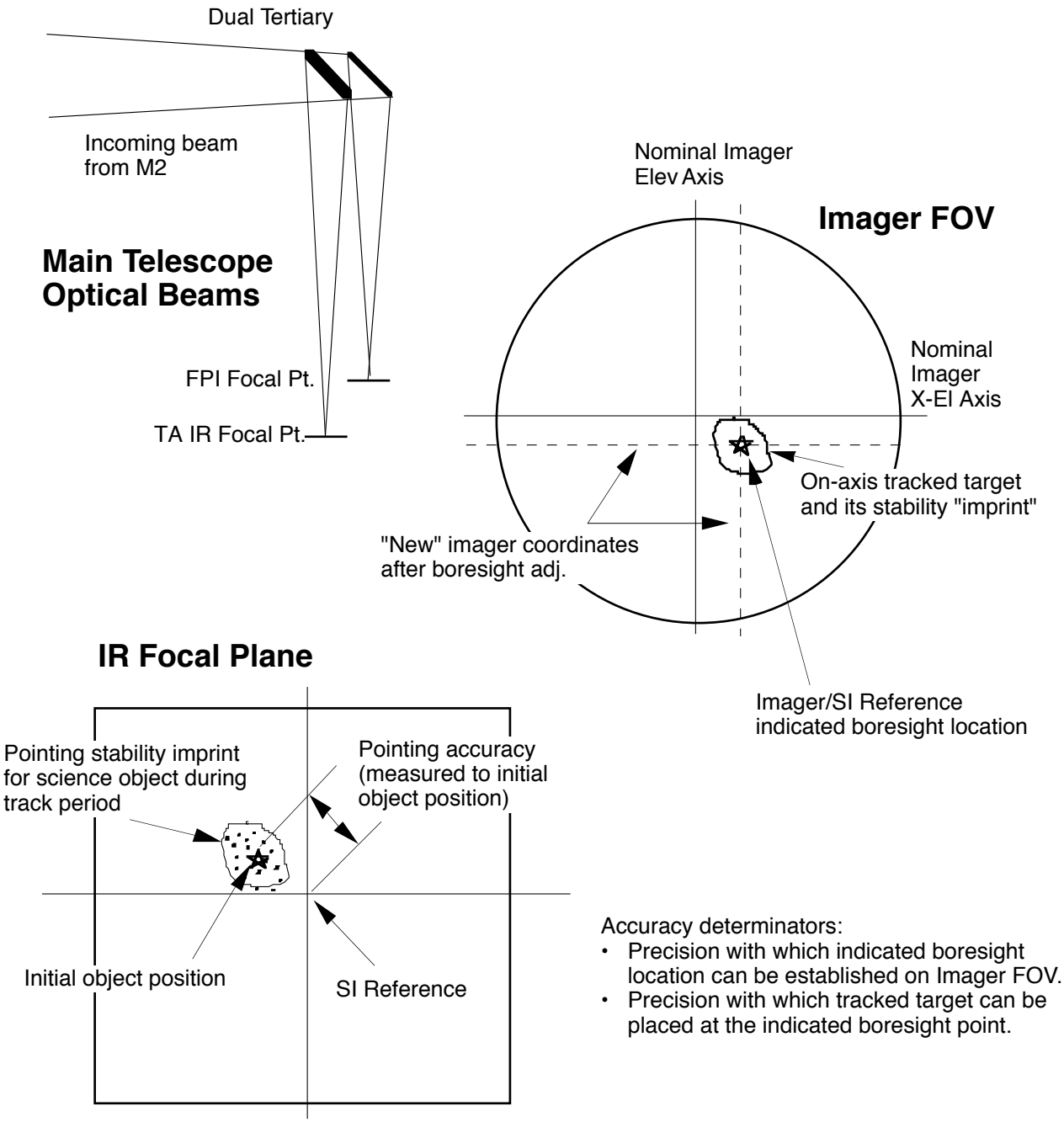
Inertial stabilization is defined as closed loop telescope pointing using inertial reference sensors for feedback control. This is a form of stabilized pointing which maintains an attained pointing direction (until directed to move) without use of a stellar reference (within drift capabilities).

3.5.4 Tracked Celestial Targets

3.5.4.1 Point Sources

The TA pointing and control subsystem shall acquire (operator assistance permitted for identification of targets) and track point sources as specified for each imager.

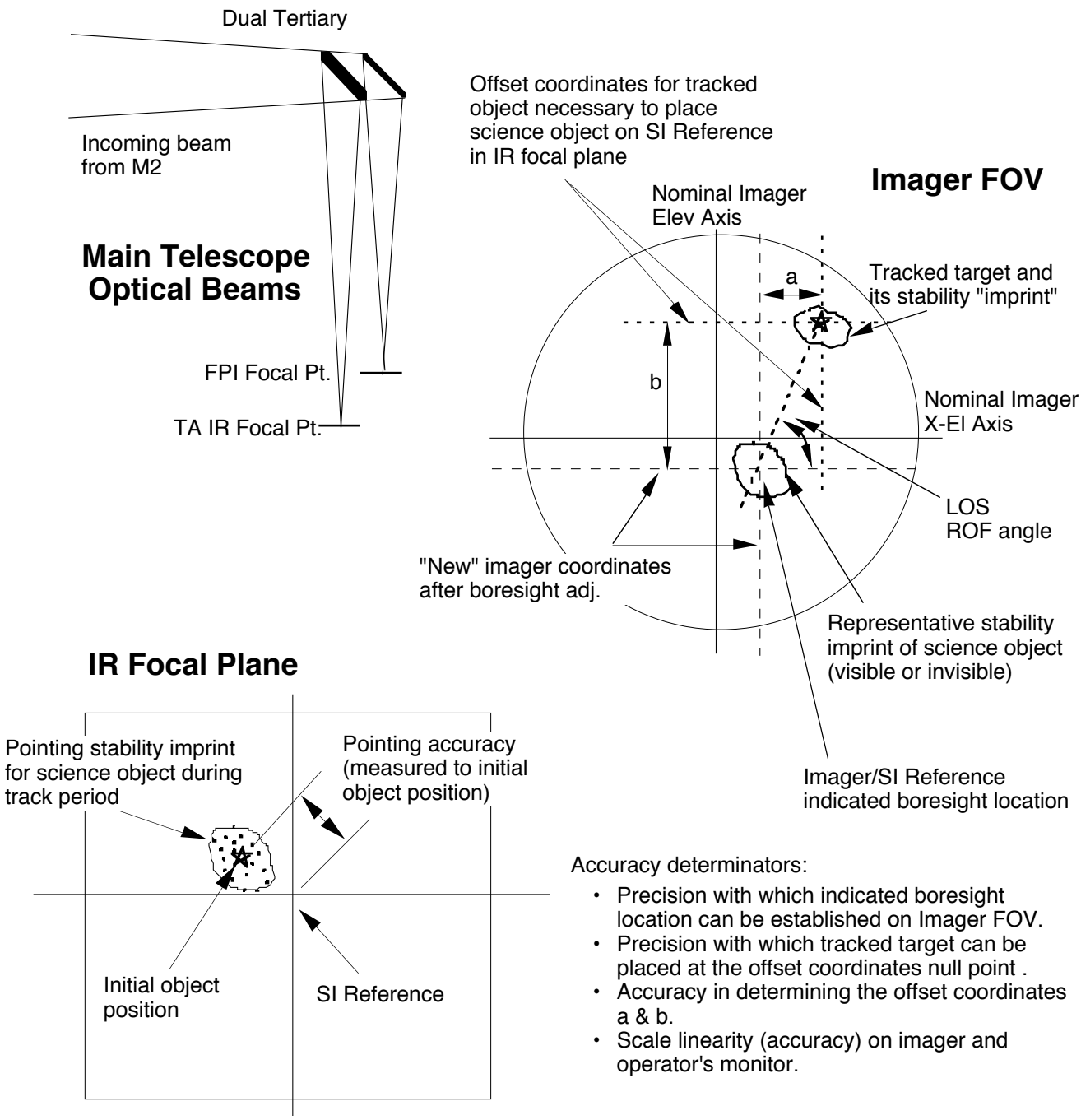
Figure 5. On-Axis Tracking



Accuracy determinators:

- Precision with which indicated boresight location can be established on Imager FOV.
- Precision with which tracked target can be placed at the indicated boresight point.

Figure 6. Offset Tracking



Accuracy determinators:

- Precision with which indicated boresight location can be established on Imager FOV.
- Precision with which tracked target can be placed at the offset coordinates null point .
- Accuracy in determining the offset coordinates a & b.
- Scale linearity (accuracy) on imager and operator's monitor.

3.5.4.2 Extended Bodies

The TA shall acquire and track the following extended bodies at night, consistent with the specified imager sensitivities: the moon, comets, and the planets Venus, Mars, Jupiter, Saturn, and Uranus, and compact nebulae or galactic nuclei with central surface brightness ≥ m_V=+12 per square arcsec. Daylight tracking of extended bodies shall include the moon and all of the above planets except Uranus. Provisions shall be made for mounting PI-furnished full aperture Sun filters, imager protecting filters, and other shields or filters determined necessary for the designed TA to be used for solar observations when desired by the PI. (See Para. 3.3.10 and SOF-1030.)

3.5.5 Axes of Control

The TA shall utilize 3 orthogonal axes of control. These 3 axes shall be the elevation, cross-elevation and LOS axes of the telescope.

3.5.6 Tracking

A TA tracking system shall provide on-axis and offset tracking capability to the accuracy and stability requirements detailed below. These accuracy and stability requirements shall be achieved at all times while the TA is exposed to operating environments defined in SOF-1030. For example, a solution could include the provision of a system consisting of the following major elements: a low drift, three-axis precision rate and/or rate-integrating gyroscope set for inertial stabilization, an electro-optical system for target acquisition and accurate tracking, a set of torque generating prime movers, a corresponding set of power drivers for the torquers, a digital processor-based digital/analog electronics control system, and an operator control and monitoring system. The control system shall not require any computational resource from the MCCS for its basic functions, but will include a data communications interface with the MCCS for supervisory control and more sophisticated functions. The system shall interface with the MCCS for electrical power, console and rack space, and command and data transfer of operational and housekeeping activities.

A stabilization and tracking scheme, or equivalent, which provides the performance capabilities shall be incorporated in the telescope pointing and control subsystem. For example, to facilitate the process of target identification, acquisition, and tracking, the design could incorporate two fundamental feedback control loops per axis, with additional inner loops as necessary: (a) an inertial reference stabilization loop, and (b) an optical sensor based target tracking control loop. Operation of the system with only the inertial stabilization loop closed would thereby result in a "relative" attitude control mode where the telescope could be slewed to any angle in the sky, within its normal range, and be held or "stabilized" there by this control scheme, allowing the system time to perform its

necessary target acquisition task before tracking. The "absolute" attitude control mode would subsequently be incorporated using an optical sensor viewing either a single, or a set of acquired celestial objects as the reference for tracking operation.

3.5.7 Override and Slewing Controls

Override controls for operator-positioning of the TA within the dynamic ranges in all axes of motion shall be provided (for example, utilizing a joy stick or equivalent). This override control shall permit the operator to move the telescope away from limits or to slew it, at any time during normal operation, to any location within the dynamic ranges of all of its three axes.

The TA shall provide variable slew rates of 0 to ≥1 degree/second in any direction over the dynamic motion control range. Resolution in rates shall be ≤ 0.1 arcsec/sec. The TA shall provide a motion rate of at least 2 degrees/sec for movement beyond the dynamic motion range (e.g., elevation axis). Totally "bumpless" starting and stopping of motion in response to overide/slew commands are not required. Maximum system acceleration capability may be impressed as impulse functions to start and stop the override and slew motions.

3.5.8 Nodding Capability

The TA shall be capable of nodding operation with amplitudes from 0 to ≥ 20 arcminutes p-p in any direction. Settling time to a stability of ≤ 1.0% of the nod amplitude shall be ≤ 2.0 seconds for a ≤5.0 arcminute nod. For larger nod amplitudes, settling time to a stability of ≤1% of nod amplitude shall be ≤ (0.4 x amplitude in arcminutes) seconds, within the FOV limits of the tracker imager in use. The TA shall be capable of performing nod maneuvers with times between initiations of nod commands as short as the required settling times associated with the respective nod amplitudes. This shall not preclude nod motions to be commandable more frequently for system setup. However, the TA will not be expected to meet the specific nodding requirements herein when these commands are imposed prior to the end of the first imager-based tracking subsystem update following TA settling to the 1% of nod amplitude error band. Nod performance shall be possible at the tracking stellar magnitude limit specified for the imager which is providing the tracking error signals. For image stability determination purposes, measurement shall be initiated at the end of the first imager-based tracking subsystem update following TA settling to the 1% error band, and continued for at least one hour or until the onset of the next nod (this nod onset occurring no sooner than the second imager-based tracking subsystem update), whichever occurs first.

3.5.9 Range of Motions

3.5.9.1 Telescope Assembly Physical Range

The TA shall provide a physical travel range in elevation of 15 to 70 degrees, inclusively, for normal modes of operation. Throughout this elevation range, a cone of 3.5 degrees half-angle accommodating both cross-elevation and LOS physical ranges, referenced to the center of rotation, shall be provided. The TA shall incorporate physical "hard stops" (with appropriate resilient "bumpers" as necessary) to preclude exceeding these motion limits. Adjustable sets of limit switches or detectors shall be installed to provide a safety shutdown function (and subsequent caging, if necessary) whenever any physical limit is approached, prior to contact with the hard stops.

Under maintenance mode, the telescope shall be capable of being rotated to an elevation angle of 90° for installation and removal of the primary mirror on the ground (see SOF-1030). The operational motion limiters shall be capable of being disabled on the ground for this purpose.

3.5.9.2 Telescope Assembly Operational Range

The dynamic operational range of travel for the telescope shall be at least ± 3 degrees in elevation, and a cone of at least 3 degrees half-angle for combined cross-elevation and LOS motions, referenced to the center of rotation. The dynamic operational range is that range in which the attitude control/fine torquer system normally works during any given observation, to keep the telescope pointed at its target.

3.5.10 Vignetting

The telescope shall be configured such that when installed in the AS and integrated with the AS cavity and its associated mechanisms and the shear layer control ramp, it shall be capable of unvignetted viewing (with the aperture door initially centered over the TA FOV) within the space defined by ±3 degrees in cross-elevation over the elevation range of 20 to 60 degrees, inclusively, with the LOS axis centered but with the VIS positioned anywhere in its operating range. For vignetting assessments, the primary mirror clear aperture diameter shall be applied, using a cone of 8 arcmin half-angle extending outward from the TA. This includes the 8 arcmin TA FOV plus diffraction margin. See Para. 3.3.18 for clear-optical-path requirements and considerations for diffraction effects. See SOF-1030 for interface details of cavity and aperture door/ramp configurations.

3.5.11 Tracking Requirements

There shall be 3 optical sensors for acquisition and tracking unless an alternative approach can be shown to provide all of the functional capabilities required herein. These sensors shall include a boresighted (i.e., mounted on the Telescope Optical Assembly structure) wide-field imager, a boresighted fine-field imager, and a main optics-sharing focal plane imager. The boresighted imagers shall be located on the TA for unvignetted viewing over the same unvignetted range as the main TA optics, with reference to the AS open port viewing interface as specified in SOF-1030.

The tracking system as a whole shall be capable of detecting and tracking targets with light intensities from the lower limit of a +16th visual magnitude star to targets as bright as the moon. Filters and shutters which are part of the imagers and designed to be used normally for the brighter targets or designed to be automatically deployed for protection from overly bright objects shall be incorporated in the imagers as necessary. Provisions shall be made to install external imager filters, as necessary, to permit solar observations. These filters, as necessary, will be provided by the individual PIs during setups for their research flights. See SOF-1030 for interface requirements.

3.5.11.1 Tracking Modes

3.5.11.1.1 <u>On-Axis Tracking Mode</u> – The TA shall provide on-axis tracking capability on point sources and extended bodies with the performances specified herein.

3.5.11.1.2 <u>Offset Tracking Mode</u> – The tracking system shall be capable of offset tracking out to the edge of each imager's FOV. This capability shall permit observations with the telescope IR beam aligned to coincide with a line-of-sight to a celestial object other than the target being tracked.

In addition to single target offset tracking, two-object (or multiple-object) offset tracking capability shall be provided. Using two or more celestial objects in any imager, the system shall sense rotation-of-field (ROF) and make necessary corrections by rotating the Telescope about the Telescope LOS. Where another technique to provide ROF compensation for offset tracking can be shown to provide equal or better performance and equal or better availability of target sets, this technique may be applied instead. Effects on polarimetry investigations shall be considered.

3.5.11.2 Wide Field Imager

A Wide Field Imager (WFI) boresighted to the main telescope, or equivalent, shall be provided for target acquisition, tracking, rotation angle correction, and wide field monitoring. The overall optical quality, focal length, field size, field flatness, spectral transmission, magnetic field insensitivity, and reflectance characteristics shall be compatible with its image sensor(s) and selected to meet system requirements.

3.5.11.2.1 Field-of-View – The WFI shall provide a field-of-view ≥ 6.0 degrees diameter. In addition, it may provide smaller FOVs (e.g., via zooming) if needed to meet the requirements below.

3.5.11.2.2 Sensitivity – Tracking capability with the ≥ 6.0-degree FOV shall be on targets at least as faint as m_V=+11 at night. Tracking capability shall also be provided on targets at least as faint as m_V=+13 at night (an appropriately smaller FOV than 6° will be permitted to achieve this). Sensor integrating times shall be commensurate with target brightness and control loop phase lag and quantization limits. TA accommodations for remote video display by the MCCS of images from this imager shall be as detailed in SOF-1030.

3.5.11.2.3 Accuracy Under WFI Tracking – When tracking on-axis on an object of 13th magnitude or brighter, the WFI shall provide pointing accuracy of 6 arcseconds plus ≤ 0.06 arcsecond per arcminute of offset, RSS. These accuracy requirements shall apply using the WFI imager for tracking over the entire operational range of telescope orientation and cavity environments depicted in SOF-1030 for the duration of each mission after initial WFI/SI reference boresighting at the onset of the flight.

3.5.11.2.4 Stability Under WFI Tracking – When tracking on-axis on an object of 13th magnitude or brighter, the WFI shall provide pointing stability of ≤ 3.2 arcseconds. Pointing stability under WFI offset tracking operations shall be ≤ 3.2 arcseconds plus ≤ 0.06 arcsecond per arcminute of offset, RSS. Provisions shall be made to permit easy upgrades in the future to achieve ≤ 3.0 arcseconds stability on-axis, and for offset tracking, ≤ 3.0 arcseconds plus ≤ 0.06 arcsecond per arcminute of offset, RSS. The WFI FOV may be less than 6 degrees diameter for targets dimmer than 11th magnitude. These stability requirements shall apply using the WFI imager for tracking over the entire operational range of telescope orientation and cavity environments depicted in SOF-1030 for each required target for periods of at least 1 hour of time.

