Science Instrument Developers' Handbook

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AFRC
Armstrong Flight Research Center
Edwards, CA 93523

German Space Agency, DLR
Deutsches Zentrum für Luft und Raumfahrt

ARC
Ames Research Center
Moffett Field, CA 94035

Science Instrument Developers' Handbook

AUTHOR:

Logyx / Jeffrey Huang, Systems Engineer	Date

CONCURRENCE:

NASA / Mark McKelvey, SOFIA Science Instrument Development Manager	Date
NASA / Jonathan Brown, SOFIA Program SE&I Lead	Date
NASA / Timothy Krall, SOFIA Lead Operations Engineer	Date
NASA / Edward Ingraham, SOFIA Observatory Systems Director	Date
NASA / John Marcrum, SOFIA Program S&MA Lead (Acting)	Date
NASA / Pamela Marcum, SOFIA Program Scientist	Date

APPROVAL:

NASA / Jeanette Le, SOFIA Program Chief Engineer	Date
DLR / Project Engineer	Date

Revision History

REV	DATE	DESCRIPTION	APPROVAL
-	6/29/2011	Initial Release	PMB
A	6/28/2015	Revision update for Announcement of Opportunity for SOFIA 3rd Generation Instruments (Phase 1). Change details are provided in Appendix F of this document.	
B	1/4/2016	Subsequent revision update to support development of SOFIA 3rd Generation Science Instruments. Change details are provided in Appendix H of this document.	

Contents

1 Introduction

1.1 Purpose and scope

The Science Instrument Developers' Handbook describes how to develop a science instrument (SI) for the NASA/DLR Stratospheric Observatory for Infrared Astronomy (SOFIA) Program. The handbook provides an overview of the SOFIA instrument program and references all necessary requirement and interface documents for instrument developers; but, the handbook does not supplant the requirements and interface documents. The handbook applies to US and German instruments, except where indicated – "only for US instruments" or "only for German instruments".

This handbook is intended to be a guide and roadmap for instrument developers interested in the following aspects of SOFIA instruments:

- Developing or completing the development of instruments
- Proposing future instruments under an Announcement of Opportunity or other call
- Proposing enhancements to existing SOFIA and/or other instruments to be adapted to operate on SOFIA
- Procedural elements and reviews to be performed for new and/or upgraded instruments
- Overview information concerning SOFIA interfaces and recommendations for optimization based on instrument type

Typically, work for new instruments (as well as for modifications to existing instruments), will be performed via external contracts. This handbook along with specific SOFIA interface requirements and the technical performance of the instrument itself would become the basis for any contractual Statement of Work (SOW). In particular, the contents of Section 8, *Airworthiness Process*, and Section 11, *Safety and Mission Assurance*, describe the airworthiness and S&MA processes that the instrument teams should expect to see required in their SOW. Section 7, *Instrument Lifecycle*, and Appendix A.1 – Deliverable Items List describe deliverable items instrument teams should expect to see required in their SOW. The SOW will also reference compliance with the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) which contains the requirements for airworthiness, safety, mission assurance, and quality assurance for Science Instruments and requires compliance with interface control documents.

This document replaces the obsolete *SOFIA Experimenter's Handbook* (OP03-001) and the *Guidelines for SOFIA SI Integration and Commissioning Plans (ICP)* (USRA-DAL-SSMOC-SCIN-PLAN-4100) documents.

1.2 Terminology

As with any NASA program, the SOFIA Observatory is replete with acronyms and jargon. Appendix B – Acronyms contains a list of the acronyms and abbreviations used in this handbook. The *SOFIA Lexicon* (SOF-DF-PD-PD-2009) contains a more extensive list of the acronyms, abbreviations, and definitions of terms used by the SOFIA Program.

The science instruments are frequently abbreviated as "SI." The term "PI" is often used to describe items related to the Science Instrument Principal Investigator (i.e., PI rack, PI patch panel). There are other Principal Investigators associated with the SOFIA Observatory. Any reference to the PI in this document refers to the Science Instrument Principal Investigator unless otherwise noted.

When describing relative locations on the aircraft, we will use the terms: fore, aft, port, and starboard. Port is on your left when facing the front of the plane and on your right when facing aft toward the telescope. Many of the seats on the Observatory face aft, thus using “right” and “left” may generate confusion. Just remember that the telescope looks out “the port” side of the airplane.

Instrument Team – refers to the Science Instrument team working for the instrument Principal Investigator to build an individual instrument.

SOFIA Science Instrument Development Team – refers to the Observatory staff working under WBS 1.05 at the SOFIA Science Center (NASA Ames Research Center) and at the SOFIA Operations Center (NASA Armstrong Flight Research Center Building 703). The SOFIA SI Development team reports to the Science Instrument Manager and consists of NASA, USRA, and other contractors.

Instrumentation – refers to sensors on the aircraft to measure parameters such as temperature, pressure, acceleration, etc. To clearly distinguish between aircraft and test instrumentation and the science instruments mounted on the telescope, the latter is referred to as the Science Instrument (SI).

1.3 SOFIA document library

NASA maintains the SOFIA Program document library using servers running Windchill software. This library is located at https://sofiacm.arc.nasa.gov and is accessible from the NASA network or using a VPN connection to the NASA network. Each instrument team should have team members with Windchill accounts so the team has access to the full SOFIA document library and the latest document versions.

Instrument teams should contact their Program point of contact for information on obtaining an account on Windchill. Tutorials and training materials for using Windchill are available in the /.Help library on Windchill.

2 SOFIA Program Overview

SOFIA consists of a German-built 2.7-meter (2.5-meter useable) telescope mounted in a Boeing 747-SP aircraft supplied and modified by NASA. Operations costs and observing time are shared by the United States (80%) and Germany (20%). Flying at altitudes up to 45,000-feet, SOFIA observes from above more than 99 percent of Earth’s atmospheric water vapor, thereby opening windows to the universe not available from the ground. SOFIA offers international science teams up to 1000 cloud-free high-altitude science observing hours per year during its two decade design lifetime. More than 50 science proposals per year will be selected through a competitive peer review process. Although the primary impact of SOFIA will be its science return, it will yield other returns as well. Compelling discoveries will follow the development of new technologies that can be demonstrated readily on SOFIA. Young scientists-in-training, educators, and journalists will also fly on SOFIA, making it a valuable training platform and public ambassador.

SOFIA observes at wavelengths from 0.3 μm to 1.6 mm. SOFIA’s diffraction-limited imaging longward of 25 μm can produce the sharpest images of any current or planned IR telescope operating in the 30 to 60 μm region.

The SOFIA Observatory concept embodies a number of key advantages that make it a unique tool for astronomy in the coming decades:

- SOFIA is a near-space observatory that comes home after every flight. Its scientific instruments can be exchanged regularly, accessed for repairs or cryogenic servicing, to accommodate changing science requirements, and to incorporate new technologies.

- SOFIA has unique capabilities for studying transient events. The observatory can operate on short notice from airbases worldwide, in both the northern and southern hemispheres, to respond to new and transient scientific opportunities.

- SOFIA's diverse range of instrumentation facilitates a coordinated program of analysis of specific targets and science questions. SOFIA's 20-year design lifetime enables long-term studies and follow-up of work initiated by SOFIA itself and by other observatories, such as the Hubble Space Telescope, Chandra X-ray Observatory, Spitzer Space Telescope, Herschel Space Observatory, Submillimeter Array, and Akari (Astro-F), as well as future facilities.

- SOFIA presents an ideal venue in which to educate students, where they can participate in hands-on, cutting-edge space technology developments.

- Because of its accessibility, SOFIA includes a vigorous, highly visible Education and Public Outreach (E/PO) program designed to exploit the unique and inspirational attributes of airborne astronomy (see http://www.sofia.usra.edu/Edu/edu.html).

SOFIA, with its large suite of science instruments and broad wavelength coverage, is capable of undertaking a huge breadth of different investigations.

The *Science Vision for the Stratospheric Observatory for Infrared Astronomy* (USRA-DAL-SSMOC-SCIN-REP-1018) summarizes the unique capabilities that SOFIA will offer to the astronomical community, and describes a number of exciting science programs that are representative of SOFIA's potential contributions. It and additional general information on SOFIA may be found at http://sofia.usra.edu.

A description of the SOFIA Program organization structure can be found in the *Program Plan for SOFIA* (SOF-DF-PLA-PM01-1000). In 2014, the SOFIA Program transitioned from development to science operations mode, which included dissolution of the SOFIA Airborne Platform Project and Science Project. This handbook may still include citations to Platform Project or Science Project documents that were released prior to the Program transition which remain applicable to current instrument developers.

The *SOFIA Concept of Operations* (SOF-DA-PLA-PM17-2000) is a useful resource for understanding the SOFIA Observatory System, the Operational Phases section may be of particular interest as it provides an overview of observatory certification and commissioning, flight series preparation, science mission operations, and post-flight operations, all of which a science instrument and instrument team are an integral part of.

3 Instrument Overview

The SOFIA Observatory supports a complement of instruments, which are categorized into classes depending on how the instrument is to be used. The three classes are: Facility, PI, and Technology Demonstration.

Table 3-1: Summary of instrument classes

	Facility Science Instruments	Science Instrument Upgrades	Technology Demonstration Science Instruments
Development	PI responsibility	PI responsibility	PI responsibility
Preliminary Design Review (PDR)	Yes	Yes	Yes
Critical Design Review (CDR)	Yes	Yes	Yes
Pre-Ship Review (PSR)	Yes	Yes	Yes
Acceptance Review (AR)	Yes	Yes	No
SI System Specification	Applies	Applies	Applies
Commissioning Time	As proposed	As proposed	Included in guaranteed time
Oversight and Approvals	NASA	NASA	NASA
Interface to SOFIA Program	NASA	NASA	NASA
Operations	SMO (after acceptance)	SMO (after acceptance)	PI responsibility
Data Analysis	GI responsibility	GI responsibility	PI responsibility
Data Analysis Pipeline	Delivered by PI and operated by SMO	Delivered by PI and operated by SMO	PI responsibility; not delivered
Data Archiving	Raw, reduced, and calibrated	Raw, reduced, and calibrated	Raw
General Investigator (GI) Access	Yes	Yes	No (except in collaboration with the instrument PI)
Retirement	As per Instrument Development Handbook	As per Instrument Development Handbook	2 years following the last GTO flight
Upgrade Eligibility	Yes, through AO proposal	N/A	Yes, through AO proposal

3.1 Facility Science Instruments

Facility science instruments (FSI) are turned over to the SOFIA Program at the completion of their Acceptance Review. Science Mission Operations (SMO) is responsible for the operation and maintenance of the Facility Science Instruments following acceptance and making them available for use by SOFIA general investigators (GIs). Instrument Teams providing facility science instruments are responsible for the development, delivery, and commissioning of the instrument. The Instrument Team will also be responsible for providing sufficient documentation to enable the SMO to operate and maintain the instrument. Instrument delivery also includes the instrument control and data analysis pipeline software, as well as the associated operating manuals.

3.2 PI Science Instruments

Principal investigator science instruments (PSI) remain under the control of the PI. The PI is responsible for the operation and maintenance of the PI Science Instruments prior to and following the Commissioning Review. The Commissioning Review marks the point when the instrument can be made available for use by SOFIA general investigators (GIs). Instrument Teams providing PI Science Instruments are responsible for the development, delivery, and commissioning of the instrument. The documentation requirements are reduced for PI Science Instruments as operations and maintenance remains the responsibility of the Instrument Team. The Instrument Team is responsible for delivering the data analysis pipeline software, as well as the associated operating manuals, unless specified otherwise in the memorandum of understanding (MOU) specific to the instrument.

3.3 Technology Demonstration Science Instruments

Technology demonstration science instruments (TDSI) are developed for the purpose of maturing and demonstrating, through a focused science investigation involving a limited number of SOFIA flights, new capabilities and methodologies of value to SOFIA and future NASA missions. SOFIA technology demonstration science instrument investigations are analogous to NASA's sounding rocket and scientific balloon suborbital investigations. Technology demonstration science instrument investigations are allowed to have higher risk and reduced reliability; in exchange they are expected to have a shorter duration and be significantly less costly than a facility instrument. Instrument Teams providing technology demonstration science instruments are responsible for the development, delivery, and commissioning of the instrument. The documentation requirements are reduced for technology development science instruments as operations and maintenance remains the responsibility of the Instrument Team. The Instrument Team is not responsible for the delivery of control or analysis software.

4 Instrument description

4.1 Science Instrument System

A SOFIA Science Instrument System installed onboard SOFIA generally consists of the following hardware components:

- Instrument Assembly – the portion of the instrument that mounts to the telescope assembly instrument mounting flange. The instrument assembly includes the instrument optical bench, cryostat(s), detectors, and electronics. Once installed, the instrument assembly will move with the telescope and thus will need to operate through the operating range of the telescope assembly. Access to the instrument assembly during flight is controlled and limited; Section 6.3 provides additional details about the access of instruments in-flight.

- Counterweight Rack (CWR) – the counterweight rack is a 19" equipment rack mounted to the telescope assembly counterweight plate. The mounting location of the Counterweight Rack on the telescope assembly is in close proximity to the instrument assembly. Like the instrument assembly, the Counterweight Rack operates through the operating range of the telescope assembly whenever the rack is installed. Access to equipment in the counterweight rack during flight is extremely limited due to the elevated height and position of the counterweight rack above main deck floor at most telescope elevation angles. This rack frame structure is provided by NASA to the instrument developer.

- PI Rack(s) – the science instrument principal investigator racks are 19" equipment racks mounted over the center wing section of the main deck floor. Equipment which needs to be accessed routinely or frequently by the instrument team during flight should be located in these racks. Instrument teams can utilize up to three PI racks to support their instruments. These dual-bay, 19-inch rack frame structures are provided by NASA to the instrument developer.

- Pressure Coupler or Optical Window Assembly (optional) – an instrument component mounted to the gate valve pressure plate (GVPP) interface inside the telescope assembly instrument flange tub (INF). This hardware typically forms part of the pressure seal between the TA cavity and cabin of the aircraft.

- Chopper interface electronics (optional) – the instrument electronics used to drive the telescope assembly secondary mirror assembly (SMA).

Non-flight ground support equipment provided by the instrument developer for supporting operations of the Science Instrument System at Armstrong Building 703 are:

- Instrument Installation Cart – the cart used to transport the SI through the ground facility, onto the aircraft, and install the instrument to the Telescope Assembly instrument flange.

- Lab cart/stand or ancillary equipment (optional) – any ground support equipment required for routine maintenance of the instrument.

Figure 4.1-1 shows an instrument assembly (FORCAST) and its Counterweight Rack mounted to the telescope assembly; the photograph view is looking “aft” in the aircraft towards the aircraft cavity forward pressure bulkhead. Figure 4.1-2 shows two PI Racks installed near the PI Patch Panel; this photograph view is looking “forward” in the aircraft.

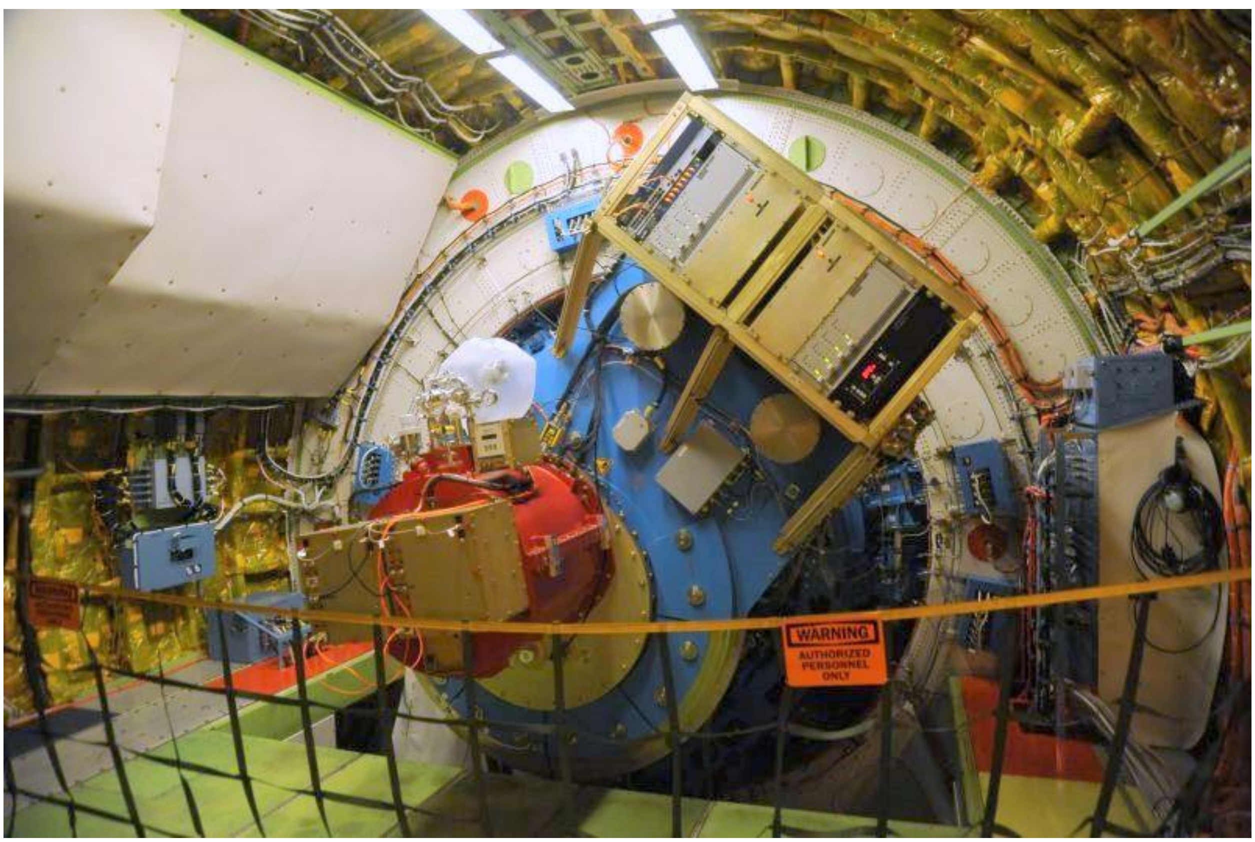


Figure Error! Reference source not found.**-1: The FORCAST instrument assembly and counterweight rack mounted n the telescope assembly**

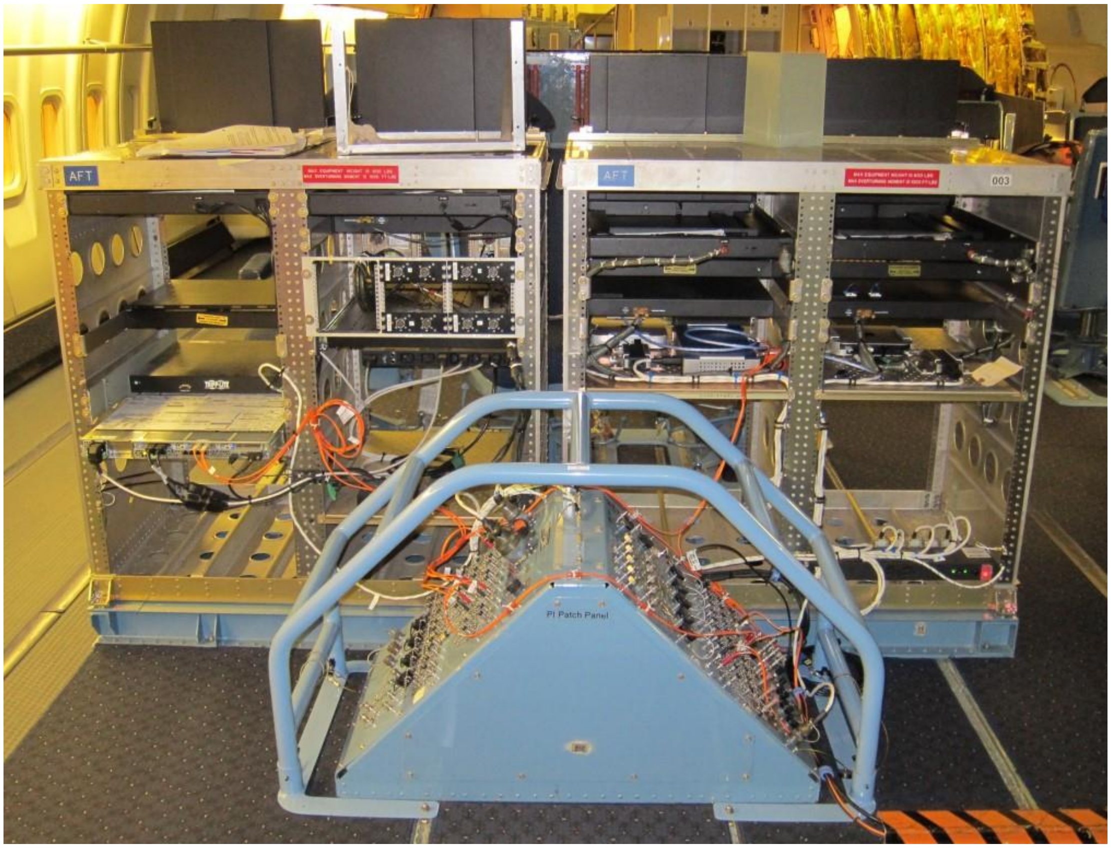


Figure 4.1-2: Two instrument PI racks mounted in the Observatory next to the PI patch panel

4.2 Other equipment

The proposed investigation may require additional equipment that is not part of the current observatory (i.e., alternate secondary mirror button, tertiary mirror with alternate coating, instrument rotator, secondary spider baffles, etc.). The SOFIA Program and Instrument team will determine whether such additional equipment should be incorporated as part of the Observatory and developed by the SOFIA Program with input from all the Instrument teams, or whether this equipment should be developed and provided by the Instrument team under the instrument contract.

4.3 Government Furnished Equipment

The SOFIA Program will support integration of selected science investigations with the Observatory with equipment, services, and facilities. Government furnished items include:

- PI rack(s),
- PI rack installation dolly,
- Auxiliary rack,
- Counterweight rack,
- Counterweight rack installation cart,
- Laboratory space at Armstrong Building 703 for integration activities,
- Technicians and supplies to support integration,
- On-aircraft vacuum system,
- On-aircraft cryocooler system,

- Cryogens for use in the laboratories at Building 703 and on the Observatory,
- Secondary mirror buttons, and
- Shipping assembly for instruments participating in SOFIA deployments

5 Requirements and interfaces

The *SOFIA Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) contains the requirements for airworthiness, safety, mission assurance, and quality assurance for Science Instruments. The *SOFIA Specification/Product Tree* (SOF-DF-SPE-SE01-068) shows the SOFIA specification structure for the overall SOFIA Program and the relationship between the *SI System Specification* and the other specifications. The parent specification of the *SI System Specification* is the *SOFIA System Specification* (SOF-DF-SPE-SE01-003), which contains the top level requirements for the SOFIA Observatory. The *SI System Specification* is the instrument product specification and contains the verifiable requirements for the science instrument system hardware and software. Within this specification are requirements to comply with 15 interface control documents (ICDs).

In addition to the specification and ICDs, the *SOFIA Science Instrument Developers' Handbook* (this document) contains a narrative description of the processes, intending to assist instrument teams with understanding the requirements and provide guidance on the design and development of SOFIA instruments.

5.1 Science Instrument System Specification

The *SOFIA Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) is a level 2 specification in the *SOFIA Specification/Product Tree* (SOF-DF-SPE-SE01-068). The SI System Specification contains the verifiable system requirements that all SIs must meet. This includes airworthiness, quality assurance, mission assurance, and safety requirements.

Because the instrument science and technical performance requirements are specific to the instrument type and scientific investigation proposed, such requirements are outside the scope of the *SE01-2028 SI System Specification.* The minimum performance requirements presented in the instrument proposal will form the basis of the top-level science and technical performance requirements for the instrument. The final top-level science and technical performance requirements will be negotiated with the SOFIA Program prior to the SI System Requirements Review (SRR). After completion of a series of flights dedicated for collecting commissioning data, the instrument team will present at its Commissioning or Acceptance Review how its top-level science and technical performance requirements were met.

To ensure the safety of the personnel onboard SOFIA and the Observatory itself, all equipment onboard the aircraft needs to be declared airworthy before it can be flown. The airworthiness approval process for science instruments is described in detail in Section 8 of this document.

The *SE01-2028 SI System Specification* levies certain safety-related requirements via citations of NASA Procedural Requirements (NPRs). At the PDR, the identified requirements are to be addressed within the Verification & Validation (V&V) presentation. Refer to Section 7.3 for more detail regarding instrument development reviews.

5.2 Science Instrument Performance Specification

The instrument selection proposals include a list of performance requirements the science instrument needs to achieve in order to execute the scientific objectives of the proposed investigation. These minimum performance requirements will form the basis of the top-level science and technical performance requirements. The final top-level science and technical performance requirements will be negotiated with the SOFIA Program prior to the SI System Requirements Review (SRR).

5.3 Interfaces

5.3.1 Introduction

The SOFIA science instrument interfaces are defined by fifteen interface control documents (ICDs). Figure 5.3.1-1 is a block diagram of the Observatory subsystems which shows the interfaces to the science instruments and the ICDs which governs that interface. Table 5.3.1-1 lists each ICD and its corresponding SOFIA document number.

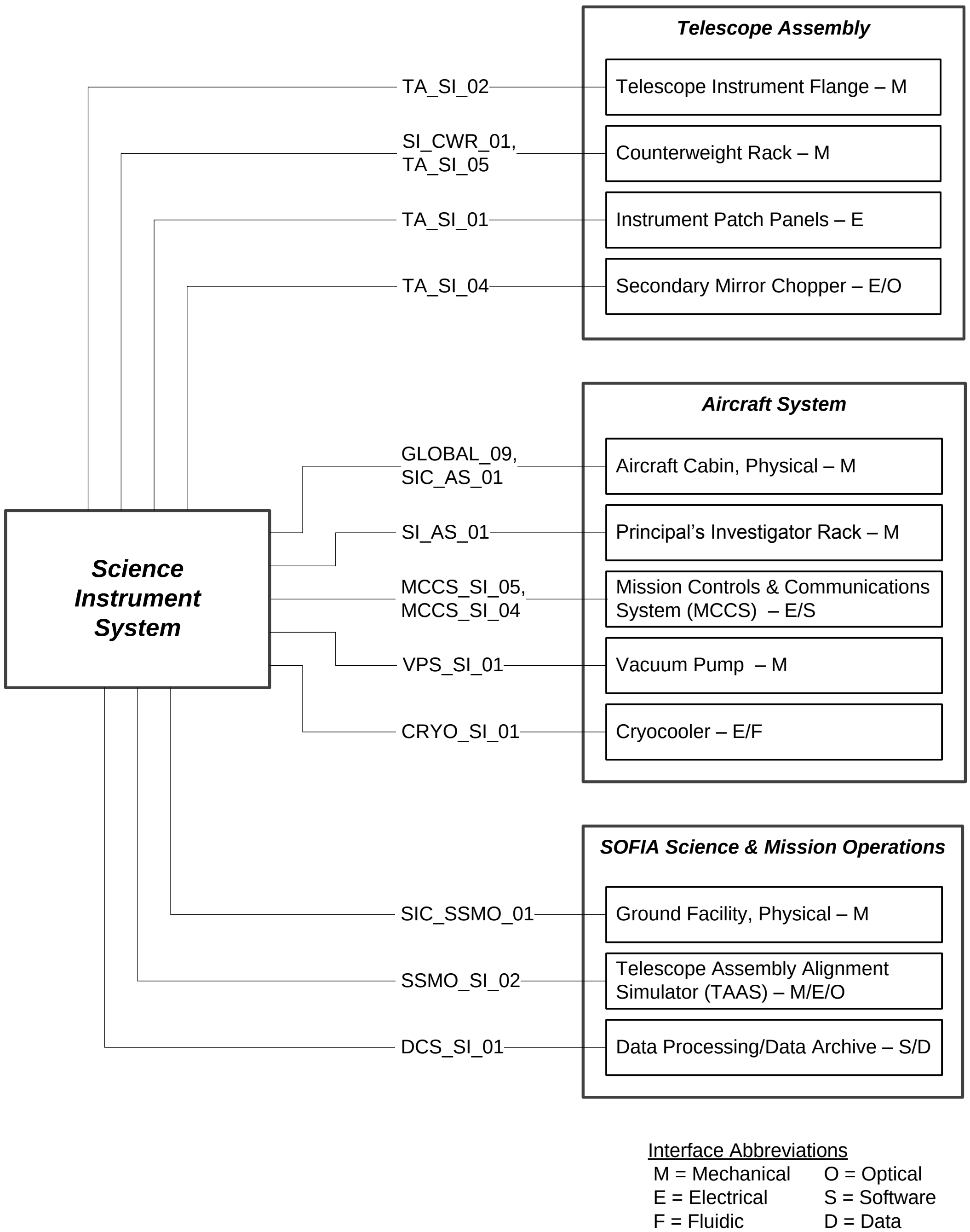


Figure 5.3.1-1: Science Instrument interface block diagram

Table 5.3.1-1: Table describing science instrument interface control documents

ICD Designator	Document Number	ICD Title	Scope
GLOBAL_09	SOF-DA-ICD-SE03-002	Science Instrument Envelope	The instrument dynamic, static, and installation spatial envelopes
TA_SI_01	SOF-DA-ICD-SE03-036	Cable Load Alleviator Device/Science Instrument Cable Interface	TA patch panel electrical interfaces to the counterweight rack and instrument assembly
TA_SI_02	SOF-DA-ICD-SE03-037	Telescope Assembly/Science Instrument Mounting Interface	Mechanical interface between the instrument assembly and the telescope flange
TA_SI_04	SOF-DA-ICD-SE03-038	TA Chopper Processor/Principal Investigator Computer Direct Analog Interface	Analog and TTL trigger interface between the instrument and chopper
TA_SI_05	SOF-DA-ICD-SE03-051	SI Equipment Rack/TA Counterweight Interface	Mechanical interface between the counterweight rack and the TA
SI_CWR_01	SCI-AR-ICD-SE03-2027	SI Equipment to Counterweight Rack	Requirements for installed equipment in the counterweight rack
SI_AS_01	SOF-DF-ICD-SE03-2015	Principal Investigator Equipment to PI Rack to Aircraft System	Requirements for installed equipment in the PI hardware racks
MCCS_SI_05	SOF-AR-ICD-SE03-2029	PI Patch Panel to PI Equipment Rack(s)	PI patch panel electrical connections to PI racks
MCCS_SI_04	SOF-DA-ICD-SE03-052	MCCS to SI Software Interface (Functional)	Commands and syntax for instrument software command to the observatory control software
DCS_SI_01	SCI-US-ICD-SE03-2023	Data Cycle System to Science Instrument	Defines data file interface for instrument data archived by the Data Cycle System
VPS_SI_01	SOF-DA-ICD-SE03-2022	SI to Aircraft Vacuum Pump	Interface to on-aircraft vacuum pump system (LHe pumping and other uses)
SIC_AS_01	SOF-AR-ICD-SE03-205	SI Handling Cart to Aircraft System	Requirements on the instrument installation cart to ensure safe transportation onto and through the aircraft
SIC_SSMO_01	SCI-AR-ICD-SE03-2017	SI Handling Cart to SSMO Facility Interface	Ground facility constraints on instrument lab carts and stands
SSMO_SI_02	SCI-AR-ICD-SE03-2020	Telescope Assembly Alignment Simulator (TAAS)/Science Instrument (SI) ICD	Interfaces between instrument and the telescope assembly alignment simulator
CRYO_SI_01	APP-DA-ICD-SE03-2059	Cryocooler System to Science Instrument (SI) ICD	Defines the electrical power, electronic signaling, and fluidic interfaces

5.3.2 Optical

The SOFIA telescope is a two-mirror bent Cassegrain design with a single Nasmyth instrument mount fed by a flat tertiary. The telescope effective aperture is 2.5 meters and provides an f/19.5 beam to the instruments (at nominal focus). The primary and secondary mirrors have aluminum coatings. The dichroic tertiary mirror has a gold coating, while the fully-reflective tertiary mirror will have either an aluminum or a protected silver coating.

The secondary mirror provides a peak-to-peak chop amplitude of 10 arcminutes between 0 and 20 Hz. The visible beam is fed into the Focal Plane Imager (FPI), which is an optical focal plane guiding system. Independent of the FPI there are two other optical imaging and guiding cameras available: a Wide Field Imager (WFI) and Fine Field Imager (FFI). Both of these cameras are attached to the front ring of the telescope.

Focusing is accomplished with an actuated secondary providing an adjustment range of ±60 cm referenced to the nominal Nasmyth focal plane location. The telescope unvignetted elevation angles range from 23 to 58 degrees, thus the instrument should be capable of supporting a rotation of ±20 degrees about the optical axis. The unvignetted field-of-view is a circle with a diameter of 8 arcminutes.

The secondary mirror chopper may be triggered from an external TTL waveform from the science instrument or from an internal signal from MCCS. This interface is described *in TA Chopper Processor/Principal Investigator Computer Direct Analog Interface TA_SI_04* (SOF-DA-ICD-SE03-038). Chopping may be performed a number of ways, depending on the preferred method of an instrument developer. The chop sync signal can be generated internally by MCCS and the TA or provided externally by the instrument developer via supply of an external TTL waveform to the chopper junction box. Establishing the chop profile can be defined and controlled using MCCS or by external analog input signals to the chopper junction box provided by the instrument developer. SOFIA instruments that chop have typically chosen to define their chop profile within MCCS and have furnished an external TTL chop sync signal at the chopper junction box interface.

5.3.3 Mechanical

The Instrument Assembly mounts to the 41-inch diameter instrument mounting flange on the telescope assembly. This mechanical mounting interface is defined in the *Telescope Assembly/Science Instrument Mounting Interface* (SOF-DA-ICD-SE03-037). The allowable instrument dynamic, static, and installation spatial envelopes are *Science Instrument Envelope GLOBAL_09* (SOF-DA-ICD-SE03-002).

Science Instrument components mounted inside the PI and Counterweight 19-inch racks are required to meet airworthiness and crash load requirements to ensure the safety of personnel onboard SOFIA. The document *Principal Investigator Equipment to PI rack to Aircraft System ICD SI_AS_01* (SOF-DA-ICD-SE03-2015) defines the requirements on installed SI hardware, limitations on rack loading, use of support trays, and NASA review process for any proposed structural modification or configuration change to the rack structure if deemed necessary by the instrument developer. The empty PI and Counterweight Rack structures furnished by the SOFIA Program are themselves certified to be airworthy before first delivery of the racks to instrument developers. Airworthiness of the rack structures themselves is maintained as long as the load limits are not exceeded and no structural or configuration changes are made to the rack structures.

The *Interface Control Document Science Instrument Equipment to Counterweight Rack SI_CWR_01* (SCI-AR-ICD-SE03-2027) provides the requirements for installed SI hardware and limitations on rack loading. Requirements on the total mass and mass properties of the loaded counterweight rack are in

Interface Control Document SI Equipment Rack / TA Counterweight Interface TA_SI_05 (SOF-DA-ICD-SE03-051).

Instruments that choose to connect to the onboard vacuum pump system will connect to the interface described in the *Vacuum Pump System to Science Instrument ICD VPS_SI_01* (SOF-DA-ICD-SE03-2022).

5.3.4 Pressure

To provide the greatest flexibility in wavelength coverage for the observatory, no window is installed in the optical path of the Nasmyth beam. A mechanical gate valve is installed between the instrument flange in the main cabin and the Nasmyth tube in the cavity for safety. This valve is opened when the observatory is operating. Once the gate valve is opened, the Instrument assembly becomes part of the pressure barrier of the main cabin; the Instrument assembly defines the interface between the shirt-sleeve laboratory environment in the main cabin and the stratospheric environment in the cavity. The pressure seal interface is defined in the *Telescope Assembly/Science Instrument mounting Interface* (SOF-DA-ICD-SE03-037). The ICD also defines the mounting interface for a pressure coupler or optical window assembly, if a science instrument chooses provide and install one to the gate valve pressure plate (GVPP) mounting interface.

It is at the discretion of the instrument developer whether or not to install a window in the path of their optical beam. If a highly hygroscopic material is selected, procedures for protecting those windows should be developed by the Instrument team and an appropriate window spare complement should be provided with the instrument.

5.3.5 Electrical

Electrical connections to the Mission Controls and Communications System (MCCS) include power, local area network, GPS, and IRIG-B timing. These interfaces are located on the PI Patch Panel near the PI Racks and are described in the *Interface Control Document Principal Investigator Patch Panel to Principal Investigator Equipment Rack(s) MCCS_SI_05* (SOF-AR-ICD-SE03-2029).

The PI racks and the telescope assembly are separated by about 25 feet. The aircraft has permanent cable installations under the cabin deck, including a set of cables which are routed through the cable load alleviator (i.e., telescope cable wrap), providing electrical and fiber optic connections between the PI Patch Panel and the TA Patch Panels. The PI Patch Panel electrical interface is described in *Interface Control Document Principal Investigator Patch Panel to Principal Investigator Equipment Rack(s) MCCS_SI_05* (SOF-AR-ICD-SE03-2029). The TA Patch Panel electrical interfaces located near the Counterweight Rack are described in *Cable Load Alleviator Device/Science Instrument Cable Interface TA_SI_01*, (SOF-DA-ICD-SE03-036).

All electrical interface connections between the instrument and Observatory patch panels will be achieved through SI-supplied jumper cables. The instrument is also responsible for supplying all “intra-SI” jumper cables—that is, direct connections within the instrument system (e.g., jumper cables connecting Counterweight Rack electronics to the instrument assembly). Appendix C of this handbook provides distance information between the various physical interfaces and locations, such as the distance between the PI Racks and the PI Patch Panel, as well as distance information between the instrument mounting flange, Counterweight Rack, TA Patch Panels, and chopper junction box on the telescope assembly.