3.5.11.3 Fine Field Imager

A Fine Field Imager (FFI) boresighted to the main telescope, or equivalent, shall be provided for target acquisition, tracking, rotation angle correction, and Fine-Field monitoring. The overall optical quality, focal length, field size, field flatness, spectral transmission, magnetic field insensitivity, and reflectance characteristics shall be compatible with its image sensor(s) and selected to meet system requirements. (Note that the design of the FFI may be nearly identical to that of the WFI as long as all requirements are met, in order to provide redundancy, common spares, etc.)

3.5.11.3.1 Field-of-View – The Fine Field Imager FOV shall be ≥ 30 arcminutes diameter.

3.5.11.3.2 Sensitivity – Tracking capability using the FFI shall include targets of m_V=+13 or fainter during night tracking and of m_V=+1 during daylight tracking at angles ≥

45° from the Sun. Sensor integrating times shall be commensurate with target brightness and control loop phase lag and quantization limits. TA accommodations for remote video display by the MCCS of images from this imager shall be as detailed in SOF-1030.

3.5.11.3.3 Augmented FFI Offset – In addition to its basic offset tracking capability, additional offset tracking angles of at least ±20 arcminutes in elevation and cross-elevation shall also be provided (i.e., a total 70 arcminutes circular "field-of-regard"). This may require a separate offset subsystem. However, if all other requirements can be met, increasing the FFI FOV to include this capability will be permitted. Accuracy in offset settings shall be ≤ 1 arcminute each in elevation and cross-elevation.

3.5.11.3.4 Accuracy Under FFI Tracking – When tracking on-axis on an object of 13th magnitude or brighter using the FFI, pointing accuracy shall be ≤ 3 arcsec. Pointing accuracy under FFI offset tracking operations shall be ≤ 3 arcsec, plus ≤ 0.06 arcsec per arcminute of offset, RSS. These accuracy requirements shall apply using the FFI imager for tracking over the entire range of telescope orientation and cavity environments depicted in SOF-1030 for the duration of each mission after initial FFI/SI reference boresighting at the onset of the flight.

3.5.11.3.5 Stability Under FFI Tracking – When tracking on-axis on an object of 13th magnitude or brighter using the FFI, pointing stability shall be ≤ 1.4 arcsecs, RMS. Pointing stability under FFI offset tracking operations shall be ≤ 1.4 arcsecs,, plus ≤ 0.06 arcsec per arcminute of offset, RSS. Provisons shall be made to permit easy upgrades in the future to achieve ≤ 0.8 arcsecond stability on-axis, and for offset tracking, ≤ 0.8 arcsecond plus ≤ 0.06 arcsecond per arcminute of offset, RSS. These stability requirements shall apply using the FFI imager for tracking over the entire range of telescope orientation and cavity environments depicted in SOF-1030 for each required target for periods of at least 1 hour of time.

3.5.11.4 Focal Plane Imager

A Focal Plane Imager (FPI), configured to view the TA's visible beam shall be provided for main focal plane tracking and monitoring, and ROF correction. The overall optical quality, focal length, field size, field flatness, plate scale linearity, spectral transmission and reflectance characteristics shall be compatible with its image sensor(s) and selected to meet system requirements. The FPI shall be mounted to track targets in the visible beam provided by the fully reflecting part of the main telescope dual tertiary. The sensing camera for this imager is envisioned to be operated in the "warm" cabin environment (actual placement of TA components will be the prerogative of the Contractor). In order to preserve the FPI/SI boresight, the FPI and the experiment detector package shall be located as close to each other as practicable. The structure supporting these units as well

as the non-shared optical elements shall be rigid and stable commensurate with tracking requirements.

The FPI shall incorporate a reticle (projected, physical, or electronic) at the visible focus. If an electronic reticle is used, its registration and orientation shall be fixed relative to the camera pixels in all operating modes, e.g., full framing, subframing, and binning. In this case, an optical system shall be provided to verify, on demand, and in a few seconds, the camera pixel and electronic reticle registration and orientation relative to the TA. The fiducial system shall be simple and be as reliable as possible. The fiducials may appear in the corners of the camera frame, out of the nominal field of view in the focal plane. As a goal, the illumination of the fiducials should be stable enough to permit verification of the stability of the camera sensitivity; also as a goal, the fiducial screen should contain a spot comparable to a stellar image to permit verification of the centroiding algorithm for the FPI.

The FPI subsystem shall be designed and mounted to the TA such that it can be removed and reinstalled as a unit, without disturbing the rest of the counterweight/instrument mount structure, by two technicians in less than four hours as a goal. The FPI design shall accommodate simple mounting on a flat table for ground "bench testing." The FPI shall incorporate an operator-initiatable automatic focus optimization capability, having the focus range commensurate with the entire IR focus range, and focus adjustment resolution commensurate with the FPI tracking requirements.

3.5.11.4.1 Field-of-View – The Focal Plane Imager shall have a field-of-view ≥ 8 arcminutes diameter.

3.5.11.4.2 Sensitivity – Tracking capability using the FPI shall include targets of m_V=+16 or fainter during night tracking and of m_V=+5 during daylight tracking at angles ≥ 45˚ from the Sun. Sensor integrating times shall be commensurate with target brightness and control loop phase lag and quantization limits. TA accommodations for remote video display by the MCCS of images from this imager shall be as detailed in SOF-1030.

3.5.11.4.3 Accuracy Under FPI Tracking – When tracking on-axis on an unchopped image of an object of 16th magnitude or brighter using the FPI, pointing accuracy shall be ≤ 0.5 arcsec. Pointing accuracy under FPI offset tracking operation shall be ≤ 0.5 arcsec, plus ≤ 0.06 arcsec per arcminute of offset, RSS. These accuracy requirements shall apply using the FPI imager for tracking over the entire range of telescope orientation and cavity environments depicted in SOF-1030 for the duration of each mission after initial FPI/SI reference boresighting at the onset of the flight.

3.5.11.4.4 Stability Under FPI Tracking – When tracking on-axis on an unchopped image of an object of 16th magnitude or brighter using the FPI, pointing stability shall be ≤ 1.1 arcsecs RMS. Pointing stability under FPI offset tracking operation shall be ≤ 1.1 arcsecs arcsec, plus ≤ 0.06 arcsec per arcminute of offset, RSS. Provisions shall be made to permit easy upgrades in the future to achieve ≤ 0.2 arcsecond

stability on-axis, and for offset tracking, ≤ 0.2 arcsecond plus ≤ 0.06 arcsecond per arcminute of offset, RSS. These stability requirements shall apply using the FPI imager for tracking over the entire range of telescope orientation and cavity environments depicted in SOF-1030 for each required target for periods of up to 1 hour of time.

3.5.11.4.5 Chopped Image Tracking – The FPI shall be capable of tracking while observing a chopped image of an object at least as faint as m_V=+14 at night, for both on-axis and offset tracking. The pointing stability for on-axis chopped image tracking shall be equal to the RSS of the unchopped stability and the chopped end-point stability requirements. This pointing stability shall also apply when nodding the telescope while tracking a chopped image as faint as m_V=+14 at night. This performance shall be achieved for chop and nod amplitudes ≤2 arcminutes p-p, over the entire range of chop frequencies.

3.5.12 External Control Inputs

The tracking subsystem shall be capable of accepting science instrument or MCCS-generated nodding, rastering and pointing commands, as well as guiding corrections from SIs which cannot use the focal plane imager. For example, arbitrary telescope mapping motions, such as circular, spiral or rectangular scan patterns, and peak-up inputs consistent with the specified slewing and nodding requirements, will be commanded. The SI or MCCS will provide pointing coordinate signals to the TA control system to implement scan patterns. The TA interfaces with the SI and the MCCS are detailed in SOF-1030.

3.5.13 MCCS Tracking Command/Response Definitions

A set of tracker commands and associated responses shall be mutually developed between the TA and the MCCS with draft ICDs submitted at least 6 months before TA Preliminary Design Review.

3.5.14 Target Identification and Acquisition

The tracking system shall allow an operator to acquire any target, suitable for tracking, located at any position within the fields-of-view of the imagers as displayed on their respective monitors. Simple, but properly human performance engineered procedures and display layout design (such as cross hairs, circles, and joystick-controlled target capture windows) shall be incorporated to assist the manual target field identification (MCCS operator) and subsequent target selection processes. For the TA, only manual target field identification and subsequent target selection are required. Automated features, such as star map generation or target field identification, will be provided by the MCCS as efficiency enhancement functional "shells" around the basic TA functions. Simple hooks, such as passive areas-of-interest (AOIs) shall be provided to enable MCCS implementation of automatic target acquisition. Emphasis shall be placed

on providing the lowest cost, simplest system, which meets functional requirements.

3.5.15 TA Attitude Measurement

To provide for a telescope attitude monitoring function, to provide for a capability to determine impending vignetted viewing, to serve as a determining source for slaving the cavity aperture door, and to assist in the implementation of a blind pointing and aircraft steering capability, the TA shall provide signals which will permit determination of the telescope angular position in the three orthogonal TA axes (relative to the TA mounted bulkhead reference indices) with an accuracy of $\leq \pm 0.1$ degree in all three axes. The signals shall be provided to the MCCS. The readout rate shall conform to the MCCS-TA interface details as specified in SOF-1030.

The attitude measurement signals may consist of inertial reference information of adequate accuracy to the MCCS to perform this function when combined with an equally accurate inertial frame provided by the MCCS. However, any other technique (e.g., using non-contacting electro-optical components) which provides information to derive relative angular displacements in the three TA degrees of freedom (DOF) may be utilized to meet the specified functional requirements.

3.5.16 Video Monitoring

Continuous target video monitoring of all imager fields of view will be provided at the workstation consoles. The TA shall share all imager FOV data as a digital facsimile with the MCCS via a fast digital network system for MCCS control and display and for video distribution throughout the observatory. The FOV vertical and horizontal axes shall represent the elevation and cross-elevation axes, respectively. See SOF-1030 for video interfaces.

3.5.17 External Disturbances

The TA shall be capable of meeting the stability and accuracy requirements with simultaneous external disturbances imposed on it in the form of: aerodynamic wind loads and pressure fluctuations in the open cavity; torques coupled through friction in the system bearing(s) and caused by aircraft rotational excursions and/or vibrations passing through the vibration isolation system and interface cables; torques coupled through displacement of the telescope center-of-mass from the center of rotation and caused by aircraft translational excursions and/or vibrations passing through the vibration isolation system; and torques simply caused by gravity on telescope static imbalance. Envelopes and profiles of the disturbances are provided in SOF-1030.

3.5.18 Telescope Balance

A TA balancing system shall be provided. Active fine balance, fully compatible with the TA pointing and control system, shall be automated using appropriate sensors and procedures; however, coarse balancing to bring the telescope into the range of a fine balancer may be a personnel assisted manual process. The following is an example of a three-mode balance system:

(a) Manual Coarse Balance: manual attachment of coarse balance weights to balance the telescope, for different science instruments, to within approximately 20% of the system axis continuous torque motor rating. Coarse balance weights to be removable to accommodate the heavier instruments.

b) Manual Fine Balance: manual adjustment (remote open loop TA operator control through the MCCS and, optionally, a local mechanical handcrank and/or local electronic control) of a fine balance mechanism to provide balancing in each axis from approximately 20% down to 1% of each axis' continuous torque motor rating.

c) Active Balance: an active closed loop balance subsystem providing automatic balancing about the three orthogonal TA rotational axes (at relatively low bandwidths compatible with the TA pointing and control subsystem) from approximately 20% down to less than 1% of each axis' continuous torque motor rating.

The combined balancing subsystem shall provide TA balancing about each axis to less than 1% of the respective axis' torque motor rating. The automatic balancing feature shall be a TA self-contained capability fully operable on the ground as well as in flight. It will be permissible for the automatic balance feature to require that the cavity aperture door be closed when automatically balancing the TA against gravity during flight. However, this shall not preclude use of the automated balancing subsystem with the door open at the option of the TA operator to counter other disturbances in addition to gravity (the RMS pointing stabilization requirements will be waived when the balance subsystem is operated in this manner). Means shall be provided for the TA to accept balance data inputs from the MCCS in the form of a predetermined set of estimated SI weight and c.g. change rates for which the TA balance control subsystem shall employ its own scheme of moving the appropriate motorized fine balance weights (in three axes) during observations without loss of track and with a goal of meeting overall RMS pointing stabilization requirements. Details of the interface command and control scheme (weight change rates, c.g. location, c.g. changes, etc.) shall be mutually consummated per SOF-1030 and its ICD process.

The TA shall meet its pointing accuracy and stability requirements, without rebalance, under moment changes up to 150 Nm around XEL and LOS and 30

Nm around EL, caused by changes in SI mass and SI c.g. during flight. The active balance subsystem shall be sized to accommodate SI mass and SI c.g. changes totaling an equivalent 800 Nm moment change around XEL and LOS and 400 Nm around EL calculated for a 10-hour flight.

3.5.19 Image Motion Compensation

The use of image motion compensation (IMC) to meet pointing stability requirements is not encouraged due to its expected "infrared noise" producing side effects on SIs. However, should circumstances demand the use of IMC, only the Secondary Mirror Assembly shall be considered for image articulation. In no case shall the image stabilizing contribution by IMC be greater than 1 arcsecond in object space.

3.5.20 Verification

Verification of PS performance during final acceptance testing will be accomplished with the worst-case SI (or facsimile) in place, no external dangling appendage to the SI such as cables or hoses, and with the TA exposed to the worst-case set of environment per SOF-1030. Where it is clear after initial flights that achieving simultaneous worst-case conditions is impracticable, analytical extrapolations or interpolations may be used to determine quantitative results.

3.6 CONTROLS SYSTEM AND INSTRUMENTATION

This section of the requirements shall apply to the complete TA electrical, control, and instrumentation systems. All activities which are associated with the TA, or any of its subsystems, requiring some method of automatic or manual control, indication, monitoring, or measurement, shall conform to the requirements in this section.

3.6.1 Controls System Description

Operational controls and instrumentation shall provide for the safe and convenient operation and monitoring of the TA and its associated auxiliary equipment. Target acquisition, automatic tracking/guiding and stabilization, telescope position, target image, temperature, pressure, time, and similar parameters shall be initiated, controlled and/or monitored from an "operator's console". During TA development and ground-based testing, the "stand-alone TA Operator's Controls and Display System (OCDS) shall be the “operator's console”. When fully integrated in the airborne observatory, the "operator's console" shall be the workstation console(s), and, except for the TA Annunciator Panel, the OCDS equipment shall be used only for ground operations when it is inappropriate to use the workstation consoles.

3.6.2 General Requirements

3.6.2.1 Basic System

The TA shall be designed to require a minimum number of types of electrical power for complete and normal operation. Where any other form of power is required within the system, such as pneumatic or hydraulic power, the TA shall provide the necessary conversion equipment, interfaces, and energy transfer elements. The TA shall be designed with components and functions that result in a control system with the required performance capabilities, a high degree of reliability and convenient operating and maintenance procedures. Emphasis shall be placed on providing the system with fault sensing and interlocking schemes to ensure personnel and equipment safety. Controls electronics shall be modular and accessible within their chassis or packaging to provide ease of maintenance or modification.

Interfaces with the MCCS are described in SOF-1030, including configuration (mounting/attachment, location, wiring), thermal/environmental, electrical power, and communications interfaces. The communications interfaces shall enable remote display by the MCCS of all parameters associated with the TA control system as well as external command inputs for all commandable functions, as detailed in SOF-1030.

3.6.2.2 Safety Interlocks

Interlocks shall be provided so that, (1) anomalous conditions in the electrical, hydraulic, pneumatic or other type of system will prevent initiation of active operation of the TA and, (2) during operation, malfunction in any subsystem will cause a cessation of operation of the TA without damage to the equipment or injury to personnel. Safety disconnect switches or circuit breakers shall be interlocked in such a manner as to disconnect power during maintenance or repairs.

3.6.2.3 Motion Limits

All motion controlled apparatus shall be provided with limit switches. Independent secondary mechanical protective features (snubbers, arresters, etc.) shall be provided to protect the system from malfunctions which carry the controlled apparatus beyond the normal operating limits (e.g., dynamic envelopes). Easily adjustable limits of travel (and limits for velocity and acceleration where necessary for safety) shall be incorporated into the system. In addition to the limits at the ends of the total elevation range, where the mechanical design warrants, limits of travel shall also be provided at the ends of the dynamic elevation range of motion. Any "hard" mechanical limit shall be located outside the geometrical solid defined by the required operational ranges of motion. The actuation of any of the adjustable electronic, electro-optical, or electro-mechanical limits shall cause all motion to be safely stopped. By proper implementation of

logic circuitry or by use of independent mechanical centering apparatus, means shall be provided to conveniently override the limit device and safely move the TA out of the limit position whenever a travel limit is actuated.

3.6.2.4 Control Logic

Safe means to energize the system shall be provided by the TA control system. After safe and proper turn-on of all necessary support subsystems and auxiliary units, initiation of active operation of the telescope (i.e., actively pointing) shall be accomplished by actuation of a single switch (or logic prompt) through automatic sequence control of interlocks and inhibit/permissive logic states. Control logic shall be incorporated so that sequences cannot be completed if one or more improper or unsafe conditions exist. Such interlocks shall be monitored by status indicators and error message processors such that if a sequence is not able to be completed the reason is immediately apparent to the operator. An annunciator with basic first fault indication, and acknowledge and test features shall be provided to exhibit reasons for shutdowns. Means shall be provided for conveniently restoring normal operation upon correction of improper conditions. Control logic interfaces shall be furnished to permit integrated system operation of the TA (start-up, operate, shutdown) remotely from the observatory workstation console. Operation from the workstation console shall be the normal mode of operation but with operation from the TA OCDS selectable as an option in ground modes. One or more emergency-stop switches (or power-kill switches) may be located at the Workstation consoles, flight deck console, and at the Principal Investigator's console as part of the MCCS. The TA control system shall initiate a rapid and safe shutdown sequence upon activation of any of these emergency-stop or power-off switches (interfaces specified in SOF-1030) in any ground or flight mode. The TA shall also provide an emergency-stop capability. Failsafe circuitry shall be used throughout the system, with manual override capability where appropriate. Proper control interfaces shall be provided by the TA to allow necessary logic input and output between the TA and the MCCS for normal control and monitoring. Emergency-stop buttons/switches shall be hard-wired into the TA shut-down logic circuit.

3.6.2.5 System Error Sensing

The tracking and stabilization system's error signals associated with each drive shall be sensed. In addition to other design dependent uses, these signals shall be made available for trouble-shooting purposes. See SOF-1030 for interface details.