5.3.6 Power

Electrical power to the Science Instrument is supplied by the MCCS at panel U401 of the PI Patch Panel located near the PI racks. Power to the Counterweight Rack and Instrument Assembly on the telescope will be routed and supplied by the instrument team via jumper cables and connections to the U400 of the PI Patch Panel and the U402 TA Patch Panel interfaces described in *Interface Control Document Principal Investigator Patch Panel to Principal Investigator Equipment Rack(s) MCCS_SI_05* (SOF-AR-ICD-SE03-2029) and *Interface Control Document Cable Load Alleviator Device / Science Instrument Cable Interface TA_SI_01* (SOF-DA-ICD-SE03-036).

A total of 6.5 KVA is currently available for use by science instruments from MCCS, with the following sub-allocations:

Table 5.3.6-1: SI power allocation from SOFIA PI Patch Panel (U401)

Type of Power	Maximum SI Power
230 VAC, 50 Hz, Uninterruptible Power Supply	1 KVA
115 VAC, 60 Hz, Frequency Converter	3.5 KVA
115 VAC, 60 Hz, Uninterruptible Power Supply	2 KVA
28 VDC	85 W

5.3.7 Fluidic

The observatory recently added the capability to support instruments utilizing closed-cycle cryocooler (CCC) systems. This was demonstrated and verified with the implemented Phase 1 SOFIA Cryocooler System which was initially designed to support operation of upGREAT, a configuration of the GREAT instrument which utilizes a cryostat with pulse-tube cold head and cryocooling system. The Phase 1 SOFIA Cryocooler System is available for use by all science instruments. The *Cryocooler System to Science Instrument (SI) ICD CRYO_SI_01* (APP-DA-ICD-SE03-2059) describes the electrical power, electronic signaling, and fluidic interfaces between the Cryocooler System and science instrument. Section 6.2.9 of this handbook provides additional information about the functional capability of the Phase 1 Cryocooler System.

The capabilities and technical details of the Phase 1 SOFIA Cryocooler System are described in the *SOFIA (upGREAT) Cryocooler System Specification* (APP-DA-SPE-SE01-2076) and *SOFIA (upGREAT) Cryocooler Concept of Operations* (APP-DA-PLA-PM17-2076).

5.3.8 Software

5.3.8.1 Mission Command and Control System

The observatory is controlled by the Mission Command and Control System (MCCS), which coordinates interactions between the aircraft, telescope, and science instrument. The Science Instrument issues commands to the observatory via the SOFIA Command Language (SCL). These SCL commands are then executed by the MCCS. The MCCS also provides, via subscription, the housekeeping data that the science instruments will use to reduce their data and populate their FITS headers. The software interface between the SI and the MCCS is described in *Interface Control Document MCCS to Science Instrument Software Interface (Functional) MCCS_SI_04* (SOF-DA-ICD-SE03-052). The *SOFIA Command Language (SCL) User's Manual* (SOF-DA-MAN-OP02-2181) is a supplemental resource useful for understanding commonly used SCL command constructs, housekeeping commands, reference frames and coordinate systems, and SI observing modes.

5.3.8.2 Data Cycle System

The SOFIA Data Cycle System (DCS) provides long-term archival and retrieval functions for raw and reduced science instrument data. The DCS stores the raw and reduced data in FITS files and utilizes the metadata keywords in FITS files to store the necessary parameters required to utilize the data for scientific investigations. The *Interface Control Document for the Data Cycle System, DCS_SI_01* (SCI-US-ICD-SE03-2023), describes the DCS and the interface for science instrument data products.

5.3.8.3 Data Reduction Pipelines

The SOFIA Data Processing System (DPS) provides data reduction capability for science instruments via instrument data reduction pipelines integrated with the DPS. This includes all facility science instruments and select Principal Investigator instruments for which the instrument MOU specifies delivery of a data reduction pipeline to NASA. Level 1 (raw, uncalibrated FITS) instrument data is processed by the DPS to produce higher level data products such as Level 2 (corrected for instrument artifacts), Level 3 (flux-calibrated), and Level 4 (higher order e.g., mosaics, spectral cubes) products. Data to be processed is handled by both the SOFIA DCS and DPS systems; the general process flow is Level 1 science data from an observing flight is ingested into the DCS Archive, followed by DPS performing data processing operations on the Level 1 science data to produce higher level data products which are then stored in the DCS Archive.

Requirements for data processing keywords in FITS metadata are described in the *Interface Control Document for the Data Cycle System, DCS_SI_01* (SCI-US-ICD-SE03-2023); these requirements apply to all SOFIA SI. The plan for the data analysis pipeline is described in *Data Processing Plan for SOFIA Science Instruments*, (SCI-US-PLA-PM17-2010). Instrument teams which will deliver a pipeline to the SOFIA Program, will coordinate with the SOFIA DPS Group to develop a set of requirements for the instrument pipeline to ensure the objectives of the pipeline are met and the pipeline can be successfully integrated with the DPS. The *SI Pipeline Acceptance Plan*, (SCI-US-PLA-SW09-2000), developed by the SOFIA Program, contains information about deliverables and milestones required for pipelines that will be integrated with the SOFIA DPS, and includes a core set of generic pipeline software requirements provided as guidance to instrument teams for formulating the pipeline requirements for a specific instrument.

5.3.9 Ground Support Equipment

The SI Assembly installation cart is an important ground support equipment (GSE) item that is used to transport the instrument assembly within the SOFIA Science and Mission Operations ground facility, including transporting the instrument onto the aircraft and installing the instrument to the telescope instrument flange. The safety and interface requirements for SI installation carts are defined in the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028), the *Interface Control Document SI Handling Cart to Aircraft System SIC_AS_01* (SOF-AR-ICD-SE03-205), and the *Interface Control Document SI Handling Cart to SSMO Facility SIC_SSMO_01*, (SCI-AR-ICD-SE03-2017). Pertaining to interface requirements, instrument carts or stands used exclusively in the SI Labs are only required to meet the interface requirements of SE03-2017. Instrument installation carts however, which are used both in the SI Labs and on the aircraft, are required to meet the interface requirements of both SE03-2017 and SE03-205. These ICDs also contain dimension and geometry information of the ramps and incline surfaces for which an instrument cart will encounter at Armstrong Building 703. All instrument installation and lab carts, or stands, are required to meet the safety requirements defined in SE01-2028.

The SOFIA Program supplies carts and dollies for the installation of the PI racks and the counterweight rack (see Section 4.3). The SOFIA Program is responsible for initial certification and periodic recertification (i.e., load test and/or inspection) of the PI rack dollies and CWR carts.

5.4 Verification and Validation

5.4.1 Purpose of Verification and Validation

From a process perspective, product (or science instrument) verification and validation (V&V) are similar in nature, but the objectives are fundamentally different. Verification shows proof of compliance with requirements—that the instrument meets each "shall" statement as proven through performance of a test, analysis, inspection, or demonstration. Validation shows that the instrument accomplishes the intended purpose in the intended environment—that it meets the expectations of the stakeholders. In essence, verification proves that "the system was built right," and validation proves that "the right system was built".

Verification relates back to the approved requirements set and can be performed at different phases of the instrument life-cycle. Verification activities include: (1) testing used to assist in the development and maturation of products, product elements, or manufacturing or support processes; and/or (2) engineering-type testing, analysis, inspection, or demonstration used to verify the status of technical progress, verify that design risks are minimized, substantiate achievement of technical performance, and certify readiness for initial validation testing. Verification tests use instrumentation and measurements and are generally accomplished by engineers, technicians, or operator-maintainer test personnel in a controlled environment to facilitate failure analysis.

Validation relates back to the concept of operations. Validation testing is conducted under realistic conditions (or simulated conditions) to determine the effectiveness and suitability of the instrument for use in mission operations by typical users. Instrument validation will primarily occur during the commissioning flights.

5.4.2 Verification Process Overview

The verification process includes verification planning, preparation, execution, reporting, and NASA assessment. These elements of the process are described in further detail in the remainder of this section.

The approved requirements to be verified for instruments are contained within the following documents:

1. *SOFIA Science Instrument System Specification* (SCI-AR-SPE-SE01-2028)
2. *SOFIA Science Instrument ICDs (see list in Table 5.3.1-1)*
3. The instrument-specific science and technical performance requirements to be established by the instrument team.
4. The instrument-specific pipeline software requirements (for facility instruments and certain PI instruments)

A block diagram of the SOFIA SI ICDs and how they interrelate to the instrument system is shown in Figure 5.3.1-1.

Airworthiness design requirements are contained within the *SOFIA Science Instrument System Specification* and SOFIA SI ICDs. See Section 8 of this document for further details.

All airworthiness design requirements are verified prior to the instrument Pre-Shipment Review (PSR). All ICD requirements are verified upon completion of the initial installation and checkout of the instrument on the Observatory. Performance requirements within the instrument-specific science performance specification are verified prior to the commissioning or acceptance review. Data reduction pipeline software requirements are also verified prior to the commissioning or acceptance review.

The NASA authorities for assessment of requirements compliance are as listed in Table 5.4.2-1.

Table 5.4.2-1: NASA verification compliance authorities

SOFIA Document	Requirements Type	NASA Compliance Authority
SI System Specification (SOF-AR-SPE-SE01-2028)	Airworthiness requirements	SOFIA Science Instrument Airworthiness Team (SIAT)
	All other requirements	Systems Engineering & Integration (SE&I)
SI ICDs	Airworthiness requirements	SIAT
	All other requirements	SE&I
SI-specific science performance	All	Science Instruments Development Manager
SI-specific pipeline software requirements document	All	SE&I

5.4.3 Verification Planning

Verification planning includes establishing the verification activities to be performed in each life-cycle phase of the instrument. Verification activities are categorized as analysis (A), inspection (I), demonstration (D), or test (T).

5.4.3.1 SOFIA SI System Specification and SI ICDs

Early in the Phase B (Preliminary Design and Technology Completion) development phase of the instrument project life-cycle, the instrument team will begin planning verification activities with SOFIA Systems Engineering & Integration (SE&I). There are two general types of verification: (1) initial verification activities performed by the instrument team for risk mitigation purposes, typically performed before PDR and CDR, and (2) final verification activities witnessed by NASA for verification close-out.

SE&I will provide the instrument team with the *SOFIA Science Instrument System Specification and ICD Requirements Verification Matrix Template* (SOF-NASA-REP-SV05-2057) which contains all requirements from the SOFIA SI System Specification and SOFIA SI ICDs. See Appendix D – Excerpt from SOFIA SI System Specification & ICD Requirements Verification Matrix Template for the general structure of the verification matrix template. The verification matrix template will be used to develop a verification compliance matrix specific to an instrument. The SI verification matrix serves as both a planning tool and a record of verification performed during the course of development of an SI. The five development phase verification planning columns—PDR, CDR, Pre-Ship, At AFRC prior to installation, and Installation and checkout—will be populated by SE&I with the recommended verification method (A, I, D, T) for each of the prescribed development phases. The template contains a column describing the recommended verification activity for each applicable development phase for each requirement. Both NASA and the instrument developer are responsible for providing inputs and maintaining certain fields of the verification matrix—for example, a set of columns is reserved for use by the SI team to self-identify compliance status while a similar set of columns is reserved for use by NASA to identify overall verification status based on a review of verification results recorded in the matrix.

After completion of the instrument SRR, the instrument team will identify which of the requirements in the matrix are applicable to the instrument and will identify the verification activities the team will perform for PDR and CDR. These initial verification activities serve to reduce risk; for example, drawings at CDR should be reviewed by the instrument team for compliance to ICD requirements, even though the definitive inspection by NASA of the as-built instrument will not be performed until after fabrication.

The instrument team will also have the opportunity to propose any desired changes to the post-CDR V&V activities recommended by NASA in the verification matrix. SE&I and SIAT will coordinate NASA review of any requested changes. Verification planning should be completed prior to PDR, and the verification matrix presented at PDR. Prior to each the PDR and CDR, the instrument team should record applicable compliance artifacts (e.g., analyses, drawings) and self-identify compliance (e.g., comply, do not comply) with each applicable requirement in the verification matrix.

The majority of SOFIA SI System Specification and SI ICD requirements compliance verification activities will be completed and closed-out before the instrument Pre-Ship Review. Several weeks before an instrument's Pre-Ship Review for shipment to Armstrong Building 703 for the first time, SE&I and SIAT will visit the SI Developer's site with a SOFIA QA Representative to conduct verification of SI hardware. The site visits by SE&I and SIAT are typically independent and may not necessarily be scheduled to coincide with one another. Verification procedures will be prepared prior to the visits and will serve as formal "as-run" records of inspection, demonstration, and tests when executed. The remaining verification activities to be performed after arrival at Building 703 will be limited to only those activities that cannot be definitively verified prior to shipment.

The verification matrix template indicates the NASA compliance authority for each requirement (i.e., SIAT or SE&I). This identifies the NASA entity that is authorized to declare, after the final verification activity is performed, whether the requirement has been satisfied or not. The NASA compliance authority will usually witness the final verification inspection, demonstration, or test or will review the final verification analysis.

5.4.3.2 SI-Specific Science and Technical Performance Specification

The instrument team will create a similar verification matrix early in project life-cycle Phase B for the SI-specific science and technical performance requirements—with the added verification planning columns for Line Operations and Commissioning flights—identifying and describing the planned verification activities for each requirement for the development phases (i.e., PDR, CDR, Pre-Ship, At AFRC prior to installation, Line Operations, Commissioning). For risk reduction purposes it is expected that verification activities will often span multiple development phases; for example, a supporting analysis for instrument science performance may be carried out prior to CDR but the definitive test may not occur until line operations or commissioning flights. The verification matrix for the science and technical performance requirements of the instrument outlining the planned verification to be performed should be completed prior to PDR and presented at the PDR.

5.4.4 Verification Preparation, Execution, and Close-Out

As described in the previous section, preparation for verification of requirements by inspection, demonstration, or test involves developing procedures, as well as facility preparation, equipment acquisition, and (if necessary) personnel certification.

Verification execution is the process of performing the verification procedures and having the NASA compliance authority review the results to determine whether the success criteria of the verification activity, as identified in the procedures, were met. The compliance authority will document the results ("Pass" or "Fail"), along with references to the documentation and associated compliance artifacts, in the verification matrix as verification activities are completed. As-run procedure records are submitted to SOFIA Configuration Management for archival.

As verification is performed during various phases of instrument development, noncompliance (or nonconformance) may be identified in which the instrument does not meet a requirement.

When noncompliance is identified during the design phase, before hardware fabrication or software coding has begun, SI Developers are strongly encouraged to explore design alternatives that would bring the instrument into compliance with the requirement unless there are compelling reasons why an instrument should be relieved of a requirement. In cases for which the NASA compliance authority believes that a deviation is warranted, the compliance authority will collect specific technical information about the instrument design to compose a deviation request to submit to the SOFIA Observatory Configuration Control Board (OCCB) for consideration, to release the instrument from its obligation to meet the requirement. It should be noted, pursuing a deviation request does not guarantee a deviation will be approved/granted, especially if the instrument is still in the design phase; each deviation request is individually evaluated to assess the specific noncompliance, justification, and potential impacts and risks of approving versus denying the deviation. In exceptions where a deviation is granted, verification of the as-built system will be performed against the specific design element which received the approved deviation (e.g., drawing) and not the requirement.

Instances in which the as-built instrument does not meet a requirement will be documented in the form of a discrepancy report filed with the SOFIA Program. Analogous to the deviation process but instead for instrument systems that have been built or fabricated, a waiver request may be submitted to release the instrument from its obligation to meet a requirement. As advised earlier, instrument developers are encouraged to explore design alternatives that would bring the instrument into compliance with the requirement, unless such design changes or modifications are technically difficult, cost prohibitive, or would significantly impact the instrument development schedule. Approved waivers will be documented in the instrument's verification compliance matrix. In certain cases, the Program may decide to grant a temporary waiver valid for a specific duration, by which time the instrument developer is responsible for bringing the instrument into compliance with the requirement per the terms agreed upon by the Program and instrument developer in the waiver.

All applicable SOFIA SI requirements must be either passed or waived before the first installation of the instrument on the Observatory. All instrument-specific science and technical performance requirements must be either passed or waived before the instrument may be accepted or commissioned.

5.4.5 Verification Activities

5.4.5.1 PDR Verification Activities

Verification activities for PDR will consist of the instrument developer delivering draft documentation and analyses based on the preliminary design of the instrument, and NASA reviewing the documentation to assess compliance of the design with SOFIA requirements. While the majority of design documentation will be delivered in the next phase of development (CDR), at PDR certain analyses are required to be delivered to show the requirements are understood in the preliminary design and the instrument developer is on track to satisfy the requirements in the next development phase.

Examples of verification activities performed for PDR include analysis of: instrument mass & c.g., cryostat vent pressure system, power budgets, physical/spatial envelopes). The results of the instrument team's PDR verification activities will be presented at the PDR.

5.4.5.2 CDR Verification Activities

Verification activities for CDR will consist of the instrument developer delivering updated and new documentation based on the detailed design of the instrument, and NASA reviewing the documentation to assess compliance of the design with SOFIA requirements. The primary method of verification used in this phase is analysis, whereas later development phases such as before shipment, will also include inspection, demonstration, and test.

Appendix A.2 – Documentation Delivery Schedule identifies the required document deliverables due from the instrument developer at CDR, for review and assessment of compliance by NASA before the CDR.

Examples of verification activities performed for CDR include analysis of: instrument assembly drawings, rack configuration drawings, instrument mass & c.g., cryostat and vent system pressure stress analysis, power consumption, physical/spatial envelopes, cart design, FITS data file header definition, and data reduction pipeline design. In this phase, the instrument should submit deviation requests to the SOFIA Program for all identified non-compliance/discrepancies of the instrument with SOFIA requirements based on the results of verification at CDR, before proceeding to build the instrument (e.g., procure materials, fabricate parts, code software).

5.4.5.3 Pre-Ship Verification Activities

NASA will develop and provide a number of procedures for conducting SI verification close-out activities before an instrument ships to Armstrong Building 703. These procedures typically require a NASA Safety and Mission Assurance (S&MA) representative to witness execution of the procedures. Examples of verification activities performed before instrument shipment are listed in Table 5.4.5.3-1 below.

Table 5.4.5.3-1: Examples of Pre-Ship verification activities grouped by verification method

Analyses	Airworthiness structural stress and loads analyses, SI center of gravity analysis, thermal analyses, alignment tolerance analysis, cryogen hazard analysis, failure modes and effects analyses, etc. Sensitivity performance models are developed prior to shipment, and updated throughout the test and commissioning program as instrument characterization improves.
Inspections	Airworthiness verification inspections, such as welding certifications, fastener specifications, etc. ICD verification inspections, such as envelope restrictions, connector types, wiring specifications, etc.
Tests	Detector characterization (dark noise, read noise, quantum efficiency, etc.), throughput characterization, image quality characterization, and mechanism characterization, at both room and operational temperatures. Measure power draw of the SI. Perform structural loads proof tests and pressure proof tests on flight hardware and SI handling equipment. Measure the mass of the flight hardware. Perform software tier tests remotely on SIL.
Demonstrations	Fit check of the SI flange to the TA instrument mounting flange. Functional testing of all operational modes and proper output format of science data, at both room and operational temperatures. If an MCCS simulator is available, perform demonstrations of command and control functions.

5.4.5.3.1 Airworthiness Inspections

The SIAT will perform inspections of the as-built instrument at the instrument developer’s site before shipment to verify the as-built instrument conforms to its design-to documentation (e.g., drawings) and to verify the instrument complies with airworthiness requirements. For this inspection the instrument hardware should be in its flight configuration. At the time of inspection, the instrument developer should communicate and identify to SIAT any parts of the instrument which are not in flight configuration, for which airworthiness inspection of those parts would need to be deferred to after instrument arrival at Armstrong Building 703 when the instrument is fully assembled.

This inspection process includes verifying the as-built instrument hardware conforms to the instrument drawings, specifications, and other configuration-controlled design documentation delivered by the instrument developer to the SOFIA Program. Documentation such as certificates of conformance (CoCs), certified material test reports (CMTRs), and travelers for safety-critical fabricated parts will also be inspected. Any noncompliance or nonconformance identified during in the inspection process will recorded in a discrepancy report for further review and possible action.

The SIAT will write the airworthiness inspection procedure and lead the airworthiness inspection activities. An SIAT representative will present their assessment of the readiness of the instrument to ship at the instrument Pre-Ship Review.

5.4.5.3.2 SE&I Verification (Non-Software)

A number of verification activities will be performed by the SOFIA SE&I Group before instrument shipment, to evaluate compliance of the as-built instrument system with SE&I requirements in the SE01-2028 SI System Specification and SOFIA ICDs. Verification performed by SE&I will first begin with review of updated analyses delivered by the instrument developer--analyses reflecting the as-built instrument system—followed by inspection, demonstration, and test verification activities.

For certain technical areas SE&I will interface directly with the instrument developer to conduct verification activities. Such activities have typically included mechanical verification (e.g., instrument mass measurement, instrument c.g. analysis inspection, instrument mounting flange inspection, instrument fit-check on TAAS, physical envelope inspections, cart load testing and inspections), electrical verification (e.g., power tests, ground tests, cable inspections & ring-out, UPS EPD response demonstration), and verification of various SE01-2028 functional, performance, safety, logistics, human factors, and material requirements. For other technical areas (e.g. software), the instrument developer may directly interface with other technical groups within the SOFIA Program to conduct verification activities but which SE&I will oversee the verification process and review verification results to assess final compliance of the instrument with SOFIA requirements in the instrument SE01-2028 and ICD requirements compliance matrix.

The instrument-specific SE01-2028 *SI System Specification* and SOFIA ICD requirements compliance matrix, developed from the SV05-2057 *SOFIA Science Instrument System Specification and ICD Requirements Verification Matrix Template* described in earlier Section 5.4.3.1 of this handbook, will be an important document which will be used by the instrument developer and NASA for verification planning and recording the verification compliance artifacts and results of all performed verification with SOFIA requirements.

SE&I will write or oversee the development of verification procedures for evaluating instrument compliance with SE01-2028 and SOFIA ICD requirements, and lead or oversee these verification activities. An SE&I representative will present their assessment of the readiness of an instrument to ship at the instrument Pre-Ship Review. At this review SE&I will provide a summary of instrument verification status (e.g., number of requirements passed, failed, and deferred), open verification items, and status of approved deviations/waivers and any that are in pending.

5.4.5.3.3 Instrument Software-MCCS Testing

The instrument developer will perform pre-integration MCCS tests on the SIL before instrument shipment, to ensure the instrument can properly send commands to MCCS, handle responses from MCCS, and execute scenarios; to demonstrate compliance with the MCCS_SI_04 ICD. The instrument team will conduct these verification activities with a team of SOFIA Mission Operations, Science Operations, and Software Systems personnel. The SOFIA Software Systems Group will lead and conduct the Tier 1-3 tests with the instrument developer. SOFIA Mission Operations (MOPS) will lead and conduct the Tier 4 tests, primarily by the Mission Director and Telescope Operator who have been assigned and dedicated to support Tier 4 tests of the new SI in the SIL and in-flight observations of the instrument onboard SOFIA.

A prerequisite to performing Tier tests is the SI team has supported the generation of an *<si>_data.xml* configuration file that establishes the SI's interface with MCCS, containing the following SI information:

1. SCL commands and response items
2. Alerts and alarms
3. Housekeeping values
4. Description of SI modes: focus, scaling, boresight pixels, etc. (See Section 3.3.5 of ICD MCCS_SI_04 for a complete list of required data.)

The instrument developer should not need to create this configuration file from scratch—SOFIA Software Systems will provide a template for the instrument developer to fill in the si_configuration items, which will become the instrument-specific *<si>_data.xml* file. Once the XML configuration file has been established, the team may proceed with conducting software Tier testing to establish SCL functionality. This testing verifies the interface and configuration definitions between the MCCS and SI, and proceeds through four incrementally increasing levels of complexity—Tier 1-4 tests which are described in the following subsections.

Tier tests are performed with the SI team computer connecting remotely to a SIL located at either the SOFIA Science Center (ARC) or the SOFIA Operations Center (AFRC). Dry-run tests will generally be performed until the instrument team and SOFIA Tier test support team are confident the instrument is ready to officially perform the Tier tests "for credit". SOFIA Software Systems will write the Tier 1-3 software test procedures; Mission Operations will write the Tier 4 test procedure. These procedures will be developed in close coordination with the instrument developer, and will contain content specific to the instrument software system, operation, and observing mode(s). Once the instrument has officially completed Tier testing the instrument, from a MCCS software perspective, is ready to integrate with the observatory. The goal is for instruments to complete all tier tests before shipment. All Tier tests must be completed before the instrument flight series. A MOPS representative will present their assessment of the readiness of the instrument to ship at the instrument Pre-Ship Review.

5.4.5.3.3.1 Tier 1: Basic Connectivity

The purpose of the Tier 1 tests is to verify TCP/IP connectivity between the instrument and MCCS—that the instrument can create a connection(s) to the MCCS session and issue a successful "login" and "logout" command (as defined in the MCCS_SI_04 ICD) under nominal conditions, and handle errors under off-nominal conditions. The Tier 1 test cases are listed in Table 5.4.5.3.3.1-1 below.

Table 5.4.5.3.3.1-1: Tier 1 test cases

Test Case	Objective
Establishing a Session	Test that the SI can connect to the MCCS via TCP/IP, login, start a session(s) and logout
Establishing a Session with Errors	Test that the SI handle various basic error cases when creating a session

5.4.5.3.3.2 Tier 2: Mission Data Handling

The purpose of the Tier 2 tests is to verify the ability of the instrument to access MCCS housekeeping (HK) data of various types as necessary, via the "get" and "subscribe" commands (as defined in the

MCCS_SI_04 ICD) and to verify the validity of the SI-provided data xml file. This Tier test also includes creation of a FITS data for inspection and ingestion into the DCS Archive. The Tier 2 test cases are listed in Table 5.4.5.3.3.2-1 below.

Table 5.4.5.3.3.2-1: Tier 2 test cases

Test Case	Objective
Establishing a Session SI Data Interface (XML Data Configuration File)	Verify that the SI-provided interface data is instantiated correctly in the MCCS
Accessing Housekeeping Data	Demonstrate that SI can access MCCS HK data in support of routine instrument use including: • display data to user via SI interface • create a data file correctly populated with the required FITS header keywords which can be ingested by the Data Cycle System (DCS)
Alerts/Alarms Handling	Demonstrate that SI can handle MCCS alert/alarm data in support of routine instrument use including: • display to user via SI interface • alarm confirmation

5.4.5.3.3.3 Tier 3: Command Handling

The purpose of the Tier 3 tests is to verify basic SOFIA Command Language (SCL) command handling and to demonstrate that the SI can successfully construct, send, and parse responses of SCL commands. Whenever possible, the SI will send all commands relevant to their observing mode. The Tier 3 test cases are listed in Table 5.4.5.3.3.3-1 below.

Table 5.4.5.3.3.3-1: Tier 3 test cases

Test Case	Objective
SCL Command Handling	Demonstrate the SI can: • format SCL commands correctly • send SCL commands to the MCCS • handle success response • change state or display information to user as appropriate.
SCL Error Handling	Demonstrate that SI can handle SCL error responses and provide useful feedback to the user. This includes: • S: Syntax check failure • E: Syntax check failure • W: intermediate warning response (as appropriate) • F: Final response for command failure

5.4.5.3.3.4 Tier 4: Observing Scenarios

The purpose of the Tier 4 tests is to demonstrate that the SI can execute observing scenarios relevant to routine science operations as documented in relevant documentation (e.g., scenarios, Line Operations test plan, Users Guides, etc.). MOPS and the SI team will agree on which Observing Examples are relevant to the SI and testing will be carried out only against those scenarios.

5.4.5.3.4 Instrument Data Product-DCS Testing

The instrument developer will perform data file tests with the DCS before instrument shipment, to verify the delivered instrument FITS data files contain the required keywords and proper values for ingestion of data files into the DCS Archive, verify the data files contain the keywords and values required to support the DCS Archive search functionality, and verify the data files contain the conditionally required keywords which will depend on the specific operating mode and configuration of the instrument

Before shipment, the instrument developer will also deliver an updated instrument-specific SI-to-DCS ICD to the DCS team for review, to ensure instrument astronomical observation templates (AOTs) are properly defined and that the SI FITS keyword list is complete and contains the required SOFIA DCS and DPS keywords/values as well definition of any instrument-unique FITS keywords. The SI-DCS ICD will be reviewed by the DCS team, and content agreed to, before any substantial data file testing with the DCS occurs.

The instrument data file ingestion tests consist of the DCS checking the FITS metadata header information to verify the required keywords for data file ingestion are present, as identified in DCS_SI_01 ICD, and that the keyword values are of the appropriate type. FITS header checks are also performed to verify the other keywords and values, identified in DCS_SI_01 and instrument SI-DCS ICD are present and appropriate. The DCS will generate a report identifying warnings for any missing keywords or values—the DCS team will work with the instrument team to fix issues with SI data files as well as identify which warnings may not require action at that time. Also, FITS keywords/values that are pipeline specific (i.e., are required by the pipeline to aid in data reduction) may be tested at this time.

The DCS team will write the test procedures and lead the SI-DCS test verification activities. A DCS representative will present their assessment of the readiness of the instrument to ship at the instrument Pre-Ship Review.

5.4.5.3.5 Instrument Data Reduction Pipeline-DPS Testing

Facility instrument developers will deliver a beta version of the instrument data reduction pipeline to the SOFIA DPS team before instrument shipment, for integration with the DPS and operation of the pipeline. The overall development process for instrument data reduction pipelines identification of associated deliverables, and delivery schedule of deliverables is described in the *SI Pipeline Acceptance Plan*, (SCI-US-PLA-SW09-2000). The schedule of pipeline development activities is primarily established by the instrument commissioning flight series date; because of this, the delivery schedule of pipeline versions and documentation in practice may not necessarily coincide with milestone reviews such as the Pre-Ship Review but may be instead driven by the dates of Line Operation and commissioning activities.

The DPS team will write the procedures and lead the instrument pipeline test verification activities. A DPS representative will present their assessment of the readiness of the instrument data reduction pipeline at the instrument Pre-Ship Review.

5.4.5.4 Post-Ship Verification Activities

Post-ship testing includes basic functional testing, at both room and operational temperatures, to verify that the baseline established at the Instrument Team’s site has not changed. Final ICD verification activities are performed, such as electrical cable safe-to-mate checks and power tests if these were not performed during an earlier NASA site visit. Tests with the Pre-Flight Integration Facility (PIF) (see Section 6.2.2) using the Telescope Assembly Alignment Simulator (TAAS) are performed to verify the physical interface and optical alignment, and testing of the instrument software in the SIL and HIL (see Section 6.2.3) will demonstrate command and control functions. For-credit SI software Tier Tests will be performed if they were not completed earlier.

5.4.5.5 EMI test

An electromagnetic interference and electromagnetic compatibility test (EMI/EMC) test will be performed with the instrument prior to flight. This test occurs on a taxiway or engine run-up area since it involves engine runs and radar use. This test ensures that the instrument systems do not cause adverse effects on the aircraft systems, characterizes any aircraft system impacts on the instrument performance (i.e. increased detector noise due to radio pick-up), and confirms the instrument grounding scheme is effective.

5.4.5.6 Line Operations

Observatory line operations may provide the first end-to-end functional tests and performance characterizations of the integrated Instrument/Observatory. Line operations are the first major validation activity, yielding the first evaluation of how well the integrated Observatory system meets the operational and system-level objectives.

The aircraft is rolled out of the hangar onto the "flight line", where the telescope cavity door is opened and the telescope is "on-sky". Typical tests during line operations may include instrument optical alignment with the telescope, focus, chopper interface and characterization, image quality and plate scale measurements, MCCS command and control, and science data transfer.

Prior to the commissioning flight series, mission simulations are performed on the flight line, in the full flight configuration, in order to verify operational procedures and minimize risk to success of the flight series.

5.4.5.7 Instrument Commissioning Flight Series

During the commissioning flight series, all modes and operational parameters of the instrument are fully characterized. The tests conducted are similar to those on line operations, but they are now in the flight environment. All instrument-specific science and technical performance requirements that have not yet passed verification will be verified during this flight series. All parameters necessary to provide the general scientific proposer with the quantitative information they need to propose to use the instrument aboard SOFIA will be characterized. A selection of science targets to provide a qualitative flavor for the capabilities of the instrument will be observed. Final verification of the instrument-specific science and technical performance requirements occurs during this flight series.

The instrument or acceptance review will include a report on instrument performance provided by the instrument team, including the verification results.

5.4.5.8 Instrument Modifications and Upgrades

Modifications and upgrades to instruments may be expected periodically, following initial installation and use on the aircraft. Depending on the nature of the upgrade, some or all of the verification process is repeated to address verification of the upgraded configuration. Upgrades that impact compliance with airworthiness or SE&I requirements will require delta verification—prior to any changes being made to the instrument, the appropriate NASA compliance authority should be informed (see Section 9.1). Upgrades that impact interfaces between the instrument and the aircraft will require regression testing or analysis for ICD requirements.

5.4.5.9 Functional & Physical Configuration Audit

This section only applies to facility science instruments.

In addition to instrument requirements compliance verification, another type of verification must also be completed before an instrument can be considered ready to be accepted as a Facility Science Instrument (FSI). The entrance criteria for an instrument Acceptance Review is summarized in section 7.7.4.1 of this handbook. FSI must complete both a Functional Configuration Audit (FCA) and Physical Configuration Audit (PCA) to confirm the configuration of the as-built instrument is accurate and complete. The outcome of the PCA also establishes a baseline configuration of the instrument before instrument acceptance.

The FCA examines the functional characteristics of the configured product and verifies that the product has met, via test results, the requirements specified in its functional baseline documentation approved at the PDR and CDR. FCAs will be conducted on both hardware or software configured products and will precede the PCA of the configured product.

The PCA examines the physical configuration of the configured product and verifies that the product corresponds to the build-to (or code-to) product baseline documentation previously approved at the CDR. PCAs will be conducted on both hardware and software configured products. Critical Safety Items (described in Section 11.1) are high priority articles inspected in a PCA. Other additional articles often inspected are Certified Material Test Reports (CMTRs), Certificates of Conformance (CoCs), equipment part and serial numbers, configuration/layout of PI Rack and Counterweight Rack equipment, power and ground cables, installation and lab carts or stands, and availability of released SI documents.

Although the PCA must be completed before the an instrument's Acceptance Review, the majority of the configuration inspection audit of the as-built instrument will be performed earlier before first shipment of the instrument to Armstrong Building 703, or shortly after arrival. The PCA is conducted by the SOFIA Program, whom will develop the audit inspection procedure. The PCA will be conducted at certain intervals during the instrument assembly process, depending on accessibility of the part or subassembly that needs to be inspected. For example, measurement and inspection of the dimensions of an instrument liquid helium reservoir may be performed early in the PCA process as the instrument is being built to confirm the as-built dimensions of the reservoir conform with its drawing, before the reservoir is integrated with the instrument with other structures being built around it. The timing of inspection of other parts may be more flexible, such as inspection of a cryostat vent pressure relief device on the outside of the instrument. Development and scope of the PCA will be pre-coordinated with SIAT, as many of these inspections will satisfy both SIAT and PCA inspections, to form a minimum essential set of inspections to be performed.

A prerequisite to the PCA is certain SI documentation for the as-built instrument must approved, released, and made available to the SOFIA Program. This documentation typically includes: specifications, drawing trees, drawing lists, drawings, engineering change orders (ECOs), manufacturing and inspection "build" records, as-built discrepancy reports, approved deviation/waiver approval requests, as-run test procedures.

6 Instrument Operations

The SOFIA operates out of the Armstrong Flight Research Center Building 703, located in Palmdale, CA, where the Science Instruments are integrated with the Telescope Assembly. Building 703 includes laboratory space for the storage, preparation, and maintenance of the science instruments. The observatory will fly several nights per week to achieve an average of 3.0 successful science flights per week during a flight campaign, returning to Palmdale each morning except in the case of a deployment.

SOFIA will occasionally be deployed to the southern hemisphere or other locations to accommodate the scientific objectives of the proposed science. All Facility Science Instruments should be capable of being deployed to remote sites. Technology Demonstration Science Instruments should be capable of being deployed if the proposed investigation includes observations requiring a deployment.

Facility Science Instruments are prepared for the commissioning flights and operated during the commissioning flights by the instrument team. Facility Science Instruments are owned and operated by the SOFIA Program following the successful completion of the instrument acceptance review. The documentation required for the SOFIA Program to maintain and operate the FSI will be delivered prior to the instrument acceptance review.

Technology Demonstration Science Instruments are prepared and operated by the instrument team for all flights, commissioning and science.

The instrument commissioning period will be scheduled by the SOFIA Program based on the instrument availability and Observatory availability. SOFIA science instrument observing time is allotted via the time allocation committee or SMO Director's discretionary time.

While the nominal configuration is for a single instrument to be mounted to the telescope, it is possible to support a dual-instrument configuration such as the simultaneous operation of HIPO and FLITECAM.

Further information on instrument operations can be obtained in the Excerpts from the SOFIA Operation Concept located in the document library.

6.1 Telescope performance

The performance requirements of the SOFIA Telescope Assembly are described in *SOFIA Telescope Assembly (TA) Requirements* (SOF-1011). This section will reference reports on measured telescope assembly performance when they become available.

6.2 Observatory facilities

6.2.1 Science Instrument Labs at AFRC Building 703

Instrument laboratories (a.k.a. instrument readiness rooms) are available at Building 703 for use by the Instrument Teams. Lab access will be limited to Instrument Teams, SMO support staff, and other key individuals authorized by the Lab Supervisor. General lab support times will be “day shift,” 0700-1630. Additional support can be arranged upon request.

Electronics: The labs will provide each SI team 1 ESD workbench, equipped with continuous resistance monitors and ionizing fans. The ESD bench will also be equipped with a multimeter, soldering station, and filtered power strip. In addition, a shared stock of power supplies, signal generators, and oscilloscopes can be drawn upon as needed.

Vacuum: Vacuum pumping systems are available for SI use. “Rough” pumps are available to reach ~10^{-3} Torr and turbo systems are available, capable of reaching 10^{-8} Torr. Furthermore, a He vacuum leak check system is available and is capable of diagnosing leaks from 10^{-2} Torr-Liter/sec down to 10^{-10} Torr-Liter/sec.

Cryocooler Compressor: A Sumitomo/SHI Cryogenics model CSA-71A cryocooler compressor is available for use in the lab to support one pulse-tube cold head and cryostat.

Storage: SI teams will be provided storage space equivalent to 1 4’x8’x2’ shelving unit and 1 6’x3’x2’ locking cabinet.

Cryogens: LN_2 and LHe will be available for SI use upon request. All capacity needs will be met with appropriate notification from the SI team as to instrument fill schedule and consumption. Personal protective equipment as required by NASA will be available in the labs. SI team members participating in instrument cryogen fills are first required to complete a short AFRC cryogen safety training course.

Other material including gases, solvents, and cleaners: Compressed He and N_2 will be available for SIs. Acetone and Isopropyl Alcohol will be available through the Building 703 tool crib. Other gases and solvents must be requested through the SMO contact for the SI team or directly through the Lab Supervisor.

Advanced Electronics diagnostic and fabrication: An electronics lab with an engineer qualified to make cables for the SIs is available. Cable fabrication requests should be pre-coordinated with the engineer and Lab Supervisor to ensure any long lead-time items such as connectors, wiring, or tools needed can be procured to support cable fabrication in the time frame needed by the SI. Cable assembly drawings from the SI team should include the necessary information and detail for the engineer to fabricate the cable. Also in the electronics lab a GHz oscilloscope and an advanced spectrum analyzer will be available.

Power: The lab wall power is sufficient for robust COTS systems to be plugged into. Both standard US 115V-60Hz and 3-phase are available on the wall. For any sensitive equipment, UPS power isolating systems are available both for standard US 115V-60Hz and for European connections at 50 Hz.

Network Access: NASA network ports are available in each lab as well as USRA-maintained Experiment network ports. NASA Guest network on WiFi is available throughout the labs. Connections for instruments are available from the SIL, HIL, and Aircraft to the lab. A connection from the SI team's home institution to their lab can be authorized with at least a 14 day notice prior to the first date of usage.

Tools: A full tool set will be available to SI teams for general purposes. These tools will be inventoried and maintained per NASA AFRC tool control policy, to which SI teams must adhere. Specialty tools can be made available with prior notification. Calibrated wrenches, inclinometers, and other tools are available for check-out through the Building 703 Tool Crib and AFRC Calibration Lab.

Office Space and Break Areas: SI teams have access to a break room, with a coffee machine and microwave located near Lab 5. Unless your lab has an area specifically marked for food consumption no food or drink is allowed in the labs. Such areas will not be in every lab and cannot be negotiated. The break room may be used as an office space and desks will also be provided in the labs for such use. A public break room with refrigerator, microwave, tables, and seating is available on the first floor.

6.2.2 Pre-Flight Integration Facility

The Pre-Flight Integration Facility (PIF) is a laboratory located at Armstrong Building 703 containing simulations of certain Telescope Assembly (TA) interfaces (i.e. Telescope Assembly Alignment Simulator, or TAAS) with the science instrument (SI) and its related equipment. Its purpose is to facilitate the installation and integration process of an instrument onto the Airborne Observatory by testing interfaces between the instrument and Observatory.

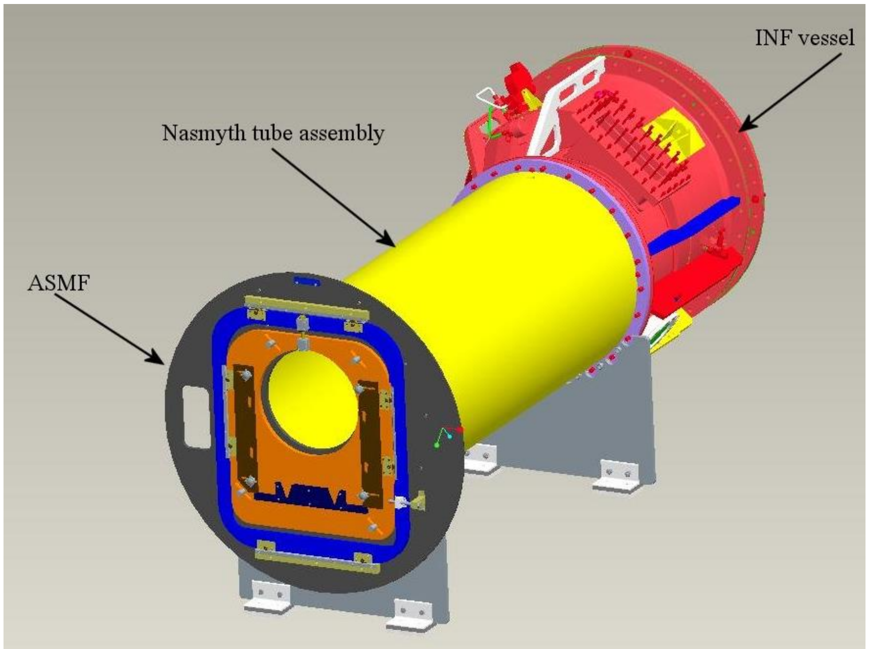


Figure 6.2.2-1: The basic structure of the telescope assembly alignment simulator

The Telescope Assembly Alignment Simulator (TAAS) consists of the following major components and associated software:

1) Telescope Assembly Alignment Unit (TAAU)
2) Large Chopped Hot Plate (LCHP)
3) Small Chopped Hot Plate (SCHP)
4) Focused Chopped Light Source (FCLS)

5) Alignment Camera (AC)

The TAAS is used to perform fit checks of SOFIA Science Instruments with the Telescope Assembly (TA) Flange Assembly and permits adjustment, checkout, test, and characterization of Science Instruments (SIs) prior to installation and use aboard the Observatory. The TAAU is the main physical structure of the TAAS, which allows the SI to be mounted at one end and the infrared sources at the other. The TAAU consists of the Instrument Flange (INF) vessel, Nasmyth tube, and Adjustable Source Mounting Flange (ASMF). The scale of the TAAU is designed so that the optical path length is 43% of the SOFIA Telescope Assembly's (TA) optical path length from the nominal focus to the TA secondary mirror.

The TAAS has three different infrared sources: the LCHP to simulate a "hot" secondary mirror for pupil imagers, a SCHP used mainly to map an SI's beam profile, and a FCLS which acts as a "point-like" source for focusing and alignment to the SI detector chip.

The TAAS also includes an Alignment Camera for purposes of maintaining the actual TA boresight transfer to the TAAS. This is accomplished by a first aligning an SI to the SOFIA TA boresight, the SI is then removed from the TA and installed onto the TAAS, and then the FCLS is then aligned to the SI-registered boresight pixel location. Herein, the TA boresight is transferred to the TAAS. The AC is installed and pixel registration of the FCLS beam on the AC is noted. In the event that the FCLS loses the boresight, the AC is reinstalled and the FCLS position is aligned to the AC boresight pixel registration.

The Alignment Camera is not used during normal operation of the TAAS and is only used to align the FCLS to the boresight.

Once an SI is mounted to the INF vessel, the INF vessel may be evacuated to check for leaks and proper mounting. The full optical path (SI to IR source) cannot be evacuated. However, the entire optical path may be purged with a dry air system in order to displace any water vapor inside the TAAS.

The TAAS is further described in the *Telescope Assembly Alignment Simulator Specification* (SCI-AR-SPE-SE01-040). Details of operation are provided in the *User's Manual for the Telescope Assembly Alignment Simulator* (SCI-AR-MAN-OP02-2068).

6.2.3 Systems Integration Laboratory

The SMO maintains multiple Systems Integration Laboratory (SIL) systems at NASA ARC and NASA AFRC for development and testing of observatory and science instrument software. The Observatory also maintains Hardware-in-the-Loop Simulators (HIL), which is similar in function to the SIL but contains more flight-like hardware. Instrument software tier tests are typically performed in the SIL.

A SIL is a self-contained simulation environment of the onboard SOFIA MCCS (Mission Controls and Communications System) computer systems. A SIL consists of several major components, some of which are identical to their flight-worthy counterparts and some of which are software simulations of other systems (the Telescope Assembly, for example). Configuration of the SIL is generally very detailed/granular, and generally strict Configuration Management procedures are followed (formal Change Control Requests must be approved by a Change Control Board).

The following is a general description of each of the components:

The Platform Interface Subsystem (PIS) consists of 4 VxWorks-based VME64x single-board computers (Motorola VG5), each running a different software binary/proxy: Session, Mission, Telescope Assembly, and Cavity Door Drive System. With the exception of the VME64x chassis (containing the 4 computers), these are identical in hardware configuration to their flight-rated counterparts onboard the aircraft. Software configuration is set by a Change Control Board based on the needs of the users.

The Telescope Assembly Image Processing Subsystem (TAIPS) consists of 3 VxWorks-based VME64x single-board computers (Motorola VG5), each running a different software binary/proxy, each connecting to an imager on the Telescope Assembly Simulator: Wide Field Imager (WFI), Fine Field Imager (FFI), and Focal Plane Imager (FPI). With the exception of the VME64x chassis (containing the 3 computers), these are identical in hardware configuration to their flight-rated counterparts onboard the aircraft. Software configuration is set by a Change Control Board based on the needs of the users.

The Workstation Subsystem consists of the Telescope Operator Workstation and In-flight Director Workstation. They are both semi-ruggedized x86-based computers with twin 1600x1200 pixel displays. The systems use the Solaris 10 operating system and make heavy use of Java to run the MCCS GUI displays. With the exception of custom airflow modifications to their chassis, these Workstations are identical in hardware configuration to their flight-rated counterparts onboard the aircraft. Software configuration is set by a Change Control Board based on the needs of the users.

The MCCS Network Subsystem consists of three Brocade MLX-4 Network switches configured to manage three distinct subnets: PIS, TAIPS, and the Experimenter’s Network. It is to this network that your Science Instrument software connects (physically). Onboard the aircraft the connection is made via Fiber Channel to the PI Patch Panel; however, in the SIL, the connection may be remote (from your institutions internet connection) or local (directly to the Experimenter’s Network Switch in the lab) via copper or Fiber Channel.

The Simulators consist of several x86 and SPARC-based computers which run a battery of software simulators, most notably including the aircraft (747) simulator and Telescope Assembly simulator.

6.2.4 Secondary Mirror Buttons

The secondary mirror can be outfitted with a selection of mirror “buttons” to either attenuate or redirect the optical path of the primary mirror central obscuration in the telescope exit pupil. The secondary-mirror button defines the central aperture stop for the telescope and prevents science instruments from imaging themselves. Specifically, the button ensures that the primary mirror hole and the edges of the tertiary mirror are not visible in the science instrument focal plane. The details of the button design depend on wavelength and other science-instrument specific considerations. For example, some buttons are reflectors (“scatter-cones”), deflecting cold sky emission into the focal plane, while others are flat, high-emissivity (black) absorbers.

Science instrument teams can select a suitable secondary mirror button from several provided by NASA or they can design and build their own.

6.2.5 Telescope Tertiary Mirror

At present only one tertiary mirror, a dichroic using a thin gold layer, exists. Various SOFIA documents refer to a “full reflective” or “aluminum” tertiary that reflects all of the light from the primary-secondary into the Nasmyth tube. The requirements for this tertiary have not been defined and this mirror has not been procured.

6.2.6 Solar filter

Various older SOFIA documents refer to a solar filter for the SOFIA primary mirror. The attachment points for such a filter exist on the primary mirror support structure and are used for attaching the airworthy primary cover used in open-door flight tests. The requirements for a solar filter have not been defined and no filter has been procured.

6.2.7 Vacuum

A vacuum pump system is available for use by the mission operations or instrument teams during flight. This vacuum system serves two purposes: to pump out the Nasmyth tub (volume between the science instrument flange and the gate valve) when needed and to support in-flight vacuum requirements of the Science Instruments. Pumping on the Nasmyth tub may after the gate valve is closed may be part of normal or off-nominal operations to reduce the pressure in the tub to protect an instrument window or instrument from condensation during descent. Some instruments may use the vacuum system to pump on liquid cryogen baths to reduce their temperature for normal operation. The observatory vacuum pump system is described in the *Vacuum Pump System Concept of Operations* (APP-DA-PLA-PM17-2074), *Vacuum Pump System (VPS) Specification* (APP-DA-SPE-SE01-2049) and *Vacuum Pump System to Science Instrument ICD VPS_SI_01* (SOF-DA-ICD-SE03-2022).

6.2.8 Blower

Older SOFIA documents refer to a “blower” in the Nasmyth tube to eliminate temperature stratification of the air in the Nasmyth tube. The as-built TA design includes fans that may already serve this purpose. At present implementation of a blower system is not planned until telescope image quality analysis indicates it is required.

6.2.9 Cryocooler

Observatory infrastructure hardware was recently installed to support operation of closed-cycle cryocooler (CCC) systems. An advantage of using a closed-cycle cryocooler system is it eliminates the need to use expendable liquid cryogens. The current implementation of the cryocooler system includes a gimbal-mounted cryocooler compressor on vibration isolators, an accessible control system with GUI display, and a pair of flexible helium supply/return lines that terminate at a disconnect panel on the TA, to which an instrument may connect its own helium lines. The present Phase 1 SOFIA Cryocooler System includes a single He compressor and associated infrastructure needed to service a single pulse-tube cold head and cryostat.

6.2.10 Workspace on aircraft

The *Layout of Personnel Accommodations (LOPA)* (APP-DF-DWG-SE02-2924) provides a graphical layout of the location of various SOFIA mission systems on the main deck of the aircraft, including the PI racks, conference tables, and seats, as well as the PI Patch Panel. A mission operations rack referred to as the Auxiliary or AUX rack, containing mission systems equipment in a rack frame structure identical to a PI rack, is typically installed in one of the PI rack locations available for use by the SI team.

The AUX rack contains the Mission Audio Distribution System (MADS) unit, a telescope status display, a slide-out workspace tray, and power strips available for use by the SI teams. The MADS unit enables SI team members to easily communicate with other SI team members, the Mission Director, Telescope Operators, Science Flight Planner, and other observatory personnel during flight, which is useful as personnel will oftentimes be seated in different areas on the aircraft and aircraft engine noise makes it especially difficult to directly communicate without the use of MADS. Installation of the AUX rack is optional; however, if the SI team elects not to have the AUX rack installed the SI team must reserve space in one of their PI racks for the MADS unit to be installed—the required space is defined in the *Principal Investigator Equipment to PI Rack to Aircraft System ICD,* SI_AS_01 (SOF-AR-ICD-SE03-2015). The SI Developer is responsible for providing any needed surface trays in their PI Racks for writing or using laptops. The SOFIA Program can provide recommendations for flight-qualified tray designs, as the AUX rack already takes advantage of two different flight-certified tray designs.

Two conference tables available for use by the SI team are located farther forward in the aircraft and are also equipped with power, MADS, and access to the experimenter's network. Each of these tables has four seats.

6.3 Instrument access during flight

SI equipment mounted in the PI rack(s) is readily accessible during flight, particularly equipment in the PI Rack bays facing the instrument team members seated at the PI rack(s) while wearing seat belts (i.e., during the take-off, ascent, descent and landing phases). Limited access to other portions of the science instrument (i.e., the SI assembly and items mounted in the CWR) is possible during flight.

The instrument counterweight rack (CWR) is especially difficult to access during flight. Only portions of the rack are within reach, and only when the telescope is caged at low elevation angles. It should be assumed in the instrument design and operations concept that the counterweight rack cannot be routinely accessed during flights.

To prevent personnel from falling into the Telescope Assembly "pit" as a result of unexpected turbulence, a TA barrier is installed forward of the science instrument across the width of the aircraft cabin. This TA barrier is a 4-foot tall net consisting of ~12"x12" square openings that extends the width of the aircraft cabin and is secured to hardpoints on the cabin floor. As an operational safety precaution, personnel must first receive permission from the Mission Director before approaching any area aft of the PI racks during flight.

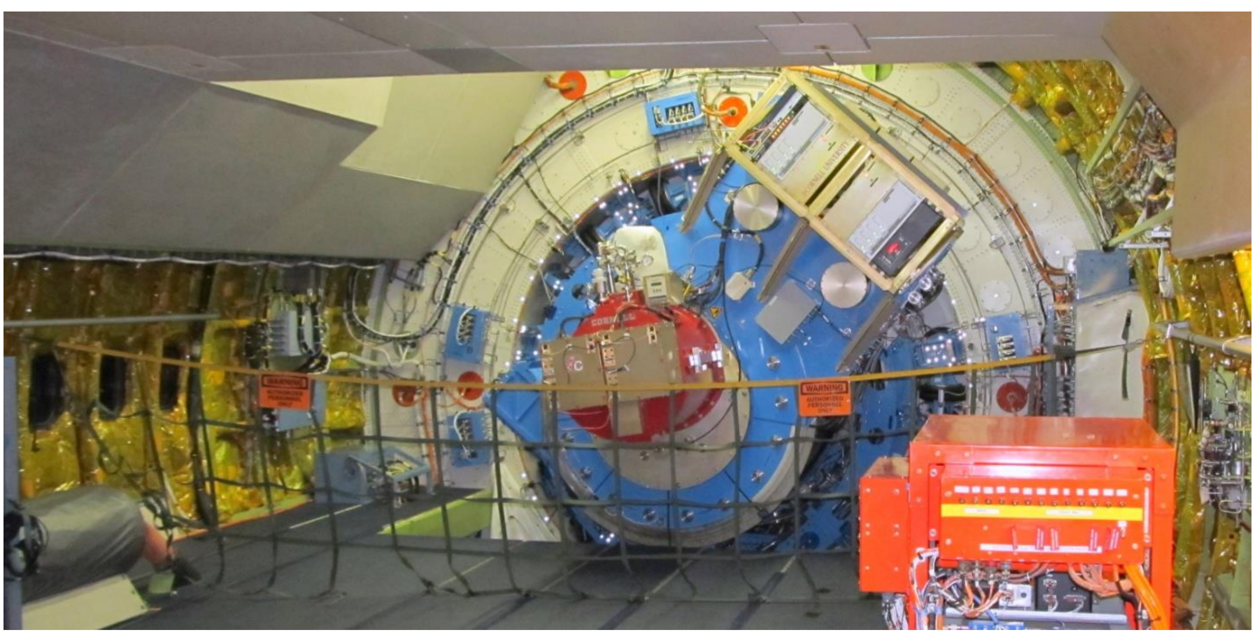


Figure 6.3-1: The telescope assembly barrier installed forward of the FORCAST instrument

The TA barrier will be installed during all flights and may also be installed during ground activities such as line operations to restrict access to the TA and instrument field of motion and to aid in simulating actual flight conditions.

Figure 6.3-2: Telescope assembly barrier floor rail mounting points

The TA barrier can be installed in a straight line across the aircraft cabin, or it can be routed around the instrument using the rail mounting system depending on the instrument design and needs for access during flight.

In-flight safety dictates that access to the Science Instrument behind the Telescope Assembly (TA) safety barrier be strictly controlled. Procedural details are specified in the *Procedure for Crossing the TA Barrier during Flight* (APP-DF-PRO-OP02-2043).

6.4 Instrument status between flights

It is the intent of the SOFIA Project to provide instruments with power and internet connectivity while the aircraft is in the hangar. This is to support instrument designs using cryocoolers, detector thermo-control systems, and maintenance of local oscillator stability, as well as provide the ability to remotely monitor the instrument's health and status. The operational details of providing this support have yet to be agreed to with aircraft operations. This section will be added to this document when an agreement is reached. This section will be updated in a future revision of this handbook.

6.5 Data Rights and Archiving

All raw science data taken in-flight from telescope-mounted science instruments on SOFIA, regardless of the instrument classification (facility science instrument, technology demonstration science instrument, etc.), observing mode, or type of observing program (including science data taken during instrument commissioning flights), are archived at the SMO. Observers acquire their restricted access data (often informally referred to as proprietary data) as well as publically available datasets through this data archive system. Pipeline-processed data from supported modes of facility instruments are also archived. The pipeline products involve standard data reductions including wavelength and flux calibrations. All archived data associated with investigations selected through the US peer review process, as well as through Guaranteed Time granted to science instrument teams, will have a one year restricted access period, during which time only the proposal Principal Investigator and his/her authorized collaborators may access the data.

6.6 Commissioning and Guaranteed Observing Times

The Instrument teams should develop a commissioning plan that minimizes the time required for testing on the aircraft and in flight, while fully characterizing instrument performance and testing all user-supported instrument modes. The number of commissioning hours is nominally assumed to be 30 research hours. The commissioning plan should justify the number of commissioning hours requested and interval between flights.

Guaranteed observing hours granted the instrument teams are described in *the Science Utilization Policies of SOFIA*, (SOF-1087). Guaranteed observing for Facility Science Instruments will be scheduled by the SMO Director within two years following the formal acceptance of the instrument. Instrument proposers should include the cost budget for guaranteed time observations (GTO) in their instrument proposal.

In addition to guaranteed time observations, the Principal Investigator of a Technology Demonstration Science Instrument may compete through the SOFIA General Investigator program for additional observing time in the period after the last GTO flight and before the instrument is retired.

6.7 Data Archiving

The SOFIA Data Cycle System (DCS) provides off-aircraft data archiving and retrieval systems for raw and reduced instrument data. *Data Cycle System to Science Instrument ICD* (SCI-US-ICD-SE03-2023) describes system and interface for the science instruments.

The SOFIA Data Archive can be accessed online on the SOFIA Data Cycle System website at https://dcs.sofia.usra.edu/. In addition to providing access to the data archive and retrieval of science data, the website offers a number of other features and services pertaining to proposal development, observation planning, and user support. Access to data and services on the website is controlled, and individual user privileges and permissions are established by the SOFIA Program.

The MCCS provides on-aircraft data archiving during a flight, before the data is transferred to the SOFIA Ground Systems data facilities. *Details of the on-aircraft archiving system will be included in a future revision of this handbook.*

6.8 Data Processing

Information on the data processing system for science instruments is in *Data Processing Plan for SOFIA Science Instruments* (SCI-US-PLA-PM17-2010). The *Software Architectural Design Document for the Data Processing System (DPS) of the SOFIA Project* (SCI-US-SPE-SW02-2019) provides the high level architecture regarding pipeline data reduction with the Data Processing System.

7 Instrument lifecycle

7.1 Proposal Preparation and Selection

7.1.1 US Provided Science Instruments

This section is out-of-date and will be updated in a future revision of this handbook.

Future US Science Instruments for SOFIA will be solicited as an appendix to the NASA Stand Alone Mission of Opportunity Notice (SALMON) Announcement of Opportunity (AO). The SALMON AO provides the overall structure and guidelines for several types of mission of opportunity solicitations. Each new opportunity is announced with a program element appendix (PEA). Future instruments will be solicited as a PEA for a Focused Mission of Opportunity (FMO) solicitation. The SALMON AO (NNH08ZDA009O) can be found in the NASA Solicitation and Proposal Integrated Review and Evaluation System (NSPIRES) at http://nspires.nasaprs.com/.

SOFIA instruments will be selected using either a single-step or two-step selection process. In the single-step selection process, there is no Phase A (Step 2) concept study report or down-selection planned. Each AO will specify whether the instrument proposal selection process will be single-step or two-step.

NASA intends to select several instruments with each call and issue new calls every 3-years with the objective of having a new instrument or upgraded instrument commissioned and ready for operation every 18-months.

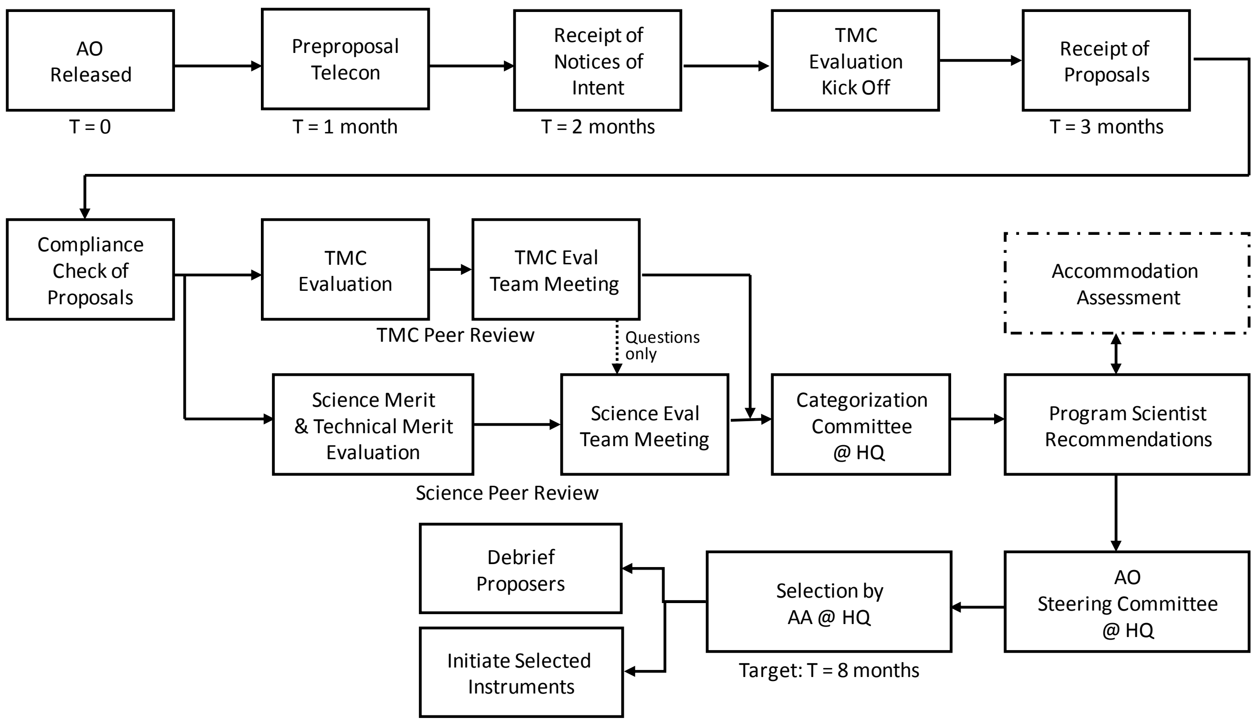


Figure 7.1.1-1: Instrument selection process flow diagram (single step selection process shown)

7.1.2 German Provided Science Instruments

DLR and DSI will establish their own processes for selecting instruments.

7.2 Science Instrument Development Advisory Group

To address changes in science instrument development plans following the selection of the science instrument for development, a Science Instrument Development Advisory Group (SIDAG) was established to advise the SI Manager and provide a transparent process. The *Instrument Rescoping Process* (SCI-AR-MEM-PM12-2019) describes the process for changing the instrument performance requirements or requesting a significant reallocation of funding following the selection of the instrument for development.

7.3 Instrument Development Reviews

The reviews discussed below in the instrument development lifecycle: Systems Requirements Review (SRR), Preliminary Design Review (PDR), Critical Design Review (CDR), Pre-Ship Review (PSR), Pre-Install Review, Test Readiness Review (TRR), Pre-flight Review, and Acceptance or Commissioning Review, will be conducted by the instrument team. The instrument team will coordinate the scheduling and agenda of these reviews with the SI Development Manager. The SI Development Manager will chair (or delegate the chair) and empanel a review team with experts within the SOFIA Program as well as experts external to the Program when needed.

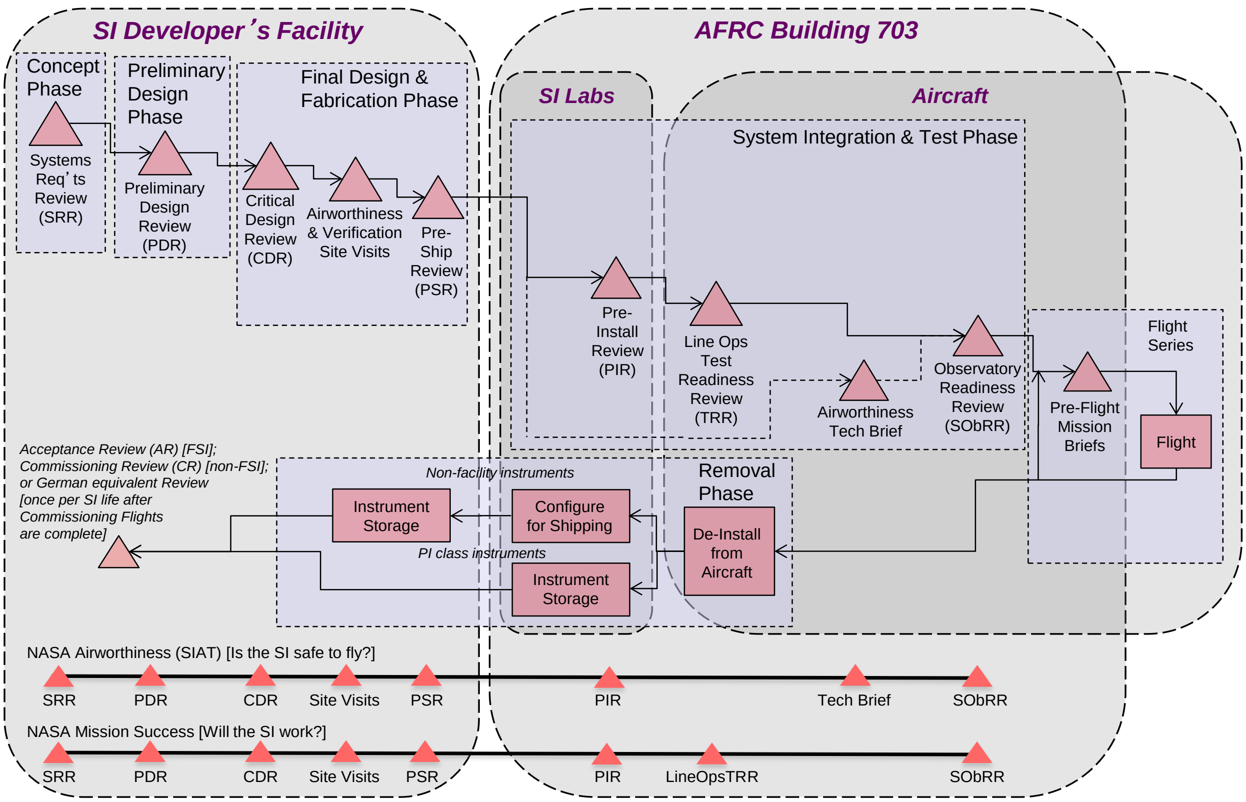


Figure 7.3-1: Instrument Development Reviews

Following instrument commissioning (PI and technology demonstration instruments) or instrument acceptance (facility instruments), pre-installation reviews and pre-flight reviews may be held at the discretion of the mission operations plan and chaired by a mission operations representative.

The proceeding sections describe the instrument development technical reviews (e.g., System Requirements Review, Preliminary Design Review), presented in the order which they occur according to the NASA project life-cycle phases (i.e., Phase A: Concept & Technology Development, Phase B:

Preliminary Design & Technology Completion; Phase C: Final Design & Fabrication; Phase D: System Assembly, Integration & Test, Launch; Phase E: Operations & Sustainment, and Phase F: Closeout).

7.4 Phase A – Concept and Technology Development

During Phase A, the instrument team is established and develops a baseline instrument concept, develops the instrument performance requirements and goals, conducts design trade studies, and prepares a development schedule. The instrument team will also develop a list of long-lead procurements (items that need to be procured prior to CDR) and a plan for defining the requirements for those components and completing the needed trade studies.

7.4.1 Systems Requirements Review

The purpose of the SRR is for the Science Instrument development team to demonstrate understanding of all system, interface and instrument performance requirements. The instrument team does this by submitting a Science Instrument *Science and Technical Performance Requirements* document stating the performance requirements the instrument needs to achieve to perform the selected science investigation, and demonstrating at the SRR that these requirements have been flowed to the appropriate instrument subsystems. Additionally, knowledge of all applicable system and interface requirements and appropriate allocations to subsystems will be demonstrated. At this review, the instrument team conveys to the SOFIA Program that for the current instrument design, requirements have been derived and flowed to subsystems where necessary and that all instrument functional, performance and interface requirements will be satisfied. The instrument team should also sufficiently articulate its planning for remaining project activities in order to justify that there are reasonable expectations that the instrument team will meet its success criteria within the allocated resources. The successful completion of the SRR will result in the freezing of design requirements and signify readiness to begin preliminary design.

7.4.1.1 Purpose

The objectives of the SRR are to confirm that: (a) definition of a producible system is complete and fully satisfies all the science investigation objectives, (b) system requirements have been logically and fully allocated to each independent system element and in turn to their respective subsystem level or below, (c) all allocated requirements are verifiable and traceable to their corresponding system level requirement, (d) preliminary verification approaches and acceptance criteria are defined, and (e) the requisite level of detail and resources are available to support the acquisition and development plan within existing constraints.

The SRR should contain a complete and comprehensive description of the system design in order to establish the baseline for which the requirements are defined. It should present the design by means of block diagrams, depicting system interfaces with external supporting systems, internal interfaces between independent system elements, and interfaces within each independent system element to the subsystem level and below. Completed modeling and analysis results that demonstrate the ability of the design to fulfill system requirements should be presented.

The requirements allocation and control process should be presented, followed by a formal delineation of all allocated requirements in a way that illustrates their completeness, traceability, and verifiability. An understanding of risk, safety, and assurance considerations should accompany a discussion of implementation. Programmatic (cost and schedule) considerations should be discussed in sufficient detail to permit assessment of relevant review objectives. A verification matrix should also be presented (see Section 5.4.3).

7.4.1.2 SRR Entrance Criteria

A number of specific activities and items are expected to be completed before an instrument is ready to enter its System Requirements Review. The activities and items listed below constitute the SRR entrance criteria for science instruments and pertain specifically to the technical review of SOFIA science instruments at the system/project level. (The criteria for technical reviews at the general subsystem level are available to the instrument developer if needed, however the criteria and guidance presented within this handbook contains specific tailoring which is intended to be more relevant and useful to an instrument developer preparing for a technical review of the instrument system/project.)

1. A preliminary SRR agenda and success criteria for the technical review have been agreed to by the instrument developer and NASA SI Development Manager.
2. The SRR technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review.

7.4.1.3 SRR Success Criteria

The following subsections contain guidelines for the content and subject areas that should be addressed in the SRR by the instrument team.

7.4.1.3.1 Design Description:

a) Results of design trades are documented and include rationale for selected alternatives. On-going or future trade studies are identified and potential impact of results on design is understood.
b) Block diagrams illustrate functional flow and clearly define interfaces with external systems.
c) Results of appropriate system analyses (e.g., performance, error budgets, reliability) illustrate adequacy of system design to accomplish mission objectives within constraints and with acceptable risk.
d) Mission critical failures have been identified. Redundancies and/or workarounds have been defined or a single-string design approach has been approved.
e) Technology development related items continue on track and mitigation plans remain viable.
f) Utilization of heritage elements has been determined. Preliminary assessment of activity needed to verify usage on the current instrument has been completed.
g) Margins for all critical resources (mass, power, data rate, etc.) meet applicable criteria.
h) Approach to verification of compatibility across all interfaces is defined.

7.4.1.3.2 Long-lead Procurements:

a) A list of long-lead procurements (items that need to be procured prior to CDR) is provided along with a rationale for why the item needs to be procured prior to CDR.
b) Results of design trades and peer reviews are documented.
c) Plans for continued requirements definition and completing any needed trade studies

7.4.1.3.3 Requirements Related Processes:

a) Instrument requirements are defined in the *Science and Technical Performance Requirements document* and are necessary and sufficient to meet the goals of the science investigation.
b) Processes for the allocation and control of requirements are documented and approved.
c) The approach for tracking and controlling allocation and reserves of key resources (such as mass, power, etc.) is documented and approved.
d) The approach to controlling and integrating all technical activities is defined and documented.

e) Plans for design, production, and verification activities are defined and documented.

7.4.1.3.4 Requirements Definition:

a) Interface requirements with external systems are defined.
b) Interface requirements between independent system elements are defined.
c) Interface requirements between subsystems and components of each independent system element are defined.
d) Functional requirements for subsystems and components of each independent system element are defined so as to fully achieve system requirements. Such requirements are verifiable and are traceable to their respective system and mission requirements.
e) Allocation of key resources (e.g., mass and power) to elements of the instrument subsystems is reasonable.
f) Mission operations, data acquisition, data processing, and data analysis requirements are fully defined.

7.4.1.3.5 Requirements Verification:

a) Preliminary approaches for the verification of all requirements have been defined.
b) Preliminary acceptance criteria have been defined at the deliverable end-item level.

7.4.1.3.6 Risk Management:

a) A risk management process is defined and utilized.
b) All significant risks, problems, and open items are identified and tracked (including programmatic, development and flight performance related items). Risk mitigation plans are appropriate. Credible triggers for exercising alternatives are defined.
c) Reliability considerations have been factored into design decisions.
d) Single point failures are compatible with approved project philosophy.
e) Lessons learned have been appropriately researched and adapted.