3.6.2.6 Stopping/Holding Brakes

Mechanical and, if necessary, "dynamic" electrical brakes (electric energy dissipation) shall be incorporated on all axes of motion of the TA. During operation, braking shall be designed to slow down and stop the TA from velocities as high as its maximum rated velocity without exceeding safe

deceleration limits and to subsequently hold the TA at any position. When the TA is in its non-operating mode, the braking system (or a separate caging system) shall hold the TA from rotation under aircraft take-off, landing, turning and maneuvering forces. This shall apply also when the TA may be severely imbalanced during maintenance and setup procedures. Brakes shall be failsafe (applied with no active power) and automatically engaged in the event of detected operating anomalies or normal deactivation of any axis (control off). The brake system response time between command issuance and application shall be such as to safely stop the telescope in harsh environments.

A caging mechanism (or set of mechanisms) may be incorporated in addition to the required braking subsystem to capture (after the TA is stopped by the brakes), gently move, and securely hold the TA in a predetermined "caged/home" position. The caging mechanism may also serve as a TA "centering" device independent of the Pointing System control loops, (if needed for convenient/efficient operational restart or for ground checkout operations) by selecting the caged "home" position to also be the TA "center" position.

Refer to SOF-1030 for brake system interfaces with the AS.

3.6.2.7 Primary Actuators

Electromagnetic torque motors shall be incorporated as primary actuators for the TA. Other types of "prime movers" may be used if proven to be superior by analysis. Supporting data shall be provided to DLR for selection of these other types of "prime movers." Environments created by electromagnetic torquers (if used), particularly variation in magnetic fields at the SI mount, shall be controlled to the levels specified herein.

3.6.2.7.1 <u>Overload Sensing</u> – Instantaneous and time dependent overload sensing and protection devices shall be incorporated in all actuator power source lines. The overload sensing devices shall cause a cessation of operation by removal of drive power, application of brakes, and annunciation of the particular overload event.

3.6.2.8 Inertial Stabilization Sensors – Attitude and/or Rate

To maximize tracking capabilities to very dim targets (i.e., relatively long integration times and thus relatively long durations between tracker corrections for pointing system drifts) inertial attitude and/or rate sensors (gyroscopes) of required accuracy and drift characteristics may be utilized to form inertial stabilization loops. The inertial reference sensors, if used, shall be in a complete packaged assembly including all electronics, heater controls, caging controls, and connector/cabling necessary to operate as a complete unit. To the extent practicable, if multiple sensors are used, they shall be of the same make and model. Sensor location(s) shall be chosen to optimize TA pointing stability. For sensors located in the unpressurized cavity, appropriate provisions shall be

incorporated to minimize thermal dissipation which may affect optics temperatures or seeing due to convection.

3.6.3 Controls and Displays

3.6.3.1 TA Operator's Controls and Display System (OCDS)

The TA shall provide a stand-alone Operator's Controls and Display System (OCDS) that includes all the necessary equipment and means for control of all functional TA subsystems during ground operations when it is inappropriate to operate from the Workstation consoles. The OCDS shall be provided as ground support equipment separate from the flight TA equipment. The functions provided and the equipment used for control of the TA shall be designed for safe, reliable and efficient control capability. Safety critical subsystems shall be designed with parallel real-time access devices for safety.

The MCCS will provide equipment and means for operation of the TA from the workstation consoles for ground and flight operations. The TA shall provide interfaces for the external control and monitoring of the TA by the MCCS. Data and communication interfaces between the TA and the MCCS shall be in accordance with SOF-1030.

3.6.3.2 Basic and Supervisory Control

The TA shall be designed and equipped, as a minimum, with all of the rudimentary necessities to perform its required basic functions reliably as an airborne telescope. The MCCS will serve as a supervisory controller to the TA, providing all airborne operator interfaces to the TA, in addition to higher-level automation functions. The TA shall provide the fundamental observing tool in the form of a basic operating telescope and the MCCS will furnish the overall mission operations control and management functions. Overall mission monitoring and control will be a major part of the MCCS charter. Implemented as an "outer layer" level of control authority over the primary level of control provided by the TA, the MCCS will function to provide all flight operator interfaces and introduce various levels of mission automation modes of operation at selected intervals during a mission. The TA shall meet the communications interface requirements of SOF-1030.

3.6.3.3 Commands and Data Interfaces

A function shall be provided to serve as the element which will coordinate all command and data interfaces between the TA and the MCCS. The TA shall collect data from TA processes/sensors and communicate the data to the MCCS, or conversely to receive command/control signals from the MCCS or the experimenter's electronics (Principal Investigator) and in turn direct these signals to the intended TA functional subsystem.

The TA shall provide means for the MCCS to access command summing junctions, digital ports, sensor outputs, inputs/outputs of controlled functions, and all parameters to be sensed. It shall send and receive discrete prompt commands and status indicators between the TA and the MCCS for activation, initiation, selection, and indication of the various modes and processes associated with TA operation. Refer to SOF-1030 for details of these communications interfaces. Primary functions shall include the following:

(a) Processing and handling of commands from the MCCS and commands from the PI electronics to implement TA operating modes and functions and to drive continuous or pseudo-continuous dynamic processes. These shall include the interchange of command prompts, sequence control inhibits and status indicators. Where safety or performance critical circuits necessitate, hard-wired interfaces shall be incorporated.

(b) Processing and handling of data from TA sensors, and the conditioning, converting, scaling and formatting of data for transmittal to the MCCS.

(c) Processing and handling of "time tags" (e.g., event markers, time-phase indices, etc.) for signals from and to the MCCS, signals from the experimenter's equipment, and signals of all sensed quantities for time indexing purposes and to unambiguously reconstruct the time of science data collection. Absolute time references will be issued by the MCCS. Refer to SOF-1030 for details.

3.6.3.4 Telescope Operation Displayed Parameters

The following listed parameters, as a minimum (to the extent applicable to the final TA design), shall be transmitted to the MCCS. Additional parameters, as dictated by the TA design and determined necessary by the TA Contractor for effective system operation, shall be included. Scaled parameter ranges shall cover the entire operating ranges of the associated subsystems including reasonable margin. Parameter resolution/accuracy shall be consistent with the values specified for the subsystems (e.g., focus, telescope attitude), or commensurate with the performance requirements and anomaly detection of the associated subsystem. Parameters to be displayed at the TA OCDS shall be left to the TA designer's engineering judgment. Refer to SOF-1030 for the list of I/O parameters.

<u>General Parameters for Display</u>:

(a) TA subsystems' operational mode status.
(b) Primary mirror temperatures (~4).
(c) Secondary mirror temperature.
(d) Secondary mirror assembly housing temperature.
(e) Spider legs' temperatures (1 each)

(f) Centerpiece interior temperature(s).
(g) Tertiary mirrors' temperatures.
(h) Inertial sensor(s) and imagers temperatures.
(i) Nasmyth tube interior temperatures (~3).
(j) Pressure window assembly temperature.
(k) Pressure window assembly position.
(l) Telescope focus location.
(m) Secondary mirror focus and centering drives' displacements.
(n) Chopping parameters (amplitude, frequency, chop angle, waveform, chop center, reference phase).
(o) Telescope attitude.
(p) RIS pressure and temperature.
(q) RIS gap gauges outputs.
(r) VIS actuators' positions and cage status.
(s) Inertial stabilization system error signals.
(t) Elapsed time meter for inertial sensor and video systems' operation.
(u) TA structure vibration sensors (accelerometers) and strain gauges.
(v) Pressure differential across pressure window assembly
(w) Primary mirror fans status.
(x) TA electronics temperatures.
(y) Fine torquer currents and voltages.
(z) Coarse elevation displacement, drive status, current, and voltage.
(aa) Fine balance subsystem position sensors.
(bb) Caging/braking mechanism status (if used).
(cc) Centering mechanism status.
(dd) Tracking fields (one for each imager, with coarse and fine field displays).
(ee) Offset tracking angular distance.
(ff) ROF measured angle (for imager in use).
(gg) Tracking errors in elevation and cross-elevation
(hh) Fine Field Imager parameters:
    (1) Filter position
    (2) Offset angles (i.e., gimbaled, if used)
    (3) Focus position
    (4) Iris setting
    (5) Target integration period
    (6) Operating status
(ii) Wide Field Imager parameters:
    (1) Zoom position
    (2) Focus position
    (3) Filter position
    (4) Target integration period
    (5) Operating status
(jj) Focal Plane Imager parameters:
    (1) Focus position
    (2) Iris setting
    (3) Filter position

(4) Target integration period
(5) Operating Status

3.6.3.5 Annunciation

The TA shall provide an annunciator sufficient to indicate the cause of any system or subsystem shutdown and, where deemed prudent for safe TA operation, to indicate any development of conditions approaching unsafe or out-of-limit operation. An annunciator is defined as an electronically controlled subsystem which provides visual information indicating the occurrence or impending occurrence of a system fault. At the occurrence or impending occurrence of any TA fault, the annunciator shall initiate a visual indication of the cause. There shall be separate visual indicators for each fault. Visual indication shall be specific and complete so that it is not necessary to refer to any other source of information to identify the fault. Provisions for at least 20% spare annunciator channels shall be provided.

The annunciator shall be furnished with sequential indication (for functions which may cause multiple annunciations) which indicate which fault condition was first to occur, fault acknowledge provisions which terminate the audible alarm, and manual reset provisions. The manual reset provision may be deleted where automated diagnostic data-save features are provided which would allow retrieval of parameter states in cases of premature annunciator resets. Subsystem design shall ensure that no false indications are initiated by normal transient conditions, such as system start-up (e.g., proper bypass logic shall be incorporated to prevent superfluous annunciation at start-up/boot-up when many parameters may be out of tolerance until placed into operating conditions). A system test feature shall be provided for testing all annunciator channels for proper operation.

Full annunciation of all observatory subsystems will be necessary at the Workstation console. Thus all parameters necessary to provide information indicating the occurrence or impending occurrence of any and all TA subsystem faults shall be transmitted to the MCCS for annunciation there (see SOF-1030 for details). It will be left to the TA designer's discretion as to the level of annunciation incorporated at the TA OCDS.

3.6.4 Telescope Assembly Electronic Equipment

The TA shall provide all electronic assemblies and control/display panels required for safe and effective operation of the TA. TA airborne electronic equipment will be transferred into MCCS-provided electronics racks on board the aircraft during observatory-level integration. The TA Contractor will not need to provide the physical console shells or equipment racks for mounting of these subsystems in the aircraft. See SOF-1030 for electronic rack interface data.

The physical, environmental, electrical power, and communications interfaces for this equipment shall be as specified in SOF-1030. The MCCS will provide the environmental controls for this equipment (e.g., cooling fans) to prevent temperature exceedance. The design of these subsystems shall consider the

operating and nonoperating environmental conditions. Refer to the applicable paragraphs of Section 3.0 herein for SR and M design criteria for the equipment. Basic human engineering practices should be used when designing functions of control devices and displays in accordance with the guidelines of MIL-HDBK-1472.

3.6.5 Signal Monitoring Provisions

Maintenance and troubleshooting test points, terminal strips, cable break-out boxes and other signal-tap devices for all major component and subassembly input and output signals shall be provided. These individual "break-out" terminals shall be designed so as to minimize EMI and provide access for signal monitoring during maintenance activities. The location and other physical interfaces for this equipment shall be as described in SOF-1030. Test points shall be provided for monitoring appropriate signals within the various TA electronics chassis. The TA shall accommodate future attachment of additional sensors in distributed locations by the MCCS for monitoring (e.g., sensors on the TA structure). At least 30 representative spare signal cables shall be provided through the Nasmyth tube, at connector panel locations at each end. One end of these spare signal cables shall terminate in a connector panel on the Telescope Assembly in the cavity. The other end shall terminate in a similar connector panel next to the flange assembly inside the cabin.

3.6.6 System Reboot

The TA computers shall attain normal operating status within 2 minutes each time the system is rebooted. This includes occasions after an abrupt system power shutdown.

3.7 ELECTRICAL POWER SUBSYSTEM

3.7.1 Electrical Power General Requirements

The TA electrical power subsystem shall perform necessary functions to operate reliably throughout each mission and to provide compatible interface with the AS and the MCCS, as specified in SOF-1030. Specific functions include processing of power from the MCCS, and distribution of power to each TA functional component, with suitable grounding, bonding, circuit protection, etc., as specified herein.

3.7.1.1 Telescope Assembly Power Consumption

The TA subassembly/component designs shall be selected to minimize power consumption, especially for powered devices located in the cavity. This shall include careful design, selection of components and time phasing of power usage.

Power consumption by the entire operating TA shall not exceed 45 kVA, steady-state.

3.7.1.2 Power Distribution Subsystem

The Telescope Assembly shall be powered by a 200V line-to-line, 115V line-to-neutral, three-phase, 400 Hz electrical system supplied from the aircraft power system. Power for the TA shall be routed through a MCCS main service panel with appropriate primary and branch circuit breakers (reference SOF-1030). The TA shall draw balanced three-phase power from the 400 Hz power source under normal operation. If required, D.C. power supplies, frequency converters and other devices shall be rated for 400 Hz power input. The TA electrical power subsystem shall not use 50 Hz power. Where necessary, 60 Hz power shall be provided by a TA power conversion subsystem to the TA. Uninteruptible power supplies (UPS) may be incorporated if necessary for proper power removal from computers using particular operating systems.

Electrical power characteristics shall be compatible with the SOFIA aircraft power subsystem as defined in SOF-1030 (IN: TA_AS_12).

3.7.1.2.1 Electrical Load Balance – Loads greater than 0.5 kVA shall be configured to utilize 3-phase steady state balanced power within the limits specified in Figure 1 of MIL-STD-704.

3.7.1.2.2 Power Factor – The steady-state full load power factor in each phase of a load shall not be less than 0.75 lagging. It shall be a design goal to achieve a power factor greater than 0.85 lagging without an attendant weight penalty or decrease in reliability.

3.7.1.2.3 Inrush Current – The inrush current demand shall be as defined in SOF-1030 (IN: TA_AS_12).

3.8 ELECTROMAGNETIC INTERFERENCE AND COMPATIBILITY

The TA shall not disturb operation of the AS, MCCS or SI by emission of Electromagnetic Interference (EMI) signals either by conducted or radiated means. As a design goal, all TA racks and cables shall be shielded such that there is a 50 dB or greater attenuation to the external environment in the frequency range of 30 Hz to 40 GHz. The TA shall be designed and constructed so as to be electromagnetically compatible with the AS, GSE, MCCS and SIs. Electromagnetic Compatibility (EMC) requires that the normal operations of the TA shall not be susceptible to or adversely affected by radiated or conducted signals or voltage variations generated by the AS, GSE, MCCS, or the SIs.

The testing requirements and procedures of test method standard MIL-STD-462 or equivalent, shall be used to determine compliance with the applicable emission and susceptibility requirements of MIL-STD-461.

3.9 PNEUMATIC AND HYDRAULIC SYSTEMS

All pressure gauges shall be aircraft industry standard types. If a pneumatic system is used with the TA, it should conform to guideline document MIL-P-87210, or equivalent. If a hydraulic power system is used with the TA, it should conform to MIL-HDBK-454, Guideline 49, or equivalent. The Contractor shall furnish all pneumatic or hydraulic power supplies necessitated by the TA design. These power supplies, if to be located onboard the aircraft, shall be powered by the aircraft 400 Hz power source. Fire resistant aircraft hydraulic fluid shall be used with any hydraulic system whose lines penetrate into the pressurized cabin. Document MIL-H-83282, or equivalent, should be used as a guide for a candidate hydraulic fluid type. In any case, all pneumatic or hydraulic systems shall conform to FAR Part 25 requirements. Where design constraints demand, non-fire-resistant fluids may be used in the cavity in moderate quantities as long as proper safety precautions are met in the system design per FAR Part 25. Pneumatic pressure relief ports shall be plumbed to be dumped overboard. Also, any pneumatic system provided shall incorporate conveniently located input ports for externally-provided pressurized air, so that the system may be operated on the ground without activating the compressors. Reference SOF-1030 for components/equipment interfaces. Air bearing (if used) pressure switches shall be incorporated at the appropriate locations and wired into the control logic circuitry to prevent or stop motion whenever the pressure is below or above a predetermined level. The occurrence of high or low pressure shall be annunciated.

Emphasis shall be placed on conforming to the following requirements in design of these systems:

a. Protection from overpressurization through the use of suitable pressure relief valves and pressure switches (with annunciation). Pneumatic pressure dump shall be external to the aircraft.

b. Design and fabrication techniques shall be employed to reduce pneumatic and hydraulic noise.

c. No pneumatic or hydraulic gauges with pressure higher than 125 psi shall be mounted at the control console. Where remote readout is required, an electropneumatic or electrohydraulic transducer shall be used for indication at the console. No lines with higher than 125 psi medium shall be routed in or through any electrical/electronic cabinet.

d. For hydraulic circuits, manually operated needle type bleed valves shall be provided at high points wherever air entrapment can occur. Continued flushing or cycling of the circuit with oil to carry off entrapped air will not be accepted in lieu of positive bleed-off.

e. A heater and heat exchanger shall be provided with any hydraulic system to regulate the maximum oil temperature to safe limits. High temperature alarm and shutdown shall be provided.

f. A hydraulic level safety switch shall be included in the system.

3.10 STRUCTURAL AND PHYSICAL PROPERTIES

3.10.1 Structural Design

The primary support structure of the TA shall possess sufficient strength, stiffness, rigidity, and other structural characteristics required to survive the critical loading conditions that exist within the envelope of handling, transportation, and flight environments, in order to ensure safety and mission success throughout its life expectancy (20 years).

3.10.1.1 Strength Requirements

3.10.1.1.1 Yield Load – The structure shall withstand simultaneously the yield loads, applied temperature, and other environmental phenomena for all specified conditions without experiencing permanent deformation. Yield load conditions consist of operating and non-operating load environments as defined in SOF-1030.

3.10.1.1.2 Ultimate Load – The structure shall be designed to withstand simultaneously the ultimate loads, applied temperature, and other accompanying environmental phenomena without uncontained failure. Ultimate load conditions consist of emergency load environments as defined in SOF-1030.

3.10.1.1.3 Fatigue/Damage Tolerance Load – The structure shall be designed to withstand the repeated loads as described in Paragraph 9.2.3 of SOF-1030 and, in addition, the following pressure and temperature cycles:

a. A cavity temperature cycle from 20 degrees C to -40 degrees C, and back to 20 degrees C, once per flight (No temperature cycle for the cabin is required).

b. A cabin-cavity pressure difference cycle from 0 to 8.9 psi, and back to 0 psi, once per flight.

c. The 8.9 psi differential pressure and -40 degrees C cavity temperature will be applied simultaneously.

d. Assume 6000 flight cycles for the life of SOFIA.

3.10.2 Structural Strength and Stiffness

Strength and stiffness of the structure and its attachments shall be controlled by the equipment performance requirements and by consideration of the handling, flight turbulence, aeroelastic effects and TA divergence, and normal landing environments. Special locking or storage provisions shall be used on individual subsystems, if required, to prevent excessive dynamic amplification during transient flight events such as takeoff, unusual turbulence and landing.