7.4.1.3.7 Safety and Airworthiness:

a) A preliminary system safety assessment identifies all requirements as well as any planned tailoring approaches or planned deviation requests.
b) Preliminary hazards, controls, and verification methods are identified and documented.
c) Any open safety issues are identified with plans for resolution.
d) Preliminary plans and schedules for all required safety submittals are defined.

7.4.1.3.8 Assurance Activities:

a) Mission Assurance requirements have been defined (materials usage, quality control, problem reporting etc.) and preliminary plans are completed.

7.4.1.3.9 Implementation Planning:

a) Program flow has been defined and required quantities of hardware and software items are defined.
b) A preliminary system level verification plan has been defined.
c) Plans for controlling technical activities (systems engineering, software development, verification, configuration control, etc.) are completed.

7.4.1.3.10 Programmatics:

a) Roles, responsibilities, and interfaces between all participating institutions are clearly defined.
b) Project organization chart clearly delineates functional responsibilities and relationships.
c) Organization and staffing plans delineate clear responsibilities and adequate assignment of current and future staff.
d) Appropriate processes and metrics are in place to track and control cost, schedule, and technical activities throughout the remaining life-cycle.
e) Appropriately detailed schedules show realistic event times as well as appropriate funded slack and are compatible with approved commissioning dates.
f) Cost to complete shows adequate spending profiles and financial reserves, and is compatible with allocations.

7.4.1.3.11 Project and Independent Review Activity:

a) An appropriate set of engineering peer reviews has been conducted and documented as needed. Resultant actions have been effectively dispositioned and executed. Appropriate additional reviews are planned.
b) Recommendations from other project or external review activity (such as an instrument development lessons learned database) that are applicable to the subject matter of the SRR have been adequately implemented.

7.4.2 Results of the Review

Action items and liens will be collected during the review. Reviewers may submit requests for action or information, referred to as RFAs and RFIs. At the end of the review the action items will be assigned with a response due date. Any action items that must be closed prior to proceeding with the preliminary design will be assigned as liens.

Actions and liens are closed by the submission to the SI Development Manager of an action closure statement including the signature of the originator of action and the review chair indicating concurrence of the successful closure of that action or lien.

Successful completion of the SRR with closure of all liens constitutes readiness to proceed with the preliminary design of the instrument and with the plans for the long-lead procurements.

7.5 Phase B – Preliminary Design and Technology Completion

7.5.1 Preliminary Design Review

At the PDR, the instrument describes the complete system design and justifies that it has completed a credible and acceptable instrument development formulation, is prepared to proceed with the detailed design, and is on track to complete the instrument development in order to meet the instrument performance requirements within the identified cost and schedule constraints.

7.5.1.1 Purpose

The purpose of the PDR is to demonstrate project readiness to proceed with the detailed design. To that end, the project demonstrates that the preliminary design meets all system requirements with acceptable risk. It shows that the correct design option has been selected, resource allocations have been made, interfaces have been identified, and verification methods have been identified. Supportive design analyses confirm compliance with requirements.

The PDR is the first major review of the overall system design and is normally held prior to the preparation of detailed design drawings and the initiation of any full-scale hardware/software development. This review is held when the design is advanced sufficiently to begin some breadboard testing and/or the fabrication of design models. When scheduling the review, the instrument developer should highlight and discuss with the review chairperson(s) any significant development areas (e.g., significant due to the amount, the criticality, the technical difficulty/complexity) that may warrant attention regarding timing of the review or composition of the review team.

The objectives of the PDR are to: (a) ensure that all system requirements have been allocated, the requirements are complete, and the flow-down is adequate to verify system performance; (b) show that the proposed design is expected to meet the functional and performance requirements; (c) show sufficient maturity in the proposed design approach to proceed to final design; (d) show that the design is verifiable and that the risks have been identified and characterized, and where appropriate, mitigation plans have been defined; (e) show that the management processes used by the mission team are sufficient to develop and operate the mission; (f) show that the cost estimates and schedules indicate that the mission will be ready for “first light” and commissioning, and operate on time and within budget and that the control processes are adequate to ensure remaining within allocated resources.

The PDR should contain a complete and comprehensive presentation of the entire design. It should present the design and interfaces by means of block diagrams, power flow diagrams, signal flow diagrams, interface circuits, software logic flow and timing diagrams. Appropriate modeling results should be presented. Traceability for all items specified for previous reviews, updated to the present stage of the development process, should be presented.

Programmatic considerations should be discussed in sufficient detail to permit assessment of relevant review objectives.

7.5.1.2 PDR Entrance Criteria

Like the earlier System Requirements Review, a number of specific activities and items are expected to be completed before an instrument is ready to enter its Preliminary Design Review. The activities and items listed below constitute the PDR entrance criteria for science instruments and pertain specifically to the technical review of SOFIA science instruments at the system/project level.

1. A preliminary PDR agenda and success criteria for the technical review have been agreed to by the instrument developer and NASA SI Development Manager.
2. The PDR technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review.

7.5.1.3 PDR Success Criteria

The following subsections contain guidelines for the content and subject areas that should be addressed in the PDR by the instrument team.

7.5.1.3.1 Design Description (including Requirements, Evolution and Heritage):

a) A complete and comprehensive definition of the entire design exists to the component level.
b) Results of trade studies and rationale for selected alternatives are defined.

c) Remaining trade studies are identified and potential impacts are understood.
d) Requirements flow-down and traceability to the appropriate subsystem of each system element, and, to the extent practical, to the component, has been completed.
e) Verification compliance matrices for instrument science & technical performance, SOFIA SI System specification, and SOFIA ICD requirements have been updated with results of verification; and verification planned for next development phase has been identified.
f) Requirements and design changes since SRR and their rationale are documented.
g) Appropriate descopes have been identified.
    a. Plans and trigger points have been identified.
    b. Impact to science objectives and deliverables has been defined.
    c. Potential impacts to mass, power, software and other resources have been quantified.
    d. Budget and schedule impacts have been estimated.
h) Long-lead items and their acquisition plans have been identified. Any fabrication needed prior to CDR has been identified.
i) Software Considerations:
    a. Preliminary requirements are identified, including language, structure, logic flow, CPU throughput and memory loading, re-use, safety, and security.
    b. Nominal operating scenarios are identified, along with fault detection, isolation, and recovery strategies.
    c. Design and development plans are defined.
    d. Verification strategies are defined including test environments.

7.5.1.4 Total System Performance (budgets/projections/margins for combined optical, thermal, mechanical, control, etc.):

a) Budgets and margins for system performance (pointing, throughput, etc.) are defined.
b) Preliminary system performance estimates are complete.
c) Estimates of critical resource margins (e.g., mass, power) have been delineated based on design maturity.
    a. Sufficient margin exists based on applicable standards. Risk mitigation strategies are defined for margins below guidelines.

7.5.1.5 Design Analyses:

a) Preliminary analyses critical to proof of design are complete.
b) Analyses required to enable detailed design should be complete.
c) Rationale and risk assessment exists for outstanding analyses that may, at completion, impact the design baseline, i.e., mass, power, volume, interfaces.
d) Status and schedule of final analyses are defined.

7.5.1.6 Development Test Activities:

a) Breadboard and engineering model development activities have been defined.
b) Test objectives and criteria have been identified.
c) Completed breadboard and engineering model test results have been iterated into the design.

7.5.1.7 Risk Management:

a) All significant risks, problems, and open items are identified and tracked (including programmatic, development and flight performance related items). Risk mitigation plans are appropriate and credible.

b) Lessons learned have been appropriately researched and adapted.
c) Reliability and maintainability considerations have been factored into the design.

7.5.1.8 Safety and Airworthiness:

a) An updated system safety assessment identifies all requirements as well as any planned tailoring approaches or planned deviation requests.
b) Preliminary hazards, controls, and verification methods are identified and documented. Drafts of hazard reports have been completed.
c) Any open safety issues are identified with plans for resolution.
d) Plans and schedules for all required safety submittals are defined and documented.

7.5.1.9 Assurance Activities:

a) Quality Assurance plans are complete including the problem reporting system.
b) Preliminary production planning and process controls (including strategy for control/verification of units of measurement) have been identified. Applicable workmanship standards have been defined.
c) Special materials considerations have been identified.

7.5.1.10 Implementation Plans:

a) Equipment and facilities for the development and test of hardware and software have been identified.
b) Preliminary planning for Systems Integration and Test activities, including science validation and calibration, as well as operations compatibility testing, has been defined. Facilities are available and, if needed, utilization agreements are in work.
c) Risks associated with I&T have been characterized and preliminary mitigations have been defined.
d) Contamination requirements and preliminary control plans are defined.

7.5.1.11 Interface Control Documents:

a) ICDs with the Observatory are understood and any preliminary ICDs needed between instrument elements are complete.
b) TBD and TBR items are clearly identified. Plans and schedules exist for their definition.

7.5.1.12 Logistics:

a) Transportation methods are identified including environmental control and monitoring considerations.
b) Preliminary identification of all GSE has been completed including instrument installation carts and instrument laboratory stands.

7.5.1.13 Ground and Mission Operations:

a) Science and mission operations concepts are defined.
b) Mission operations unique ground systems have been defined.
c) Preliminary plans are defined for test activities at Armstrong Building 703, integration with the Observatory, commissioning, and operations.
d) Preliminary planning for involvement and training of SOFIA instrument scientists and mission operations teams are defined.

7.5.1.14 Programmatics:

a) Organization and staffing plans delineate clear responsibilities and adequate assignment of current and future staff.
b) Appropriate processes and metrics are in place to track and control cost, schedule, and technical activities throughout the remaining life-cycle.
c) Preliminary configuration management plan has been defined.
d) Appropriately detailed schedules show realistic event times as well as appropriate funded slack and are compatible with approved commissioning dates.
e) Updated cost and Integrated Master Schedule (IMS) schedule inputs are ready to submit after review comments are incorporated.
f) Cost to complete shows adequate spending profiles and financial reserves, and is compatible with allocations.

7.5.1.15 Project Review Activity:

a) Timely response to actions and liens from previous reviews has occurred. Resultant actions have been implemented effectively. Schedule for completion of any outstanding actions is defined.
b) An appropriate set of engineering peer reviews has been conducted and documented. Resultant actions have been effectively dispositioned and executed. Appropriate additional reviews are planned.
c) Recommendations from other project or external review activity that is applicable to the subject matter of the PDR have been adequately implemented.

7.5.2 Results of Review

It is recognized that instruments may not fully satisfy all of the above criteria at the time of the PDR. Subsequent to the review, therefore, the review chairperson(s), in consultation with the review team, will assess the degree to which the above criteria have been met, the criticality of the areas where there are shortfalls, how straightforward and likely to succeed are the project's recovery plans, and other relevant factors in making a judgment as to whether the PDR has accomplished its objectives and has been successfully completed. Successful completion may be contingent on the responses and closure to some or all of the actions generated at the review. In some cases a "delta" PDR may be required for the instrument to successfully pass this milestone.

Successful completion of the PDR constitutes readiness for detailed design to proceed.

7.6 Phase C – Final Design and Fabrication

7.6.1 Critical Design Review

At the CDR, the instrument team describes the complete system design to the review team and justifies that the maturity of the design and development effort is appropriate to support proceeding with full scale fabrication activities and is on track to complete the instrument and ground system development and mission operations in order to meet the science investigation performance requirements within the identified cost and schedule constraints.

7.6.1.1 Purpose

The purpose of the CDR is to demonstrate that the maturity of the design and development effort is appropriate to support proceeding with full scale fabrication activities and instrument development is on track to complete the flight and ground system development and mission operations in order to meet mission performance requirements within the identified cost and schedule constraints. To that end, the instrument team demonstrates that the final detailed design, as represented by completed drawings and analyses, supported by results of breadboard and engineering model evaluation, will meet the final performance and interface specifications and the required design objectives.

The CDR is held near the completion of the final design stage, including the completion of engineering model evaluations, as applicable, and of breadboard development and test. Although substantial completion of drawings is expected, the review should be held prior to any design freeze and before any significant fabrication activity begins. When scheduling the review, the instrument developer should highlight and discuss with the review chairperson(s) any significant development areas (significant due to the amount, the criticality, the technical difficulty/complexity, etc.) that may not be sufficiently mature and may warrant consideration regarding either timing of the review or composition of the review team. Start of some fabrication or purchase, typically long lead items, off-the-shelf hardware or common buy items, before CDR is common and generally acceptable; however, the instrument developer should consult with the review chairman to obtain concurrence with respect to any significant flight hardware fabrication that will take place before CDR.

The objectives of the CDR are to demonstrate that: (a) all elements of the design are compliant with functional and performance requirements, (b) the verification approach is viable and will confirm compliance with all requirements, (c) risks have been appropriately identified and mitigated or are on track for timely mitigation, (d) the design is sufficiently mature to proceed with full scale fabrication, (e) the management processes used by the instrument team are sufficient to develop and operate the mission, and (f) the schedules and cost estimates indicate that the instrument will be ready to be commissioned and operate on time and within budget and that the control processes are adequate to ensure remaining within allocated resources.

The CDR should represent a complete and comprehensive presentation of the entire final design. It should present the final design and interfaces by means of completed drawings, block diagrams, power flow diagrams, signal flow diagrams, interface circuits, software logic flow and timing diagrams, modeling results, and breadboard and engineering model test results. Traceability for all items specified for previous reviews, updated to the present stage of the development process, should be presented. The results of verification activities conducted up to CDR (see Section 5.4.5.1) should also be presented.

Programmatic considerations should be discussed in sufficient detail to permit assessment of relevant review objectives.

7.6.1.2 CDR Entrance Criteria

As with earlier instrument technical reviews, a number of specific activities and items are expected to be completed before an instrument is ready to enter its Critical Design Review. The activities and items listed below constitute the CDR entrance criteria for science instruments and pertain specifically to the technical review of SOFIA science instruments at the system/project level.

1. A preliminary CDR agenda and success criteria for the technical review have been agreed to by the instrument developer and NASA SI Development Manager.

2. The CDR technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review.

7.6.1.3 CDR Success Criteria

The following subsections contain guidelines for the content and subject areas that should be addressed in the CDR by the instrument team.

7.6.1.3.1 Design Description (including Requirements, Evolution and Heritage):

a) A complete and comprehensive definition of the entire design exists to the piece-part level.
b) Trade studies and rationale for selected alternatives are complete. Impacts of trade decision have been fully integrated into systems requirements, design, verification, operations, etc.
c) Requirements flow-down and traceability has been completed.
d) Verification compliance matrices for instrument science & technical performance, SOFIA SI System specification, and SOFIA ICD requirements have been updated with results of verification; and verification planned for next development phase has been identified.
e) Requirements and design changes since PDR and attendant rationale are documented.
f) Potential de-scopes have been identified.
    a. Plans and trigger points have been identified.
    b. Impact to science objectives and deliverables has been defined.
    c. Impacts to mass, power, software and other resources have been quantified.
    d. Budget and schedule impacts have been determined.
g) A high percentage of drawings (> 80 %) are completed:
    a. Number and title of all drawings have been identified,
    b. Status and schedule of drawing completion (e.g.: draft/preliminary/under review/final) have been defined.
    c. Rationale for outstanding drawings is defined and impact understood.
h) Software Considerations:
    a. Requirements changes since PDR are identified, including those to language, structure, logic flow, CPU throughput and memory loading, re-use, safety, and security.
    b. Current operating scenarios are identified, along with fault detection, isolation, and recovery strategies.
    c. Current software performance estimates exist. Results meet requirements.
    d. Software Requirements Document is approved. Document includes verification matrix mapping requirements to subsystems or CSCIs.
    e. Software Development Plan is approved and includes lines of code estimate, number of builds, tools, and procedures to be utilized, and the verification strategy including planned test environments.

7.6.1.3.2 Total System Performance (budgets/projections/margins for combined optical, thermal, mechanical, control, etc.):

a) Budgets and margins for system level performance (pointing, throughput, etc.) are fully defined.
b) System performance estimates are complete. Margins are adequate or viable corrective actions are in work.
c) Current estimates of critical resource margins (e.g., mass, power) are regularly updated based on design maturity.

7.6.1.3.3 Design Analyses:

a) All analyses critical to proof of design are complete.
b) Additional outstanding analyses have acceptable completion dates and potential impacts are understood and can be reasonably accommodated.
c) Schedules for required updates of analyses are defined.

7.6.1.3.4 Development Test Activities:

a) Breadboard and engineering model development activities have been completed. Results are understood and have been iterated into the final design.
b) Viable rationale exists for any outstanding testing that may at completion impact the design baseline, i.e., mass, power, volume, interfaces.
c) Potential impact of other outstanding activity is understood and can be reasonably accommodated.

7.6.1.3.5 Risk Management:

a) All significant risks, problems, and open items are defined and tracked (including programmatic, development, and flight performance related items). Risk mitigation plans are credible and will retire risks in a timely fashion.
b) Lessons learned have been appropriately researched and adapted.

7.6.1.3.6 Safety and Airworthiness:

a) An updated system safety assessment identifies all requirements as well as any planned tailoring approaches and accepted deviations.
b) Analysis of system hazards, identification of control methods, and definition of verification methods is complete. Documentation has been approved. Updated hazard reports have been completed.
c) Verification of hazard controls is on-track.
d) Safety critical items have been identified. Preliminary schedule for fabrication of safety critical items is established, and NASA inspection points identified.
e) Airworthiness data package has been submitted to the SIAT and approved.
f) Hazardous integration and test procedures and appropriate controls have been identified.

7.6.1.3.7 Assurance Activities:

a) The Instrument Quality Plan is complete, including the problem reporting system.
b) Preliminary production planning and process controls (including strategy for control/verification of units of measurement) have been identified. Applicable workmanship standards have been defined.
c) Physical Configuration Audit plan has been completed, and schedule for NASA inspection points established.

7.6.1.3.8 Implementation Plans:

a) Equipment and facilities for the development and test of hardware and software have been identified.
b) Planning for instrument integration and commissioning, including science validation and calibration, as well as EMI/EMC testing, is defined.
c) Risks associated with I&T have been characterized and mitigations are on track for timely closure.

d) Contamination requirements and control plans are defined. Required implementation activities are complete.

7.6.1.3.9 Interface Control Documents:

a) Up-to-date ICDs, with external systems as well as between system elements, are approved. No TBDs exist.
b) Deviations have been approved for known noncompliance(s) with SOFIA SI System Specification or SOFIA ICD requirements.

7.6.1.3.10 Logistics:

a) Transportation considerations have been fully defined including environmental control and monitoring requirements.
b) Preliminary design of all GSE has been completed including instrument installation carts and instrument laboratory stands.
c) Preliminary transportation container design has been completed.

7.6.1.3.11 Ground Operations, Mission Operations:

a) Science and mission operations concepts are fully defined.
b) Plans are defined for test activities at Armstrong Building 703, integration with the Observatory, commissioning, and operations.
c) Planning for involvement and training of instrument scientists and of mission operations teams are defined.

7.6.1.3.12 Programmatics:

a) Organization and staffing plans delineate clear responsibilities and adequate assignment of current and future staff.
b) Appropriate processes and metrics are in place to track and control cost, schedule, and technical activities throughout the remaining life-cycle.
c) Final configuration management plan has been defined.
d) Appropriately detailed schedules show realistic event times as well as appropriate funded slack and are compatible with approved launch dates.
e) Cost to complete shows adequate spending profiles and financial reserves, and is compatible with allocations.

7.6.1.3.13 Project Review Activity:

a) Timely response to actions from previous reviews has occurred. Resultant actions have been implemented effectively. Schedule for completion of any outstanding actions is defined.
b) An appropriate set of engineering peer reviews has been conducted and documented. Resultant actions have been effectively dispositioned and executed. Appropriate additional reviews are planned.
c) Recommendations from other project or external review activity that is applicable to the subject matter of the CDR have been adequately implemented.

7.6.1.4 Results of Review

It is recognized that instruments may not fully satisfy all of the above criteria at the time of the CDR. Subsequent to the review, therefore, the review chairperson(s), in consultation with the review team, will assess the degree to which the above criteria have been met, the criticality of the areas where there are shortfalls, how straightforward and likely to succeed are the instrument developer's recovery plans, and other relevant factors in making a judgment as to whether the CDR has accomplished its objectives and has been successfully completed. Successful completion may be contingent on the responses and closure to some or all of the actions and liens generated at the review. In some cases a delta-CDR may be required for the instrument to successfully pass this milestone.

Successful completion of the CDR constitutes readiness to proceed with full-scale fabrication.

7.6.2 Pre-Shipment Review

The Pre-Shipment Review (or "Pre-Ship Review") requires a demonstrated level of sub-system and integrated instrument performance, a successful review of all interfaces, a successful completion of airworthiness approval by the SIAT, and a detailed description of instrument operations. All required plans and procedures for work to be performed at Armstrong Building 703 prior to installation on the Observatory are to be completed and released as SOFIA documents.

At this review the instrument developer describes the current status of all activities and establishes that all instrument and ground system verification activities have been successfully completed and that the system is ready for delivery to Building 703 for final testing and integration with the Observatory.

7.6.2.1 Purpose

The purpose of the PSR is to demonstrate that the flight system is ready for shipment to Armstrong Building 703 for tests and integration on the Observatory.

The instrument developer demonstrates that all verification activities of the instrument that can be completed in a laboratory environment have been successfully completed, that all discrepancies of any type have been satisfactorily resolved, and that planning and preparation for all remaining activities has been completed.

The PSR is conducted prior to shipment of the instrument to Building 703 and after successful completion of all laboratory testing and verification activities. When scheduling the review, the instrument developer should highlight and discuss with the review chairperson(s) any significant problem areas that may pose difficulty during the review.

The objectives of the PSR are to demonstrate that: (a) all functional performance testing of the instrument has been successfully completed, (b) all discrepancies are fully understood and satisfactorily resolved, including completion of corrective actions as well as planning and preparation of any required follow-on actions, (c) any changes since the CDR have been evaluated, have been successfully incorporated into appropriate system elements, have been verified, and are compatible with any interfacing system element, and (d) planning and preparation for shipping and subsequent laboratory testing at Building 703 is complete.

7.6.2.2 PSR Entrance Criteria

The following activities and items constitute the PSR entrance criteria for science instruments:

1. A preliminary Pre-Ship Review agenda and success criteria for the technical review have been agreed to by the instrument developer and NASA SI Development Manager.
2. The Pre-Ship Review technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review.

3. Instrument airworthiness inspection has been completed.
4. Instrument SOFIA SI System Spec verification has been completed through PSR.
5. Instrument SOFIA ICD verification has been completed through PSR.
6. Demonstration of SI FITS data file ingestion into DCS Archive has been completed.
7. Instrument pipeline beta version delivered and demonstrated to function correctly using lab/test data. (FSI only)
8. Instrument MCCS tier tests has been completed.
9. Instrument system software verification has been completed.
10. NESC cryogen reservoir analysis with full model has been completed. (SE01-2028, parid 3.5.3.3.1)
11. Pressure test of cryogen reservoirs has been completed. (SE01-2028, parid 3.5.3.3.1)
12. Pressure test of pressure vessels/lines/components has been completed. (SE01-2028, parid 3.5.3.3.2)
13. Instrument installation cart has been load test certified. (SE01-2028, parid 3.5.2.3)
14. Instrument lab cart/stand has been load test certified. (if applicable; SE01-2028, parid 3.5.2.3)
15. Instrument lifting ground support equipment has been load test certified. (SE01-2028, parid 3.5.2.5)
16. Instrument Travel Sheet has been approved and released on Windchill. (SOFIA Program will provide this document.)
17. Instrument has approved deviations/waivers for identified discrepancies of instrument with SOFIA SI System Specification and ICD requirements, or path to resolution is defined.

7.6.2.3 PSR Success Criteria

The following subsections contain guidelines for the content and subject areas that should be addressed in the PSR by the instrument team.

7.6.2.3.1 Requirements / Design Update:

a) Requirements and design changes to hardware or software since CDR and attendant rationale are documented. Mission implications and interface compatibility have been considered, and verification updates (analyses and tests) have been completed.
b) Current calculations of all critical resource margins remain adequate and based on actual measured values.
c) Analyses of the current design are complete and demonstrate adequate margin.

7.6.2.3.2 Completed Verification Results:

a) All laboratory-based verification activities at the instrument developer's institution have been successfully completed.
b) Verification compliance matrices for instrument science & technical performance, SOFIA SI System specification, and SOFIA ICD requirements have been updated with results of verification; and planned verification to be performed before instrument installation/integration with SOFIA has been identified.
c) Software interface testing in the SIL or HIL have been successfully completed.
d) Current calculations for systems performance have been updated as appropriate with system test results and continue to demonstrate full compliance with system requirements.
e) All discrepancies (nonconformances, anomalies, failures, "cannot duplicates," etc.) are fully understood. Corrective actions are completed, and plans and preparations for any required

follow-on actions are completed. All noncompliances and nonconformances have approved waivers.

7.6.2.3.3 Safety and Airworthiness:

a) System Safety Assessment has been updated and approved, reflecting any changes from CDR.
b) Hazard reports have been updated and approved by the SSWG. Hazard mitigations have been implemented or schedule for implementation has been established.
c) Instrument has received airworthiness approval from the SIAT.

7.6.2.3.4 Risk Management:

7.6.2.3.5 Assurance Activities:

a) Physical configuration audit (PCA) has been completed.
b) All discrepancies have been reviewed for acceptable closure. Any items requiring special attention or monitoring during subsequent activity, including during mission operations, have been identified and appropriate action planned.
c) Proof load tests of instrument carts or stands have been completed.
d) Tests for pressure relief devices (PRDs) of instrument cryogen vent systems have been completed.

7.6.2.3.6 Logistics:

a) Transportation plans are fully defined. Shipping containers, handling equipment, environmental control and monitoring equipment are verified and available.
b) Armstrong Building 703 facilities are available and have been verified to meet requirements.
c) Laboratory check-out procedures are approved and include appropriate system performance testing.

7.6.2.3.7 Mission Operations:

a) Required team training to support laboratory and Observatory operations have been identified and scheduled.

7.6.2.3.8 Review Activity:

a) All actions from all previous reviews are closed. Resultant actions have been implemented effectively.
b) An appropriate set of engineering peer reviews has been completed and documented. Resultant actions have been effectively implemented.
c) Recommendations from lessons learned, other instruments, or external review activity has been adequately implemented.

7.6.2.3.9 Results of Review

It is recognized that instruments may not fully satisfy all of the above criteria at the time of the PSR. Subsequent to the review, therefore, the review chairperson(s), in consultation with the review team, will assess the degree to which the above criteria have been met, the criticality of the areas where there are shortfalls, how straightforward and likely to succeed are the instrument developer's recovery plans, and other relevant factors in making a judgment as to whether the PSR has accomplished its objectives and has been successfully completed. Successful completion may be contingent on the responses and closure to some or all of the RFAs generated at the review. In some cases a delta-PSR may be required for the instrument to successfully pass this milestone.

Successful completion of the PSR constitutes readiness for shipment of the instrument to Armstrong Building 703.

7.7 Phase D – System Integration and Test

There are four parts to instrument integration following delivery to Armstrong Building 703: laboratory tests, TAAS tests, aircraft integration tests, and flight tests. The testing philosophy is to test as early in the process as possible with the minimum number of subsystems required. SOFIA is a valuable asset with significant operations costs. No test should be performed during a flight that has not been practiced on the ground. No test should be performed on the aircraft that can be performed in the laboratory.

Laboratory tests occur in the Science Instrument readiness rooms located at Building 703. These tests are to verify that the instrument has been reassembled and no damage has occurred during shipment and the instrument is ready to be tested on the TAAS or installed on the aircraft. The instrument team determines what tests are performed depending on the instrument design and requirements. Generally, these consist of a leak check of the vacuum system, warm functional tests, and cold functional tests. The instrument team should confirm that the instrument has survived shipping, has been properly reassembled, is free of vacuum leaks and thermal shorts, and is ready for integration with the Observatory.

The TAAS is described in Section 6.2.2. The instrument team determines what tests are performed using the TAAS depending on the instrument design and requirements.

A Pre-Install Review is conducted generally two weeks before scheduled installation date, to ensure the instrument is ready to install, to coordinate logistics of installation, and to confirm the readiness of Observatory telescope and aircraft systems. Following integration with the Observatory, aircraft integration tests are performed to confirm proper installation and cabling of the instrument. Aircraft integration tests include a warm functional test, if the instrument is installed warm, and a cold functional test. These tests verify the instrument is ready for hangar tests, EMI tests, and/or line operations.

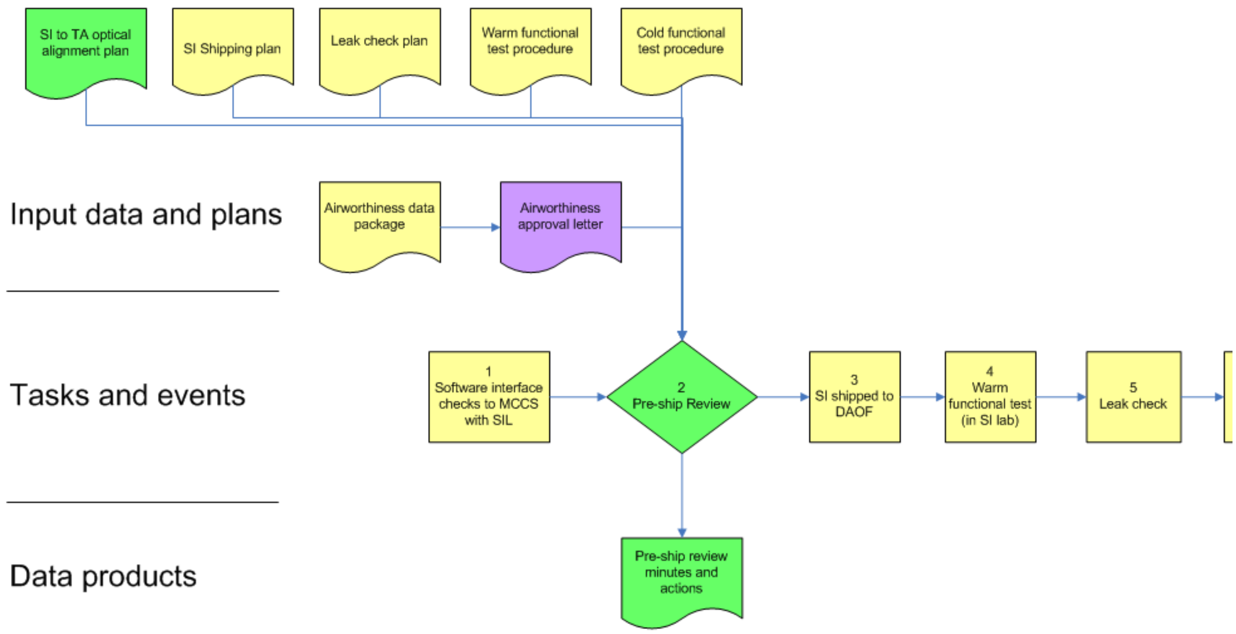
Hangar tests are tests performed by the instrument on the aircraft while the aircraft is in the hangar (i.e., integrated tests for which sky sources are not required).

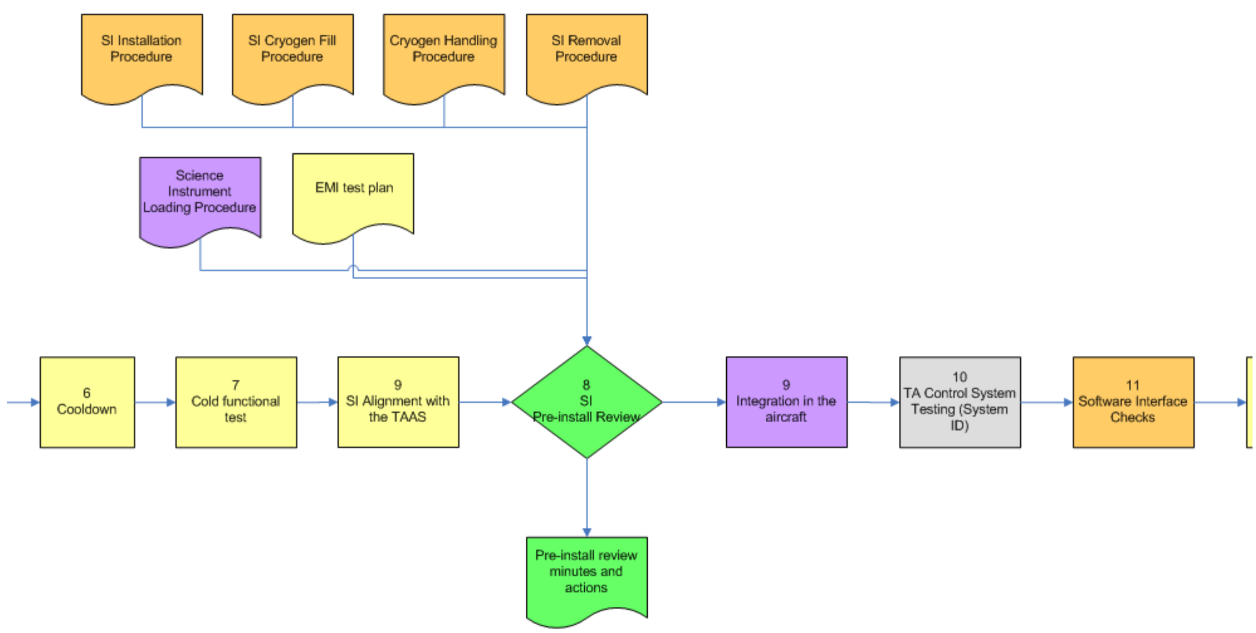
An electromagnetic interference and electromagnetic compatibility test (EMI/EMC) test will be performed with the instrument prior to flight. This test occurs on a taxiway or engine run-up area since it involves engine runs and radar use. This test ensures that the instrument systems do not cause adverse effects on the aircraft systems, characterizes any aircraft system impacts on the instrument performance (i.e., increased detector noise due to radio pick-up), and confirms the instrument grounding scheme is effective.

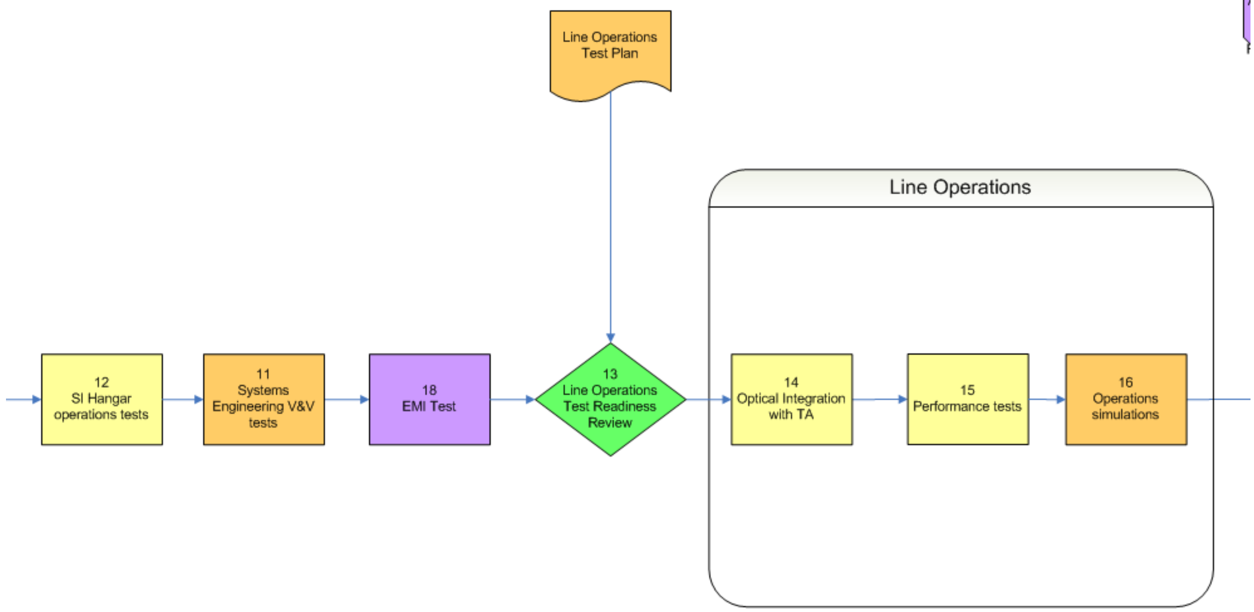
Line operations are tests performed out on the flight line. In addition to instrument tests, mission simulations – observing flight rehearsals – are performed to familiarize the mission crew to the operation of the instrument and the instrument team with in-flight procedures.

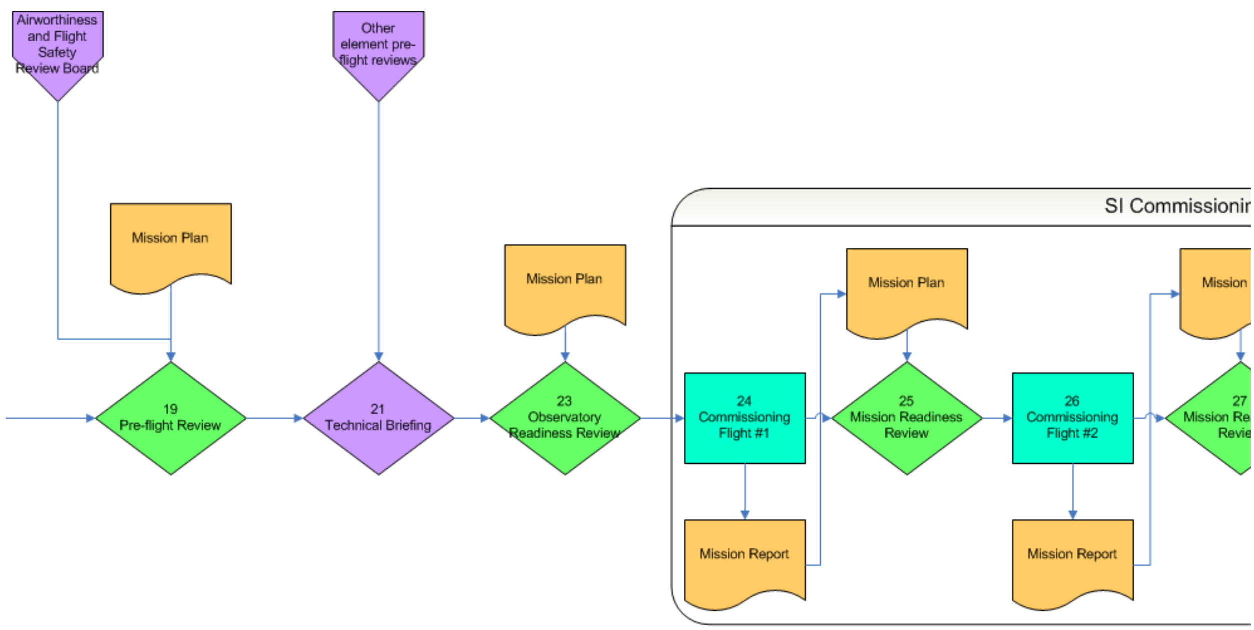
Instrument control software integration testing should occur as early as possible. The instrument control software interface with the MCCS can be tested remotely or in person using the Systems

Integration Laboratory (SIL). This testing should occur prior to the instrument Pre-Ship Review to ensure the software will be ready for instrument integration with the Observatory. Final testing of the instrument control software will occur on the Observatory in the hangar when possible and during line operations for those tests requiring sky targets.






Line Operations Test Plan
Line Operations
12
SI Hangar operations tests
11
Systems Engineering V&V tests
18
EMI Test
13
Line Operations Test Readiness Review
14
Optical Integration with TA
15
Performance tests
16
Operations simulations


Airworthiness and Flight Safety Review Board
Other element pre-flight reviews
Mission Plan
Mission Plan
19
Pre-flight Review
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SI Commissionin
Mission Plan
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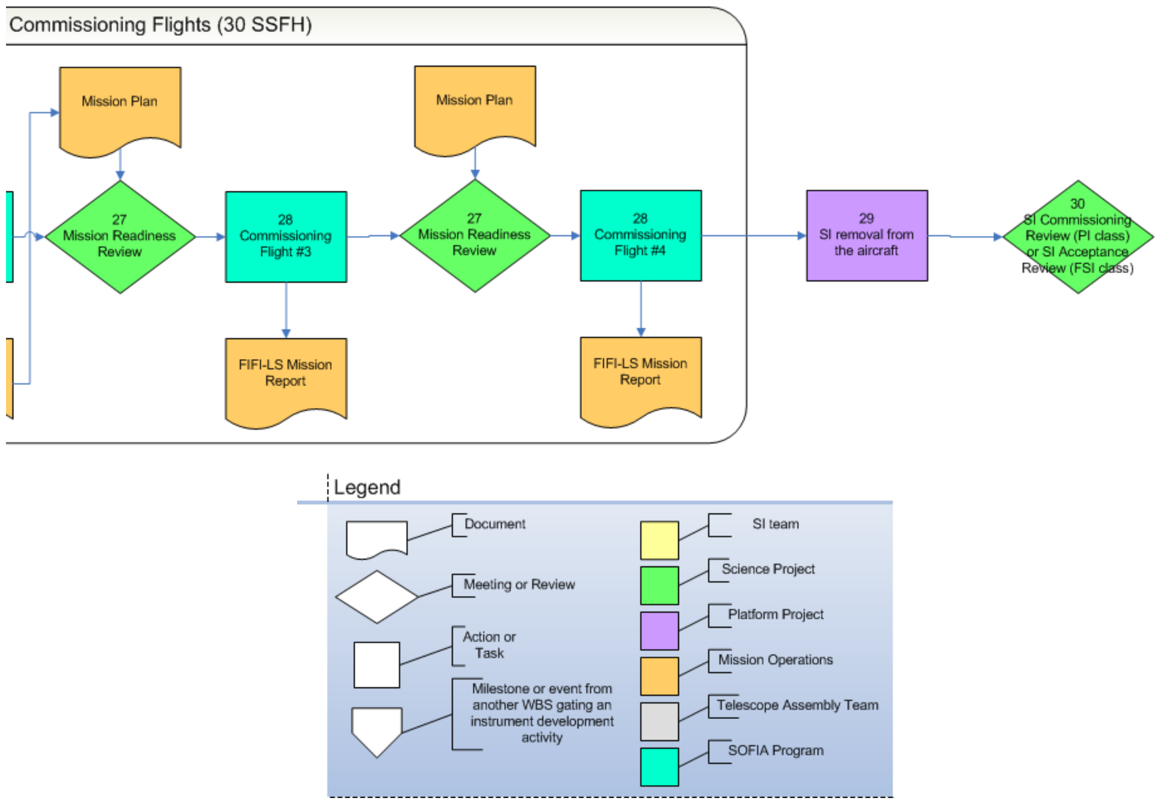

Figure 7.7-1: Example flow of events for the integration and commissioning of a science instrument

7.7.1 Pre-Installation Review

The Pre-Installation Review (or "Pre-Install Review") is held prior to each installation of the instrument onto the aircraft. This review is to ensure that all the subsystems are ready for instrument installation and that the roles and responsibilities of team members participating in the installation are understood.

The Pre-Install Review is to demonstrate the readiness of a science instrument to install aboard SOFIA. This necessarily means that all required ground checks of the instrument have been successfully performed. Following shipment of the science instrument to the observatory, the instrument team has successfully unpacked and re-assembled the instrument. It is expected that verification of stated instrument sensitivities has also been performed.

The Pre-install Review will cover the results of instrument control software testing with the SIL or HIL. The review will also cover testing of the instrument with the TAAS to verify mechanical interfaces and optical alignment if applicable. Instrument teams are expected to provide a first-pass at the location of the science instrument bore-sight. The Instrument teams should give the final science instrument reference frame information to the SOFIA support staff before a pre-install review. This information should be provided by the instrument team before the pre-ship review.

For the first installation of an instrument onto SOFIA, the verification status of all instrument verification against the instrument-specific science & technical performance, SOFIA SI System Specification, and SOFIA SI ICDs requirements conducted up to PSR will be presented. With the exception of requirements that will be verified after installation or during commissioning, all applicable requirements must be declared pass (complies) or have approved deviations or waivers.

For subsequent installations of an instrument on SOFIA (i.e., an instrument which has been installed on SOFIA before), a determination will be made by NASA whether any delta airworthiness or ICD verification is required before the instrument can be installed. This is to ensure the instrument maintains compliance with SOFIA airworthiness and ICD requirements. This determination is contingent on the instrument team providing a statement prior to the Pre-Install Review identifying whether or not any change has been made to the instrument compared to a previously (approved) installed configuration; and if changes have been made, providing a summary description of the changes and supplying any needed updated documentation to show that, with the configuration change, the instrument remains in compliance with SOFIA airworthiness and ICD requirements.

All science instrument PI and Counterweight racks should be assembled and functional, and all required instrument cabling should be verified and ready for installation. The Instrument team should inform Mission Operations of the desired position of the Auxiliary Rack if the rack will be used. A schedule for performing security scans of all instrument computers and SI team laptops that connect to MCCS should be coordinated with Mission Operations.

All required installation procedures should be available at this time. The Instrument team should provide a schedule for cryogen servicing and any specific time periods the instrument needs power on the aircraft. The instrument team should also indicate any specific telescope secondary mirror button needed by the instrument.

Prior to installation, science instruments will have to undergo conformance inspections. Such inspections should be clearly stated as required in the commissioning plan for each instrument. All flight planning should be completed and approved before the Pre-Install Review.

7.7.1.1 PIR Entrance Criteria

The entrance criteria for a science instrument Pre-Install Review are the following:

1. Instrument developer has provided instrument status input to NASA prior to the Pre-Install Review; Mission Operations will prepare and distribute presentation charts and materials to cognizant participants prior to the review.
2. The Pre-Install Review technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review.
3. All RFIs/RFAs/action items from previous reviews have been dispositioned.
4. Functional testing of the instrument at Building 703 has been successfully completed (or is on schedule to be completed) and the SI team believes the instrument is ready for installation.
    a. Instrument warm and cold functional checks have been completed.
    b. Instrument cryogen hold time has been verified (if instrument uses liquid cryogens)
5. Instrument has obtained approved deviations/waivers for all identified noncompliance of the instrument with SOFIA requirements; deviations/waivers have been verified to be active and applicable.
6. The instrument has obtained airworthiness approval; compliance of instrument configuration with airworthiness requirements has been verified.

   a. Airworthiness physical inspection of external features of instrument has been completed, or a plan exists to perform the inspection before installation.
   b. Hazard reports have been approved and identified mitigations have been implemented.
7. All ICD verification has been successfully completed, or a plan exists to complete all required verification prior to installation. Compliance of instrument configuration with SOFIA requirements has been verified (or re-verified, if a significant change was made to the instrument or instrument subsystem following a Pre-Ship Review or previous Pre-Install Review).
   a. Instrument verification with SOFIA SI System Specification requirements has been completed up to PIR.
   b. Instrument verification with SOFIA ICD requirements has been completed up to PIR.
   c. Instrument MCCS tier tests have been completed.
   d. FITS file ingestion into DCS Archive has been demonstrated.
   e. Data reduction pipeline execution has been demonstrated.
8. All SI cart load test and inspection activities have been successfully completed, and the cart is certified for use.
9. A proposed installation schedule has been developed. (SOFIA Program will provide this schedule.)
10. All installation procedures are approved, or if not, a plan exists to obtain approval prior to installation.
11. Telescope secondary mirror assembly button swap has been completed (if applicable).
12. The Instrument Configuration sheet describing the current configuration of the instrument is current and complete.

7.7.1.2 PIR Success Criteria

The success criteria typically presented at an instrument Pre-Install Review is inclusive of all responsible groups and stakeholders, including the instrument team, and is used to assess the readiness of organizations and groups participating in the install and solicit the concurrence and approval from stakeholders, before instrument installation activities can commence. Below are the success criteria for an instrument Pre-Install Review; note not all items in the list are the direct responsibility of the instrument team (e.g., instrument team is not responsible for reporting the readiness of Observatory systems).

1. The instrument is ready for installation.
2. Airworthiness physical inspection of external features of instrument has been completed, or a plan exists to perform the inspection before installation.
3. The instrument has obtained airworthiness approval.
4. All ICD verification has been successfully completed (i.e., SOFIA SI System Specification verification, SOFIA ICD verification, SI-MCCS tier tests, SI-DCS tests, data reduction pipeline tests), or there is an agreed-upon plan to complete all required verification prior to installation.
5. Instrument has obtained approved deviations/waivers for all identified noncompliance of the instrument with SOFIA requirements.
6. Any instrument software changes from the prior flight series of the instrument are communicated.
7. The Instrument Configuration sheet describing the current configuration of the instrument is current and complete.
8. All SI cart load test and inspection activities have been successfully completed, and the cart is certified for use.
9. The installation schedule has been agreed to and is achievable.
10. All installation procedures are approved, or if not, agreed-upon forward actions exist to obtain approval prior to installation.
11. Telescope secondary mirror assembly button swap has been completed (if applicable).

12. Observatory systems are ready for installation.
13. The Observatory hardware and software configuration has been communicated and is understood.
14. Personnel, procedures, and support equipment (e.g., the lift truck) are ready and available to support installation.
15. Critical lifts are known and support equipment and personnel are available.
16. The roles and responsibilities of team members during installation are understood.
17. Appropriate safety briefings are planned.
18. Tool control procedures have been communicated to the SI team.
19. The cryogen fill schedule (if applicable) has been coordinated.
20. All forward actions requiring completion prior to installation have been agreed to and will be tracked to closure.

7.7.2 Test Readiness Review

A Test Readiness Review ensures the test article, test facility, support personnel, and test procedures are ready for testing and data acquisition, reduction, and control. The entrance and success criteria for a TRR from NPR 7123.1B Appendix G are listed below. A TRR checklist—hardware or software checklist depending on the type of test to be performed—will be used to determine readiness of the project to start formal test.

7.7.2.1 TRR Entrance Criteria

1. A preliminary TRR agenda, success criteria, and instructions to the review team have been agreed to by the technical team, project manager, and review chair prior to the TRR.
2. The objectives of the testing have been clearly defined and documented.
3. Approved test plans, test procedures, test environment, and configuration of the test item(s) that support test objectives are available.
4. All test interfaces have been placed under configuration control or have been defined in accordance with an agreed-to plan, and version description document(s) for both test and support systems have been made available to TRR participants prior to the review.
5. All known system discrepancies have been identified and dispositioned in accordance with an agreed-upon plan.
6. All required test resources, people (including a designated test director), facilities, test articles, test instrumentation, and other test-enabling products have been identified and are available to support required tests.
7. Roles and responsibilities of all test participants are defined and agreed to.
8. Test safety planning has been accomplished, and all personnel have been trained.

7.7.2.2 TRR Success Criteria

1. Adequate test plans are completed and approved for the system under test.
2. Adequate identification and coordination of required test resources are completed.
3. The program/project has demonstrated compliance with applicable NASA and implementing Center requirements, standards, processes, and procedures.
4. TBD and TBR items are clearly identified with an acceptable plan and schedule for their disposition.
5. Risks have been identified, credibly assessed, and appropriately mitigated.
6. Residual risk is accepted by program/project leadership as required.
7. Plans to capture any lessons learned from the test program are documented.

8. The objectives of the testing have been clearly defined and documented, and the review of all the test plans, as well as the procedures, environment, and configuration of the test item, provides a reasonable expectation that the objectives will be met.
9. The test cases have been analyzed and are consistent with the test plans and objectives.
10. Test personnel have received appropriate training in test operation and health and safety procedures.

7.7.3 Observatory Readiness Review

The SOFIA Observatory Readiness Review (SObRR) is held prior to each Observatory flight series. The objective of this review is to confirm that the Observatory is ready to fly. In preparation for this review the instrument team should confirm that any open issues are being worked, that the instrument team believes they have had enough practice and simulations, and that they believe the Observatory is prepared to support their observing plan. The instrument team should communicate any changes made to the instrument configuration since the Pre-Install Review and deliver an update to the instrument configuration sheet (Section 9.3) to the SOFIA Program. The first SObRR, or a SObRR held following a major instrument modification, will be a more extensive review covering the instrument modification and overall instrument readiness for flight. As operation becomes routine, this will become a shorter review.

The SObRR follows the installation of the instrument on the Observatory and the completion of integration testing, including EMI testing, line operations, and operational scenarios simulations. At the SObRR:

a) Mission operations plans are complete for all routine and contingency scenarios.
b) Mission operations systems are complete and available.
c) Operations team staffing is in place. Required personnel certifications have been approved.
d) Adequate end-to-end operational simulations of flight and ground mission systems have been completed by actual operations team

Any verification that can be completed with ground testing should be completed before the SObRR. Only those verifications that require flight should remain open.

At the SObRR, the flight plans for the flight series will be presented by the mission operations team.

Prior to each individual flight there will be a Mission Crew brief held ~2 hours prior to the scheduled take-off time. Instrument teams will be asked to report the instrument status at the Mission Crew brief and report any issues or risks that may have developed since the SObRR and status any science instrument actions from the SObRR.

7.7.4 Acceptance Review

The acceptance review only applies to facility instruments. All other US instrument classes will undergo a commissioning review instead. German instruments that are not FSIs will be commissioned by a process established by DLR.

The objectives of the SI Acceptance Review are to:

- Demonstrate the end-to-end SI performance
- Demonstrate readiness of the SI to conduct science operations on-board SOFIA
- Demonstrate readiness of the SI to be made available to the general science community
- Demonstrate readiness of the SI to be operated and maintained by SOFIA staff

- Demonstrate that the technical data package is complete and reflects the delivered system

After the successful completion of the acceptance review, the formal SI Acceptance process begins. Section 7.7.4.3 provides an overview of the instrument acceptance process after completion of the SI Acceptance Review. After the acceptance review and closure of any liens, the *Material Inspection and Receiving Report* (DD-250) is signed and the SOFIA Program takes possession of the science instrument. Once the instrument is formally accepted by NASA, SOFIA Mission Operations is responsible for the operation and maintenance of the instrument. The entrance and success criteria for an SI Acceptance Review are below.

7.7.4.1 AR Entrance Criteria

1. The SI has successfully completed the previous planned milestone reviews, RFIs/RFAs have been dispositioned, and plans to complete open work are defined.
2. A preliminary agenda, acceptance criteria, and instructions to the review team have been agreed to by the PI, the NASA SI Development Manager, USRA SI Development Manager (if applicable), Observatory Systems Director, Operations Director, Chief Engineer, Project Scientists, Facility Scientist, Chief Safety Officer, and review chair prior to the review.
3. The Acceptance Review technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review:
    a. Results of SI characterization and performance testing
    b. SI verification results
    c. SI validation results
    d. Up-to-date Acceptance Data Package; data package criteria listed in Appendix E – SI Acceptance & Commissioning Data Package Content
    e. Up-to-date airworthiness documentation
    f. Baselined as-built hardware documentation
    g. Required safe shipping, handling, checkout, maintenance, and operational plans and procedures
    h. SI software documentation compliant with *SOFIA Software Management Plan (SMP)* (SOF-DA-PLA-PM20-2011)
    i. An audit (FCA/PCA) has been performed on the instrument hardware and software and any identified discrepancies are minor
4. All deliverables defined in the *SI Pipeline Acceptance Plan* (SCI-US-PLA-SW09-2000) have been delivered to the in-house pipeline team.
5. SSMO staff have been trained in the operation and maintenance of the instrument, as certified by the SOFIA Operations Director or designee.

7.7.4.2 AR Success Criteria

1. SI capabilities and operating modes have been successfully demonstrated in flight.
2. SI performance and limitations have been determined and documented.
3. The in-house pipeline team has received all the necessary deliverables to allow them to complete development of the data reduction pipeline and calibration.
4. SI engineering and maintenance processes and procedures have been validated.
5. Risks are known and manageable.
6. TBD and TBR items are resolved.
7. Acceptance data package is complete and reflects the delivered system.

8. SI software documentation is compliant with the SOFIA Science Project Software Management Plan (soon to be replaced by SOFIA Software Management Plan).
9. An audit (FCA/PCA) has been performed on the instrument hardware and software and any identified discrepancies are being tracked within the appropriate NASA system.
10. SSMO staff are trained in the operation and maintenance of the instrument.

7.7.4.3 SI Acceptance Process

After the successful completion of the instrument Acceptance Review, the following activities take place in parallel:

1. All actions from the Acceptance Review that are identified as being required for formal acceptance must be resolved and closed out. Once this is accomplished, the Acceptance Review Chair (NASA SI Development Manager) must then inform and obtain concurrence from the Acceptance Review Panel that the actions have been successfully closed.
2. S&MA performs a final physical configuration audit (PCA) of the safety/airworthiness-related external features of the instrument hardware. Any discrepancies found during the PCA must then be communicated to and addressed by the SI Development team.
3. NASA review and approval of the Acceptance Data Package must be obtained.

When these activities have been completed, the SOFIA Facility Scientist writes a memorandum to the SOFIA Program manager recommending acceptance of the instrument. The memo includes a list of any liens, risks, or waivers against the SI which are recommended to be accepted along with the instrument. The Facility Scientist then requests approval to accept the instrument at the SOFIA Program Management Board (PMB).

After PMB approval is obtained, the Facility Scientist and S&MA Lead sign the *Material Inspection and Receiving Report* (DD-250) and the SOFIA Program takes possession of the instrument. This step constitutes formal acceptance of the instrument. Once the DD-250 is signed, the SOFIA Mission Operations team takes full responsibility for the operation and maintenance of the instrument.

This entire process should be completed within 45 days after the SI Acceptance Review. This process is described in the flow diagram shown in Figure 7.7.4.3-1 below.

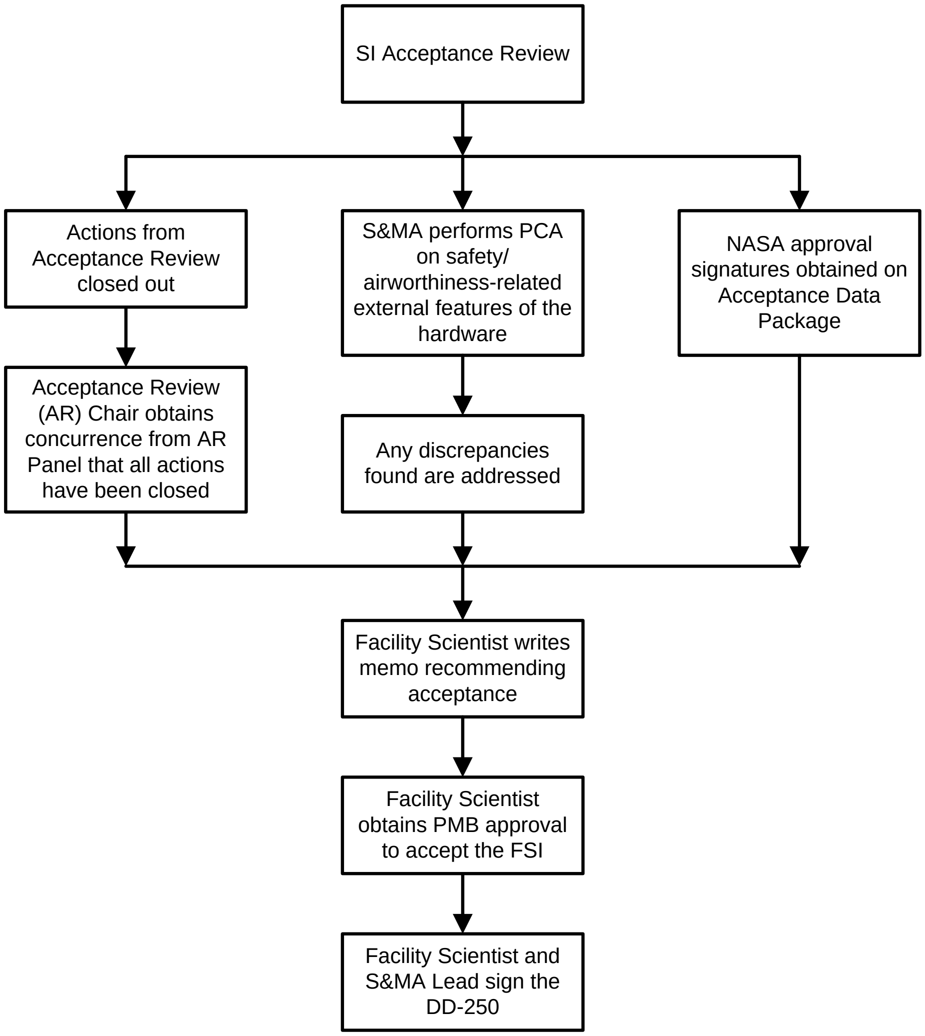

Figure 7.7.4.3-1: Process flow for the SI Acceptance process

7.7.5 Commissioning Review

This section only applies to US non-facility instruments. The US PI instruments, special purpose instruments, and technology demonstration instruments will hold a Commissioning Review rather than an Acceptance Review. The Commissioning Review will be similar to an Acceptance Review, but will not involve the items related to a delivery of the instrument for operations and maintenance of the instrument by the SOFIA Program. At this review the instrument will present the objectives and goals outlined in the instrument Commissioning Plan and the results of commissioning data collected. The instrument team will also present the status of verification with its science and technical performance requirements. The objectives and entrance and success criteria for an instrument Commissioning Review is very similar to an Acceptance review, with the criteria of a Commissioning Review being a subset of what is required for an Acceptance Review since ownership of the instrument is not transferred to NASA.

The objectives of the SI Commissioning Review are to:

- Demonstrate the end-to-end SI performance
- Demonstrate readiness of the SI to conduct science operations on-board SOFIA

- Demonstrate readiness of the SI to be made available to the general science community
- Demonstrate readiness of the SOFIA staff to support the SI
- Demonstrate that the technical data package is complete and reflects the as-built system

7.7.5.1 CR Entrance Criteria

1. The SI has successfully completed the previous planned milestone reviews, RFIs/RFAs have been dispositioned, and plans to complete open work are defined.
2. A preliminary agenda, acceptance criteria, and instructions to the review team have been agreed to by the PI, the NASA SI Development Manager, USRA SI Development Manager (if applicable), Observatory Systems Director, Operations Director, Chief Engineer, Project Scientists, Facility Scientist, Chief Safety Officer, and review chair prior to the review.
3. The Commissioning Review technical products identified in Appendix A.1 – Deliverable Items List and Appendix A.2 – Documentation Delivery Schedule have been delivered by the instrument developer to NASA and have been made available to cognizant participants prior to the review:
    a. Results of SI characterization and performance testing
    b. SI verification results
    c. SI validation results
    d. Up-to-date Commissioning Data Package; data package criteria listed in Appendix E – SI Acceptance & Commissioning Data Package Content
    e. Up-to-date airworthiness documentation
    f. Baselined as-built hardware documentation
    g. Required safe shipping, handling, checkout, maintenance, and operational plans and procedures
4. (If applicable) All deliverables defined in the *SI Pipeline Acceptance Plan* (SCI-US-PLA-SW09-2000) have been delivered to the in-house pipeline team.

7.7.5.2 CR Success Criteria

1. SI capabilities and operating modes have been successfully demonstrated in flight.
2. SI performance and limitations have been determined and documented.
3. (If applicable) The in-house pipeline team has received all the necessary deliverables to allow them to complete development of the data reduction pipeline and calibration.
4. SI engineering and maintenance processes and procedures have been validated.
5. Risks are known and manageable.
6. TBD and TBR items are resolved.
7. Commissioning data package is complete and reflects the as-built system.

7.8 Phase E – Operations

7.8.1 Post Acceptance Support

Following acceptance, the facility instruments will be operated and maintained by the SMO team. *The details of post-acceptance Instrument Team support are in work and will be added to this document when they become available.*

7.9 Phase F – Closeout

Each science instrument should reliably contribute high quality science observations that maximize the scientific return of flight opportunities and the unique capabilities of SOFIA. Instruments that do not demonstrate sufficient science productivity will be removed from the suite of instruments available to the general observing community.

The retirement of Science Instruments is necessary in order to keep the number of supported instruments available to the SOFIA observer community at a manageable level and to make way for new instrumentation by freeing up resources including funding, personnel, and flight hours. Facility Science Instruments will be retired after a time at which the cost of their maintenance and support is no longer commensurate with their ability to competitively deliver science.

Technology Demonstration Science Instruments are retired after two years from the date of the last flight of guaranteed observing time.

Each year, science and mission operations personnel, instrument scientists, mission directors, information systems and mission operations leads will summarize observatory performance and accomplishments and report to the Science Mission Operations (SMO) Director on the scientific and operational performance of each instrument. Instruments will be evaluated for overall science productivity considering the following:

- Performance, reliability and success on the telescope
- Maintenance and operations costs
- Proposal subscription rate
- History of publications that use data from the instrument
- Science capability compared with other existing observatories and platforms

An instrument will be considered for retirement if any of the following conditions apply:

- Instrument performance has degraded significantly from original capabilities
- Instrument has failed and requires costly repairs
- Instrument reliability significantly reduces successful flight hours
- Instrument operating constraints significantly limit science return
- Instrument scientific contribution has been marginalized by newer operational technologies, competing observations, or other factors
- The NASA Strategic Plan has restructured relevant scientific priorities

The Science Mission Operations (SMO) Director and the NASA Project Scientist will organize and co-chair a review of any instrument that is not scientifically productive. The review panel of scientists and Instrument Teams with relevant experience will consider input from the Instrument Team, the general observer community, SMO science and operations staff, and others to formulate a recommendation to either retire the instrument or to continue operations, possibly under specific conditions. If the review results in the recommendation to permanently retire an instrument from SOFIA service, the SMO Director and NASA Project Scientist will communicate this recommendation to the NASA Program Scientist and the SMD Astrophysics Director and recommend the final disposition of the instrument and supporting hardware (e.g., to be returned to the developing institution, made available to new developers, placed in storage at NASA). The NASA SMD Director of Astrophysics has final authority to decide on retirement or replacement of a science instrument.

8 Airworthiness Process

The primary purpose of SOFIA science instrument airworthiness certification is safety. Receiving airworthiness certification will significantly reduce the likelihood that either the aircraft or the personnel onboard will be harmed. The guidelines presented in this handbook follow those of the NASA Armstrong Flight Research Center Flight Safety and Review Process as outlined in DCP-X-009. The S&MA and Airworthiness Certification requirements that are verifiable (i.e., those for which specific objective evidence of verification closure are required) will be found within the *SOFIA Science Instrument System Specification*, SOF-AR-SPE-SE01-2028.

The following are topics that pertain to the airworthiness of a science instrument:

- Anything that can cause injury to personnel
- Anything that can cause a fire
- Commands by one system to others that result in hazardous conditions
- Anything that affects the aircraft pressure boundaries
- Foreign Object Damage (FOD) and equipment security
- Pressure systems
- Cryogens
- Toxic substances
- Radiation, both ionizing and non-ionizing

The purpose of this airworthiness and certification procedures chapter is to lead a SOFIA science instrument builder through the certification process with information and examples of all aspects of an instrument design that are required to comply with NASA airworthiness regulations. These requirements include mechanical and electrical design and analysis, instrument construction, testing, hazard identification and analysis, operations, and instrument maintenance.

Certification is not difficult, but it does require following specific steps from preliminary design through instrument construction, installation, operations, and maintenance for the purpose of maintaining a safe environment aboard the Observatory.

8.1 Science Instrument Certification: General Process & Overview

8.1.1 Science Instrument Airworthiness Team

The Science Instrument Airworthiness Team (SIAT) is a group of engineers within the SOFIA Program that review the instrument for airworthiness. The Science Instrument Airworthiness Team (SIAT) is the verification authority for airworthiness requirements. The SIAT members consist of specialists from NASA and include: flight operations engineers, structural engineers, system safety personnel, and quality assurance representatives.

Science Instrument airworthiness is established by the verification of the SIAT requirements in the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) and the ICDs called out in section 3.11 of the specification. The SIAT is the verification authority for a subset of these requirements, the complete set of which comprises the airworthiness requirements. The verification of these requirements will result in the SIAT releasing an airworthiness letter to the chair of the Airworthiness & Flight Safety Review Board (AFSRB) endorsing the airworthiness of the instrument and representing the instrument at the AFSRB meetings. The risks specifically associated with operating the science instrument onboard

SOFIA will be incorporated with the risks of the observatory as one entity. Final airworthiness approval of a science instrument as part of the SOFIA platform will be determined by the AFSRB.

8.1.2 Flight Readiness Review

The Flight Readiness Review Board is a group of AFRC engineers that conduct an independent review and assessment of the entire SOFIA aircraft configuration and operation and assure that proper, adequate planning and preparation have been accomplished, resulting in the project being conducted in an acceptable, safe manner. This review should include, where applicable, the design, fabrication, performance, and documentation of all software and hardware associated with the project as well as ground and flight operational procedures. Since this review is conducted by aircraft engineers with their emphasis on aircraft systems, the SIAT was established as a subcommittee of the FRR to understand and evaluate the airworthiness and safety aspects of the science instrument designs.

8.1.3 Airworthiness and Flight Safety Review Board

The Airworthiness and Flight Safety Review Board (AFSRB) is tasked with ensuring the flight safety of all projects conducted at Armstrong Flight Research Center. The AFRC Center Director appoints the chairperson and the members of the AFSRB. The AFSRB members are the line organizational Directors, ex Officio members, the Chief Pilot, and the Chief of the Safety Office. Other US Government personnel may be appointed to the AFSRB as necessary to provide a thorough review. The AFSRB will declare the airworthiness of the SOFIA aircraft for a given aircraft configuration—with an instrument or instruments installed—following a Technical Briefing (a.k.a. Tech Brief) on that configuration. Once SOFIA has received the airworthiness approval for an instrument from the AFSRB, it is unlikely the program will need to re-present on that instrument unless changes that affect airworthiness are made to the instrument configuration.

8.1.4 Instrument reviews

The SIAT will participate in the instrument development reviews (PDR, CDR, etc.) to provide guidance and voice concerns as early as possible in the instrument development process and documentation. See Section 7 for a discussion of the content of these reviews.

8.1.5 Construction, Inspection & Testing

Throughout the development of a science instrument, periodic inspection may be necessary to verify the compliance of instrument components with approved standards. This may include the selection of suppliers, instrument parts and materials, material quality, and test witnessing or review of test results. Members of the Science Instrument Airworthiness Team (SIAT) will be dispatched for physical inspection when necessary.

If significant changes are made to an instrument after the Science Instrument Airworthiness Team has reviewed the design, those changes should be communicated to the SIAT. It is preferable that the Science Instrument Airworthiness Review Team is informed of such changes prior to incorporating them on the science instrument. See Section 9.1 for a more detailed discussion.

Appendix A of this handbook includes a section that lists the items to be included in the science instrument Airworthiness Data Package.

8.2 System Safety

SOFIA System Safety Personnel will take information and airworthiness deliverables provided by the Science Instrument Team and generate initial hazard reports in standardized program templates. Identified hazards will be based largely on the products called for in the remaining sections of this chapter. The resultant hazard reports will be refined in the SSWG prior to being released for any subsequent reviews. The SOFIA System Safety Working Group (SSWG) will summarize residual risk scores from these HRs on AFRC Hazard Action Matrices. The Science Instrument Airworthiness Team reviews the work of the SSWG before it is presented to the appropriate organization or individuals for final assessment of risk acceptance. A more comprehensive treatment of the System Safety process can be found in Section 11.

8.3 Structural Load Analysis

The structure of the science instrument and its components should be able to withstand nominal and emergency conditions on the aircraft. These requirements include not only the science instrument itself but also any devices mounted in the counterweight rack and PI rack. To demonstrate an instrument's structural integrity, the instrument team will submit a structural analysis report providing the verification material to comply with the structural requirements (paragraph ID 3.5.2) in the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028).

The structural analysis report should contain analysis of region(s) in which the highest stress concentrations could exist or where damage or structural failure is most likely to occur. Although a finite element model can be used to help identify these areas, it is not required. Analysis should include all likely stresses, including some of the most commonly overlooked calculations (e.g. bending failure, pure bolt tension or shear, and shear tear-out values). For counterweight rack and PI rack equipment, focusing the analysis on the bolt and bolt attachment points of electronic devices may be adequate. An extensive analysis of the entire enclosing structure of these devices is usually unnecessary.

Drawings of design characteristics classified Critical per Section 11.1, Risk-Tailored Assurance Approach, are to be provided to the Science Instrument Airworthiness Team (SIAT) for review prior to the CDR. The drawing package should include both detailed and assembly drawings, and torque values should be specified for any fastener shown on a drawing.

8.3.1 Calculating Loads

Section 3.5.2.1 and Tables 3.5-1 and 3.5-2 of the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) contain the load factors and factors of safety to be applied for Science Instruments.

8.3.1.1 Mass & Center of Gravity

The mass and center of gravity of all mechanical systems is provided in the Structural Analysis Report. This information will be used to calculate weight and balance of both the SI Assembly and the Counterweight Rack, which is required for certification of the installed system onto SOFIA. The full operational range of weights and centers of gravity of the SI Assembly, Counterweight Rack, and PI Rack(s) should be documented prior to flight and final weighing will be performed Armstrong Building 703 prior to instrument installation.

8.3.1.1.1 Mass

A mass budget includes, for every item that is needed to produce a working instrument, a parts description, quantity used, and three mass categories: estimated, as designed, and as built. See Table 0-1 as an example. The "as designed" data is generally a weight calculation either hand calculated or acquired from a computer aided design (CAD) tool. The "as built" data should be entered as actual hardware is received and weighed. All inertial loads calculations should be performed with the maximum predicted weight plus a margin appropriate for the level of maturity and design uncertainty. This margin may be as high as 25% early in a project.

A note on using CAD to calculate mass properties: CAD systems often introduce small errors in calculating volume/mass of components by, for example, approximating complicated geometries by constructing discrete constant section divisions. The number of divisions can usually be controlled by the user. One should always verify first by performing hand calculation that the CAD properties are sufficiently accurate for the analysis.

Table 0-1: Example of a mass budget table

			MASS CATEGORIES (lbs)		
Drawing #	**Description**	**Quantity**	**Estimated**	**Designed**	**As Built**
9611200-1	0.0625" Stainless 304 Steel Plate	1	3.5	3.49	3.52
9611200-2	0.125" Stainless 304 Steel C-channel	1	5	4.87	4.95
9611200-3	0.375" diameter CRES rivets	8	1	0.97	0.98

8.3.1.1.2 Center of Gravity

The Center of Gravity (CG) of a system is the location of the mass center of its combined components. For illustration purposes, Figure 8.3.1.1.2-1 shows an example of a simple enclosed system where the CG location of each component relative to a reference line is known. If we assume that the weight and location (relative to some reference location) of each component are known, then the location of the CG of an instrument multiplied by the total weight is equal to the sum of the weight of each component multiplied by the CG distance of that component from the reference location. The total weight (W) is the sum of the individual weights (w_i) of the components.