3.10.3 Factors of Safety

This paragraph has been deleted.

3.10.4 Pressure Components Requirements

3.10.4.1 Components for Cabin Pressure Containment

All components which function to contain aircraft cabin pressure shall meet the requirements of the FAR Part 25 through amendment 25-89, section 25.365 and 25.843. Proofing shall be accomplished at the highest level of assembly suitable. The components include:

1. Flange assembly, including pressure window assembly
2. Nasmyth tube
3. Rotation isolation system, including rotor, stator elements, coarse elevation system
4. Support cradle assy
5. Vibration isolation system assembly, or all other TA-to-aircraft attachment assemblies
6. All seals, both floating air seals as well as elastomer seals
7. Any TA provided bulkhead or aircraft penetrations

3.10.4.2 Other Components

All pressure components which do not function to contain cabin pressure shall meet the requirements of the FAR Part 25 through amendment 25-89, section 25.1433 for vacuum systems, section 25.1435 for hydraulic systems, or 25.1438 for pressurization and pneumatic systems, and section 25.1301 for all of these systems. The components include:

1. Hydraulic or Pneumatic Systems
2. All pipes, tubes, hoses, and fittings
3. Pressure regulators
4. Valves
5. Filters
6. Accumulators

For any TA hydraulic system, a failure analysis shall ensure safe operational characteristics and minimized risks to other essential equipment. Since a TA hydraulic system itself does not perform an essential function for the Aircraft System, an endurance test according to FAR Part 25, section 25.1435 is not required. Proofing shall be accomplished at the highest level of assembly suitable.

3.10.5 Fasteners

Methods of fastening, materials, finishes and associated test methods should be in accordance with MIL-HDBK-454, Guideline 12, or equivalent, except for critical applications. Critical applications and torque values for such applications shall be in accordance with MIL-STD-1515 or equivalent. Critical applications are defined as any fastener use where loss or failure of the fastener could cause one or more of the following:

(a) Loss of the Observatory.
(b) Loss of the TA.
(c) Preclusion of continued mission and landing within the design limitations of the aircraft using normal pilot skill due to TA structural failure.
(d) Significant injury to occupants of the aircraft or ground personnel due to TA failure.
(e) Rendering of major subsystems or science instruments inoperative or causing their loss (destruction).

3.11 AIRBORNE SUPPORT AND GROUND SUPPORT EQUIPMENT

3.11.1 Airborne Support Equipment

The Contractor shall furnish all airborne telescope ancillary equipment, defined as TA Airborne Support Equipment (ASE), necessary for special TA adaptations in its aircraft environment during in-flight system performance characterization or for special services or unique interfaces to science instruments. The ASE consists of components which are not a permanently installed part of the TA and which are required for infrequent but essential special functions. The ASE may be of original or commercial design and may include general or special purpose tooling, test equipment, test optics, alignment apparatus, and similar items. Each item of TA ASE shall be identified by the Contractor.

3.11.2 Ground Support Equipment

The TA shall furnish all ground-based ancillary equipment, defined as Ground Support Equipment (GSE), necessary to support general TA operations and handling on the ground. The GSE is defined to consist of equipment which is not a permanent part of the TA, but equipment which will be used in general operations in conjunction with the TA in order to handle, install, and test the TA.

The GSE may be of original or commercial design and may include general or special purpose tooling, test equipment, test optics, consoles/enclosures, hoists slings, covers, cradles, shipping containers, and other appropriate equipment. Each item of GSE shall be identified by the Contractor.

3.12 MATERIALS, PARTS, AND PROCESSES

3.12.1 General

All parts, materials, and processes used in the design and fabrication of the Telescope Assembly and related components shall be identified, documented, and described. Industry, international, or applicable standards (including guideline documents MIL-HDBK-5400 and MIL-HDBK-454) may be tailored and used for TA parts, materials, and processes as appropriate. Particular consideration shall be given to the attributes for those items that will be subjected to the environmental extremes of the telescope cavity.

Only parts, materials, and processes of acceptable reliability and quality characteristics appropriate to their application for a 20 year service - high availability and use rate program shall be selected for application in TA hardware. The program objective shall be to minimize part and material types, utilize standard part types to the maximum extent possible, assure adequate derating and application, and ensure that minimum quality levels are maintained. The Contractor's materials and parts program shall be described in the SRM&QA Plan.

3.12.2 Standardization

Standardization and commonality shall be maximized in the selection of parts, wiring, materials, and related items required in the design, fabrication, installation, and maintenance of the TA. As a goal, the equipment design should minimize the number of different types of modules and electronic assemblies, cards, microelectronic devices, connectors, and parts. Materials, parts and processes shall be suitable for the intended application including the life cycle environmental profile. Interchangeability and substitution should be a principal goal in the design of components, parts, assemblies, and equipment.

3.12.3 Materials

Materials shall not be used, which through outgassing or other physical phenomena, cause the deterioration of other materials, or degradation of performance in the TA equipments, or exposure of other equipment, systems, components, or personnel to potentially hazardous materials when used in their intended environment.

Where practicable, fungus inert materials shall be used. Combustible materials or materials that can generate toxic outgassing or toxic products of combustion shall not be used if cost-effective alternatives exist. Items that may otherwise produce

deleterious outgassing in unpressurized areas shall be baked for a sufficient time to drive out all but an acceptable level of outgassing products prior to installation in the TA. A protective plating or coating shall be applied to all metals which are not corrosive resistant, except where electrical grounding is required or for items which are hermetically sealed.

All TA surfaces in the cavity shall not crack, chip, corrode, flake, or outgas under any ground or flight environment given in SOF-1030, including repeated cycles, over the lifetime of the airborne facility.

The suitability and durability of materials used for parts, the failure of which could adversely affect safety shall be determined on the basis of established reliability, experience or test; conformance to standards (such as industry or government) that ensure their having the strength and properties assumed in the design data; and the effects of natural and induced environmental conditions such as temperature, humidity, vibration, acoustics, shock, etc., expected in use.

3.12.4 Processes

The methods used for processes and fabrication shall produce consistently acceptable parts and structure. If fabrication processes such as bonding, welding, or heat treating require close control for compliance to requirements, the processes shall be performed under established industry accepted process/fabrication specifications. New fabrication methods shall be substantiated by a test program (including samples as appropriate).

3.12.5 Off-the-Shelf Equipment

The Contractor shall be responsible for the quality level of all off-the-shelf equipment. The use of off-the-shelf equipment does not relieve the Contractor of meeting the requirements of this specification, including the ability of the equipment to meet the safety, reliability, maintainability, and environmental requirements. Market surveys of off-the-shelf equipment shall be conducted to ensure those chosen meet specification requirements and are safe, reliable, and maintainable.

3.12.6 Electronic and Electrical Parts, Components and Assemblies

The items below represent general electronic assemblies and components requirements. They shall not be construed to be all inclusive.

3.12.6.1 Parts

Electronic and electrical parts, except for safety-critical parts (parts whose failure could jeopardize life or the system) may be commercial grade, military grade, or established extra reliability/test extra (ER/TX) parts at the option of the

Contractor. To enable design and configuration control and analysis, reprocurement and maintenance, each part shall be identified through an industry-recognized or military part number, or specification-control or source-control drawing. Specification and source control drawings shall include the characteristics to be controlled, the qualification requirements, any screening requirements, and the qualified source(s). Commercial grade parts shall be from a supplier of demonstrated quality parts, verified by the Contractor.

In the application of electronic parts and materials, the parts and materials selected shall be used within their electrical ratings and environmental capabilities (e.g., any ambient or hot spot temperatures, voltage, current, or power dissipation). Derating shall be accomplished as necessary to assure the equipment reliability within the specified operating conditions. Derating shall be accomplished based upon cooling conditions (either ambient or forced air) applied to the equipment when installed.

All safety-critical parts shall be traceable by lot date code from the time of receipt through after manufacturing screening and testing, to installation into operational hardware.

3.12.6.2 Power Supplies

TA DC power supplies which are not integral to a commercial off-the-shelf component, or which may present a hazard in emergency depressurization conditions shall be interlocked with a cabin-pressure monitoring switch so that the power supplies will be automatically turned off in the event of loss of cabin pressure. Optionally, the Contractor may elect to shut all TA power off in the event of cabin depressurization. The power supply outputs shall be protected by automatic cutouts upon overvoltage or overcurrent events. MIL-HDBK-454, Guideline 8, or equivalent should be followed. The power supplies shall not be damaged and shall return to operation upon removal of abnormal conditions. Power supplies shall be operated at not more than 80 percent of their rated outputs under full load conditions.

3.12.6.3 Power Amplifiers

TA power amplifiers shall be designed to be fully compatible with the loads to which they will be connected. They shall be conservatively sized to minimize component failures and be equipped with proper protective circuitry such as instantaneous current limiters, timed overload protectors, phase loss detectors, overvoltage clamps, and others. EMI generated by the power amplifiers and power supplies shall be within the requirements specified herein.

3.12.6.4 Discharging Devices

High voltage circuits and capacitors shall be provided with automatic discharging devices (unless they inherently carry 30 volts or less) which operate within two seconds after power removal. The discharging device shall insure that the capacitor or high voltage circuit is discharged to 30 volts or less within two seconds. These protective devices shall be positive acting, highly reliable, and shall actuate automatically when the power is removed. When resistive bleeder networks are used to discharge capacitors, the bleeder network shall consist of at least two equal valued resistors in parallel.

3.12.6.5 Wiring Selection

Wiring shall be of a type suitable for the application. MIL-HDBK-454, Guidelines 17, 20, 69, and 71, and MIL-W-5088 or equivalents should be used in wire and cable applications. Wire shall be selected commensurate with the rated maximum conductor temperature and heating effects of bundles, conduit, and other enclosures. Typical factors to be considered in wiring selection are voltage, current, ambient temperature, mechanical strength, abrasion, flexibility, pressure altitude requirements and the extremes of flight and non-flight environments. Electrical insulation materials should be in accordance with MIL-HDBK-454, Guideline 11, or equivalent.

3.12.6.6 Connectors

a. Type and Selection
All connectors shall have locking features, e.g., jack screws or circular bayonet type. Test connectors shall be located in accessible locations. TA/MCCS interface connectors and test connectors shall be per SOF-1030. All unmated connectors shall be protected with metal or plastic caps or otherwise suitably protected during maintenance, storage, and shipment. Only protective caps specified by acceptable specifications or standards and designed for mating with specific connectors shall be used. Unmated connectors which may contain electrically "hot" circuits while in environmentally hazardous areas shall be furnished with moistureproof and vaporproof caps. Connectors in enclosed cabinet-mounted equipment need not be provided with protective caps unless an environmental hazard exists. The selection and use of connectors should conform to MIL-HDBK-454, Guideline 10, or equivalent, including connectors for printed wiring circuit boards.

b. Connector Keying
The use of identical connectors in adjacent locations shall be avoided. When the use of identical connectors cannot be avoided, multi-contact connectors, including printed wiring assembly connections, shall be keyed, polarized, or of a contact configuration or size to physically prevent improper positioning, mating, or installation.

c. Spare Pins and Terminals
Multiple connectors and terminal boards used with interconnecting and interfacing major units and assemblies shall provide a minimum of 10% spare connector pins and terminals. MIL-HDBK-454, Guideline 10, or equivalent, should be used as a guide. In no case, shall less than two spare pins or terminals be available. Spare pins (contacts) shall be located on the periphery of the connector(s) and ends of terminals.

d. Pin Assignments
Pin assignments and isolation (separation) of pins within a connector shall be such that a short circuit resulting from a bent pin contacting adjacent pin(s) or case will not represent a safety hazard to the TA or Observatory. Connector design shall consider possible pin-to-pin and pin-to-case shorts, and particularly those short circuit potentials which are critical to safety and reliability. There shall be only one wire per pin, and a pin shall not be used as a terminal or tie-point for multiple connections.

e. Connector Wear Adapters
A connector wear adapter shall be provided for all TA/MCCS interface connectors, TA test connectors, and connectors which are expected to undergo frequent deliberate disconnections. Use of the wear adapter is intended to minimize connector fatigue due to repeated connector interruptions. The adapter connector that directly interfaces with the TA shall be of equivalent flight quality.

f. Module and Backplane Connections – Where electronic circuit boards or modular construction are used, ground potential and operating voltages shall be assigned to pins of all plug-in assemblies in a uniform manner, so that a given potential (e.g., power, ground, or signal) is applied to pins of the same number on all plug-in assemblies which utilize similar packaging.

3.12.6.7 Cables

All cables between TA-supplied subsystems shall be provided by the TA. Cables connecting the TA to the MCCS shall be provided as specified in SOF-1030. Requirements for cables between separated TA modules and TA-supplied cables between TA and MCCS should be in accordance with MIL-HDBK-454, Guidelines 65 and 66, or equivalents.

3.12.6.8 Grounding, Bonding, and Shielding

Grounding, bonding, and shielding interface design criteria should be in accordance with MIL-HDBK-454, Guidelines 1 and 74, or equivalents.

3.12.6.9 Electrostatic Discharge

The TA shall be designed to prevent electrostatic discharge (ESD) from degrading system performance or damaging components. Electrostatic discharge control should be in accordance with MIL-HDBK-454, Guideline 75 for Class 1, 2, and 3 parts, or equivalent. When parts sensitive to ESD are utilized in the equipment, protective circuits shall be incorporated in the equipment to ensure that ESD sensitive parts and subassemblies are protected in all phases of handling and testing. Warning labels shall be affixed to the protective packaging and to the equipment. Warnings shall be provided in all relevant areas of the equipment technical manual. Identification markings shall be affixed on all ESD sensitive subassemblies so as to be visible to maintenance personnel prior to maintenance handling of the equipment. Spare parts, modules, printed circuit board subassemblies, and so forth, shall be protected from ESD damage.

3.12.6.10 Corona and Breakdown Prevention

Electrical and electronic subsystems and components shall be designed so that their specified performance will not be impaired by self-generated corona discharge in normal operating environments, and that such discharge shall not be a source of interference which affects the operation of other facility equipment. MIL-HDBK-454, Guideline 45, or equivalent, should be followed. The equipment shall be designed and manufactured with electrical clearance spacing, leakage (creepage) distances, and insulation levels adequate to prevent electrical breakdown under the specified service conditions of humidity, condensation, barometric pressure, temperature, service life, contamination, and operating voltage (including transients).

3.12.6.11 Thermal Design of Electrical/Electronic Equipment

Thermal design should be in accordance with MIL-HDBK-454, Guideline 52, or equivalent. Cooling methods other than air cooling shall not be used.

3.12.6.12 Interchangeable and Replacement Items

Parts which are identified as interchangeable or replaceable parts for the equipment shall be easily removable and replaceable. These parts shall not be mounted by means of rivets, spot welding, or hard curing compounds. If, in order to check or remove a part, it is necessary to displace some other part, the latter part shall, whenever practicable, be so wired and mounted that it can be moved without being disconnected and without causing circuit detuning or instability. No unsoldering or soldering of connections shall be necessary when the front panel or any subchassis is removed for maintenance purposes. Design shall be such that where plug-in modules or assemblies are used, they can be easily inserted in the proper location when correctly oriented without damage to equipment or parts being engaged. Plug-in modules and assemblies shall be designed to prevent insertion when incorrectly oriented.

3.12.7 Structural Welding

Structural welding should be in accordance with MIL-HDBK-454, Guideline 13, or equivalent.

3.12.8 Castings

Castings shall not be used in the TA design unless specifically waived by DLR .

3.12.9 Electrical Overload Protection

The TA equipment should be designed to meet the electrical overload requirements of MIL-HDBK-454, Guideline 8 for Class 2 equipment. Protective devices employed in the equipment shall be in a readily accessible, safe location.

3.12.9.1 Resettable Circuit Breakers

Circuit breakers or other resettable devices shall be used to protect circuits. MIL-HDBK-454, Guideline 37, or equivalent should be used.

3.12.9.2 Spare Fuses

When fuses are used, a minimum of one spare fuse for each size and rating, but a quantity of not less than 10 percent of the total, shall be incorporated in the equipment and shall be contained in the same compartment.

3.12.10 Lubricants

Lubricants used in the TA shall be suitable for the intended use including environmental considerations. The number of lubricants should be held to a minimum. Low volatility should be used where practical. Each lubricant shall be chemically inert with regard to the material(s) it contacts. Consideration of toxicity shall be given prior to material selection.

3.12.11 Thread Compounds

3.12.11.1 Thread Locking and Retaining Compounds

Thread locking and retaining compounds shall be used as appropriate and shall be applied in such a manner that the required level of locking or retaining is achieved and maintained. Such compounds shall:

(a) Not be used where required electrical conductivity is impaired.
(b) Not be used where failure of the compound would endanger personnel or damage the equipment.
(c) Be compatible with the material and finish to which they are bonded and shall have no detrimental effect on the material or finish.
(d) Not cause or accelerate corrosion.

3.12.11.2 Antiseize Compounds

Antiseize compounds shall be used where parts are subject to disassembly for repair, shipping, maintenance, etc. Graphite base antiseize compounds shall not be used.

3.12.12 Dissimilar Metals and Corrosion Protective

Dissimilar metals shall not be used in combination unless they are suitably coated to prevent electrolytic corrosion. The use of dissimilar metals shall be limited to applications where similar metals cannot be used due to peculiar design requirements. Metal parts shall possess corrosive resistance characteristics or be furnished with corrosion protective finishes.

3.12.13 Stress Corrosion

The TA design shall consider stress corrosion for metallic materials used in load bearing application throughout the life of the TA.

3.12.14 Nonmetals

Nonmetals used, including plastics, composites, etc., and protective finishes, shall be moisture and flame resistant, shall not support fungus growth, shall not support combustion, and shall not be adversely affected by the natural and induced environments of handling, shipping, storage, or ambient conditions encountered during operation of the system. Nonmetals may be specially treated to conform to this requirement.

3.12.15 Cabinets and Enclosures

Cabinets, enclosures, etc., shall be selected or designed to provide protection for the contained equipment against shock, vibration, and other natural and induced environmental conditions which may be encountered during the life cycle of the TA including transportation, shipment, storage and aircraft installation and operational use.

3.12.16 Workmanship

The TA shall be fabricated, processed, tested, and handled such that the finished products are of sufficient quality to ensure reliable operation, safety, and service life. Workmanship for electronic equipment should be in accordance with MIL-HDBK-454, Guidelines 5 and 9, or equivalents. The products shall be free from nicks, burrs, sharp edges and corners, loose material, contamination and corrosion.

3.12.17 Environmental Stress Screens

Environmental stress screens on electronic components (vibration and temperature cycling within design limits) shall be conducted to precipitate latent defects at levels of assembly where defect correction is most cost effective. Any screening program shall be mandatory only for safety-critical and mission-essential parts.