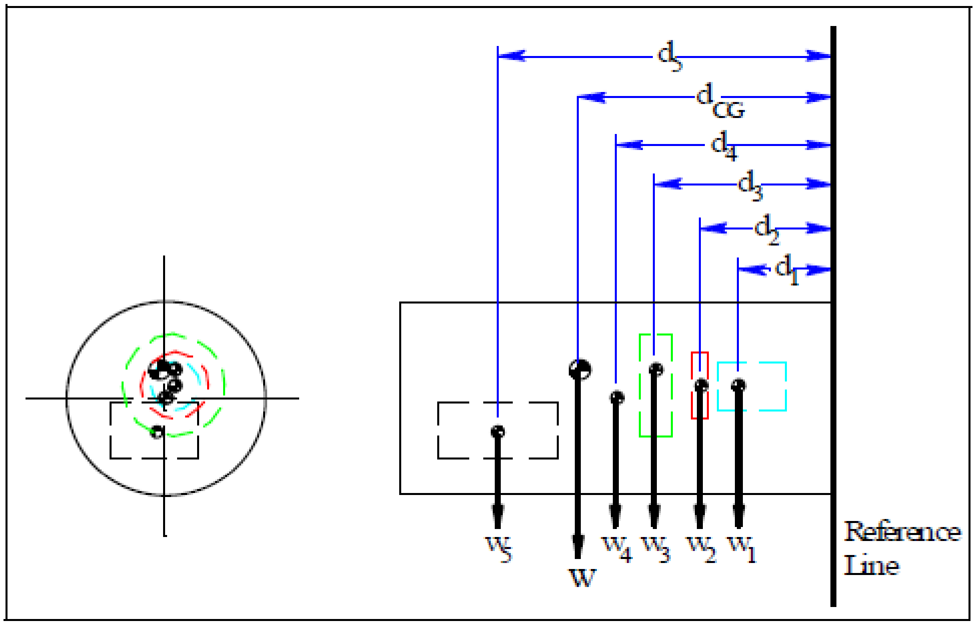

Figure 8.3.1.1.2-1: An example of center of gravity locations of each component and the entire system. The weight of the enclosure is w4.

The general equation for calculating an object's center of gravity is:

$$d_{CG} = \frac{\sum_{i=1}^{n} d_i w_i}{\sum_{i=1}^{n} w_i} \ .$$

Similarly, the CG location in the other two axes is obtained using the previous equation.

8.3.1.2 Load Path

A load path diagram is included in the Structural Analysis Report. Consider the assembly of significant mass components and how both external and connecting loads are applied to them. Trace load paths from the individual components all the way to the Instrument Flange. An example load path diagram can be provided upon request.

8.3.1.3 Free Body Diagram

The Structural Analysis Report should include a "Free Body" diagram that shows all applied loads, reactions, and any necessary dimensions for design characteristics classified Critical per Section 11.1, Risk-Tailored Assurance Approach. As an example, see Figure 8.3.1.3-1. Check critical portions of all load-carrying structure, using simplified structures such as beams or infinite plates, where possible.

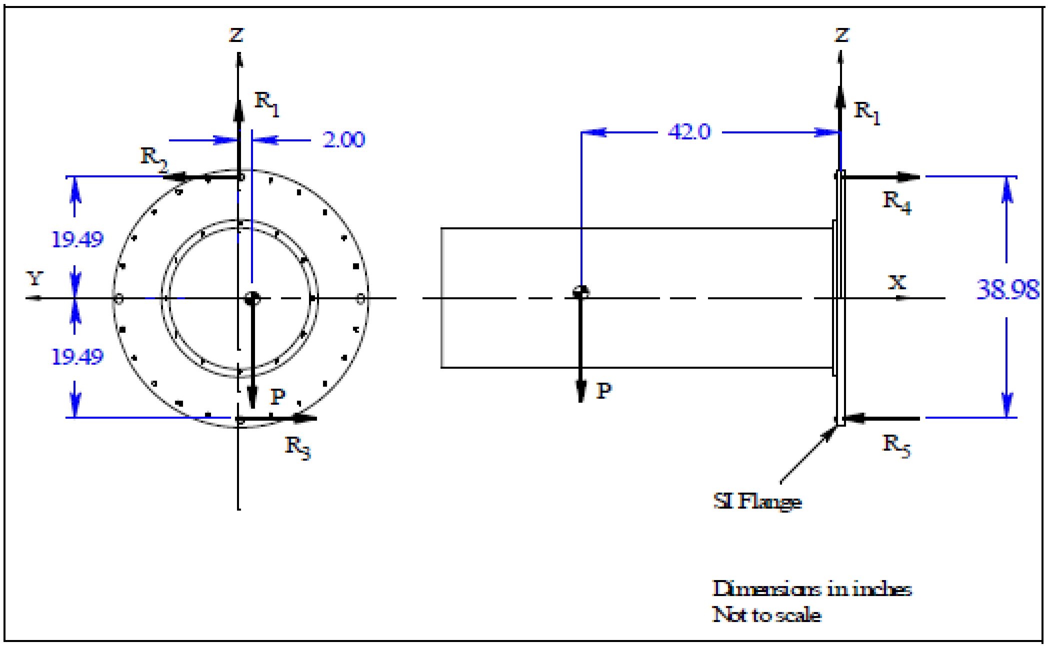

Figure 8.3.1.3-1: An example of a free body diagram

8.3.1.4 Reaction Forces

The Structural Analysis Report should include the calculations of the reaction forces at the instrument flange bolts and show that they have positive margin. (This should not require reaction force calculations for all 20 bolts.)

To the extent that the system can be adequately modeled as a statically determinate system (a system whose reaction loads distribution is unaffected by the system elasticity), use the following static loading equations of the sum of forces and moments equaling zero to determine reaction loads.

The following equations show summation of forces and moment as depicted previously in Figure 8.3.1.3-1.

P = loading factor x Weight (for example, 6.0G x 276 lbs.)

$\Sigma F_X = 0$: $R_4 - R_5 = 0$

$\Sigma F_Z = 0$: $R_1 - P = 0$

$\Sigma F_Y = 0$: $R_3 - R_2 = 0$

The summation of the moments about the centroid of the SI Flange is zero.

$$\circlearrowleft + \; M_X = 0: \; 19.49R_2 + 19.49R_3 - 2.0P = 0$$

$$\circlearrowleft + \; M_Y = 0: \text{ Etc.}$$

Overlapping assumptions can be used to simplify the analysis. For instance, when looking at a beam, assume that the ends are 'Simply Supported' for calculating maximum stress at the center of the beam, and assume that the ends are 'Fixed' for calculating maximum stress at the end attachments. Document any assumptions made and explain why such assumptions make the analysis conservative.

8.3.1.5 Science Instrument Flange & Fittings

The Structural Analysis Report should show that the SI Assembly Flange/Cryostat remains attached to the Instrument Mounting Flange (IMF) of the TA during the worst-case loading conditions defined by the Ultimate Load Factors listed in the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028). The dowel pins on the IMF should be used to carry all shear loads. Attachment bolts are supplied by the Observatory but the SI Flange should be designed to withstand the loads reacted by the bolts. The designers are not obligated to use all of the available bolts in the connection.

Per the *Telescope Assembly / Science Instrument Mounting Interface,* SOF-DA-ICD-SE03-037, Figure 4-1, the IMF is equipped with four dowel pins, two bolt patterns of twenty each clearance holes (one for use with nuts and the other for use with nut plates), and four jack screw holes. The instrument does not need to use all four dowel pins, but two should be used, one for position and shear support and the other for angular positioning. The pin specifications are documented in *Telescope Assembly/Science Instrument Mounting Interface*, SOF-DA-ICD-SE03-037. The fittings (bolts, nuts and washers) for installation are supplied by the Observatory.

The following data describes the type of bolt, nut and washers that will be supplied by the Observatory for mounting the SI Flange to the IMF:

Bolt: MS21250, tension, steel, external wrenching, flanged, 12-point, 180 ksi, 450ºF

Nut: NAS1804, self-locking, extended washer, double hexagon, alloy steel, 180 ksi, 450º F

Washers: NASM20002C8, countersink washer under bolt head, plated steel NASM20002-8, plain washer under nut, plated steel

Bolt strength: 180 ksi min ultimate tensile for alloy steel. For ½-20 bolt, the minimum ultimate strength is 30,900 lbs.

Installation Information:

Torque the nut (not the bolt) per L3 TPS 2-404 [14], 630-1070 in-lbs dry bolt, 440-650 in-lbs lubed bolt. If nut plates are used and bolt heads are wrenched, the installation torque should be the maximum torque indicated (i.e. 1070 in-lbs dry). Washers should be used under bolt heads and nuts when using nuts for installation. When using nut plates, washers should be used under bolt heads.

NOTE: Off-the-shelf nut plates that fit the IMF are not available. A custom plate that retains the NAS1804 nut will be fabricated and provided by the Observatory.

The total mass and CG of the SI Assembly / Cryostat should remain within the limits defined in *Telescope Assembly/Science Instrument Mounting Interface*, SOF-DA-ICD-SE03-037 paragraph 4.2.

8.3.1.5.1 Pressure Coupler

If the SI provides a pressure coupler to interface with the Pressure Window Subassembly of the TA, the mass load of the pressure coupler on the TA should not exceed the limit given in *Telescope*

Assembly/Science Instrument Mounting Interface, SOF-DA-ICD-SE03-037 paragraph 4.4.6. If interfacing with the hard points on the Gate Valve Pressure Plate (GVPP), analysis should be provided showing that the loads on each of the four (4) GVPP hard points do not exceed the limit or ultimate loads defined in *Telescope Assembly/Science Instrument Mounting Interface*, SOF-DA-ICD-SE03-037 paragraph 4.10.1.

8.3.1.6 Science Instrument Flange Failure Modes

Several calculations may have to be made to determine local stresses in the flange around the pins and bolts. These provide stress estimates in areas of possible failure. Possible failure modes around the pins are modeled after lug-and-shear pin analysis, commonly used in the aircraft industry. A typical lug is shown in Figure 8.3.1.6-1. The analysis of lugs and shear pins provides a conservative approach in determining failures of a flange. In general, SI Flanges do not really approximate a true lug as the radius of the flange is large relative to the diameter of the pin. Typical joint failures for lugs are shown in Figure 8.3.1.6-2. The possible failure modes are:

- Tension failure (applicable for true lug; can be omitted for flange analysis)
- Shear tear-out of the flange at pin location
- Bearing failure of flange at pin location
- Bolt loads

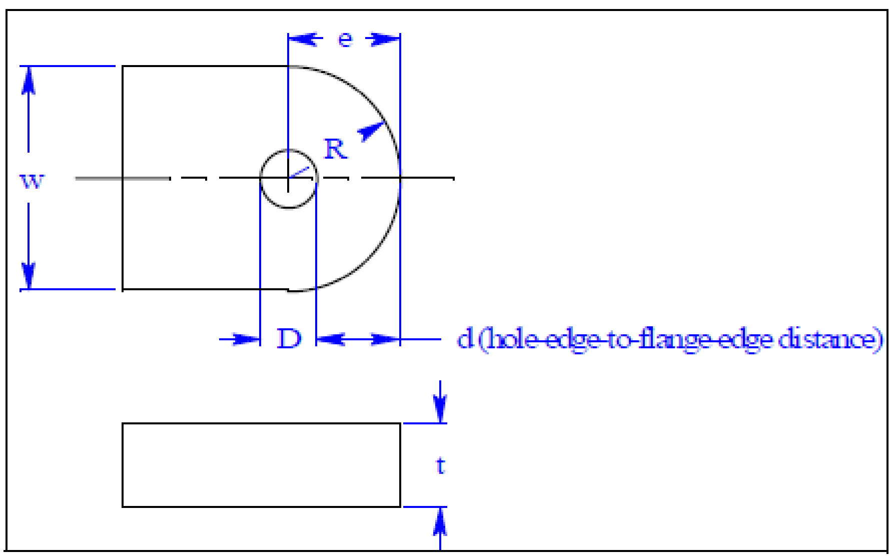

Figure 8.3.1.6-1: A typical single pin lug. The edge distance measured from the center of the pin hole to the edge of the flange along the centerline (e).

When a flange is in compression, it may fail due to crippling, which is a local failure. Crippling is generally a problem only when the flange width is much larger than its material thickness (b/t >=15, where b = flange radial width and t = flange thickness). It may also fail due to long or short column buckling. Methods for determining these critical stresses are not discussed in this section, but can be found in Bruhn's Analysis and Design of Flight Vehicle Structures.

In shear tear-out, a piece tears out from the hole to the flange edge. Using simplifying assumptions, calculate the shear load that the shear pins should withstand and show that they will survive.

Bearing refers to a contact area in a fitting, as between a shear pin and flange, where compressive loads are transmitted between concentric parts. Calculate the bearing loads that the shear pins should withstand and show that those loads are within margin.

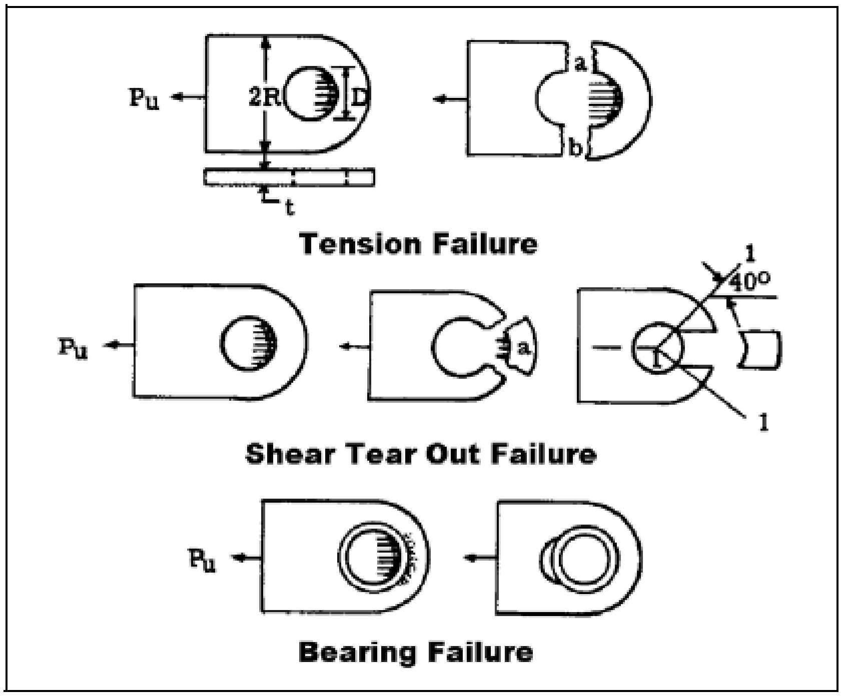

Figure 8.3.1.6-2: Typical joint failures for lugs

8.3.1.7 Counterweight Rack Components and CG Limits

The Counterweight Rack (CWR) is available to the Instrument team to mount electronic equipment to be used on board the telescope. Figure 8.3.1.7-1 is a photograph of a counterweight rack. The rack will be loaded with equipment on the ground then mounted to the TA’s Balancing Main Plate, commonly known as the Counterweight Plate (CWP).).

Figure 8.3.1.7-1: A counterweight during installation on the telescope

The total weight of the CWR and the electronic equipment should not exceed the limit specified in *SI Equipment to Counterweight Rack ICD*, SCI-US-ICD-SE03-2027, paragraph 4.1(a), and *SI Equipment Rack / TA Counterweight Interface*, SOF-DA-ICD-SE03-051, paragraph 3.1(f). The CWR is mainly constructed out of extruded Aluminum 6061-T6. Detailed specifications on the loads and mounting of equipment on to the rack can be found in the interface controlled document *SI Equipment Rack / TA Counterweight Interface*, SOF-DA-ICD-SE03-051.

The center of gravity (CG) of the SI equipment payload in the CWR should be within the limits specified in SI_CWR_01 paragraph 4.1(b). If this is to be verified at the integrated CWR level (i.e., by test instead of analysis) without the center support struts, the center of gravity of a populated CWR should be within the limits specified in TA_SI_05 paragraph 3.1(g).

The Structural Analysis Report should include an analysis that shows that any equipment attached to the rack will not break loose from the rack in the worst-case loading conditions defined by the Ultimate Load Factors listed in the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028). As specified in SI_CWR_01 paragraph 4.1(e), equipment should be attached to the CWR using aircraft-certified hardware, and an analysis should be provided showing that the fastener hardware will withstand the maximum loads. Single attachment points should not exceed the maximum loads specified in SI_CWR_01 paragraph 4.2(b).

8.3.1.8 PI Rack Components, Weights & Overturning Moments

A Principal Investigator (PI) Rack will be available to the Instrument Team to mount electronic equipment. As many as three PI Racks of equipment can be physically accommodated on the main deck. Figure 8.3.1.8-1 shows a PI Rack. These racks are constructed to accommodate standard 19-inch wide front-panel mounted chassis boxes and custom-fabricated trays. These trays will be available to the Instrument teams for equipment mounting, or the Instrument Team may provide their own. Structural analyses have been performed to determine the load and moment limits for the chassis and tray. These numbers can be found in *Principal Investigator Equipment/Rack to AS Interface* (SOF-DA-ICD-SE03-2015), paragraphs 4.5 and 4.6.

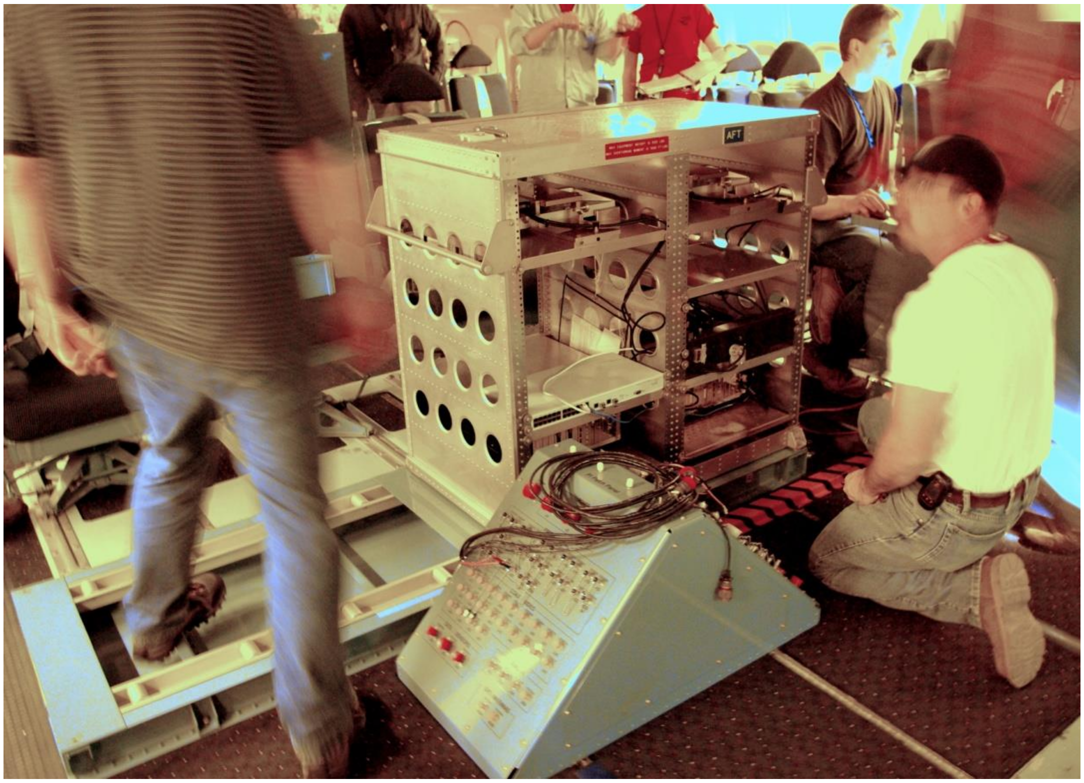

Figure 8.3.1.8-1: A PI rack during installation

Principal Investigator Equipment/Rack to AS Interface (SOF-DA-ICD-SE03-2015), paragraph 4.3, specifies the maximum total weight of the PI rack.

The Structural Analysis Report should include an analysis of the rack overturning moment, determined by calculating the moment contribution from all equipment placed in the rack including chassis and tray assemblies as well as free-standing (i.e., non-rack mount) equipment that may be fastened to the top of the rack. The moment contribution of each item is measured from the moment reference at the base of the rack (the top face of the support pallet) and should not exceed the limit defined in *Principal Investigator Equipment/Rack to AS Interface* (SOF-DA-ICD-SE03-2015), paragraph 4.4.

The Structural Analysis Report should include an analysis that shows that any equipment attached to the rack will not break loose from the rack in the worst-case loading conditions defined by the Ultimate Load Factors listed in the Cabin / Airframe column in *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028). As specified in *Principal Investigator Equipment/Rack to AS Interface* (SOF-DA-ICD-SE03-2015) paragraphs 4.5 and 4.6, fastener hardware used to attach support trays and SI equipment to the PI rack should be aircraft-certified, and an analysis should be provided in the Structural Analysis Report showing that the fastener hardware will withstand the maximum loads. Aircraft-certified hardware should be used to attach any free-standing equipment to a support tray. Any chassis unit that has slotted attachment holes in the chassis face plate should use a pair of bearing angles or large area washers at all such attachment hole locations.

Sliding rails may also be used for attachment of SI hardware to the PI rack (e.g., for computer keyboards and displays to be deployed to the slide-out position during flight) or used internally within SI hardware. When sliding rails are used, an analysis showing airworthiness of the sliding rails should be provided by the Instrument Team, per *Principal Investigator Equipment/Rack to AS Interface* (SOF-DA-ICD-SE03-2015), paragraph 4.7.1. Sliding rails should be lockable in the stowed position. For equipment used in the slide-out position for prolonged periods of time in flight, the sliding rails should be lockable in the slide-out position.

8.3.2 Margins of Safety

The stress calculations in the Structural Analysis Report should use a Margin of Safety (MS) according to the formula:

$$MS = \frac{\text{allowable stress}}{\text{applied stress}} - 1 = +X.X$$

Margins of Safety are always rounded down (e.g., +0.107 is +0.10). Any non-negative MS values are acceptable. Margins of Safety should be calculated for tension, bending, shear, torsion, etc. When parts are under combined loading, depending on the type of loading involved, a resultant or total load should be used in determining the Margin of Safety. For analysis involving fittings, a special factor such as a fitting factor or bearing factor should be included in the design or applied stress. Only one special factor would be used at one time, not in combination. The Margin of Safety with fitting factor is as follows:

$$MS = \frac{\text{allowable stress}}{\text{applied stress x fitting factor}} - 1 = +X.X$$

where the fitting factor is 0.15. (A fitting factor applies to fastened joints with large numbers of fasteners. Since holes for the fittings are a bit oversized, it is unrealistic to expect all the fasteners to carry the load. The fitting factor is an additional margin required to account for this.)

When accounting for a design safety factor, the typical Margin of Safety formula is the following:

$$\text{MS} = \frac{\text{Design Allowable Stress (material)}}{\text{Max Stress (von Mises) x Design Safety Factor}} - 1 = +\text{X.X}$$

where the Design Allowable Stress is the allowable material strength for yield or ultimate depending on the Margin of Safety being calculated, Max Stress is calculated from FEA or another method of analysis, and Design Safety Factor is specified such as in paragraph 3.5.2.1 and Table 3.5-2 of the *SOFIA Science Instrument System Specification SOF-AR-SPE-SE01-2028*. For ductile materials (e.g., most metals), it is required that the factor of safety be checked against both yield and ultimate strengths. The yield calculation will determine the safety factor until the part starts to plastically deform. The ultimate calculation will determine the safety factor until failure. For brittle materials these values are often so close as to be indistinguishable, so it is usually acceptable to only calculate the ultimate safety factor. Note when calculating Margin of Safety for Ultimate Load Factors, a Design Safety Factor need not be applied.

8.3.3 Summary

The Structural Analysis Report includes the following information:

- Specific calculations showing how results were produced
- Statement(s) explaining if component masses were determined by measurement (test) or calculation (analysis)
- A summary table of the calculated margins of safety
- A list of assumptions used in calculating margins of safety
- A copy of all hand-calculated stress values – handwritten notes do not need to be typed
- A copy of all computer calculated stress values – should include enough information that would allow an independent reviewer to understand it and identify any errors

8.3.4 Welding Certification

All structural welds should be completed by a certified welder who adheres to a Program recognized standard. Science Instrument Teams should be prepared to show the standard to which all welds conform and documentation proving that the weld has been inspected and is acceptable according to that standard. Examples of certifying organizations include the American Welding Society (AWS), American Society for Testing & Materials (ASTM), National Aerospace Standards (NAS), American National Standards Institute (ANSI), and the Society of Automotive Engineers (SAE). Where inspection is required per *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028), the Structural Analysis Report should include proof of weld integrity (e.g., the results of a dye penetrant test, ultrasonic inspection, x-ray or gamma radiographic inspection, magnetic particle inspection, borescope inspection, infrared imaging, or hardness testing). If necessary, consult with the Science Instrument Airworthiness Team (SIAT) for clarification of which inspection type is most appropriate for your instrument.

8.4 Pressure Vessels

The Structural Analysis Report includes analyses of all pressure vessels. These include the cryogenic reservoir (inner vessel) if applicable, and the cryostat shell (outer vessel). The analyses should include:

• Stress analysis on the inner vessel due to internal pressure loads.

• Stress analysis on the outer vessel and window due to the combined loadings of external pressure and emergency landing (inertial) loads. (This will suffice to verify the SI's contribution to the aircraft cabin's pressure containment.)

Cryogenic reservoirs should be designed to safely vent the cryogen boil off into the cabin in the event of sudden vacuum loss. Other failure modes, such as formation of an ice plug in the fill/vent tubing, window breakage, and O-ring failure, should be considered while designing a cryostat.

The gate valve of the Telescope Assembly normally acts as the pressure barrier between the outside atmosphere and the cabin of the SOFIA aircraft. When the valve is open, however, the science instrument then becomes the pressure barrier. This is one example that demands pressure testing of certain science instrument components to ensure safety of the crew and aircraft. Cryogen dewars, or cryostats, are the other most common form of pressure vessels in a science instrument that are also required to undergo pressure testing. Pressurized liquid cylinders that are transported are to be designed and fabricated in accordance with the United States Department of Transportation (DOT) specifications and are subject to applicable DOT regulations.

The main structures of a cryostat may be divided into two parts: the cryostat shell and the internal components. The inner components may mainly consist of cryogenic reservoir(s) and optical/mechanical components. The cryostat should be analyzed to show that it will not fail catastrophically due to the worst-case inertial loads, the pressure loads, and the combination of both. In addition to the analysis, the cryogenic reservoirs are required to undergo qualification and acceptance pressure tests as described later in this section. The structural analysis should incorporate the material properties at low temperatures when applicable.

8.4.1 Stress Analysis due to Internal Pressure Loads

Pressure on the wall of a cylindrical container produces a combined stress state, with the principal stresses being the hoop stress and the longitudinal stress as shown in Figure 8.4.1-1.

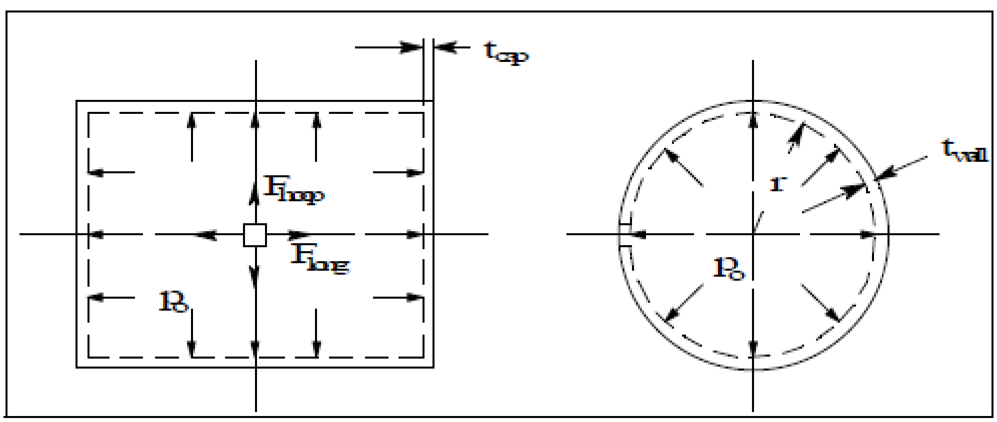

Figure 8.4.1-1: A cylindrical vessel with flat end caps. The small square section indicates an element in the cylindrical wall.

The hoop stress is given by:

$$F_{hoop} = \frac{pr}{t}$$

where p is the internal pressure, r the cylinder radius, and t the wall thickness. The longitudinal stress is:

$$F_{long} = \frac{pr}{2t}$$

The required thickness is then selected to lower the combined stress level below the material allowable stress levels.

Note: The stresses above are valid for thin-walled vessels only, where $\frac{r}{t} > 10$.

There are multiple failure criteria for combined stress fields. The most commonly used is the Maximum-Distortion-Energy (von Mises) stress criterion, which calculates a value that may be compared to uniaxial strength test results from the principal stresses. The equation is:

$$F_{comb} = \sqrt{F_{hoop}^{\ 2} - F_{hoop} F_{long} + F_{long}^{\ 2}} < F_{yield}$$

For the present case (cylindrical vessel), where F_{hoop} is twice F_{long}:

$$F_{comb} = .866\, F_{hoop} < F_{yield}$$

Using the equation above, the thickness of a cylindrical vessel can be obtained.

If a science instrument includes any cylindrical pressure vessel with flat ends (rather than hemispherical), calculate corner stresses using methods other than hoop stress. Finite element analyses are certainly acceptable, and if that is not possible refer to Roark’s Formulas for Stress and Strain by Warren C. Young. In the Sixth Edition of this book, Tables 28 and 29 include formulas for stress and moment calculations of cylinders with flat ends. More information can be provided upon request.

8.4.2 Pressure Loading

There are two kinds of pressure loading to consider: cryostat internal pressure and cabin differential pressure.

8.4.2.1 Cryostat Internal Pressure

The SI Cryostats and cryogenic reservoirs are considered pressure vessels and are subject to qualification and acceptance requirements specified in *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) paragraph 3.5.3.3, Qualification and Acceptance of Pressure Vessels and Pressurized Systems (PVS). These requirements are based on factors of the Maximum Normal Operating Pressure (MNOP) for liquid nitrogen reservoirs and factors of the maximum pressure, or P_{max}, for liquid helium reservoirs. For example, for a nitrogen cryogenic reservoir in a vacuum cryostat vessel and vented to the cabin atmosphere at sea level through a 1.0 psi relieve valve, the maximum normal operating pressure may be 14.7 + 1.0 = 15.7 psi. The maximum pressure for a helium reservoir is more dependent upon the instrument configuration including pressure relief devices, surface area of the reservoir, assumed heat flux values, and other criteria. Instruction for calculating the maximum pressure for helium reservoirs can be found in Appendix C of the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028).

8.4.2.2 Cabin Differential Pressure

Since the SI Cryostat will usually act as a cabin pressure containment component during flight, it is subject to the same rules as the rest of the cabin pressure enclosure in the aircraft. The rules state that the structure should be designed to be able to withstand the pressure differential loads corresponding to the cabin maximum emergency relief pressure setting multiplied by a factor of 1.33 for Limit Pressure Load and by a factor of 1.33 x 1.5 for Design Ultimate Pressure Load. The maximum emergency relief pressure of the cabin is set at 9.4 psid.

The IMF-mounted components are typically configured with an evacuated cryostat that houses the IR detector and is separated from the cavity pressure by a vacuum window. For this part of the system the cabin pressure containment occurs in two stages: the cryostat shell (with normal operating pressure difference equal to the cabin absolute pressure) and the window (with normal operating pressure difference equal to minus the cavity absolute pressure). For airworthiness considerations, one could choose to consider just one of the two barriers active and assume the other has failed. This means that one could consider either the cryostat shell or the window as the barrier with a maximum working pressure of 9.4 psi.

A more conservative and realistic approach is to choose only one of the barriers as cabin pressure containment, and take its maximum expected operating pressure to be 14.7 psi (rather than 9.4 psi), which is the pressure that it sees on the ground with the cryostat evacuated in sea level atmospheric pressure. For the part of the IMF-mounted instrument that does not provide this two-part containment (for example, an unpressurized optics box as shown in Figure 8.4.2.2-1), the maximum expected operating pressure of 14.7 psi should still be used, since the INF / IMF may be evacuated with the on-board vacuum pump. The pressure barrier should be analyzed to the following pressures:

Limit Pressure Load = 1.33 x 14.7 = 19.6 psi

Design Ultimate Pressure Load = 1.5 x 1.33 x 14.7 = 29.4 psi

The pressure containment of an SI should not experience yield stresses when Limit Pressure Load is applied. The ultimate stress in the containment material may not be exceeded when Design Ultimate Pressure Load is applied.

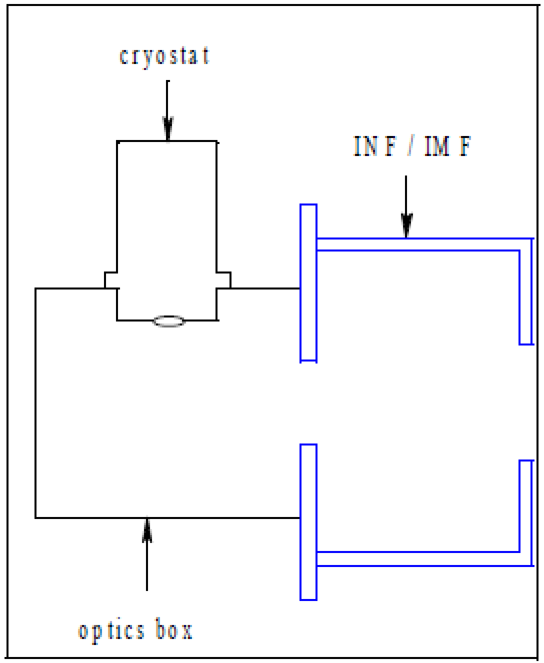

Figure 8.4.2.2-1: Schematic drawing of an instrument mounted on the telescope INF with unpressurized optics box as the cabin pressure barrier

When the gate valve is open and the science instrument is the pressure boundary, use the following Design Ultimate Pressure value to be certain that the strength of the instrument construction will be sufficient:

Table 8.4.2.2-1: Design ultimate pressure values

Parameter	Pressure Limit (psi)
Max Cabin delta Pressure (dP)	8.90
Emergency Relief Pressure (P)	9.4
Max Emergency Relief Pressure	9.75
Design Ultimate Pressure	2 x P = 18.8

The *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) paragraph 3.5.3 contains requirements on pressure vessels.

Relief valves will also be periodically inspected and retested for proper operation. All relief valves should be examined externally for corrosion, damage, plugging of external relief valve channels, mechanical defects, and leakage. Records of these inspections and retests should be kept on file.

Any relief devices that are part of the science instrument system should be capable of venting the full flow (the maximum vent pressure should be less than the proof pressure). If a liquid Helium reservoir is used, see *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) paragraph 3.5.3.2 and Appendix C of the specification.

8.5 Electrical Systems

Although it is not required to use particular types of wire or connectors, the preference of Armstrong is to use aircraft-approved wiring such as MIL-W-16878/4 with Teflon insulation and MIL-C-38999 Series I or II connectors. An excerpt from the NASA Armstrong procedures for selecting wires, connectors, building electrical assemblies, and installing wires follows here as design guidance.

8.5.1 Wires

Preferred wire types are:

MIL-W-16878/4 (type E) silver-coated stranded copper conductor with extruded polytetrafluoroethylene (PTFE) insulation or equivalent. This does not include polyvinylchloride (PVC).

- Wire stranding is recommended to be the maximum number available by specification for the particular wire size concerned.
- Shielding is recommended to be of silver-coated braided copper construction with 90% minimum coverage.
- Where required, cable jacketing is recommended to be of polytetrafluoroethylene (PTFE) material.

Cables and other multiconductor assemblies are recommended to be fabricated from the basic components listed in Military Specification MIL-W-16878D (uses MIL-W-16878 conductors) or MIL-C-27500 (uses MIL-W-22759), as required.

For example: M27500 V 22 RC 4 S 06

M27500 – Cable specification identification number.

V – Color code of inner conductors; to be specified by the purchaser.

22 – Gauge of the conductors within the cable assembly.

RC – Manufacturer is to construct cable using MIL-W-22759/11 conductors; silver coated copper wire with PTFE insulation.

4 – Number of individual conductors in the cable’s construction.

S – Specifies single silver coated copper shielded cable with 90% coverage.

6 – Cable with PTFE tape wrapped, 200°C, jacket material.

8.5.1.1.1 Wire Selection

Select wire so that the rated maximum conductor temperature is not exceeded for any combination of electrical loading, ambient temperature, and heating effects of bundles, conduit, and other enclosures. Factors to be considered in the selection are: operating voltage, circuit current, temperature, mechanical strength, voltage drop, abrasion, flexure, and pressure altitude requirements.

Wires will be of sufficient size to ensure that they will provide adequate current-carrying capability and that voltage drops will be within limits required to provide satisfactory operation of equipment.

Voltage drop effects should be carefully considered during wire gauge selection, especially when low-impedance devices (such as multiple strain gauges, meter movements, etc.) or long wire runs are used. To avoid unnecessary weight, use the smallest size wire compatible with operational and performance requirements. Wire selection guidance is contained in Section 6 of SAE AS50881, including wire current capacity derating factors such as altitude and wire bundling effects.

8.5.1.1.2 Minimum Wire Size

It is recommended that:

Wires smaller than 24-gauge not be used except for multiconductor cables and when specified for design purposes.

Wire smaller than size 22-gauge not be used where it will be subject to excessive vibration, repeated bending, excessive handling, or frequent connection/disconnection at terminals.

Single conductor wire smaller than size 22-gauge not be routed in bundles with fewer than three other wires be adequately supported at the terminators.

Wiring coated in polyvinylchloride (PVC) insulation is prohibited due to toxic threats that exist when PVC burns. See the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) paragraph 3.10.2.2.1 for details.

8.5.2 Connectors

Stowed detached connectors within a science instrument are recommended to follow the same guidelines of the aircraft, which are:

- Clamp stowed connectors to structure members, tie to cable runs. Take special care to ensure that fluids cannot enter the connector. Use drip loops and/or other protective measures.
- When connectors are tied to wiring runs, protection against abrasion or damage by the connector adapter or backshell may be provided by the use of tape or other approved anti-chafe materials firmly secured around the concerned connector areas.
- Connectors should not be tied to a wire bundle of less than one-half the diameter of the connector.
- Where possible, stowed connectors should be visible for inspection.
- Protect connectors while stowed by the use of protective covers or by wrapping and securing with environment-compatible materials.
- Plastic dust covers are not a substitute for metal protective covers or adequate wrapping methods and will not be used on articles intended for flight.
- For connectors mounted on pressure bulkheads, see the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028) paragraph 3.10.2.3.

8.5.3 Assemblies

An electrical assembly contains electronic components used for interfacing between the aircraft or its subsystems. The following guidelines are recommended for the general installation of electrical parts that incorporate wiring and are installed in boxes, chassis, circuit boards, and similar equipment:

- Parts leads should be free of dirt, grease, oxides, scale, or other contamination. All surfaces to be soldered should have a bright appearance.

- Leads should be formed so that all except very small parts are mounted flush to a chassis or circuit board.
- Leads should have stress bends. At least one-sixteenth (1/16) inch of the lead next to the part body will not be bent. The bend in the lead will have a radius not less than 2 times its diameter.
- Part leads should be insulated by sleeving if a possibility of shorting to an adjacent terminal, part, or surface exists.
- Whenever possible, attach part leads such that the part identification information is visible after the assembly is completed.
- Solid hookup or bus wire should be avoided. If solid hookup or bus wire is specified due to design or installation requirements, the solid hookup or bus wire should be rigidly supported for lengths greater than one inch.
- Secure flexible, insulated part leads when their exposed length exceeds one inch.
- Support wiring so that soldered connections are not subjected to mechanical loads.
- Shaft-mounted parts should not be warped, distorted, nor have threads stripped by the tightening of the shaft nut.

Unless otherwise specified, parts should be secured by means other than their leads when the following conditions apply:

- The weight of the part is one-half ounce or greater.
- The total length of the part leads exceeds one inch for two leads, one and one-half (1 ½) inch for three leads, or two inches for four leads.

The hardware used for mechanically mounting parts should incorporate provisions to prevent looseness or movement from vibration, including the use of self-locking nuts, lock washers, adhesives, and similar materials. When utilized, lock washers should not bear directly on nonmetallic surfaces

When self-locking nuts are used, round or chamfered-end hardware should extend at least the full round or chamfer through the nut. Flat-end hardware will extend at least one full thread through the nut. The nut should not bottom out against the grip or shank portion of the fastener. Nylon insert type self-locking nuts will not be used on electrical terminals.

8.5.4 Wiring Installations

When installing wiring in the science instrument, the following guidelines are recommended:

- Do not route AC and DC wiring in the same bundle and, wherever possible, do not route in close proximity.
- Route audio and similar wiring of radio communication equipment separately from wiring of other equipment, where feasible.
- Separate antenna cables from any other antenna cable or cable group, where feasible.
- Wiring and ground return paths will be installed so as to minimize EMI.
- Route wiring to equipment performing duplicate functions separately to prevent damage to one system affecting the other, where feasible.

The design of SOFIA aircraft electrical systems utilizes a variety of standards adopted and instituted by the NASA Armstrong Flight Research Center. The following guidelines are recommended for the development of science instruments that are destined to be installed on SOFIA:

MIL STD 704	Defines the power characteristics and distribution of aircraft electrical power.
MIL-C-38999	Defines the specification for hermetically sealed connectors, electrical, circular, miniature, and high density (Ref. Section 3.4)
MIL-STD-461E	Defines the requirements for the control of Electromagnetic Interference Characteristics of Subsystems and Equipment (Ref. Section 2.2/3.5.6)
MIL-STD-810	Defines the Environmental Engineering Considerations and Laboratory Tests (Ref. Section 2.2)
MIL-W-16878F (1)	Defines the specification for wire type, insulation, selection, and size, (FSC: Electrical Wire and Cable) (Ref. Section 3.4)
NASA-STD-8739.3	Defines the criteria of soldered electrical connections, the training and certification of technicians and soldering inspection personnel
NASA-STD-8739.4	Defines the criteria of crimping, making interconnecting cables, harnesses, and installing wiring
SAE AS50881	Defines the design and installation considerations for aerospace wiring and wiring systems.
DOP-O-401	Defines additional guidance on specific Armstrong flight research and modification requirements that are not covered in standard production aircraft maintenance manuals

8.5.5 Solder & Flux

NASA Technical Standard NASA-STD 8739.3, Change 3, contains guidelines for soldered electrical connections, as excerpted below.

8.5.5.1 Solder

Types and Usage: Solder used for tinning and solder connections should conform to ANSI/J-STD-006. Flux-cored solder is recommended to be either composition SN60 or SN63 containing flux types R or RMA, or equivalent. For all soldering applications where adequate subsequent cleaning is not practical, solder containing flux type R should be used. Solid solders (no flux) for use in solder pots should be of the same composition.

High Temperature: For soldering operations where connections are to be subsequently reheated, the use of high temperature solder alloy is permitted (e.g., SN96AG04A). The type of high temperature solders and the connection requiring the high temperature solder should be specified on the engineering documentation.

8.5.5.2 Flux

Types and Usage: it is recommended that all fluxes used for tinning and soldering operations conform to ANSI/J-STD-004.

Rosin Flux. Flux types R, RMA, or equivalent should be used. For all fluxing applications where adequate subsequent cleaning is not practical, only type R, or equivalent, flux should be used. Liquid flux used with flux-cored solder should be chemically compatible with the solder core flux and with the materials with which it will come in contact.

8.6 Radiation

For the purpose of this document, ionizing radiation generally refers to radioactive sources where non-ionizing radiation refers to light sources (i.e., arc lamps or lasers). Any ionizing radiation emitted from a science instrument should abide by regulations established in Armstrong Centerwide Procedure DCP-S-009 Chapter 11. This document will assist with direction to obtain a Nuclear Regulatory Council (NRC) license for radioactive materials, ensuring proper security is applied to the instrument with such material, and also defines what regular inspection and testing criteria are required to safely maintain the instrument.

Science instruments using any Class 3B or higher class laser that emits energy external to the SI should indicate so in the System Safety Analysis.

The general laser classifications are:

Class 1 Laser – considered to be incapable of producing damaging radiation levels, these are exempt from any control measures or forms of surveillance with the exception of applicable requirements for embedded lasers.

Class 2 Laser – low power and divided into two subclasses, 2 and 2a. A Class 2 laser emits in the visible portion of the spectrum (0.4 – 0.7 µm) and eye protection is normally afforded by the aversion response, including blink reflex.

Class 3a Laser – medium power lasers and laser systems. A Class 3a laser normally would not produce a hazard if viewed for only momentary periods with the unaided eye. This class of laser may present a hazard if viewed using collecting optics.

Class 3b Laser – medium powered lasers and laser systems. A Class 3b laser can produce a hazard if viewed directly. This includes intra-beam viewing of specular reflections. This class laser does not usually produce a hazardous diffuse reflection.

Class 4 Laser - high power and a hazard to the eyes and skin from direct beam and to the eyes from diffuse reflection. Class 4 lasers can also be a fire hazard.

8.7 Cryogens

Use of cryogens at Armstrong Building 703 and onboard the SOFIA aircraft may differ from the rules by which Science Instrument Teams currently operate. Armstrong Flight Research Center abides by industry standards for use of cryogenic materials and should comply with local regulations for hazard communications and aircraft safety. See *Cryogen Handling Procedure* (USRA-DAL-SSMOC-MOPS-PRO-2115), for the handling of cryogens in the laboratory. Each Science Instrument will have a written procedure for cryogen servicing in the Building 703 laboratories and onboard the SOFIA aircraft. See *Science Instrument On-Aircraft Cryogen Fill Procedure Template* (USRA-DAL-SSMOC-SCIN-PRO-1042), for a template for the development of an instrument-specific cryogen fill procedure for on the aircraft.

8.8 Software Airworthiness

The Science Instrument Airworthiness Team (SIAT) is primarily focused on software hazards whose severity is not reduced by the Mission Controls & Communication System or (MCCS), such as an instrument inadvertently commanding itself into a configuration that poses a threat to the aircraft or crew. The System Safety Analysis should show that the instrument software meets the following safety criteria:

- That instrument software does not cause or contribute to the science instrument system or aircraft reaching a hazardous state
- That instrument software does not fail to detect or take corrective action if the instrument system does reach a hazardous state
- That instrument software does not fail to mitigate damage if a failure occurs

To perform an adequate review, the System Safety Analysis should include:

1. A functional description of the instrument software, especially the software and hardware interfaces
2. An analysis that shows the hazardous effects of software faults (Fault Tree analysis or Failure Modes & Effects analysis)
3. Design details of any hardware mitigations to any software faults
4. Plans and/or results of tests designed to verify the effectiveness of any mitigation

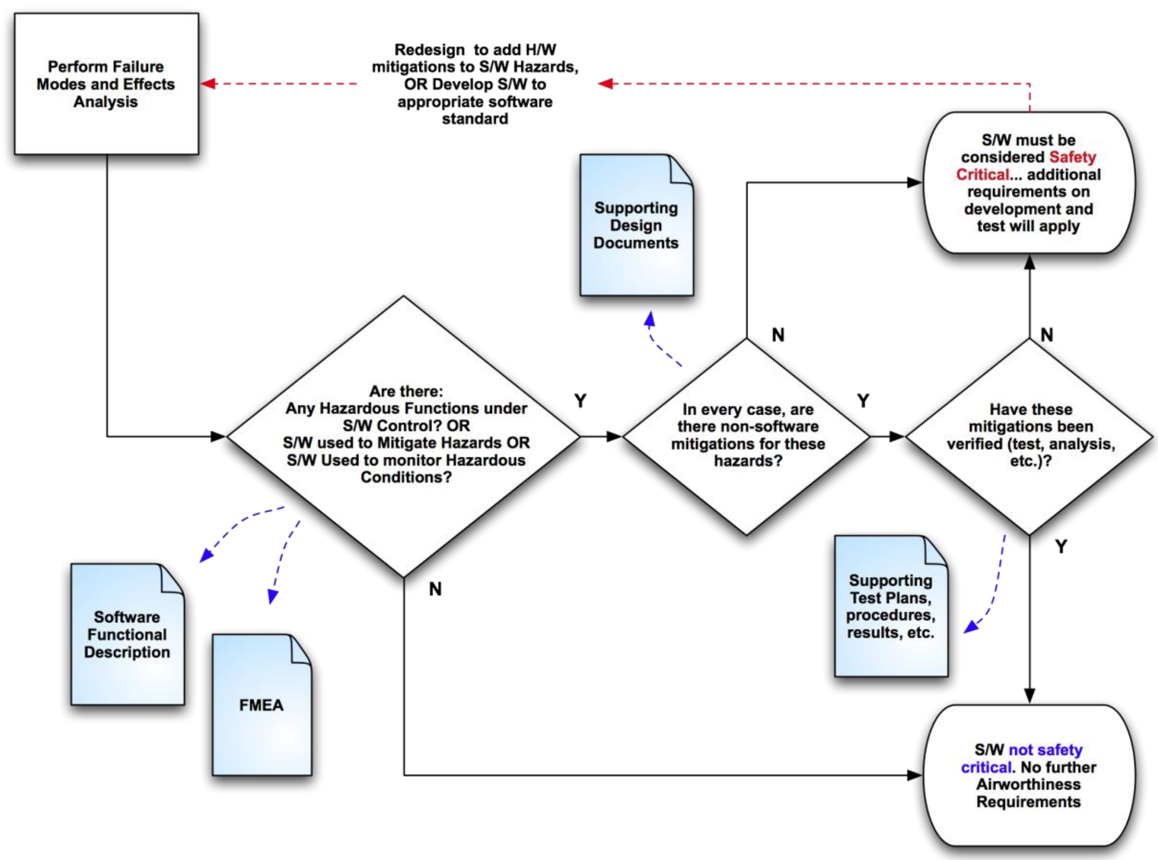

Figure 8.8-1: Software airworthiness flow diagram

To ensure the safety of the aircraft and crew, additional requirements may be levied if the science instrument software is capable of:

- Causing a hazardous condition
- Preventing or controlling a hazardous condition
- Is the only method of detecting an actual or impending hazardous condition

In preparation for installation on the SOFIA aircraft, the instrument configuration, including the software versions loaded, will be documented.

Table 8.8-1 is an example of a software functional hazards analysis that should be included in the System Safety Analysis to aid the SIAT in understanding the operation of the science instrument. This is a list of software hazards produced by the HIPO Science Instrument Team while undergoing airworthiness review. (Note: SE09-081A_HIPO_SSA is for reference only).

Table 8.8-1: An example software functional hazards analysis

Function	Software Role	Hazard(s)	Mitigation
Detector Operation	Controls voltage level and clock waveforms sent to the detectors	Detector damage and/or fire caused by excessive voltage	Hardware incapable of generating unsafe voltages
Detector Temperature Stabilization	Controls heater voltage	Excessive voltage supplied to heater, causing instrument detector damage, premature nitrogen boil-off, and fire	Maximum voltage is 10 VDC, which is insufficient to cause fire. Heater complete contained within evacuated dewar. Nitrogen boil-off rate significantly less than rate that would occur if dewar vacuum was lost
Filter Wheel Position	Controls filter wheel rotational position via stepper motor	Continuous rotation of filter wheel, overheating motor and/or controller	Motor current limited by motor driver unit, motor driver unit is fused
Camera Lens Position Control	Controls position of camera lenses within optical box via stepper motor	Lens stage overruns limit switches, stalling against filter wheel or front wall of dewar and overheating as a result	Motor current limited by motor driver unit, motor driver unit is fused
Interface with Instrument Operator	Interface is via software	None	N/A
Store Acquired Data	Writing to local disks, sending data across network	None	N/A
Interaction with other SOFIA systems via MCCS	Interfaces with other SOFIA systems via SCL	None	Mitigated by MCCS design

8.9 SOFIA Contacts

As a Science Instrument Team pursues airworthiness certification, inquiries to SOFIA team members can be made at any time. Contact the SI Development team at Ames Research Center or your COR with technical questions. Those technical questions will be forwarded to the appropriate technical expert.

9 Instrument Change Control

After the instrument team has submitted their airworthiness documentation package and completed SOFIA SI System Specification & ICD verification, the SIAT and SE&I need to be alerted to any changes to the instrument that could impact airworthiness, SI System specification, or ICD compliance. The Program also needs to be alerted to any changes that could change the scientific performance or characteristics of the instrument.

Changes made to a science instrument fall into three categories: those that impact the instruments airworthiness data package, referred to as "airworthiness configuration changes;" those that impact SI System specification or ICD compliance, referred to as "instrument spec or ICD configuration changes;" and those that do not impact airworthiness or interfaces and are internal to the instrument, referred to as "instrument configuration changes." By default, any change that is going to require the revision of a document in the current airworthiness data package is an airworthiness configuration change. Changes that may impact SI System specification or ICD compliance may require some delta verification. For PI instruments and Facility Instruments prior to acceptance by the SOFIA Program, the PI will be primarily responsible for determining the initial categorization of the changes. Once a Facility Instrument is accepted by SOFIA, it will be the responsibility of the SMO Instrument Scientist to categorize these changes.

9.1 Science Instrument Configuration Change Request

Prior to the implementation of an airworthiness configuration change, the instrument team will submit a science instrument configuration change request (SICCR) to the SOFIA Program for approval and forwarding to the airworthiness team. This form will include a description of the change, why the change is required, the impact of the refusal of the change, and the date required for the approval of the change. It will also list which document(s) in the airworthiness data package need to be revised and the description of any new documents that may be added to the package as a result of this change.

This SICCR is submitted to the SOFIA SI Development team for review, approval, and forwarding to the airworthiness review team. The airworthiness review team then needs to respond by the listed due date either with an approval of the change, approval of the change with additional analysis or documentation requested, or denial with explanation.

Once the change has been approved, the instrument team implements the change and submits the appropriate document revisions to the SOFIA Program for entry into the SOFIA configuration management system. This document package is then resubmitted to the SIAT.

9.2 Instrument Log Notebook

In order to ensure that the instrument team does not unwittingly make changes that impact airworthiness, once the initial airworthiness data package has been submitted, the instrument team will maintain an Instrument Log Notebook. Whenever an instrument component that is part of the flight system (i.e., opto-cryo assembly, counterweight rack, PI rack, and associated harnesses) is modified, the instrument team will make an entry into the notebook indicating the date of the change, the reason for the change, and a description of the change made.

The Instrument Log Notebook will be available for review by the SIAT at their request at any time. The SIAT will review the notebook several weeks prior to instrument pre-install reviews and report to the

SOFIA SI Development Team whether they have any concerns about the instrument history since the previous review so those issues can be addressed prior to or at the pre-install review.

While it would be convenient for the notebook to be electronically available for project review, for practical matters a physical notebook that remains with the instrument may be a better option. One possible option would be a binder with loose-leaf sheets that can be removed and periodically scanned with a sheet feed scanner for uploading to an accessible document repository.

9.3 Instrument Configuration Sheet

The Instrument Team will develop an Instrument Configuration Sheet appropriate for their instrument describing the instrument hardware and software configuration. This sheet will be a brief form that will list the software versions loaded on the instrument flight computers as well as information on the instrument that may vary from flight to flight, such as the channels installed, the filter wheel complements, the detector serial number, the window serial number, etc. This form establishes, for each installation, a record of the instrument configuration on the aircraft. The instrument configuration sheet will be included in Observatory Configuration Change Requests for the aircraft, serving as documentation for the instrument configuration for a particular installation. The SMO may use these instrument configuration records for instrument anomaly investigation and science data processing.

The Instrument Configuration Sheet will be updated by the Instrument Team (or Instrument Scientist for Facility Instruments following acceptance) and submitted to the SOFIA Program prior to each pre-installation review.

The Instrument Team should also provide a Version Description Document (VDD) for each software integration test that records the versions of the software being tested.

9.4 Document Configuration Management

Systematic document configuration management ensures that there are no differences between the configuration of the "as-built" product and the configuration defined in design documents. Product configuration documents include:

- The currently authorized revisions of all applicable drawings and referenced specifications, plus any unincorporated "redlines" and any approved but unincorporated engineering change orders
- As-run procedures for production, assembly, inspection and test, including any "redlines"
- Waivers, deviations and other nonconformity documents.

Instrument documents delivered to the SOFIA program (see Appendix A.1 – Deliverable Items List) will be assigned SOFIA document numbers and entered into the SOFIA configuration control system when delivered. The instrument team may use the SOFIA configuration infrastructure (Windchill) if they wish for instrument team internal configuration control; however, accessibility should be evaluated. The Instrument Quality Plan should document the process for approval, release and subsequent revision of drawings, plans, procedures, specifications, and other key documents. This document control process will include:

- QA Lead approval on all documents and their subsequent changes
- A unique document designator (e.g., alphanumeric) on each page of each document
- A version designation (e.g., Rev 0, 1, 2, 3 or Rev -, A, B, C) on each page of each document
- A change control process (e.g., Engineering Change Orders [ECO] or other change requests) that ensures that all functions that approved initial release also approve all changes

All instrument design documents will be formally released and revision controlled no later than CDR or before their use for procurement or fabrication, whichever occurs first.

To ensure Computer Aided Design (CAD) drawings and models delivered to NASA and archived in the SOFIA configuration control system can be accessed and opened properly (in the case of a facility-class SI accepted by NASA), the drawings and models must be saved and created using the Professional edition of the applicable CAD software package (e.g., SolidWorks, AutoCAD, ProEngineer/CREO), and not the Student or Academic edition.

10 Environments and Design Guidelines

This section presents definition of the environments to which SIs will be exposed and related design considerations and guidelines. These are offered as design guidance, not verifiable requirements, and are intended to support and dovetail with those in the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028).

10.1 Cabin Environmental conditions

10.1.1 Temperature and Humidity

Generally speaking, the SOFIA 747-SP cabin environmental conditions during flight provide a comfortable shirt-sleeve environment characteristic of commercial airliners, with the cabin temperature maintained at around +20°C ± 4°C. It should be noted that the pressurization and air conditioning systems for a 747-SP aircraft do not provide stable conditions such as in typical office or laboratory spaces, and air temperature shifts may occur on timescales of a few minutes.

Typically, the humidity of the SOFIA 747-SP aircraft cabin air is quite low during stratospheric flight.

It should also be noted that SI equipment in the SOFIA 747-SP aircraft cabin may at times be subject to significantly more extreme temperature and humidity environments. The nominal base of operations in Palmdale, CA experiences wide variations in ambient temperature characteristic of the California high desert. While the SOFIA aircraft is nominally housed in an enclosed hangar, there are situations that result in the aircraft being left unpowered on the tarmac during the daylight hours, and this can lead to high cabin temperatures. Also, for tropical deployment sites, high ambient temperatures combined with relative humidity approaching 100% should be anticipated on a routine basis.

SOFIA Systems Interface Requirements (SOF-AR-ICD-SOF-1030), Section 9.8 and Figure 8A, *Steady-state Temperature Environment (degrees C)*, provide temperature ranges for various defined operating and non-operating conditions.

10.1.2 Pressure

The SOFIA cabin is pressurized in flight and generally maintains a pressure altitude of less than approximately 8,000 ft. The actual cabin pressure is settable by the flight crew at the flight engineer station. The telescope Nasmyth tube Gate Valve assembly, when closed, acts as the pressure barrier between the pressurized cabin and the unpressurized telescope cavity. When this Gate Valve assembly is open for observations, the instrument flange or instrument pressure coupler mounted in the interface flange forms the pressure barrier between the pressurized cabin and the unpressurized telescope cavity.

The pressure differential is generally maintained at 8.9 psid or less, with an emergency pressure relief valve setting of 9.4 psid (maximum emergency relief pressure is 9.75 psid).

Figures to be added in a future revision of this handbook.

10.1.2.1 Arcing and Coronal Discharge, and design considerations

Though the SOFIA 747-SP cabin is pressurized and generally maintains a pressure altitude of approximately 8,000 ft., reduced atmospheric pressure, combined with typically low relative humidity, increases the possibility of coronal discharge and arcing between high voltage components and ground potential.

High voltage leads should be sufficiently insulated to prevent flashover. Normal cabin pressure is equal to 7,500 ~ 8,000 ft, and for a given voltage the break down distance is ~1.3 x greater than at sea level pressure. For equipment exposed to the stratospheric conditions outside at 41,000 ft altitude (i.e., in those portions of the SI assembly that are exposed to stratospheric atmosphere when the gate valve is open), the equivalent distance is greater by a factor of 5 x greater than at sea level.

These conditions should guide SI equipment design with respect to lead separation, insulation for high voltage components, avoiding sharp bends, solder peaks, and other best practices. High voltage components and cables should be clearly marked and, where practical, electrical and mechanical interlocks should also be used. Contacts on terminals carrying 50 volts or more to the ground should have guards to prevent accidental contact by personnel.

The SOFIA Electrical Power Distribution Subsystem (EPDS) includes an Emergency Power Disconnect (EPD) relay, which removes all power from the SI power buses (including UPS-protected buses) in the event of a cabin decompression. This EPD relay will open when the pressure altitude of the SOFIA cabin gets to 20,000 ft.

All SI equipment with internal high voltages, including COTS items such as oscilloscopes, spectrum analyzers, etc., should be assessed for ability to withstand the reduced atmospheric pressures associated with pressure altitudes of up to 20,000 ft. without arcing or corona discharge (many COTS items are only certified up to pressure altitudes of ~10,000 ft., and modifications such as additional insulation or potting with dielectric materials may be indicated).

10.2 Nasmyth Tube environmental conditions

Once the telescope Gate Valve is open for in-flight observatory operations, the environmental conditions in the telescope Nasmyth tube and SI mounting interface tub will be very similar to those in the telescope cavity, as defined by *SOFIA Systems Interface Requirements* (SOF-AR-ICD-SOF-1030), Section 9.8, though the temperatures are likely to be somewhat higher due to radiative, conductive and convective heat transfer from the TA electronics, cabin environment and attached instrument assemblies. Temperature gradients may also exist, and to the extent that these may affect image quality, efforts will be made to characterize and if necessary minimize such gradients using fans or blowers.

Unsteady Computational Fluid Dynamics (CFD) flow simulations and acoustic models of the TA cavity and Nasmyth tube have predicted acoustic resonance patterns (“organ pipe” modes) at 28 Hz and 84 Hz, which could lead to an amplification of acoustic energy at the SI mounting flange with respect to the pressure fluctuations within the SOFIA TA cavity.

To address concerns regarding microphonic pickup by sensitive SI receivers, measurements of Nasmyth tube acoustic energy have been made by DSI during Flight 046. Figures 123 and 124 present the measured Power Spectral Densities (PSDs) from the two microphones in both the aligned TA “Reference Configuration” and the misaligned “Configuration B” as a function of frequency, at a typical observing altitude of 43,000 ft. and at a lower altitude of 37,000 ft., respectively. Figure 125 presents the Sound Pressure Levels (SPLs) measured by the microphones during flight at 43,000 ft., and also shows the SPL at the 37,000 ft. altitude (aligned TA “Reference Configuration” only), as well as CFD simulation results for both TA configurations at 41,000 ft.

Figures to be added in a future revision of this handbook.

The results of these measurements were quite encouraging, as they showed that the SPLs and the amplitudes of the “organ pipe” modes were ~2 orders of magnitude lower than had been predicted by CFD simulations and also indicated very little sensitivity to TA alignment configuration. The 1st mode (predicted at 28 Hz) was observed at 20 Hz, and while it was far lower than predicted by the CFD simulations and acoustic models, the results did reflect the expected result that it becomes more significant at lower altitudes due to the higher atmospheric density.

The SPL of 116 dB close to the Nasmyth tube gate valve at 43,000 ft. corresponds to a pressure fluctuation of 13 Pa (RMS), while the SPL of 118.5 dB at 37,000 ft. corresponds to a pressure fluctuation of 17 Pa (RMS).

10.3 Vibration

The SOFIA 747-SP aircraft exhibits a low level of vibration characteristic of large jet aircraft. In addition, the instrument assembly mounted on the TA flange is isolated from the airframe vibrations during observing integration periods by the telescope Vibration Isolation Subsystem (VIS). The most severe vibration environment an instrument will experience is when the telescope assembly is caged and braked, which occurs during aircraft taxi, takeoff, landing, and maximum reverse thrust events. Caging and braking the telescope is a safety measure for the telescope assembly and aircraft that happens to result in a more severe vibration environment for instruments during these three specific phases of a flight.

In-flight vibration measurements have been made using a triaxial accelerometer during various phases of typical flights at the telescope flange with the telescope in caged and braked, locally and inertially stabilized and tracking configurations. Measurements were also taken at the Counterweight Rack (CWR), PI rack, and on the aircraft floor seat track in the vicinity of the telescope “pit” and aft MCCS rack. These are provided within the captioned figures in this section as representative of the worst-case vibration environmental conditions to which instruments will be routinely subjected in flight.

Measurements taken at the aft seat track indicate that the highest recorded acceleration is approximately 3g in the Y (lateral) axis at takeoff. At other phases of flight, accelerations in Z (normal) can reach 1.7g due to turbulence for one “bump” and continuous accelerations during turns can be as high as 1.2g in Z for several minutes.

Measured vibration environmental data characterizing the vibration environment to which SI equipment will routinely be subjected, will be added to this handbook as data becomes available.

10.4 Electromagnetic Interference / Compatibility

SOFIA has an electromagnetic environment that might impact the performance of some instrument concepts. The aircraft is equipped with radios operating at a variety of frequencies as well as radar. The telescope uses a system of strong fine and course positioning torquer motors to position and stabilize the telescope. There are also various electrically actuated solenoid valves, a chopping Secondary Mirror Assembly (SMA) and associated drive circuitry. While the selected torquer motors are quite efficient and therefore have relatively weak magnetic stray fields, possible magnetic interference to the SI is a concern.

Prior to the initial flight with an instrument or following instrument modifications for which it is deemed necessary either by the Instrument Team or aircraft operations, an EMI test is performed. The EMI test is a ground test to ensure that the science instrument creates no interference with the aircraft electrical systems and that it is operating as designed. Likewise, this examination will determine if any of the aircraft or observatory systems create electrical interference with the science instrument. Successful EMI testing is finished by approval of the documented results of the Science Instrument Airworthiness Team.

The radiated EMI environments in the SOFIA aircraft cabin and telescope cavity are TBD in *SOFIA Systems Interface Requirements* (SOF-AR-ICD-SOF-1030), section 9.9, *Electromagnetic Interference (EMI) Environment*, and have not been well characterized as a fully integrated system. The Instrument Team is advised that there are several active telescope and MCCS subsystems operating in close proximity to the instrument and instrument racks.

SOFIA Science Instruments should of course be designed and fabricated using accepted astronomical and/or aerospace industry best practices with respect to susceptibility to radiated Electromagnetic Interference (EMI) environments, notably electromagnetic fields and Radio Frequency Interference (RFI).

The frequency ranges of aircraft avionics are listed in Table 10.4-1. The instrument should be designed to avoid spurious response, and to limit electromagnetic radiation to the lowest practical level (preferably under 100 milliwatts), at these frequencies.

Table 10.4-1: Aircraft systems frequencies

Aircraft Systems	Frequency (Range)	Rx	Tx	Power Output	Comments
HF Radio	3.0 ~ 29.999 MHz	☑	☑	125 W carrier SSB 400 W peak	28000 channels available Commonly used frequencies: HF1: 10.0 MHz HF2: 13.339 MHz
VHF Radio	118 ~ 137 MHz	☑	☑	25 W carrier	760 channels available for VOX com Commonly used frequencies: VHF1: 121.5 MHz Guard / Emergency com VHF2: 133.65 MHz
VHF Omni-Range (VOR) Instrument Landing System (ILS) Navigation	108 ~ 117.975 MHz	☑			200 channels narrow band for VOR / ILS
UHF Radio	220.0 ~ 399.95 MHz	☑	☑	30 W carrier	7000 channels for Air-to-Air and Air-to-Ground com, including Air Traffic Control (ATC) com Commonly used frequencies: 348.6 MHz 243.0 MHz Guard / Emergency channel
Automatic Direction Finding (ADF)	190 ~ 415 kHz 510 ~ 535 kHz	☑			Non-directional beacon
DME	960 ~ 1213 MHz		☑	300 W (min) 600 W (max)	
DME interrogator	1025 ~ 1150 MHz	☑	☑	500 W	Pulsed
Glideslope Receiver (GS)	329.3 ~ 335.0 MHz	☑			
ALT-4000 Radar Altimeter 1 & 2	4.3 GHz	☑	☑	1 W (max)	Used below 2500 feet AGL
XM Weather	2332.5 ~ 2345.0 MHz	☑			
Weather Radar 1 & 2 (X-Band)	8 ~ 12 GHz	☑	☑	12 kW (max)	Predictive windshear and forward turbulence sensing (smoother flightpath)
ATC Transponders 1 & 2 / Traffic Alert and Collision Avoidance System (TCAS II)	1030 MHz	☑			
ATC Transponder / Traffic Alert and Collision Avoidance System (TCAS II)	1090 (+/- 3) MHz		☑	500 W (max)	Pulse 235/sec
Iridium Satellite (SATCOM) Telephone	1626.4 MHz	☑	☑	5 W	
InmarsatC (SATCOM)	1626.4 ~ 1645.5 MHz	☑	☑		Inflight internet, long range communication, high rate data transfer (a.k.a. "SkyNet") Alternative to UHF and/or HF for Data / VOX Installed: Activation anticipated Spring 2015
Global Positioning System (GPS)	1.57542 GHz (L1 signal) 1.2276 GHz (L2 signal)	☑			
Compass 1 & 2		☑			
CMA-3024 GNSSU MkII GPS Sensor	1.57542 GHz	☑			Crash Locator

Many instruments are expected to be fairly insensitive to low frequency magnetic interference, whereas others may exhibit significant susceptibility to it. In particular, superconductor-insulator-superconductor (SIS) heterodyne receivers may be susceptible to an unstable magnetic environment. The same is true for various instruments using squid amplifiers as low noise amplifiers in their readout circuits.

The magnetic stray field environment of the telescope was measured in the vicinity of the interface flange prior to the telescope installation in the aircraft using portable Hall sensor flux meters. The results of this study were documented in a July 2002 publication *Measuring Magnetic Interference Caused by the SOFIA Telescope Drive System* and are summarized below.

The dominant effect, as in any ground-based telescope, is the change of the magnetic field vector when rotating an instrument in azimuth or elevation. The maximum possible change of the field will be twice the earth's field strength (for reference, -479 mG to 479 mG in Augsburg, where the test was conducted at a MAN facility).

The next weaker effect is the residual magnetization of telescope parts like stator magnets, yoke parts and other magnetized items. In SOFIA, their magnitude is no larger than 25 mG (5% of the earth's field) and should not be an issue for an SI at all if the SI is rigidly attached to the SI flange, as the orientation with respect to the telescope, and hence the field will not change (the orientation with respect to the geomagnetic field will change, though).

The measurements of the magnetic stray fields of the torquer motors confirmed the magnetic field signatures at a maximum of ~10 mG at the Hall sensor.

Hydraulic brake release and fastening pulses are the next in line: Their magnitude is no larger than 3.2 mG (0.7% of the geomagnetic field) and even less (< 1.2 mG) within the SI assembly envelope.

Fine drive nominal torques were not detectable at all with the sensitivity of about 0.3 mG. This should thus be negligible for any instrument.

Based on this study, it was concluded that an instrument that can operate on a ground-based observatory will not be affected or degraded by telescope magnetic stray fields. The measurements did detect a 10 kHz component to the electromagnetic stray field signature from the fine drive torquer motor control circuits, and this should be considered by the SI designer as this can be picked up by any high impedance electronics and not only by devices sensitive to magnetic fields.

As integrated into SOFIA such TA control circuits will be somewhat enclosed by MCCS rack structures and it is expected that the 10 kHz signature will be more effectively shielded as compared with the test setup at MAN, where no special measures were undertaken to suppress it.

11 Safety and Mission Assurance

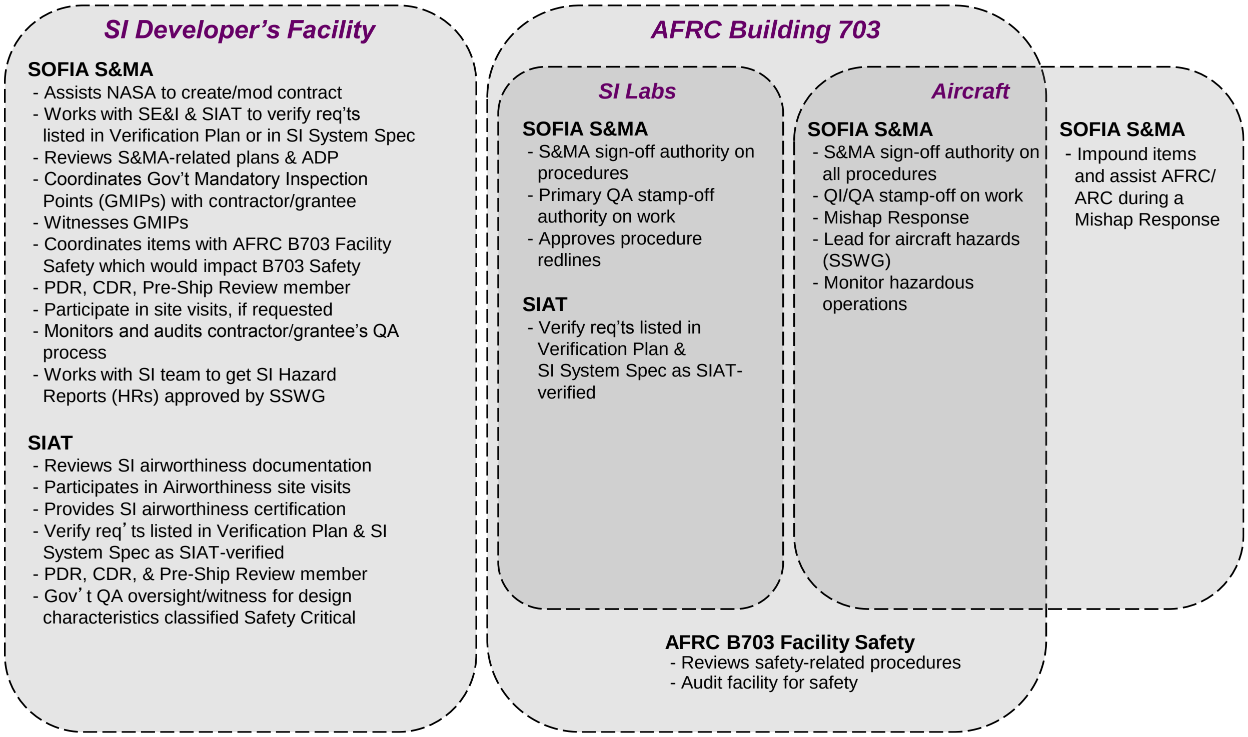

Figure 11-1: S&MA Responsibilities

The Science Instrument development team is required to develop a quality assurance plan that defines the developer's Quality Assurance process. This plan is provided to NASA for review. It is expected that this quality assurance plan will provide details to elements defined in the following subsections.