3.12.18 Spares

The Contractor shall provide spares provisioning recommendations based on operational and maintenance plans, availability objectives, influence of design, and other pertinent factors such as cost. The recommendations shall include consideration of spares location (ground vs. available in-flight). In particular, primary candidates for spares shall be:

(a) Standard components or subassemblies known to have low MTBFs.
(b) Mechanical parts subject to wear.
(c) Items requiring periodic preventive maintenance.
(d) Unique items which may fail during the lifetime of the Observatory, in normal use (i.e., items not commercially available).
(e) Electronic boards.

3.12.19 Marking

Internal and external markings shall be applied for identification and location per design drawings (reference designators). The guidelines of standard practice document MIL-SP-130, or equivalent, should be used. These markings shall be permanent for the life of the part or assembly. Marking shall not adversely offset the leakage path between conductors or any other factor of the TA equipment. The marking data shall be visible to maintenance personnel without the necessity for disassembly of any part or of adjacent functional or structural parts. Assembly drawings (or photographs) with the required part identification may be substituted for miniaturized or otherwise difficult to label components.

TA items which by intent or by material disposition are not suitable for use in flight articles, and which could be accidentally substituted for flight or flight spare hardware, shall be red tagged or stripped with red paint, or both, to prevent such substitution. The red tag shall be conspicuous and marked "NOT FOR FLIGHT." The red paint shall be material compatible and the stripes unmistakable.

3.12.20 Paint and Coatings

Insofar as practicable, all applicable parts of the TA located in the cavity shall be coated with high emissivity, stray-radiation suppressing infrared black paint. All assemblies and equipment on the cabin side shall be color coordinated using the following two basic colors: Federal Standard 595, color No. 27886 (semigloss

off-white) and color No. 25183 (semigloss blue). The gloss or lusterless versions of these colors may also be used if available.

3.13 TRANSPORTABILITY

3.13.1 General

Packaging, handling, transportability, and transportation requirements and constraints shall be interfaced and integrated into the design of TA equipment to achieve the lowest life cycle cost. Adequate fixtures, containers and procedures shall be provided for handling, storage, preservation, packaging and shipping of the TA (as disassembled for shipping), to protect the quality of the TA and prevent physical and functional damage, loss, deterioration, and other kinds of degradation. Shock and vibration environments associated with transportation shall be evaluated to ensure adequate container and fixture design and protection for the handling and transportation environments.

Transportability shall be a consideration in the planning and design of the TA to ensure an efficient and safe transportation and handling capability by all required modes. Handling, tiedown, and slinging points shall be incorporated in the design of TA equipment as needed to guarantee transportability and complement installation, maintenance, and other handling requirements. Full consideration shall be given to the safety aspects of the TA equipment and its sectionalization and disassembly capability for transport purposes, with ease of reassembly for operational use also maintained as a design objective. For safe handling, the center of gravity of the integrated TA and dematable TA subassemblies over 50 lbs (23 kg) should be determined in 3 axes and clearly marked on the hardware and drawing.

3.13.2 Ground Handling

The TA and its dematable subsystems shall have provisions for attachment of handling fixtures to permit TA installation and removal in the AS with associated ground handling equipment. The individual TA components, particularly optics and other sensitive structures, shall be assessed for the allowable shock and other loads to which they may be exposed during ground handling.

3.13.3 Transportation

The TA shall be designed for transportability by normal commercial means (i.e., commercial aircraft, truck, etc.), and shall be transported using equipment specifically designed to protect the TA hardware during ground and air transportation. Vibration, shock, pressure, temperature, humidity and contamination shall be controlled during transportation to not exceed hardware environmental design levels. Means shall be provided for any necessary protection against deterioration or damage to items in storage.

Provisions shall be made on the TA dematable components' structure for suitable tie down and lift attach points for securing to the transport vehicle, enclosure, or

container, for transportability and handling. Attach points shall not interfere with the assembly, checkout, or integration functions. All deliverable handling and transportation equipment shall be compatible with the applicable structural and environmental requirements.

3.13.4 Packaging for Transportation

The TA packaging system shall be designed so the TA can be handled and transported without damage or degradation. The packaging design shall ensure that loads induced in the TA during transportation and handling will not produce stress, internal loads or deflections that may result in damage to the equipment. Covers shall be provided for mirrors and other hardware subject to damage when not installed in the TA or undergoing test.

3.13.5 Disassembly/Assembly

Equipment requiring disassembly for shipment shall be designed for ease of disassembly and reassembly with minimum personnel and tools.

3.13.6 Cleanliness and Contamination

The system design shall assure compatibility with established industry standard procedures for handling and processing of cleaned items (e.g., optics) to maintain the items' cleanliness.

3.13.7 Handling, Storage and Transportation Conditions

ESD-sensitive items, such as electronic assemblies and associated spare parts shall be handled, stored and transported in sealed packages using appropriate antistatic wrapping material. The antistatic material shall be grounded through a resistor prior to removal. The grounding resistor shall have a value between 100,000 ohms and 1 megohm.

Handling, storage and transportation conditions shall be controlled to acceptable limits. Cleanliness shall be maintained during handling, storage, and transportation using appropriate protective covers and containers. Environmental exposure (temperature, humidity, shock) during handling and transportation shall not exceed those specified for acceptance.

3.13.8 Transportation of Pressure Systems

Consideration shall be given for pressurized systems to be transported with pressure exhausted to reduce hazards to personnel and mission-critical hardware during non-operative transport.

3.14 SAFETY, RELIABILITY, AND MAINTAINABILITY

The Contractor shall establish, implement, and maintain effective documented procedures for TA design control and verification of the design in order to ensure that specified requirements and TA needs are met. System needs include the aspects of design control for safety, reliability, maintainability (supportability), usability, and availability considering the 20 year operational life of the TA. Human factors shall also be a major consideration in safety, usability, and maintainability. Analysis of the functional requirements contained herein shall be conducted and a detailed mission profile and time-line generated that will define specific performance functions related environmental stress levels, duty cycles, and maximum duration of environmental exposure for each mission phase, and the 20 year life cycle. The analysis shall result in definition of the TA configuration, the preparation of system models, and generation of qualitative and quantitative factors as appropriate, to guide TA design and serve as a guide for design evaluation. The Contractor shall maintain a continuous effort to control design practices and documentation to assure the incorporation of reliability, maintainability, safety, human engineering, and quality requirements into the design and production activities. The Contractor should use the applicable requirement and guideline documents listed herein, industry and international standards and manuals, and other related documentation as applicable to meet system requirements. The Contractor shall provide and document, for DLR approval, a Safety, Reliability, Maintainability and Quality Assurance (SRM&QA) Program Plan that addresses: (a) the overall TA system as well as ASE, GSE and spare/repair parts, and (b) both FAA certified and non-certified systems. A preliminary SRM&QA Program Plan shall be included in the response to the RFP. Controlling documentation recommended includes:

(a) Criteria for product selection, application, and derating.

(b) Redundancy, diversity and separation techniques for reliability achievement.

(c) Guides for assuring producibility, repairability, and inspectability.

(d) Considerations for special tooling, processes, special test and inspection equipment, test points and special interface gages.

(e) Guides for reliability, maintainability, quality, safety, and human engineering tradeoffs.

(f) Tolerancing guidelines.

(g) Consideration of maintainability design criteria and maintenance requirements including support equipment.

(h) Consideration of environmental and cleanliness control requirements for fabrication and test.

(i) Guides for the identification of products for traceability.

(j) Criteria for electrical grounding, bonding and shielding.

(k) Criteria for preservation, packaging, handling, storage and transportation.

(l) Worst-case analysis of tolerance buildup in applicable parts and materials and utilization in design decisions.

(m) Part parameter drift analysis for consideration of part long term parameter worst-case drift over the life cycle of the TA.

3.14.1 Safety

The Contractor shall achieve the safety objectives to identify and evaluate TA design and operational activities to assure measures are taken to minimize risks. MIL-STD-882 should be used as a guideline in accordance with the requirements of Appendix A herein. The Contractor's system safety effort shall be described in the SRM&QA Plan.

The TA shall be designed for safe use, operation, handling, and maintenance. As a part of equipment design, safety factors shall be given major consideration, including, as a minimum, the effective application of the human engineering criteria together with the representative safety criteria herein. The primary emphasis should be the development of safety design criteria, and the accomplishment of safety assessments to identify and evaluate potential hazards for their elimination or for reduction of associated risk to an acceptable level. Provisions for the safety of personnel during installation, operation, handling and maintenance shall be required. MIL-HDBK-454, Guideline 1, and MIL-HDBK-1472, Guideline 5.0, paragraph 5.13, or acceptable equivalents should be used.

3.14.1.1 Safety Criteria

Safety criteria shall be applied during TA design and fabrication to eliminate or control potential hazards that could cause injury to personnel during TA handling, installation, operation, and maintenance, or could cause damage to the TA or adjacent equipment/property during such operations. Consideration shall be given to hazard potentials of flammable materials, carcinogens, gases or fumes, and other hazardous or restrictive substances. Mercury, asbestos, and radium shall not be used. Glass fibers shall not be used as an outer surface or covering on cable, wire, or other items where they may cause skin irritation to operating personnel.

The following general safety criteria shall be utilized to form a baseline for developing detailed safety criteria (to the extent they fit within personnel, system, support, and operating constraints and objectives).

(a) The TA equipment shall be designed for safe use, operation, and maintenance. Systems that are designed in accordance with accepted design standards (e.g., the ASME Boiler and Pressure Vessel Code) are considered to be "designed for minimum risk." Where this approach to hazard control is not used, the system shall be designed so that no single hardware/software failure or operator error can result in a catastrophic or critical hazard (Hazard Resolution Priority 1 or 2) as defined in Figure A-1.

(b) Control and minimize potential hazards to personnel, equipment, and material where such hazards cannot be avoided or eliminated.

(c) Isolate hazardous substances, components, and operations from other activities, areas, personnel, and incompatible materials.

(d) Consider alternate approaches to minimize risk from hazards that cannot be eliminated. Such approaches include safety interlocks, safety brakes, redundancy, fail-safe design, system protection, fire suppression, overload sensing devices, and protective clothing, equipment, devices, and procedures.

(e) When alternate design approaches cannot eliminate the hazard, provide warning and caution notes in assembly, operations, maintenance, and repair instructions, and distinctive markings on hazardous components and materials, equipment, and facilities to ensure personnel and equipment protection.

(f) Incorporate "fail-safe" designs and principles where analysis indicates failures could or has the potential to disable the system or cause a critical or catastrophic event.

(g) Incorporate TA mounting provisions which prevent any secondary failures from propagating to the extent that the TA comes loose from its mounts.

(h) Incorporate design to preclude any critical damage in case the movement limiting devices fail to secure the TA during takeoff, landing, or in conditions of moderate to severe turbulence.

3.14.1.2 Equipment Emanations

Protection shall be provided for personnel and equipment from TA emanation of ionizing radiation, microwave radiation, X-radiation, microwave and RF radiation, laser radiation, ultrasonic, fluid, and air pressure.

3.14.1.3 Thermal Hazard Protection

TA equipment which, in normal operation, exposes personnel to surface temperatures which could cause burns/injury, shall be appropriately guarded. Surface temperatures induced by climatic environment are exempt from this requirement.

3.14.1.4 General Grounding Provisions

The design and construction of the TA shall ensure that, during test and operation of the TA and ancillary equipments, all electrically conductive external surfaces (including enclosures, guards, shields, flanges, metal cased readouts, structures, shafts, etc.) shall be at none other than ground potential. Provisions for the external ground connection to the test equipment shall ensure continuous and permanent connection with sufficient mechanical strength to minimize the possibility of ground disconnection. Such ground path shall have sufficiently low impedance and ample capacity to conduct safely any operating or fault currents imposed on it including the operation of overcurrent devices in the circuit.

3.14.1.5 Safety Information for Drawings and Documents

Criteria which govern the requirements for personnel and equipment safety shall be included on/in drawings, test procedures, and other documents to be delivered with the TA. Information covered shall include, but not be limited to, hazardous items and operations, and items subject to degradation including electrostatic discharge, handling, cleaning fluids, moisture, etc.

3.14.1.6 Carcinogens

Certain chemicals have been identified by the U.S. Occupational Safety and Health Administration (OSHA) as cancer-producing substances (carcinogens). Before using any materials which might contain these chemicals, they shall be evaluated in accordance with the Code of Federal Regulations (CFR), Title 29, Chapter XVII, Part 1910, or acceptable equivalent.

3.14.1.7 Gases or Fumes

Materials installed in the TA shall not liberate gases which, when combined with the atmosphere, form an acid or corrosive alkali, nor shall they liberate toxic or corrosive fumes which would be detrimental to the performance of the equipment or health of the equipment operators. The materials also shall not liberate gases which will provide an explosive atmosphere.

3.14.2 Reliability Assurance

The primary emphasis shall be on parts, materials, and reliability design analyses, including redundancy in trade studies. There are no quantitative reliability or reliability test demonstration requirements. The Contractor's reliability effort shall be described in the SRM&QA Plan.

3.14.2.1 Design for Reliability

Techniques shall be used which have proven successful in achieving reliable TA equipment design. Preference shall be given to software and hardware designs that have proven successful in the intended mission environment. Part standardization, type and quantity minimization, stress derating, redundancy, fault isolation, credible single point failure (SPF) minimization, and stress-strength analysis shall be used in the design. Program peculiar criteria shall be developed for use in the design. A Failure Mode, Effects and Criticality Analysis (FMECA) shall be performed to identify credible failure modes of the TA. An FMECA report shall be submitted to DLR for approval.

Optimum application of all redundancy techniques (active, passive, and graceful degradation) shall be used. To the extent described in Paragraph 3.14.2.2 below, credible single point failure modes shall be avoided. Insofar as practicable, design for redundancy shall utilize independent paths of operation or communication and provide an adequate degree of assurance of effective successful operation during intermittent failure modes.

3.14.2.2 Mission Essential Equipment Criteria

Mission essential equipment (MEE) is defined as any TA equipment that is essential for mission success. Mission success is defined as operation of the TA within specification from TA turn-on until mission completion and shutdown. MEE includes: airborne equipment for which there is no redundant backup; equipment used in the operations at critical mission times; any equipment necessary for control or the initiation of real-time commands that are mission critical (time critical), and GSE required for mission preparation. Insofar as practicable, mission essential equipment credible single point failures (SPFs) shall be eliminated by functional or block redundancy. Unavoidable SPFs shall be justified, based on risk analysis and measures implemented to minimize risk. Risk analysis and justification for any mission essential equipment SPF shall be submitted for DLR approval. For SPFs, the ability to recover from inflight failure by some means shall be emphasized. Redundant functions or degraded operating capability following a credible SPF shall be considered to preserve at least the capability for partial mission success. The following design approaches shall be considered:

(a) Develop design architectures which make maximum use of redundancy potential at interfacing subsystems where possible.

(b) Implement designs that at least assure partial science data return if a single inflight failure occurs.

(c) Implement functions that cannot be protected by redundant schemes by conservative design approaches, high reliability parts application and use of proven technologies.

3.14.2.3 Redundancy

Where redundancy may be required, as a goal, the TA design shall consider the following:

(a) The capability to check out redundant items as part of normal checkout sequence.

(b) The capability to establish status and detect failure of redundant items.

(c) Provisions to minimize the probability that all redundant items can be lost by a single credible cause or event.

(d) Isolation between redundant items to prevent loss by a single credible cause or event.

(e) The capability to reconfigure hardware elements.

3.14.2.4 Failure Tolerance

The TA shall be required to be fail-safe against any fault that could cause an immediate threat to personnel, TA, aircraft, or other equipment. Within the constraints of safety, if a failure will result in failure to complete the mission, the TA shall be designed to fail operational (fail-soft), if practicable. The fail soft condition may require the introduction of redundancy for continuance of mission success.

3.14.3 Maintainability Assurance

3.14.3.1 Maintainability

As a goal, the TA and components included as part of the TA shall use maintainability design criteria to guide the design process for the purpose of detecting, preventing, and correcting maintainability design deficiencies. The design criteria shall include: lessons learned; general accessibility, work space and clearance; interchangeability; standardization; modularity; limitation of number of tools, accessories and support and handling equipment; testability of parts, adjustments and connections; ease of assembly and removal of mirror assemblies, including handling, mobility and transportability; inherent

maintenance characteristics; use of commercially available parts and off-the-shelf equipment, etc. Guideline document MIL-HDBK-791 should be used to provide guidance for the maintainability analysis and design effort. The Contractor's maintainability effort shall be described in the SRM&QA Plan.

Maintenance engineering analysis shall be performed for the TA, subsystems, and equipments. Maintenance engineering analysis shall require the examination and analysis of proposed and actual designs in order to establish the most effective and efficient maintenance procedures for preventive, progressive, and corrective maintenance, and to identify maintenance resource requirements (e.g., repair parts, skills and equipment). When it is determined by maintenance engineering analysis that a proposed or actual design is deficient in meeting qualitative or quantitative maintainability requirements (e.g., access, space, standardization, mean-time-to-restore, and mean-time-to-repair), the maintenance engineering analysis record shall provide the necessary factual data as guidance for accomplishing design or redesign.

3.14.3.2 Maintainability Design Criteria

Maintainability design criteria, standards, and policy shall be defined, documented, and utilized to optimize maintenance and maximize operational readiness.

The following maintainability guidelines shall be considered in the design of the TA.

(a) Minimize downtime due to maintenance by using:

(1) Maintenance-free design
(2) Standard and proven design and components
(3) Simple, reliable, and durable design and components
(4) Modular design

(b) Minimize maintenance downtime by designing for rapid and positive:

(1) Prediction or detection of malfunction or degradation
(2) Localization to the affected assembly, rack, or unit
(3) Isolation to a replaceable or repairable module or part
(4) Correction by direct replacement, adjustment, or repair
(5) Verification of correction and operability
(6) Identification of parts, test points, and corrections

(c) Minimize maintenance costs by designs which minimize:

(1) Hazards to personnel and equipments
(2) Requirements for Contractor maintenance

(4) Unnecessary maintenance
(5) Personnel skills

(d) Minimize the complexity of maintenance by designing for:

(1) Compatibility among system equipment and facilities
(2) Standardization of design, parts, and nomenclature
(3) Interchangeability of like components, material, and spares
(4) Minimum maintenance tools, accessories, and equipment
(5) Adequate accessibility, work space, and work clearances

(e) Minimize the maintenance personnel requirements by designing for:

(1) Easy handling, transportability, and storability
(2) Minimum numbers of personnel and maintenance specialties
(3) Simple and valid maintenance procedures and instructions

(f) Minimize maintenance error by designing to reduce:

(1) Likelihood of undetected failure or degradation
(2) Dangerous, awkward, or tedious job elements
(3) Ambiguity in labeling or coding of equipment

3.14.3.3 Testability

Overall testability design objectives, goals, thresholds and constraints shall be established. Alternative diagnostic concepts to include varying degrees of built-in-test (BIT), manual or off-line automatic test equipment (ATE), diagnostic test points, etc., shall be evaluated and a diagnostics concept selected. The evaluation shall include:

(a) Partitioning. The TA shall be partitioned based upon the ability to confidently isolate faults.

(b) Fault Detection and Isolation. Each item within the TA shall have sufficient points for measurement or stimulus of internal circuit nodes so as to achieve an inherently high level of fault detection and isolation. Built-in test devices (if used) shall maintain their accuracy under all operating conditions required by the equipment. These devices shall be provided with connections or access for their operational checkout or calibration.

(c) Built-in Test. Where it is cost-effective, the TA shall incorporate the capability to have critical mission functions monitored by BIT. If used, BIT tolerances shall be set to optimize fault detection, isolation and false alarm characteristics, and BIT indicators shall be designed for maximum utilization by operator and maintainer.

(d) Test Points. Internal and external test points shall be included as an integral part of the electronic system design so as to permit the functional and static parameters of the equipment to be monitored, evaluated and isolated, and to enable efficient calibration or alignment. The number of test points shall be adequate to provide the scope of maintenance required by the maintenance concept; test points shall include conveniently located terminal strips and cable "breakout boxes." Protection shall be provided in the test point circuitry to prevent equipment damage caused by the external grounding of test points or incorrect voltage applications.

(e) Failures. Provisions for testing shall be so designed that any failure of BIT devices (if used) will not degrade equipment operation or cause equipment shutdown unless equipment is specifically designed to shut down in case of BIT device failure.

3.14.3.4 Special Tools

The design of equipment shall be such that the need for special tools for adjustment, maintenance, replacement, and installation is kept to a minimum. Only when a required function cannot be provided with an existing standard tool shall special tools be considered. Any special tool required for operation and maintenance shall be furnished by the Contractor. Where practicable, special tools that may be required during operational flight sequences shall be mounted securely in the equipment in a convenient and accessible place, or in a central accessible location. Special tools shall be capable of performing the required functions throughout the life of the equipment they support.

3.15 INTERFACES

3.15.1 Interface Control Documents

Draft Interface Control Documents (ICDs) shall be submitted at least 6 months before TA PDR. Baseline ICDs shall be developed before or at PDR and submitted for placement into SOF-1030. Final ICDs shall be developed by or at CDR.

3.15.2 Interface Gage and Fixture Program

The Contractor shall establish and maintain an interface gage and fixture program to ensure maintainability and interchangeability of major components at Telescope Assembly and Aircraft System interfaces, including fabrication and test fixtures.

A working gage committee shall be established to review product drawings for dimensional adequacy, establish interface tolerance structures, and determine requirements for special interface gages.

3.16 TEST PROGRAM

The Contractor shall establish and implement a test program. The test program shall be documented in an Integration and Test Plan and implemented by test procedures. The I&T Plan and associated test procedures shall be submitted for DLR approval. The Contractor's complete test program for the TA hardware and software shall encompass development, qualification, burn-in, software, preshipment, acceptance, and other related testing. The Contractor shall select test methods, environments, and parameters so as to permit the collection of empirical design and performance data and the correlation of such data throughout the complete test program. Design suitability shall be demonstrated in a development test program, as applicable, prior to the start of formal preshipment and acceptance testing. All required tests shall be as specified in Section 4.0.

3.17 SOFTWARE DESIGN

TA software shall be designed, developed, managed, tested and documented in accordance with the guidelines of ISO 9000-3 supplementing the requirements of ISO 9001 for software. Activities and documentation generated (including Version Description Documents) shall be in accordance with the guidelines of AHB 5333.1. Documentation shall be submitted for DLR review. All software and firmware shall be developed and managed in functionally allocated modules, with each module designated as a Computer Software Configuration Item (CSCI).

All deliverable TA software applications shall include a capability for detailed system monitoring and troubleshooting.

Use of unique Contractor pre-developed proprietary source code shall be kept to a minimum and use of which shall be approved by DLR . ANSI C-X3-J11 shall be the high order language ("C") utilized to the maximum extent practicable, to allow portability to other "UNIX" operating systems. Use of assembly code shall be kept to a minimum, being restricted to I/O drivers and critical timing loops, if used.

Contractor's modification of purchased vendor software is discouraged (unless the software is otherwise designed and intended to allow incorporation of modifications) and shall not be allowed without prior DLR approval. The Contractor shall provide complete documentation in English of all purchased or licensed TA software in accordance with prevailing commercial practices (including Version Description Documents). If purchased vendor software modifications are authorized, all applicable documentation shall be annotated to

reflect the impact of such modifications. All deliverable commercial software that is required for the operation and maintenance of the TA shall be licensed in the name of NASA. The following is a minimum set of deliverable and non-deliverable TA software items.

Deliverable software items:

* Run-time versions of developed TA software including the run-time licenses. These licenses shall be delivered with NASA designated as the registered user.
* Special libraries, fonts, etc. that do not require a license.
* Developed TA source code.
* Build procedures to ensure the setup of a development environment in the SSMOC facility.
* Developed TA software.
* Special tools needed to load the TA software onto the subsystems.

Non-deliverable software items:

* Standard TA software development environments such as CASE tools.

The Contractor shall prepare in English and maintain a Software Development Plan (SDP) for TA software which defines the Contractor's engineering discipline and management control practices for software. The SDP shall be submitted for DLR approval. Software shall be tested in accordance with Section 4.0.

3.18 FEDERAL AVIATION CERTIFICATION

The TA shall be designed to meet the structural and airworthiness requirements of FAR Part 25. The TA ancillary equipment to be installed in the aircraft shall be designed to meet the guidelines of FAA Aircraft Circular AC 25-10, or equivalent.

NOTE: AC 25-10 sets forth a method of compliance with the requirements of FAR Part 25 pertaining to installation of miscellaneous electrical equipment in transport airplanes that is non-essential for specific operation of the airplane.

3.19 DESIGN DOCUMENTATION AND SUPPORT DATA

The design disclosure technical data package and maintenance support data shall be provided to DLR using the English language by the TA Contractor. The deliverable product drawings and associated lists shall provide the necessary design, engineering, manufacturing, and quality assurance requirements information necessary to enable the procurement or manufacture of an interchangeable item which can duplicate the physical and performance characteristics of the original product, without additional design engineering

effort or recourse to the original design activity. This documentation shall include the following, as a minimum:

(a) Design drawings (mechanical, electrical, instrumentation, optics; assembly, shop, schematic, block, flow, wiring, printed circuit, ray trace, etc.)
(b) Installation drawings and description
(c) Tooling and simulator drawings
(d) Interface documentation
(e) Software design documentation
(f) Functional description and operating instructions
(g) Maintenance (troubleshooting) aids
(h) Corrective and preventive maintenance procedures (maintenance instruction manuals)
(i) Engineering design reports, analyses, and notes (may be in German)

Documentation quality requirements shall be as specified in Section 4.0 of this specification.

3.20 CUSTOMER FURNISHED EQUIPMENT

The following Customer Furnished Equipment (CFE) will be furnished by DLR . The CFE shall be maintained in accordance with ISO 9001.

(a) Mission Controls and Communications System (MCCS) Simulator
(b) Telescope Mounting Interface Simulator

3.21 ON-SITE SUPPORT AND TRAINING

On-site support in the U.S. for TA installation, integration, checkout and testing shall be furnished by the Contractor. Support shall include personnel in the following disciplines as a minimum: optics, mechanical engineering, electrical/electronic engineering, automatic pointing and control, and technical services. Training of personnel in the operation, engineering, maintenance, and repair of the TA shall be provided in the U.S. in accordance with agreements reached by NASA and DLR on operations responsibilities.

3.22 TA ELECTRONIC SIMULATOR

A TA electronic simulator shall be furnished by the contractor. This simulator shall be designed to be used by the MCCS for validating interface compatibility during the debugging and checkout phase of development. This simulator shall be comprehensive enough to provide simulated output signals for all TA signals to the MCCS and to simulate the acceptance and nominal resultant output for all MCCS provided prompts/inputs to the TA. Signal formats, communications

protocols, timing, hardware and cable interfaces, and all other necessary interface parameters shall be made to be system-compatible for proper simulation.

3.23 SUBMITTALS AND DELIVERABLES

As a minimum, the contractor shall deliver all of the listed items in Appendix B, SOFIA Telescope Assembly Development Contract Submittals and Deliverables.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 RESPONSIBILITY FOR VERIFICATION

The Contractor shall be responsible for the performance of all inspections, analyses, demonstrations and tests as specified herein and in the Contractor furnished Verification Plan. This plan shall be a part of the Contractor's I&T Plan. The Contractor may use the company or other facilities suitable for the performance of the verification requirements specified herein. DLR reserves the right to witness all Contractor inspection, demonstration and testing and to separately perform, or have performed, any of the tests defined in applicable specifications where such tests are deemed necessary to assure that system hardware/software conform to prescribed requirements. DLR shall be advised when major TA verification inspection, demonstration and testing are to be conducted so that a representative may be designated to witness the event when so desired. The absence of any verification requirement herein shall not relieve the Contractor of the responsibility for assuring that all hardware/software submitted to DLR for acceptance comply with all requirements of the contract.

4.1.1 Contractor Quality System

The TA Contractor shall plan and implement an effective quality system covering the supplies and services being procured. The quality system shall be implemented in accordance with ISO 9001. Contractor certification to ISO 9001 is not required. DLR reserves the right to audit the quality system for conformance to ISO 9001. A Quality System Plan (QSP) shall be part of the required SRM&QA Plan. It shall be used for conduct of the total quality system effort and shall define the Contractor engineering discipline and management control practices for TA design, quality and verification. The QSP shall include the disciplines necessary to ensure TA needs are met. The term "needs" as applied herein is defined as all aspects of design inputs/outputs including safety, quality, human engineering, usability, reliability, maintainability, and availability. The Contractor shall establish and maintain documented procedures to control and verify the design of the TA in order to ensure that the requirements specified herein are met.

4.2 QUALITY VERIFICATION

4.2.1 Verification of Requirements

As part of the Contractor's Verification Plan, a Requirements Verification Matrix following the example given by Table 1 shall be prepared by the Contractor listing all requirements herein and showing the method of verification for each requirement (i.e., inspection, analysis, demonstration and/or test). The initially

proposed matrix shall be submitted for DLR approval. Some requirements may be verified using several different methods depending on the verification step being conducted. Items to be tested and methods to be used as final verification before shipment and as final verification after integration with the AS will be viewed with higher levels of importance.

Table 1. Sample Requirements Verification Matrix

Requirements Paragraph Number	**Telescope Assembly Requirements Verification Matrix** Requirement	Inspection	Analysis	Demonstration	Test*

* Use the letters DQPF to depict the following tests respectively: Development, Qualification, Preshipment, and Final Acceptance. More than 1 type of test may apply for verification of some requirements.

4.2.2 Verification Methods

Verification of the TA requirements listed in the Requirements Verification Matrix, including those associated derived requirements addressing broad safety specifications, shall be accomplished by the methods defined below. Note: The Contractor may propose other methods of verification for consideration by DLR .

4.2.2.1 Inspection

Inspection is a verification method that consists of visual examinations of the TA or elements of the TA, including documentation (drawings, specifications, other pertinent design data, processes, procedures, etc.) to determine compliance with TA requirements defined in this specification. Inspection of documentation would also include determination of compliance to drawing standards and identification of key element characteristics, tolerancing and datum control, processes, etc. Inspection is nondestructive and also includes simple physical manipulation, gauging and weight and balance measurement, etc.

Interface control documents (ICDs) shall be verified by inspection, analysis, and demonstration of internal and external interfaces specified in SOF-1030. ICDs are considered complete when the details of the required interface testing are specified in the TA test procedures for those interfaces defined in the applicable interface control documents and are verified by inspection for compliance.

4.2.2.2 Analysis

Analysis is a verification method that consists of examination of analytical data in the form of mathematical solution and study-type comparison to form logical conclusions. Specifications, drawings, previous test data and other related data are used. Mathematical simulations are considered an analytical tool. Certain requirements necessitate that testing be accomplished to obtain specific test data (which alone does not satisfy the specification requirement) to support the analysis or simulation required for verification. The Contractor shall establish system tolerances on analytical predictions used to demonstrate compliance with specification requirements. These tolerances shall reflect anticipated variations in TA performance requirements such as may be represented by the following examples:

a. TA parameters that change with temperature, atmospheric pressure and other environmental factors.
b. TA parameters that change with failures or manufacturing tolerances.
c. TA parameters that critically affect system performance or stability.
d. TA parameters that are not accurately known (if they are significant).
e. TA parameters that change as a result of aging or wear.

4.2.2.3 Demonstration

Demonstration is a verification method where success is determined by observation alone. Included in this category are exercises that require simple quantitative measurements, such as time to remove/replace the primary mirror, major components, etc.

4.2.2.4 Test

Test is defined as verification that a specification requirement is met by a thorough exercise of the applicable item under measured environments, with predefined conditions, in accordance with approved test procedures, involving the systematic collection of test data. The data are used to verify that the specified requirements are met.

This method also includes verification by similarity of design, construction, and environmental requirements to other equipment so tested. Some items under "test" may be expected to be satisfied by previous testing on other programs and applications on the basis of "similarity." Verification by similarity will be accomplished using available test data from previous development and qualification programs whenever possible. When verification by similarity is proposed, the test data from the earlier qualification shall be available along with design data to substantiate the following:

(a) The subsystem/item is to perform a function in the new application similar to that performed under earlier "qualified" application.

(b) The new environment and operating limitations are no more demanding or degrading than those of the earlier "qualified" application.

(c) The new subsystem/item does not incorporate differences that would invalidate the criteria of "a" or "b" above.

(d) The subsystem/item operates satisfactorily in its current/previous application as indicated by its service life and maintenance history data.

4.2.3 Qualification Testing

Qualification tests are those environmental tests conducted on a TA configuration item to verify that the element will be capable of satisfying specification requirements with sufficient design margin. Examples are vibration, acoustic, thermal, and vacuum tests. Qualification tests shall be conducted where applicable, to ascertain that adequate margins exist in the final design to ensure all requirements contained herein are met. These tests should be planned and conducted as a series at unit, subassembly and assembly configurations, and at

conditions which exceed the range of environments and stress expected in the intended use or exposure. Qualification tests shall be applicable when analysis of existing qualification data on the hardware element are not sufficient to indicate adequate qualification. The qualification test unit may be a deliverable unit.

4.2.4 Development Testing

Development tests are engineering tests conducted on a system or subsystem during development to characterize some aspect of performance or proof of structural design. For example, development testing may include a modal survey to verify the analytical dynamic model of the TA for use in aircraft/bulk loading event simulations or for use in examination of elastic effects upon TA control precision and stability. The data obtained should be adequate to define mode shapes, mode frequencies, and mode damping ratios of all modes which occur within the frequency range of interest. Static load testing should also be considered. Development tests are performed to Contractor defined requirements and procedures. These tests shall be conducted, where applicable, to verify hardware and software design concepts and to identify hardware and computer program problems early in their design evolution so that any required corrective action can be taken prior to starting formal preshipment or acceptance testing. These tests should be used to confirm design and performance margins, risk assessments, testability, reliability, maintainability, and compatibility with system safety. Development tests may be limited to items with minimal design heritage or those which are judged to pose significant potential risk to safety, reliability, or performance.

4.2.5 Burn-In Testing

Each deliverable electronic TA equipment shall be subjected to a burn-in of at least 100 hours at a minimum of 40°C. The last 30 hours shall be failure free. The relative humidity need not be controlled. If a failure occurs within the period specified to be failure-free, burn-in on that equipment shall be stopped and repairs accomplished prior to initiating a complete 30 hour failure-free period. Additional failures shall result in additional burn-in extensions until the final 30 hours of burn-in are failure-free.

4.2.6 Software Testing

4.2.6.1 Coding and Testing

A coding and testing phase shall be conducted, consisting of the actual translation of the design specification in the chosen software language(s). The phase will be subjected to in-process review, and to final inspection. Following the final inspection, the code shall be subjected to the quality assurance review process to assure that the final code meets the requirements of the functional and design specifications.

4.2.6.2 Test and Integration

A test shall be conducted to verify that the TA software meets system requirements. A quality assurance review shall be conducted to assure that test results verify integrated software/firmware are qualified and ready for use. The tests may be conducted in conjunction with hardware acceptance testing.

4.3 TELESCOPE ASSEMBLY PRESHIPMENT TEST

A preshipment test shall be planned and conducted to verify conformance to all requirements contained herein to the extent consistent with TA operation on the ground. For example, star tracking capability may be planned to be verified using stellar objects limited in dimness to those able to be acquired and tracked at the test site on the ground. Simulated vibration, thermal or aero-acoustic disturbances, if any, will be allowed to be of limited and practicable levels consistent with cost and schedule constraints. Environmental stress screening of the completely assembled TA before shipment is not required. Except for those limitations clearly imposed by location on the ground and operation of the TA's intended environment in the aircraft, the preshipment test shall be complete in all other respects. This test shall be formulated to verify that the system to be shipped to NASA has been designed, manufactured, assembled, and adjusted so that its performance will satisfy all requirements when installed and flown in the SOFIA aircraft. The DLR approved Requirements Verification Matrix shall apply. This test shall accurately measure performance parameters to reveal any inadequacies in the design and manufacturing processes such as safety, functionality, workmanship, parts and materials. The TA preshipment test shall include, but not be limited to, all performance requirements verification (as limited by operation on the ground), EMI and EMC tests, system safety tests, component pressure verification tests, power consumption test, mechanical/electrical/electronic interface verification (previously obtained verification results may be used), and physical properties verification (mass properties, center of gravity, geometric properties, etc.). The preshipment test shall be performed on all deliverable items including spares. Tests on spares shall include environmental stress screening (qualification testing) and burn-in on all deliverable electronic equipment.

4.4 FINAL ACCEPTANCE TESTING

An observatory level integrated system test will be performed after delivery of the TA to NASA and installation and integration into the SOFIA aircraft. Upon TA delivery to the NASA facility, Contractor-supported initial tests shall first be conducted, as necessary, to ensure TA readiness for integration with the AS. Subsequent to TA installation in the aircraft, Contractor-supported acceptance testing shall be conducted to demonstrate: successful TA integration with the AS, MCCS, and SI; compatibility between the TA, MCCS, AS, SI, and computer

software; and full compliance with the requirements herein. Final Acceptance Testing will be performed mostly in-flight. Most of the tests performed in the preshipment test will be expected to be repeated. Acceptance testing may require several flights to complete.

4.5 TEST DOCUMENTATION

4.5.1 Test Procedures

Test procedures shall be prepared by the contractor and approved by DLR prior to the start of testing. Test procedures shall include precise requirements for data to be collected, including step-by-step test processes and the success criteria for each test to verify compliance.

NOTE: RATC-160 defines a series of standard environmental test conditions and test procedures for determining the performance characteristics of new aircraft equipment in accordance with FAA guidelines and should be considered in the generation of test requirements and procedures.

4.5.2 Test Failures

A unit failure during any test at the assembly level and above shall immediately stop the test. DLR shall be notified of the failure, probable cause, corrective action(s) to take, and plans for retesting.

4.5.3 Test Reports

Test reports shall be submitted to DLR for all assembly level tests and shall include:

(a) All data taken
(b) Concise, complete report of results and conclusions
(c) Documentation of all failures and corrective actions taken

4.6 TEST AND MEASURING EQUIPMENT

4.6.1 Test Equipment

The Contractor shall control, calibrate and maintain test, inspection and measuring equipment to demonstrate conformance of the TA to specified requirements in accordance with ISO 9001.

4.6.2 Test Conditions

Test conditions, including standard ambient, controlled environment, tolerances for test conditions, accuracy of test instrumentation calibration, and stabilization of test temperature should be in accordance with test method standard MIL-STD-810, or equivalent.

4.6.3 Test Sequence

The environmental test sequence, where required, shall be selected to be representative of the life cycle mission profile.

4.6.4 Test Fixtures

Test fixtures required for TA inspections and tests shall be qualified with dummy loads or by analysis.

4.7 TEST REVIEWS

4.7.1 Test Readiness Reviews

A formal notification of "Test Start" is required to DLR at least 30 days prior to the start of the activity for any test called out in the Requirements Verification Matrix, occurring at the Contractor's or other designated test facility. DLR reserves the authority to hold a test readiness review and to approve the following test planning activity for compliance:

(a) Overall objectives of the test(s)
(b) Hardware status
(c) Test equipment calibration and certification status
(d) Fixture certification status
(e) Verification and approval status of appropriate test procedure(s)
(f) Test setup and data recording requirements
(g) Test safety requirements
(h) Software status and validation
(i) Changes to hardware/software/procedures
(j) Test schedules
(k) Contractor and DLR test monitoring requirements
(l) Test resources
(m) Failure/success criteria including retest requirements, etc.

4.7.2 Post-Test Reviews

DLR reserves the right to hold/attend post-test review meetings to review test results and determine compliance with test requirements, performance parameters, and overall test objectives. The reviews will consider anomalies discovered during the test, necessary corrective actions, test data/report requirements, nonconformances, work-around plans, next scheduled tests, hardware allocations

and other items, as appropriate. Normally, these meetings will be a part of periodic status reviews unless otherwise requested by DLR.

4.8 SPARE PARTS INSPECTION AND TEST

Spare parts shall be inspected and acceptance tested in accordance with approved test procedures and the requirements herein.

4.9 TELESCOPE ASSEMBLY CERTIFICATION FOR SHIPPING

The Contractor shall provide the required documentation to certify successful completion of the preshipment test; all specification and contract requirements have been met, including structural design; subsystem design, subsystem operation, performance, safety, maintainability, and reliability requirements have been verified; and airworthiness qualities and performance have been demonstrated. DLR will accept the TA certification for shipment after reviewing and accepting the test documentation verifying successful demonstration of compliance to the requirements specified herein.

The Contractor shall configure the TA for delivery in accordance with the requirements of Section 5.0 herein.

4.10 TECHNICAL DATA QUALITY

Deliverable technical data shall be inspected by the Contractor to ensure adequacy and accuracy. Legibility and control of reprints shall be such that every line, number, letter, and character data is clearly legible and readable, using the English language. Reproductive quality shall be of such clarity as to produce a fourth generation copy which will meet the preceding legibility and contrast requirements. Materials shall be high-grade commercial and of a quality entirely suitable for its intended purpose and long term storage.

Technical manuals and supporting documentation shall be developed in accordance with accepted industry guidelines. The quality of nondeliverable Contractor controlled technical data developed for internal use only shall be controlled by the requirements of the Contractor's quality system.

4.11 INSPECTION FOR DELIVERY

4.11.1 Prepackaging Inspection

The inspection of items prior to packaging shall include, as a minimum, the following:

(a) Items have satisfactorily passed applicable inspections and tests.

(b) There shall be no evidence of external damage such as cracks, contamination, finish discrepancies, or other defects which may interfere with functioning, fit, or logistics, or may cause deterioration over time.

(c) Connector pins shall not be bent or damaged.

(d) All connector covers are properly in place after inspection of connector condition.

(e) All visible components, parts, assemblies and the TA are properly identified and serialized.

(f) All mirror and ancillary covers are properly positioned and secured.

(g) Cables and other items requiring restraint are properly secured.

4.11.2 Inspection for Preparation for Delivery

Packages and packs, and inspection of the preservation, packaging, packing and mailing for shipment, shall be in accordance with the requirements of Section 5.0 and the documents specified therein.

5.0 PREPARATION FOR DELIVERY

5.1 GENERAL REQUIREMENTS

The requirements specified herein govern the preparation for shipment and the transport of the TA to the NASA or other U.S. facility. The methods of preservation, packaging, and packing utilized for shipment, together with necessary special control during transportation, shall adequately protect the TA from damage or degradation of performance due to the natural and induced environment encountered during transportation and handling and subsequent storage, as stated herein.

5.2 CLASS OF SHIPPING AND HANDLING

The TA is classified as Class I equipment, program critical, in accordance with NHB-6000.1, which in the event of loss, damage, or delay in shipment would seriously impact program schedule and cost and therefore determines requirements.

5.3 PRESERVATION AND PACKAGING

Selection of preservation and packaging shall be in accordance with guideline document NHB 6000.1 for Class I equipment, and shall be the responsibility of the Contractor.

5.3.1 Cleaning

Prior to packing, items shall be cleaned to a level of cleanliness commensurate with performance requirements, and shall be prepackaged to assure maintenance to specified cleanliness levels in accordance with optical industry standard procedures. The cleaning shall also conform to established industry procedures for electrostatic discharge for electronic components and shall be noncorrosive.

5.3.2 Sensitive Electronic Item Packaging

Sensitive electronic item protection and packaging shall be in accordance with established industry standards.

5.3.2.1 Lead, Terminal and Connector Protection

Lead, terminal and connector configurations shall be maintained as manufactured without causing loads, chafing, or stresses which could damage the item. Materials used to maintain item position, configuration and protection shall be

noncorrosive, electrostatic free, and shall permit item removal without damage to the item.

5.3.2.2 Wraps and Cushioning Materials

Wraps and cushioning materials, when required for additional item protection, shall be noncorrosive. Wraps and cushioning in direct contact with electrostatic sensitive items shall conform to electrostatic protection requirements specified herein.

5.3.2.3 Unit Protection

Items subject to degradation from electrostatic charging, electromagnetic forces, or both, shall be protected. Unit packs shall be marked with the sensitive electronic device symbol.

5.3.3 Protective Caps

Connectors disconnected for shipment shall be provided with protective caps to prevent damage to the connectors. Caps shall fully protect the connector and shall be noncorrosive.

5.4 PACKING LEVEL

Packing equipment should be level B in accordance with the guidelines of NHB 6000.1 and referenced specifications. The TA and component parts should be packed in this equipment in accordance with industry standard methods, and should be cushioned or isolated and packed in a suitable container(s) in accordance with guideline document NHB 6000.1 requirements, or acceptable equivalent.

5.5 MARKING

Marking shall be in accordance with guideline document NHB 6000.1 or equivalent, including a NASA Critical Item Label.

5.6 SHIPPING DOCUMENTS

Shipping documents, test logs and other supporting data shall be adequately packaged and protected during shipment to prevent damage and preserve legibility.

6.0 NOTES

6.1 PROGRAM REVIEWS

DLR reserves the right to review general progress of the contract in terms of management, systems engineering, technical work, and SRM&QA activities at prime contractor and subcontractor levels.

6.2 SYSTEM SAFETY ANALYSES

Appendix A, System Safety Analyses and Documentation Requirements, is mandatory for use. This Appendix provides the tool for the contractor to implement the system safety requirements of this specification, to help make risk management decisions, and to use in the approval process.

6.3 ABBREVIATIONS AND ACRONYMS

AHB	Ames Handbook
AOI	Area-of-Interest
ARC	Ames Research Center
AS	Aircraft System
ASE	Airborne Support Equipment
ATE	Automatic Test Equipment
BIT	Built-in Test
CDR	Critical Design Review
CES	Consoles and Electronics System
CFE	Customer Furnished Equipment
c.g.	Center of Gravity
CSCI	Computer Science Configuration Item
dB	Decibel
DC	Direct Current
DLR	German Space Agency (Deutsches Zentrum fuer Luft-und Raumfahrt)
DOF	Degree of Freedom
EE	Essential Equipment
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ER/TX	Extra Reliability/Test Extra
ESD	Electrostatic Discharge

FAA	Federal Aviation Agency (USA)
FAR	Federal Aviation Regulation
FFI	Fine Field Imager
FL	Flight Level
FMEA	Failure Modes and Effects Analysis
FMECA	Failure Mode, Effects and Criticality Analysis
FOV	Field-of-View
FPI	Focal Plane Imager
FWHM	Full-Width-Half-Maximum
g	Gravity, Units of Gravitational Force
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
GSF	Ground Support Facility
GUI	Graphical User Interface
Hz	Hertz
ICD	Interface Control Document
ID	Inner Diameter
I/O	Input/Output
IR	Infrared
IRD	Interface Requirements Document (SOF-1030)
IRS	Inertial Reference Sensor
ITP	Integrated Test Plan
K	Degrees Kelvin
kg	Kilogram
km	Kilometer
kVA	Kilovolt-ampere
LAN	Local Area Network
LED	Light-emitting Diode
LOS	Line-of-Sight
m	Meter
MCCS	Mission Controls and Communications System
MIL-STD	Military Standard
mm	Millimeter
MOU	Memorandum of Understanding
MSSO	Mission Support System and Operations
MTBF	Mean Time Between Failures
m_v	Visual Magnitude
NASA	National Aeronautics and Space Administration
NHB	NASA Handbook

NM	Nautical Miles
NMI	NASA Management Instruction
NSP	Nonstandard part
NTSC	National Television Standards Committee
O&SHA	Operating and Support Hazard Analysis
OCDS	Operator's Controls and Display System
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PHA	Preliminary Hazard Analysis
PS	Pointing Subsystem
QPL	Qualified Parts List
QSP	Quality System Plan
RF	Radio Frequency
RIS	Rotation Isolation Subsystem
RMS	Root Mean Square
ROF	Rotation-of-Field
RSS	Root Sum Square
SCDP	Safety Compliance Data Package
SDP	Software Development Plan
SFT	System Functional Test
SHA	System Hazard Analysis
SI	Science Instruments
SLC	Shear Layer Control
SMA	Secondary Mirror Assembly
SOFIA	Stratospheric Observatory for Infrared Astronomy
SOW	Statement of Work
SPF	Single Point Failure
SPO	SOFIA Project Office
SRM&QA	Safety, Reliability, Maintainability and Quality Assurance
SRT	System Readiness Test
SSA	System Safety Analysis
SSHA	Subsystem Hazard Analysis
SSPP	System Safety Program Plan
SVT	System Vibration Test
TA	Telescope Assembly
TBD	To be Determined
TBS	To be Supplied
TTL	Transistor to Transistor Logic
UPS	Uninterruptible Power Supply

U.S.	United States (of America)
VIS	Vibration Isolation Subsystem (of the TA)
WBS	Work Breakdown Structure
WFI	Wide Field Imager

6.4 SRM&QA TERMS AND DEFINITIONS

Development Testing: Tests performed with minimum rigor and controls to prove a design approach. Included are tests performed to minimize technical risks and to assist in design engineering activities. These tests can encompass material selection, design tolerance verification, and identification of operational characteristics.

Failure: The inability of a system, subsystem, component, or part to perform its required function.

Fail-operational: The ability to sustain a failure and retain full operational capability for safe mission continuation.

Fail-safe: Ability to sustain a failure and retain the capability to successfully terminate the mission.

Hazard: Existing or potential condition that can result in or contribute to a Category I, II, III, or IV hazard as defined below:

- Category I (Catastrophic) Death or permanent disabling injury and/or damage resulting in cost > $1M or loss of science capability > 3 months.

- Category II (Critical) Severe injury/illness or lost time injury (> 6 months) and/or damage resulting in $250K < cost < $1M or 4 wks < delay < 3 months in science capability.

- Category III (Marginal) Minor injury/illness or 1 day < lost time injury < 6 months and/or damage resulting in $25K < cost < $250K or 1 wk < delay < 4 wks in science capability.

- Category IV (Negligible) No lost time injury/illness and/or damage ≤$25K or ≤1 week delay in science capability.

Maintainability: A measure of the ease and rapidity with which a system or equipment can be retained in operational status through preventive maintenance or restored to operational status following a failure. It is a characteristic of equipment design and installation, personnel availability in the required skill

levels, adequacy of maintenance procedures and test equipment, and the physical environment under which maintenance is performed.

Qualification Testing: The process of testing and analyzing hardware or software configuration items and systems to prove that the design will survive the anticipated accumulation of acceptance test environments; expected handling, storage, and operational environments plus a specified qualification margin. Testing can include temperature, vibration, shock, salt spray, software stress testing, etc.

Quality Assurance: All those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.

Redundancy: The use of more than one means of accomplishing a given function so that more than one must fail before the article fails to perform.

Reliability: The probability that an item will perform its intended function for a specified interval under stated conditions.

Safety Critical: An item or function, the failure of which may result in loss of life, personnel injury/illness, and/or equipment damage as defined above for a Category I or II hazard, if corrective action is not successfully completed in a finite period of time.

Single Point Failure (SPF): A single point failure is any single hardware failure or software error which results in the cessation of normal operation.

System Safety: Application of engineering and management principles, criteria, and techniques to optimize safety and reduce risks within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle.

Testability: A design characteristic which allows the status (operable, inoperable, or degraded) of a system or any of its subsystems to be confidently determined in a timely fashion. Testability attempts to quantify those attributes of system designs which facilitate detection and isolation of faults that affect system performance.

Version Description Document: A written cover sheet accompanying a deliverable product (software or documentation),which provides precise description of the version being delivered.

APPENDIX A

SOFIA TELESCOPE ASSEMBLY

SYSTEM SAFETY ANALYSES AND DOCUMENTATION REQUIREMENTS

1.0 GENERAL

In support of the design, development and fabrication of the Telescope Assembly (TA), a System Safety Plan shall be implemented to ensure the identification and control of hazards associated with the operation and maintenance of the delivered system. As a minimum, the System Safety Plan shall consist of:

(a) Performing formal safety analyses to systematically review all systems, subsystems and components of the TA for the identification and control of hazards;
(b) Assessing the risk of identified hazards using a Hazard Risk Assessment Matrix. Figure A-1 contains the Hazard Risk Assessment Matrix used at NASA/Ames and is provided as a reference. The Contractor shall include a Hazard Risk Assessment Matrix in their SRM&QA Plan;
(c) Documenting identified hazards on a Hazard Report form. Figures A-2, A-3, and A-4 contain the Hazard Report Form used at NASA/Ames and is provided as a reference. The Contractor shall include a Hazard Report Form in their SRM&QA Plan;
(d) Assuring that proper design attributes are incorporated to either eliminate or control identified hazards; and
(e) Tracking hazards from initial identification through closure.

The System Safety Plan shall address all hardware and software associated with the TA, including airborne and ground support equipment.

2.0 HAZARD ANALYSES

As a minimum, the following System Safety analyses shall be performed on the TA:

(a) Preliminary Hazard Analysis (PHA)
(b) System Hazard Analysis (SHA)
(c) Operations and Support Hazard Analysis (O & SHA)
(d) Quantitative Risk Analysis

These analyses shall identify potential hazards and safety risks associated with the TA design including: hardware, software, Airborne Support Equipment, Ground Support Equipment, operations and maintenance. Each System Safety analysis shall be

documented in a formal report (including associated Hazard Reports) and submitted for approval by NASA through DLR.

Where Quantitative Risk Analysis is utilized, the Contractor shall either identify in the SRM&QA Plan the subsystems that will be analyzed or the type of hazard/risks that would warrant the use of quantitative assessment methodology.

3.0 HAZARD RISK ASSESSMENT

For each identified hazard, the Hazard Risk Assessment Matrix contained in the Contractor's SRM&QA Plan shall be used to classify the associated hazard severity category and probability of occurrence. The definition of the hazard severity categories and the probabilities of occurrence are provided in the following paragraphs and within Figure A-1 as a reference.

3.1 HAZARD SEVERITY CATEGORY

Figure A-1 (Block 1), identifies four discrete Hazard Severity categories. The hazard severity category that is assigned, expressed as a Roman numeral, is independent of the number of controls in place to mitigate the hazard and therefore represents the worst credible event that could happen. Once assigned, the severity category remains the same throughout the life of the system unless eliminated by redesign. The imposition of controls may reduce the probability of occurrence and thereby reduce the risk of a hazard to an acceptable level. However, those controls will not change the severity of the consequences should the potentially hazardous event occur.

3.2 HAZARD PROBABILITY

Figure A-1 (Block 2), identifies four qualitative levels of Hazard Probability. A probability level, expressed as a letter code, is assigned to each hazardous condition based on engineering judgment considering such factors as exposure, location of the facility/ aircraft, environmental influences, the system design features, safety devices, protective systems, warning devices, and procedures that are in place for controlling the identified hazard. The probabilities assigned are that the causal event(s) will occur, not that the effect will be the worst potential consequence.

4.0 HAZARD REPORTING

All identified hazards shall be documented on a Hazard Report (HR) form. Pages 1 and 2, and the continuation page of the form are provided (Figures A-2, A-3 and A-4) as a reference.

It is intended that the HR form be used to track each hazard from identification through closure. The HRs associated with the hazard analyses listed in section 2.0 of this Appendix shall be forwarded to DLR for review and approval when all HRs for each hazard analysis are completed in accordance with the following three stages of evolution.

They shall be forwarded upon completion of: (1) Page 1 of the HR (HR initiation); (2) Block 9 of the HR (determination of planned actions by the organization responsible for controlling the hazard); and (3) Block 10 of the HR (verification that the hazard control actions have been taken and are complete).

The following instructions should be used as guidelines for completing the HR form:

a. 1) FAC/PROJ: The name "SOFIA" shall be used.

b. HAZARD REPORT#: A series of Hazard Report numbers have been assigned to the Telescope assembly. The alpha-numeric format for these numbers is defined as "ARCX-03-STxxx-H." These numbers shall be assigned sequentially from ARCX-03-ST100-H through ARCX-03-ST299-H. If additional numbers are required they can be obtained from NASA through DLR.

c. 2) BUILDING #: This block is "N/A" (Not Applicable) for the Telescope Assembly hazards.

d. 3) REFERENCE: This field is intended to provide information supporting an audit trail. If the Hazard Report is being written as the result of a safety analysis, then the analysis report number should be entered here. If there is no supporting analysis, this block may be left blank.

e. 4) SYSTEM: The name "Telescope Assembly" shall be used.

f. HAZARD TYPE: This block need not be used.

g. KEYWORD: A simple keyword should be entered that relates to the type of hazard that is being reported (i.e., fire, shock, rotating equipment, etc.)

h. 5) DESCRIPTION OF POTENTIAL HAZARD: This field is intended to be a narrative description of the condition(s) from which the hazard arises, its cause(s) and effect(s). It should include any necessary clarifying information to ensure that the hazard description is not misunderstood by reviewers who may not be intimately familiar with the system.

The following is an example of the desired format:

Hazard: Exposure of personnel to electric shock due to:
Cause(s): (1) Personnel contact with high voltage live circuit, or bare conductor.
(2) Equipment is inadequately bonded/grounded allowing exposed surfaces to have potential voltage
(3) Deteriorated insulation caused by vibration/chaffing

Worst case feasible effect(s): Death

i. 6) EXISTING CONTROLS: For each hazard cause, list any/all existing controls. Number each identifiable control to correspond with its respective cause. If there is no existing control, enter the word "None" to correspond with the uncontrolled hazard cause.

j. 7) INITIAL HAZARD RISK ASSESSMENT: The HR originator will record the INITIAL HAZARD RISK ASSESSMENT in accordance with the HRA Matrix (Figure A-1) and the guidance provided in paragraph 3.0 herein.

k. 8) RECOMMENDED CONTROLS: Number each recommendation to correspond with it's respective cause. If there are no recommendations, so state as 'None.'. When the recommendation(s) listed under this section will further reduce the initial HRA, then the phrase "Implementation of the above recommended control(s) will reduce the probability of occurrence to (Level A, B, C, or D) and the final HRA to (1, 2, 3, or 4)" shall be entered just above the signature line. When the recommendation(s) listed under this section will not further reduce the initial HRA, then the phrase "Implementation of the above recommended control(s) will not further reduce the initial HRA" shall be entered just above the signature line. Whenever possible, specific requirements shall be cited with each recommendation (e.g., ANSI Z35--1).

l. ORIGINATOR: Identify the first name, middle initial (if applicable), and the last name of the analyst.

m. ORGANIZATION: Identify the name of the company that the HR originator works for, or the company performing the analysis.

n. 9) PLANNED ACTION(S): This block is to be completed by the person having management responsibility for the safety of the TA design. Planned action(s) should be numbered to correspond to the numbered recommended controls.

o. 10) METHODS OF VERIFICATION: This block is to be completed by the person designated to verify that the action(s) stated in block 9) have been completed. Verification should be numbered to correspond to the numbered planned action(s). When there is more information to be recorded than there is room in fields 5 through 10, it should be continued on the Continuation Sheet (page 3 of the HR).

p. 11) FINAL HAZARD RISK ASSESSMENT: To be completed by NASA through DLR.

q. 12) REVIEW BOARD CONCURRENCE: To be completed by the NASA through DLR.

r. 13) RESIDUAL RISK ACCEPTANCE: To be completed by NASA through DLR.

s. 14) HAZARD CLOSURE: To be completed by NASA through DLR.

5.0 HAZARD TRACKING AND CLOSURE

Hazard Reports are used as a means for tracking and resolving all hazards that are assigned a risk assessment of 1, 2, or 3. The HR documents a description of the potential hazard, any controls already in place, additional recommended controls, the planned actions, methods of verification, the final hazard risk assessment, and subsequent disposition (closure status). An HR is considered closed only if:

(1) The hazard has been eliminated by design and the design has been confirmed, or

(2) The hazard has been reduced to an acceptable level (controlled hazard) in accordance with the hazard precedence criteria and this reduction has been verified by successful completion of an engineering analytical study, safety inspection, verification test, procedure and/or training program requirements, or

(3) The hazard has been assessed and the risk accepted with the HR signed off by the NASA SOFIA SR&QA Manager and the SOFIA Project Manager via DLR.

Figure A-1 SOFIA Hazard Risk Assessment Matrix

1. HAZARD SEVERITY

A hazardous condition whose worst case feasible effects (immediate or long term cumulative) on personnel and/or the system (equipment/hangar facility/aircraft) may be:

CATEGORY I	(CATASTROPHIC)	Death or permanent disabling injury and/or damage resulting in cost > $1M or loss of science capability > 3 months.
CATEGORY II	(CRITICAL)	Severe injury/illness or lost time injury (> 6 months) and/or damage resulting in $250K < cost ≤ $1M or 4 wks < delay ≤ 3 months in science capability.
CATEGORY III	(MARGINAL)	Minor injury/illness or 1 day < lost time injury ≤ 6 months and/or damage resulting in $25K < cost ≤ $250K or 1 wk < delay ≤ 4 wks in science capability.
CATEGORY IV	(NEGLIGIBLE)	No lost time injury/illness and/or damage ≤ $25K or ≤ 1 wk delay in science capability.

2. HAZARD PROBABILITY

LEVEL A	(PROBABLE)	Likely to occur several times in the life of the system.
LEVEL B	(REMOTE)	Likely to occur once in the life of the system.
LEVEL C	(IMPROBABLE)	Not likely to occur in the life of the system.
LEVEL D	(HIGHLY IMPROBABLE)	Occurrence is considered to be extremely unlikely in the life of the system.

3. HAZARD RISK ASSESSMENT (HRA) MATRIX

Hazard Severity

Hazard Probability	I	II	III	IV
A	1	1	2	3
B	1	1	2	3
C	2	2	3	4
D	3	3	4	4

4. HAZARD RESOLUTION PRIORITY

Initial HRA		Priority
1	(UNACCEPTABLE)	Resolve or accept residual risk prior to any testing or flight.
2	(UNDESIRABLE)	Resolve or accept residual risk prior to start of research.
3	(ACCEPTABLE WITH REVIEW)	Resolution is desirable.
4	(ACCEPTABLE WITHOUT REVIEW)	Resolution is not required.

5. RESIDUAL RISK ACCEPTANCE

	Final HRA	Required Sign-Offs
1	(UNACCEPTABLE)	Project Mgr., User Division Line Mgmt., User Org. Dir., Center Director.
2	(UNDESIRABLE)	Project Mgr., User Division Line Mgmt.
3	(ACCEPTABLE WITH REVIEW)	Project Mgr., User Branch Line Mgmt.
4	(ACCEPTABLE WITHOUT REVIEW)	Project Mgr.

Figure A-2 SOFIA Hazard Report, Page 1

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HAZARD REPORT

Page 1 of 3

1) FAC/PROJ: **SOFIA**
2) BUILDING #: **N/A**
3) REFERENCE: _____
4) SYSTEM: **Telescope Assembly**

HAZARD REPORT #: **ARCX-03-ST-____-H**
FINAL HRA : _____
CLOSED DATE: _____
HAZARD TYPE: _____
KEYWORD: _____

5) DESCRIPTION OF POTENTIAL HAZARD (Include hazardous conditions, cause(s) & effect(s))

6) EXISTING CONTROLS

7) INITIAL HAZARD RISK ASSESSMENT

_____	_____	_____
SEVERITY	PROBABILITY	HAZARD RISK ASSESSMENT

8) RECOMMENDED CONTROLS

ORIGINATOR: _____ ORGANIZATION: _____ DATE: _____

INSTRUCTIONS

A) ORIGINATOR - (Blocks 1-8) Describe potential hazard, existing controls, and recommended controls, assign initial HRA, and forward to DQA.
B) DQS - Log in and forward to Responsible Individual.
C) RESPONSIBLE INDIVIDUAL - (Block 9) Describe planned action, sign, and forward a copy to DQA.
D) DQS - Review planned action for concurrence and notify Responsible Individual.
E) RESPONSIBLE INDIVIDUAL - (Block 10) Describe method(s) and/or documentation to verify that planned actions have been taken. Sign and date after verification and forward to DQA.
F) DQS - (Block 11) Assign final HRA.
G) REVIEW BOARD CHAIRMAN - (Block 12) Review Blocks 1-11 and sign if concur that the planned actions reduce the HRA to the level specified in Block 11.
H) DQS - (Blocks 13 & 14) Obtain additional signature as required, closed out Hazard Report and update files.

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Figure A-3 SOFIA Hazard Report, Page 2

Page 2 of 3

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HAZARD REPORT

HAZARD REPORT #: **ARCX-03-ST-____-H**

9) PLANNED ACTION(S)

ESTIMATED COMPLETION DATE: _____

FACILITY/PROJECT MANAGER: _____ DATE: _____

10) METHODS OF VERIFICATION

VERIFIED BY: _____ DATE: _____

11) FINAL HAZARD RISK ASSESSMENT

SEVERITY	PROBABILITY	HAZARD RISK ASSESSMENT

12) REVIEW BOARD CONCURRENCE

CHAIRMAN: _____ DATE: _____

13) RESIDUAL RISK ACCEPTANCE

PROJECT MANAGER: _____ DATE: _____
(FINAL HRA 1, 2, 3 AND 4)

USER BRANCH LINE MGR: _____ DATE: _____
(FINAL HRA 3)

USER DIVISION LINE MGR: _____ DATE: _____
(FINAL HRA 1 AND 2)

USER ORG. DIRECTOR: _____ DATE: _____
(FINAL HRA 1)

CENTER DIRECTOR: _____ DATE: _____
(FINAL HRA 1)

14) HAZARD CLOSURE

SYSTEM SAFETY OFFICE (DQS): _____ DATE: _____
(FINAL HRA 3 AND 4)

SR&QA OFFICE (DQ): _____ DATE: _____
(FINAL HRA 1 AND 2)

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Figure A-4 SOFIA Hazard Report, Continuation Page

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HAZARD REPORT CONTINUATION SHEET

HAZARD REPORT NO: **ARCX-03-ST-____-H**

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APPENDIX B

SOFIA TELESCOPE ASSEMBLY
DEVELOPMENT CONTRACT SUBMITTALS AND DELIVERABLES

The list below includes the minimum set of products and services to be furnished and delivered per requirements of the contract.

Item	Quantity Required	Document Type(1)	Delivery Date(s)	SOF-1011 Section/Para.
PLANS				
• Program Management Plan	4 sets	1	60 days after award*	
• System Engineering Management Plan	4 sets	2	60 days after award*	
• Software Development Plan	4 sets	1	60 days after award*	3.17
• Preliminary SRM&QA Plan	4 sets	3	With proposal	3.14
• SRM&QA Plan	4 sets	1	60 days after award*	3.14
• Contractor Work Breakdown Structure and Associated Dictionary	6 sets	2	60 days after award*	
• Baseline Contractor Integration & Test Plan (including Contractor's Verification Plan and Requirements Verification Matrix)	6 sets	2	2 wks before PDR*	3.16.1, 4.1, 4.2.1
• Final Contractor Integration & Test Plan (including Contractor's Verification Plan and Requirements Verification Matrix)	6 sets	1	60 days before CDR*	3.16.1, 4.1, 4.2.1
• Configuration Management Plan	4 sets	2	60 days after award*	
• TA Alignment Plan and Procedure	4 sets	2	120 days after PDR	
• Spares Provisioning Recommendation (Logistics Support Plan)	6 sets	2	2 wks before CDR	3.12.18
REPORTS AND ANALYSES				
• Preliminary Stress Analysis	6 sets	2	2 wks before PDR*	
• Final Stress Analysis	6 sets	2	90 days after PDR*	
• Preliminary Hazard Analysis (PHA)	6 sets	2	24 days before PDR*	2.0 App. A
• System Hazard Analysis (SHA)	6 sets	1	24 days before CDR*	2.0 App. A
• Operations & Support Hazard Anaysis (O&SHA)	6 sets	2	24 days before CDR*	2.0 App. A
• Quantitative Risk Assessment (if required)	6 sets	1	24 days before CDR*	2.0 app. A
• Preliminary Failure Mode, Effects and Criticality Analysis (FMECA) Rpt.	6 sets	2	24 days before PDR*	3.14.2.1
• Final Failure Mode, Effects and Criticality Analysis (FMECA) Report	6 sets	1	24 days before CDR*	3.14.2.1

* Reissue as required.

SOFIA TELESCOPE ASSEMBLY
DEVELOPMENT CONTRACT SUBMITTALS AND DELIVERABLES
(Continued)

Item	Quantity Required	Document Type(1)	Delivery Date(s)	SOF-1011 Section/Para.
• Initial systems engineering budgets (including mass, power, pointing stability error, optics image quality error, etc.)	4 sets	3	90 days after award	
• Up-dated systems engineering budgets (including mass, power, pointing stability error, optics image quality error, etc.)	4 sets	3	Monthly after initial (during design phase)	
• Risk analysis and justification for probable SPF on any mission essential equipment	4 sets	1	Upon identification*	3.14.2.2
• Request for authority to modify purchased vendor software	2 sets	1	Before PDR	3.17
• Test Readiness Review (DARA option) documentation	4 sets	1	30 days before test	4.7.1
SYSTEM / EQUIPMENT				
• Completely installed, integrated, and fully tested (observatory level) Telescope Assembly including ASE, GSE, and designated spares	1 lot	NA	Acceptance test completion	
• Simulator for TA communications and input/output signals for MCS (i.e., OCDS simulator for MCS interfaces)	1 lot	NA	30 mos after award	
• Matched tooling, gages, etc., necessary for interface definition and development (e.g., matched tooling for bulkhead interfaces)	1 lot	NA	30 mos after award	
IN-PLANT REPRESENTATION				
• Accommodations for in-plant NASA representative at contractor site	1 office	NA	60 days after award	
• Accommodations for in-plant DCMCI representative (if negotiated)	1 office	NA	12 mos after award	
TECHNICAL DESCRIPTION DOCUMENTATION				
• Description of Airborne Support Equipment, Ground Support Equipment, and other special tooling plus all relevant documentation	6 sets	3	36 mos. after award	
• Description of support equipment and tools needed from the Observatory integration contractor or NASA for TA installation, integration, checkout, test, operations, and maintenance in the U.S.	6 sets	3	36 mos. after award	
* Reissue as required.				

SOFIA TELESCOPE ASSEMBLY
DEVELOPMENT CONTRACT SUBMITTALS AND DELIVERABLES
(Continued)

Item	Quantity Required	Document Type(1)	Delivery Date(s)	SOF-1011 Section/Para.
TECHNICAL DESIGN AND MAINTENANCE SUPPORT DATA:				
• Preliminary Design Drawings	8 sets	2	2 wks before PDR	
• Final Design Drawings	8 sets	2	2 wks before CDR	
• As-built System Drawings	8 sets	3	1 wk after shipment	
• As-installed System Drawings	8 sets	3	1 wk after final acceptance	3.19
• Draft ICDs	8 sets	2	6 mos. before PDR	3.15.1
• Baseline ICDs	8 sets	1	2 wks before PDR	3.15.1
• ICD revisions	8 sets	1	As developed	3.15.1
• Final ICDs	8 sets	1	2 wks before CDR	3.15.1
• Software design documents	6 sets	2	2 wks. before CDR	3.19
• Final as-built system software documentation	8 sets	3	1 wk after final acceptance	
• Functional Description, Operation & Maintenance Manual(s) (including installation, servicing, inspection, theory of operation, operational procedures, and maintenance for hardware and software)	8 sets	3	1 wk after final acceptance	3.19
• Engineering design reports and notes (may be in German)	4 sets	3	2 yrs after award or as dev'lpe	3.19
• Complete documentation of all purchased or licensed software including Version Description Documents (and any modification)	2 sets/version	3	At delivery	3.17
• License for commercial software, if used	1 lic/applic.	3	At delivery	3.17
• Design phase computer input files to working math models used for analyses and simulation of structural, optical, thermal, control systems, and other TA disciplines	2 sets	2	As developed	
• Final software files for all computerized models used during the design phase	2 sets	3	At delivery	
TESTS AND TEST DOCUMENTATION				
• Qualification Tests as necessary		NA		4.2.3
• Development Tests as necessary		NA		4.2.4
• Preshipment Test in Germany		NA		4.3
• TA Certification for Shipment	1 each	1	Before shipment	4.9
• FAA (or LBA) Certification	1 each	NA		3.18
• Final Acceptance Test after observatory integration in the U.S.	1 lot	NA		4.4

SOFIA TELESCOPE ASSEMBLY
DEVELOPMENT CONTRACT SUBMITTALS AND DELIVERABLES
(Continued)

Item	Quantity Required	Document Type(1)	Delivery Date(s)	SOF-1011 Section/Para.
• Test Procedures	6 sets	1	4 wks before tests	4.5.1
• Test/Demonstration/Inspection Reports	6 sets	2	2 wks after event	4.5.3 (TRs)
• Verification-by-Analysis Reports	6 sets	1	2 wks after completion	
• Notification of All TA Verification Tests	1 notice	NA	30 days before tests	4.7.1
• Notification of Test Failures (when applicable)	1 notice	NA	1 day after test failure	4.5.2
TECHNICAL SUPPORT				
• TA installation, integration & test support in the U.S.	1 lot	NA	At Obs. I&T start	3.21
• TA maintenance and operations training in the U.S.	1 lot	NA	At Obs. I&T start	3.21

(1) Document Type Codes:

Type 1: APPROVAL - Document requires DARA approval. Approval or disapproval will occur within 30 days of receipt. In the event such action is not obtained in the 30-day period, upon notification to DARA of the situation, the contractor will be permitted to proceed on the basis of tacit approval. Neither approval nor waiver of approval shall relieve the Contractor of obligations to meet requirements of the contract.

Type 2: REVIEW - Document requires DARA review and dissemination of comments. All document reviews will be completed within 30 days after receipt. Work may proceed during the review period, pending DARA consideration of the document. The absence of a notice of disapproval shall constitute approval. Neither approval nor waiver of approval shall relieve the Contractor of obligations to meet requirements of the contract.

Type 3: INFORMATION/DATA - Document to be submitted for the purpose of forwarding technical information, project status, project progress, future planning, and/or any other data.

APPENDIX C

SOFIA TELESCOPE ASSEMBLY

DEVIATIONS AND WAIVERS

1.0 SOF-1011 Requirement:

3.12.8 Castings

Castings shall not be used in the TA design unless specifically waived by DLR.

1.1 DLR Deviation (SOF-RFW-MT-001, 11.04.97):

For the bearing sphere it is intended to use a casted part.

2.0 SOF-1011 Requirement:

3.3.8 Optical Materials and Coatings

……The primary, secondary, and non-dichroic tertiary mirrors shall be delivered coated with bare aluminum. ……

2.1 DLR Deviation (SOF-RFW-MT-005, 27.04.98):

Cancel the requirement on delivering the TA with a coated Primary Mirror.

2.2 DLR Rationale:

a. The coating of the Primary Mirror is never required during testing, integration and verification of the TA. The 4% reflectance of the polished Zerodur is absolutely sufficient.

b. Here in Europe the closest location for REOSC to coat the SOFIA Primary Mirror is in Palo Alto, Spain. Transporting the mirror there and back is a very tedious, risky and time consuming task.

c. Since a special coating facility for the SOFIA Primary Mirror will be built up in the US it is more convenient to perform the first coating in the US, which is much easier, less time consuming and risky.