11.1 Risk-tailored Assurance Approach

Certain design characteristics of SOFIA Science Instruments are classified as **Safety Critical**—a failure to meet the flight hardware or software requirements for that characteristic could cause or lead to severe injury, major damage, or mission failure if performed or built improperly, or allowed to remain uncorrected. Such instrument design characteristics are required to follow additional configuration management and change controls, including the usage of special identification markings on drawings of Safety Critical design characteristics and the written approval from the SOFIA Science Instrument Airworthiness Team before changes can be made to Safety Critical instrument design characteristics. These controls are to ensure the information pertaining to instrument Safety Critical design characteristics available to the SOFIA Program is accurate and proposed changes to these items receive proper review and concurrence from SIAT. A part or assembly constituting a Safety Critical design characteristic may also be referred to as a Critical Safety Item (CSI).

> **Note:**
>
> Design characteristics considered **Safety Critical** typically include the following:
>
> 1. The instrument assembly structure mounted to the telescope, consisting of instrument mounting flange, outer structure, fasteners, and externally mounted components of the instrument assembly.
> 2. Equipment inside the PI Rack and Counterweight Rack, emphasis on equipment mounting to rack, equipment structure, and containment of internal components.
> 3. All components and parts that contact liquid helium.
> 4. All pressure relief devices and burst disks associated with venting of cryogen reservoirs.
> 5. Any window subassembly forming part of the instrument pressure boundary with the telescope Nasmyth Tube or forming part of the pressure boundary of the vacuum annulus/jacket surrounding liquid helium reservoirs.
> 6. Overcurrent protection devices in PI Rack, Counterweight Rack, and instrument assembly.
> 7. Electrical safety ground jumper cables or straps.
> 8. Additional items as required by the SIAT Lead.

The SI Developer should include a complete list of Critical Safety Items in the instrument System Safety Assessment (SSA). The CSI list will first be included in the SSA delivered for the Preliminary Design Review (PDR) and the list will be updated in subsequent revisions of the SSA delivered at CDR and before shipment, reflecting the configuration of the final as-built instrument. By CDR, the following note should be included in the notes section of each CSI drawing stating, "*Modification of this Critical Safety Item (or specific characteristic) requires written approval by the NASA Science Instrument Airworthiness Team (SIAT)*".

As changes to a CSI may be made during the instrument development process, the instrument team should notify their SIAT POC of the specific CSI being changed along with a description and reason for the change. It is recommended that the instrument team provide a redline drawing showing the proposed modification to a part or assembly or provide a draft drawing for any new part or assembly. SIAT will review the submitted documentation and engage the instrument team as necessary for additional information before approving a change. The goal is to keep this review and approval process short, so as not to impact the schedule and ongoing development of the instrument.

11.2 Quality Planning

Before initiating design, build and verification activities, key aspects of the SI Development project should be planned to minimize technical, cost and schedule issues. The Instrument Team's planning decisions should be documented in the Instrument Quality Plan to define:

a) How the Instrument Team's existing practices will be tailored for this project

b) The documented plans and procedures that need to be developed for key hardware and software design, build and verification activities.

c) Any technical standards and specifications chosen by the Instrument Team for application

d) The type and timing of key requirements, design and readiness reviews (e.g., PDR, CDR, Pre-Ship)

e) How processes for hardware and software development will be monitored and controlled by the Instrument Team including Special Processes (see Section 11.6.4, Control of Special Processes)

f) How the resulting components, assemblies and systems will be inspected and tested to verify conformity to requirements

Note:

The plan for process control and product verification could take the form of a flow chart showing the sequential points for monitoring, control, inspection and test and a table identifying the methods, frequency and criteria to be used at each of these process control and product verification points.

g) What new or upgraded fabrication, assembly, inspection, test, non-destructive examination (NDE) or measurement methodology or equipment are necessary

h) Which fabrication, assembly, inspection, test and NDE processes need to be qualified as capable of achieving requirements and which personnel need to be trained and certified based on demonstrated proficiency

i) How key records of conformity to requirements will be generated, compiled and protected to ensure their availability throughout the anticipated life of the Science Instrument

j) Identification of anticipated outsourcing / acquisitions of materials, technical services, Special Processes, NDE, etc., including how the supplier's goods and services will be monitored and verified (e.g., witness or perform source inspections/tests, receiving inspection/test)

Further guidance can be found in the *SOFIA Quality Plan (SQP)*, SOF-NASA-PLA-PM21-2090, which will assist in all quality areas from procurement control, inspection, audits, through nonconformance reporting and tracking.

11.3 Training and Certification

Only trained and competent personnel will be assigned to perform the work. For operations where specialized training and/or demonstrated proficiency (i.e., certification) is required by NASA or the Instrument Team, records of training and certification will be maintained and be available for NASA review. Also see Section 11.6.4, Control of Special Processes.

11.4 Procurement Control

This section does not apply to technology demonstration instruments.

The instrument team is responsible for the adequacy and quality of all purchased articles, materials, and services in support of the instrument development.

11.4.1 Supplier Selection

For procurements involving design characteristics classified as Safety Critical, the QA Lead will evaluate supplier capability before award.

11.4.2 Procurement Documents

The QA Lead will review the procurement document packages for all procured components of design elements classified as **Safety Critical** to ensure all appropriate NASA and Instrument Team requirements are flowed down to suppliers.

The Instrument Team will have the supplier provide:

- Certified Material Test Reports of chemical and physical properties for raw materials (e.g., bar stock and sheet metal) and for the raw material incorporated into threaded fasteners
- Certifications of Conformance to purchaser and supplier product requirements for:
    - Procured components and assemblies
    - Special Processing (e.g., weld, solder, bonding, anodize, plate, heat treatment)
    - Non-destructive examination (NDE) services (e.g., radiography, dye penetrant, ultrasonic, magnetic particle)

11.4.3 Source Inspection / Supplier Surveillance

For procurements involving design characteristics classified Safety Critical, the Instrument Team should plan and implement appropriate surveillance activities including witnessing key processing steps, inspections and tests at the supplier or sub-supplier's facility and reviewing or participating in the qualification of key processes performed by the supplier or sub-supplier for Special Processes (e.g., weld, composite lay-up, bonding, etc.) and Non-Destructive Examination (e.g., radiography, ultrasonic, etc.).

11.4.4 Receiving Inspection

Upon receipt of a procured item, the Instrument Team will perform a receiving inspection to ensure adequacy of delivered items. The receiving inspection should be tailored to the criticality and complexity of the article and the degree to which source inspections were performed by the Instrument Team in the supplier's facility. Receiving inspections should include opening each shipping container and verifying that the identity (e.g., part number) and quantity of the contained articles match both the accompanying shipping documents and relevant contract, purchase order, etc. During receiving inspections, articles should be protected from ESD damage and contamination.

11.4.5 Conformity Records for Procured Articles

Raw material, product and process conformity records delivered by the supplier and acceptance records generated by the Instrument Team (e.g., source and receiving inspection) will be maintained and be available for NASA review.

11.5 Identification control

Where appropriate as determined by the Instrument Team, unique identifiers (e.g., part / serial / lot numbers) should be assigned. This includes parts produced from a drawing, parts associated with design characteristics classified as Safety Critical, parts where there are multiple units that may have different detailed characteristics (i.e., windows, optical elements, filters, detectors, etc.) or parts that may have a limited lifetime. Where multiple units with the same drawing / part number exist, unique unit identification should be assigned (e.g., serial number, date code, lot number). Serial or lot numbers of scrapped articles or materials will not be used for other similar articles or materials.

11.5.1 Article Labeling

When physically possible, materials, components and assemblies should be permanently labeled with their part, serial or lot numbers using such methods as indelible ink stamp, engraving, etc. This will facilitate their positive identification while in stock, in production or in service. When articles or materials cannot be permanently labeled, they should be tagged or bagged with their part / serial / lot numbers until incorporated into an assembly. Production planning documents (e.g., travelers, assembly procedures) should record the part, serial or lot incorporated into each assembly. Records should also identify the part / serial / lot numbers for any removals, replacements or modifications after initial assembly. Article labeling allows the as-built configuration of a component or assembly to be compared to the configuration identified in the Instrument Team's change-controlled drawings and associated specifications.

11.5.2 Identification List

Upon initiation of design activities, the QA Lead will establish and maintain an Identification List (e.g., Bill of Materials or Indentured Parts List) containing Instrument Team or Supplier-designed articles and Commercial-Off-The-Shelf (COTS) articles). This list will indicate the part and type number for articles and materials and the applicable type of group or individual identification. This list will map to drawing assembly hierarchy and include individual drawing parts lists.

11.6 Fabrication Control

This section does not apply to technology demonstration instruments.

The Instrument Team will monitor its production operations to ensure as-built articles conform to all specified requirements in engineering drawings and associated specifications in accordance with the institutions procedures and "best practices" as determined by the Instrument Team.

11.6.1 Fabrication Planning and Records

The QA lead will ensure that fabrication planning documents define the required sequence for fabrication and assembly of parts associated with design characteristics categorized as Safety Critical. Additionally, travel sheets will be provided for design characteristics classified as Critical.

11.6.2 Limited Life Items

Articles whose service life is limited by age or usage will be controlled to prevent inadvertent use of expired articles. Articles limited by age will be labeled with expiration dates. Care will be taken to determine whether the manufacturer's expiration date is based on storage at other than room ambient conditions. Articles limited by usage will have their usage cycles or durations logged.

11.6.3 Cleanliness Control

Articles having defined characteristics of cleanliness should be controlled with documented methods to maintain and assess conformance to these requirements. Test or inspection should be performed to verify cleanliness prior to use.

11.6.4 Control of Special Processes

Special Processes are those production and Non-Destructive Examination (NDE) processes used when conformance to requirements cannot be determined solely by evaluating the output. Special Processes include, but are not limited to, welding, bonding, solder, composite lay-up, heat treatment, handling ESD-sensitive devices, radiography, dye penetrant, and ultrasonic examination.

The control of Special Processes for structural Safety Critical design characteristics will include:

– Training of personnel and periodic re-certification of their proficiency based on demonstration, test scores, lab analysis of sample coupons, etc.

– Pre-qualification and subsequent control of processing parameters and environment (e.g., temperature, time, pressure, humidity, electrical grounding) to minimize unintended variability or damage

– Control of limited-life processing materials (e.g., weld rods, resins, epoxy, radiography film and developing chemicals)

– Control of harmful processing materials or equipment (e.g., contaminants, static generating tools and materials)

11.7 Inspection and Test

The instrument team will plan and conduct an inspection and test program that demonstrates ICD, Science Instrument System Specification and functionality requirements are met. This test program may include subsystem tests, integrated demonstration of instrument capabilities, or individual component testing.

11.7.1 Inspection and Test Planning

The QA Lead will ensure that the necessary planning is developed for run-for-the-record Verification and Validation (V&V) providing:

- Sequence of inspections and testing at successive levels of fabrication and assembly
- Verification of article conformity to design requirements at the earliest possible stage
- Availability of calibrated inspection and test equipment
- Coordination of inspections and tests conducted or witnessed by Government QA Representatives
- Efficient use of equipment, facilities, and personnel

The QA Lead will notify Government QA Representatives whenever inspections or tests at the facilities of the Instrument Team or their suppliers will verify a requirement that requires a NASA witness per the Verification Plan (see Section 5.4.3, Verification Planning).

Note: The recommended lead time for participation by Government QA Representatives is:

- Three business days when overnight travel to the Instrument Team's facility is not involved.
- Five business days when overnight travel is involved.
- Twenty business days when international travel is involved.

Also see Section 5.4.3, Verification Planning.

11.7.2 Inspection and Testing During Fabrication / Assembly

The QA Lead will determine appropriate inspection points and in-process test points during the fabrication and assembly process to ensure the effective verification of product conformity to requirements. Inspections should be chosen to verify hardware was built to match the drawings and no workmanship issues exist. Required inspection points will be defined in accordance with Section 11.6.1, Fabrication Planning and Records.

The QA Lead will review any in-process test procedures, and witness testing as necessary, to ensure that articles are not damaged and that tests are performed as documented. The QA Lead will ensure that test records identify the configuration of the test unit (i.e., part / serial numbers and revision levels), include an unambiguous Pass/Fail declaration, and include QA acceptance that the test procedure was performed as specified. Inspection and test records will be maintained and be available for NASA review. The QA Lead will document inspection nonconformities and test anomalies in accordance with Section 11.8, Nonconformance Reporting and Tracking.

11.7.3 Metrology Control

Proof of calibration controls will be available for all equipment used to process articles and perform inspections and tests that will ensure the conformity of design characteristics that have been classified as Safety Critical. These records will be maintained and be available for NASA review. The Instrument Team will determine the measurements to be made and the devices necessary to verify product and process conformance to specified requirements. These devices include test hardware and software, gauges, meters, etc. Devices or software will be controlled, calibrated and verified in accordance with a documented procedure.

11.8 Nonconformance Reporting and Tracking

11.8.1 Segregation of Nonconforming Articles

The QA Lead will implement controls to ensure that nonconforming articles are not commingled with conforming articles and will describe in the instrument Quality Plan the process by which nonconforming articles will be identified, tracked, and segregated from conforming articles.

11.8.2 Nonconformance Reporting

The QA Lead will document each nonconformance using a suitable reporting format that contains, as a minimum:

a) A unique tracking number

b) Initiator’s name

c) Identification of the nonconforming article (e.g., name and part number)

d) Description of the nonconformance (e.g., Diameter is 0.56)

e) The relevant design criteria (e.g., Diameter should be 0.55 max.)

f) The chosen disposition (i.e., Remedial Action or Correction) for the nonconformance:

  - Return to supplier
  - Rework to comply with original specification
  - Repair to comply with alternate acceptance criteria
  - Use As-Is
  - Use as lab spare or lab storage
  - Scrap

g) Engineering rationale for reduced safety margin caused by Use As-Is or Repair dispositions

h) Defined alternative acceptance criteria when additional processing (i.e., Repair) will not return the article to compliance with the original specification

i) Results of re-inspection following Rework or Repair

j) Signatures of personnel who reviewed and authorized the disposition

k) Reference to the Corrective Action Request number if corrective action will also be taken to eliminate the underlying cause and preclude similar additional nonconformities

Note: Remedial Actions for a nonconforming article are typically handled using a form called a Nonconformance, Deficiency or Discrepancy Report. When necessary, longer term actions to preclude additional similar nonconformities are handled separately using a form typically called a Corrective Action Request (CAR). CARs can be issued to suppliers, or used internally to identify the underlying root causes, develop a plan and schedule for cause removal, verify the implementation and effectiveness of planned Corrective Actions and track the Corrective Action plan to closure.

11.8.3 Nonconformance Disposition

For the disposition of Critical Safety Items that are nonconforming, if the Instrument Team proposes to "Use As-Is" or "Repair" for alternate acceptance criteria, the Instrument Team will also obtain NASA QA approval through the NASA Contracting Officer or the Contracting Officer's Representative (COR). NASA in-house instruments will work through the responsible Project Manager. Following completion of any additional processing, articles will be re-inspected or retested to verify conformity to the original spec for Rework or to the approved alternate acceptance criteria for Repair.

11.9 Shipment

11.9.1 Packaging, Packing and Containers

Articles will be packaged to prevent deterioration, corrosion, damage, and contamination using appropriate materials (e.g., ESD bags, shrink film, desiccant). For small shipments, dunnage such as Styrofoam peanuts, foam sheets, bubble wrap, and foam end/corner blocks should be used within the container.

Special packaging, packing and containers will be used to protect critical, sensitive, dangerous, or high-value articles. When necessary, engineered shipping containers should be used including cushion materials, blocking, and/or bracing to reduce the effect of sudden impact, movement within the container, vibration, etc. As appropriate, environmental and handling requirements should be marked on the exterior of the packaging and/or container.

For high-value equipment like the SI or PI rack electronic equipment, shipping containers should contain shock monitors with data loggers.

11.9.2 Handling and Transportation

The Instrument Team will ensure handling devices and transportation vehicles are suitable for the articles and materials being shipped to prevent damage.

Road transportation can subject shipments to high-G acceleration loads from potholes, expansion joints, frost heaves and low-G, high-frequency, continuous vibration that could cause significant contact fretting wear over long distances.

For high-value items, shipping containers should be secured from movement within transportation vehicles. Loading methods, personnel and equipment should also be selected and controlled to minimize the chance of damage. A shock measuring instrument should be used to log significant shock loads during transportation. Shock stickers or shock recorders should be used. Shock recorders are available from the NASA procuring S&MA organization if requested by the Instrument Team approximately three weeks prior to the planned transportation of the instrument.

To prevent any scratches or damage to the mating surface of the instrument flange to ensure a proper mating seal when the instrument is installed, it is recommended the mating surface of the instrument flange be protected by a cover, such as Plexiglas or similar, prior to shipment as well as after shipment whenever the instrument is not mounting to SOFIA or the TAAS.

11.10 Software Assurance

Table 11.10-1: Software deliverables supporting software assurance

SOFIA Document Category Type	Title	Notes
PM20	Software Development Plan (SDP)	Describes SI-specific software development approach, documentation tailoring, process of recording bugs, maintaining Software Configuration Management, etc.
SW01	Software Requirements document (SRD)	Reviewed at SRR
SW02	Software Architectural Design Specification	Reviewed at PDR/CDR
SW04	Software User's Guide	If necessary, drafted for review at PDR/CDR and maintained thru final version of software
SW05	Software Test Reports	Published after witnessed tests
SW06	Software Version Description Document (VDD)	Published with each software release delivered for integrated test activities; Describes software delivered on SW07 in an auditable sense (i.e., with md5 hash values or equivalent) with description of specific changes in this release as well as known problems
SW07	Software Media Release	This is the actual software on CD/DVD, including Executables, Source Code, APIs, libraries, make files, and other files required to build the executables
SW08	Software Analysis Report (SAR)	For maintenance releases (e.g., after first series of integration exercises), analyzes the problems found, describes required software changes, verification test and regression tests
SV01	Verification & Validation Plan (SVVP)	Reviewed at PDR
SV02	Verification Test Procedures	Reviewed at CDR and approved by TRR
SE03	Interface Control Document (ICD)	Reviewed at SRR and revised at PDR/CDR/TRR; would describe, at a minimum, specific values for DCS integration for proposal tool, keyword meanings, pipeline execution parameters, etc.

The SOFIA software assurance practices are described in *SOFIA Software Assurance Plan (SSAP)* (SOF-NASA-PLA-PM21-2091). These practices rely on a defined software process and lifecycle in which documented artifacts are created in advance of defined reviews (see Section 7 of this handbook for further discussion of SRR, PDR, CDR, TRR) for the purpose of allowing NASA S&MA and SE&I staff to assure that software requirements, plans, design and procedures are adequate for meeting allocated technical performance. For more details on the software development and assurance processes for SOFIA, see *SOFIA Software Management Plan (SMP)* (SOF-DA-PLA-PM20-2011).

The documentation artifacts that lend themselves to these software assurance activities are identified in Table 11.10-1 (also see Appendix A.1 – Deliverable Items List of this SI Developers' Handbook for a summary of specific software and software-related documentation deliverables):

The specific software lifecycle required for an SI differs between Facility Instruments in which NASA accepts delivery and maintenance responsibilities and PI or Technology Demonstration Instruments which do not become part of the SOFIA Observatory. The level of software assurance is determined by a classification system. The *SOFIA Software Management Plan* (SOF-DA-PLA-PM20-2011) describes the classifications used for Science Instrument software.

Guidance – prepare for Software Assurance activities by:

1. Reviewing the *SOFIA Software Management Plan (SMP)* (SOF-DA-PLA-PM20-2011), first,
2. Reviewing the *SOFIA Software Assurance Plan (SSAP)* 9SOF-NASA-PLA-PM21-2091),
3. Reviewing a sample Version Description Document (VDD) to understand how software will be delivered for test activities,
4. Drafting a PM20 SI-specific Software Development Plan that would describe how Software Configuration Management, verification, defects/bugs will be tracked and documentation will be managed by the SI team thru a lifecycle that is tailored to the specific SI.

Consider: In some cases, the SOFIA Program has facilitated the hosting of defect tracking and Software Configuration Management tools which can be negotiated on an SI-by-SI basis.

11.11 Audits and Reviews

This section does not apply to technology demonstration instruments.

The QA Lead should perform periodic audits or reviews to ensure the SI development team is implementing its processes in accordance with applicable internal and NASA requirements. The QA Lead should facilitate NASA surveillance activities, as discussed in Section 11.15, Government Surveillance of Activities.

11.12 Mishap Reporting

The Instrument Team will report "mishaps" where injuries or significant costs are incurred, or had the potential to injure of cause significant costs as described in their contract. The *SOFIA Program Mishap Preparedness and Contingency* Plan (SOF-DF-PLA-OP05-2000) defines the classification categories of a mishap, how to respond to a mishap, and how to report a mishap event. In addition, NPR 8621.1, *NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping* provides requirements to report, investigate, and document mishaps, close calls, and other unidentified serious workplace hazards to prevent recurring accidents.

11.13 Reliability

Verifiable requirements pertaining to Science Instrument reliability are contain within the *Science Instrument System Specification* (SOF-AR-SPE-SE01-2028). Section 10 of this handbook describes the environment in which the science instruments will operate on SOFIA. These environmental conditions should be taken into consideration throughout the design of the science instruments.

11.14 System Safety

All hazards associated with the operation of SI end items on the SOFIA Observatory or at NASA Installations will be communicated by the Instrument Team to NASA in a System Safety Assessment

(SSA) delivered prior to the Preliminary Design Review (PDR), updated prior to the Critical Design Review (CDR), and updated upon the delivery of the airworthiness data package for airworthiness approval.

Completion of the SSA is done by systematically assessing the components of a science instrument system to determine if the design and construction of parts and assemblies will survive expected operational circumstances both in flight and on the ground. The SSA is designed to identify, eliminate or mitigate all safety risks posed by a science instrument system.

The hazard assessments include "Integrated Hazards" (i.e., hazards that can cross the boundary between systems). This would include any hazards that the aircraft systems can induce into the SI and the SI can induce into the aircraft systems.

The risk of asphyxiation or hypoxia to personnel due to the rapid dilution/displacement of oxygen within the SOFIA cabin environment will be assessed for each instrument. Each SI Developer will be asked to submit the volume of LHe and LN2 cryogens contained within their instrument. Depending on the volume of cryogens, hazard mitigations may be defined and implemented to reduce this risk. The worst case scenario considered is the event in which all liquid cryogen rapidly boils off into the gas phase inside the aircraft cabin. The loss of vacuum surrounding a LHe reservoir is one example of a functional failure that would result in a rapid boil-off of LHe. The volume of LHe (as opposed to LN2) is the primary cryogen of concern given its low heat of vaporization, low boiling temperature, and high liquid-to-gas phase expansion ratio. The rapid boil-off event is considered for both the flight and ground operational environments of SOFIA.

Because the possibility of a rapid boil-off event exists, the behavior and effect of such an event must be analyzed, understood, and have hazard mitigations implemented as necessary. Scenarios that could contribute to the onset of accelerated cryogen boiling will be reviewed as part of the system safety assessment and hazard analysis performed with written assessment of science instrument design features that minimize risk if such an event occurs.

Despite constantly venting the aircraft cabin with outside air and the partial pressure of O_2 inside the aircraft cabin it is still necessary to evaluate oxygen displacement that results from the sudden introduction of He gas inside the cabin. No specific mitigations are generally required by the instrument team during flight. Details about aircraft cabin volume, cabin pressure environment, and ventilation system are available in the SOFIA whitepaper, *SOFIA Cryogen Gas Quantity Rationale*.

In the ground operational environment, hazard mitigations may need to be implemented to ensure the safety of personnel, depending on the volume of cryogens within an instrument. Unlike in flight, the aircraft provides limited or no active ventilation of cabin air when on the ground. The entry doors to the aircraft are also routinely closed during periods of no personnel activity on the aircraft—the worst case scenario considered is significant oxygen displacement from the cabin resulting from a rapid cryogen boil-off event. The SOFIA Program may define and implement procedural and operational mitigations for instruments carrying a large volume of cryogens, such as requiring a certain number of aircraft doors be opened and the use of portable fans to increase ventilation whenever an instrument is onboard, and use of additional oxygen sensing monitors during normal ground operations as well as first re-entry into the aircraft following closure of the aircraft cabin.

Further guidance can be found in the *SOFIA Safety Plan (SSP)* (SOF-NASA-PLA-PM21-2089). To assist you in your SI hazard analysis there are four generic SI hazards in Appendix G for you review. These hazards are: *Generic SI* Cryostat Overpressure and Habitable Atmosphere Hazards, *Generic SI and SI-provided EGSE* Electrical Hazards, *Generic SI* - Aircraft Platform Pressure Boundary Hazards, and *Generic SI and SI-provided GSE* Structural Hazards.

Table 11.14-1: Definitions of the four hazard severity classifications

Description	Class	Definition
Catastrophic	1	Death, permanent disability, life threatening injury A condition that may cause the destruction of facility on the ground, major system, vehicle, termination of project, or loss of the only opportunity for critical data Recovery or replacement cost equal to or greater than $1 million
Critical	2	Lost time injury or occupational illness A condition that may cause major loss/damage to facility, system, equipment, flight hardware, vehicle, long term project delay, or loss of major project critical data Recovery or replacement cost equal to or greater than $250K, but less than $1 million
Marginal	3	Minor injury (medical attention) A condition that may cause loss of flight (return to base, test shut-down, etc.), loss of minor project critical data, minor loss or damage to facility, system, equipment, or flight hardware Recovery or replacement cost equal to or greater than $25K, but less than $250K
Negligible	4	No adverse safety impact (first aid only) A condition that may cause loss of non-critical data, subject the facility, system, or equipment to more than normal wear and tear Recovery or replacement cost less than $25K

The result of the assessment is a collection of documented potential hazards, which are classified according to the probability of the event occurring and the severity of the event if it occurs. Table 11.14-1 provides guidance for assigning the severity category for a hazard and Table 11.14-2 provides guidance for assigning the probability category for a hazard. Table 11.14-3 is the matrix of hazard categories that determined based on the severity and probability categories. Note that the hazard categories for human safety are slightly different than for equipment.

Table 11.14-2: Definition of the five hazard probability classifications

Class	Approximate Numerical Probability (P)	Description
A	Expected $P > 10^{-1}$	Expected to occur often in the life of the program or item. Expected to be experienced continuously in ongoing programs.
B	Probable $10^{-1} \geq P > 10^{-2}$	Will occur several times in the life of a program or item.
C	Likely $10^{-2} \geq P > 10^{-3}$	Likely to occur sometime in the life of a program or item, but multiple occurrences are unlikely. Controls have significant limitations or uncertainties.
D	Unlikely $10^{-3} \geq P > 10^{-6}$	Unlikely to occur in the life of the program or item, but still possible. Controls have minor limitations or uncertainties.
E	Improbable $P \leq 10^{-6}$	Occurrence theoretically possible, but such an occurrence is far outside the operational scope. Typically, robust hardware, operational safeguards, and/or strong controls are put in place with mitigation actions to reduce risk from a higher level to an improbable state.

Table 11.14-3: The hazard action matrix

	A: Expected	B: Probable	C: Likely	D: Unlikely	E: Improbable
1: Catastrophic	Major	Major	Major	Intermediate	Minor
2: Critical	Major	Major	Intermediate	Intermediate	Minor
3: Moderate	Major	Intermediate for human safety; Minor for hardware	Intermediate for human safety; Minor for hardware	Minor	Minor
4: Negligible	Minor	Minor	Minor	Minor	Minor

11.15 Government Surveillance of Activities

NASA S&MA plays a key role in verifying science instruments are airworthy, from design through fabrication and assembly, to final test and integration. This includes monitoring and ensuring quality processes implemented by the SI Developer are effective and being followed properly. As certain design characteristics of an instrument may be classified as Critical and will have more stringent process requirements, S&MA will pre-coordinate site visits to minimize impact to the instrument team whenever possible. Besides being responsible for oversight and verification, S&MA would also like to be the instrument team's consultant on Safety, Reliability, Quality Assurance, and Risk Management topics.

11.15.1 At Instrument Team's Facility

S&MA requirements for both Airworthiness and Mission Success will be monitored by NASA at the Instrument Team's facility. These periodic visits will review overall implementation of the S&MA requirements detailed in this document, including:

a) Review the Instrument Quality Plan
b) Review other key Instrument Team operating plans and procedures
c) Participate in key technical reviews (e.g., PDR, CDR, Pre-Ship, Installation)
d) Review key Instrument Team quality practices (e.g., procurement, control of materials, configuration management, tests, etc.)
e) Review the Instrument Team's qualification of key in-house fabrication and NDE processes
f) Witness key inspections and tests
g) Review key records to verify instrument conformity to requirements
h) Review Instrument Team's "Use As-Is" and "Repair" dispositions

11.16 At AFRC Building 703

General information related to the Instrument Team's activities at the Armstrong Flight Research Center Building 703 defined in USRA-DAL-SSMOC-MOPS-PRO-0130, *SOFIA Science Investigator Information for DAOF* (DAOF was the former name of AFRC Building 703).

11.16.1 Receiving Inspection

A packing list identifying shipment contents will be present upon delivery to the Armstrong Building 703. When the instrument arrives at Building 703, a visual inspection will be performed to verify that there is no visible damage to the container, its packing and packaging materials or the contained articles. Shock measuring instruments, if employed, will be downloaded and their data reviewed for excessive shock loads. NASA ARC and/or AFRC QA will be present during receiving inspection.

11.16.2 In the Science Instrument Laboratories

Safety and Mission Assurance (S&MA) is performed in the SI Labs per the *Science Project System Safety and Mission Assurance Plan*, SCI-AR-PLA-PM21-2000. The SMO operates the SI laboratories and has created generic SI Lab procedures based on flow down of these S&MA requirements. A NASA QA Representative or designee will monitor work in the SI Labs. This includes conformity verification for Government Mandatory Inspection Points (GMIPs).

Some recurring tasks such as cryogen servicing and lifts that have safety implications are performed in accordance with written procedures. Lab procedures are developed by the Instrument Team in coordination with the SMO team. Most SI Lab documents are prepared by the SMO team as part of their SI Lab activities (e.g. non-conformance reports, metrology, travel sheet, as-run procedures, etc.). See Appendix A.1 – Deliverable Items List.

11.16.3 On the Aircraft

On the aircraft, NASA may impose Government witness requirements it deems necessary to ensure the SI is ready to fly safely. These witness points will be part of the task procedure.

Some recurring tasks, such as cryogen servicing, that have safety implications are performed in accordance with written procedures. On-aircraft procedures are developed by the Instrument Team in coordination with the SMO team. Most SI aircraft documents are prepared by the SMO team as part of their mission operations activities (e.g. non-conformance reports, metrology, travel sheet, as-run procedures, etc.). See Appendix A.1 – Deliverable Items List.

12 Roles and Responsibilities

12.1 Instrument team

The science instrument principal investigator is responsible for the conception, design, and development of the instrument. The SI PI provides all facilities necessary to design, develop, and build the instrument prior to delivery. The instrument team defines the SI-specific science and technical performance required to achieve the scientific investigation proposed and develops the verification matrix for the performance requirements. The instrument team reviews the SI requirements verification matrix template provided by SSP SE&I that contains the instrument requirements from the SI System Specification and the SI ICDs, identifies which requirements are applicable to the instrument, and identifies the preliminary instrument verification activities to be performed prior to CDR. The instrument team is responsible for planning, performing, and documenting the pre-CDR verification activities. The instrument team assists in planning, performing, and documenting post-CDR verification activities and waiver requests.

The Principal Investigator (PI) will designate a person within the SI staff who is responsible for the Quality Assurance (QA) functions for the SI development team. In this document, this person will be referred to as the QA Lead. The QA Lead should have the freedom to flow quality issues up to the Principal Investigator (PI). The QA Lead is responsible for creating and maintaining an effective quality assurance system for all items procured and produced for a Science Instrument development. All procedures or instructions developed for the procurement, production, assembly, inspection, test, or evaluation of SI items should be reviewed and approved by the QA Lead. The QA Lead is also responsible for verification of conformity to requirements. While the QA Lead could also have other responsibilities, enough time should be allotted to adequately perform the QA functions. No team member should ever act as a QA check for their own work. If this might occur, the PI should temporarily assign QA duties to another person.

12.2 SOFIA SI Development Manager

The Science Instrument Development Manager is the cost account manager and principal engineer for the SOFIA Instrument Development WBS (1.05), thus is responsible for the cost, schedule, and technical performance of all US Science Instruments in development.

The Science Instrument Development Manager is the compliance authority for the requirements contained in the instrument-specific science and technical performance specification. As compliance authority for these requirements, the Science Instrument Development Manager submits deviation and waiver requests to the SOFIA Program where warranted.

12.3 SOFIA Systems Engineering and Integration

SE&I is responsible for providing to the instrument team an SI requirements verification matrix template that contains the SI requirements from the SI System Specification and the SI ICDs, and is pre-populated with recommended, post-CDR final verification activities. SE&I will provide most of the procedures for final verification of the SI System Specification and SI ICD requirements. SE&I is the compliance authority for the requirements contained in the SI System Specification and SI ICDs other than airworthiness requirements. As compliance authority for these requirements, SE&I submits deviation and waiver requests to the SOFIA Program where warranted.

12.4 SOFIA Safety and Mission Assurance

SOFIA S&MA supports the final verification activities for compliance to SI System Specification and SI ICD requirements other than airworthiness requirements and reviews and concurs on the compliance results.

The operations and work of the Instrument Team and their suppliers are subject to evaluation, review, audit, survey, and inspection by Government QA Representatives who will verify that:

- The Instrument Team meets acquisition requirements.
- All materials, processing, articles, and related services conform to critical safety items per Section 11.1, Risk-Tailored Assurance Approach.

Further guidance can be found in the *SOFIA Program Safety and Mission Assurance Plan* (SOF-DA-PLA-PM21-1086).

12.5 SOFIA Science Instrument Airworthiness Team

The SIAT is the compliance authority for the airworthiness requirements contained in the SI System Specification and SI ICDs. As compliance authority for these requirements, the SIAT submits deviation and waiver requests to the SOFIA Program where warranted. Prior to flight of a science instrument, the SIAT will provide a written letter indicating that a science instrument is accepted as an airworthy article for the SOFIA aircraft.

12.6 Transition to mission operations

Following the completion of the acceptance review (facility instruments) or commissioning review (PI or Technology Demonstration instruments), responsibility for the operation and maintenance of the instruments shifts from Science Instrument Development (WBS 1.05) to Mission Operations (WBS 1.07). For facility instruments, this transition shifts responsibility for operation and maintenance from the Instrument Team to the SMO staff. For non-facility instruments, this transition is more a programmatic shift within the SOFIA Program on who is responsible for funding and oversight of the Instrument Team.

12.7 Instrument Scientists

For each science instrument, a member of the Science Mission Operations (SMO) staff is assigned as an instrument scientist. The instrument scientist performs the following roles:

a) Serve as the point of contact between the SMO and the instrument team for the science operations of the instrument
b) Participate in the development of the instrument, with a primary focus on understanding instrument performance, capabilities, operating modes, and limitations
c) Responsible for operating the instrument following acceptance by the SOFIA program for facility instruments
d) Report to the SMO and the SOFIA program on updates to the instrument capabilities for inclusion on the website, in observing proposal calls, and other documentation

e) Assist the instrument teams in the design of the Astronomical Observing Templates (AOTs), serve as point of contact to the Information Systems Development group, and participate in the Working Group on AOTs
f) Understand, operate, and validate the data analysis pipeline for the instrument
g) Oversee calibration of the science data
h) Assist in flight planning, selecting calibrations observations for flights, making calibration Astronomical Observing Requests (AORs), and ensuring calibrations are appropriately assigned and the products are validated before insertion into the archive for release to the observers
i) Monitor and report the performance of the instrument, such as sensitivity, dark current, bad pixels, etc.

12.8 Mission Operations

Mission Operations is responsible for several areas in support of overall SOFIA operations. For flight operations Mission Operations is responsible for pre-flight planning, in-flight operations of mission systems by the telescope operator, mission director, and in-flight planner, and post-flight aircraft mission system checks.

In direct support of Science Instruments on the ground, Mission Operations is responsible for the management of five Instrument Readiness Rooms (IRRs) at the Armstrong Building 703 used for pre-flight preparation of Science Instruments. Management of the IRRs includes the following;

- Supplying Cryogens and compressed gases for each Science Instrument

- Technician support, if requested, to Science Instrument teams for cryogen fills (both in IRR and on aircraft)

- Technician support to Science Instrument teams for installation of Science Instrument, Counterweight racks and PI racks on the aircraft

- Providing Counterweight Rack dolly/lift device and PI rack dolly

- Providing standard laboratory instrumentation (i.e., multimeters, oscilloscopes, vacuum pumps, leak detector, etc.) in each IRR

- Providing a selection of hand tools (i.e., metric and SAE wrenches, sockets, and Allen wrenches)

Note: For the purpose of tool control, all Mission Operations provided tools for IRR use will be engraved. Also, any tools intended for use on the aircraft should be permanently marked and inventoried on form D-WK324-7 prior to aircraft entry and reviewed again upon exit.

- Providing a gantry crane capable of lifting 1 ton for use in the IRRs

In addition, Mission Operations will provide a single point of contact for Science Instrument team needs to include information for shipping/receiving, training required, IRR operations/procedures, etc. Information for Mission Operations ground support to Science Instrument teams is provided in the following three documents;

1. *Early Science Lab Orientation*, USRA-DAL-SSMOC-MOPS-PLAN-1400. 17 Dec 2008

2. *SOFIA Science Investigator Information for DAOF*, USRA-DAL-SSMOC-MOPS-PRO-0130, 21 June 2010

3. *Early Science Laboratory Facilities*, USRA-DAL-SSMOC-MOPS-TN-0500

All of these documents are available on the NASA SOFIA Windchill depository.

Appendix A.1 – Deliverable Items List

This appendix is a provisional deliverable item list (DIL) that will be included in the Science Instrument contract listing the hardware, software, and documentation to be delivered with a Science Instrument.

Hardware (applies to facility instrument only)

1) Complete science instrument assembly (i.e., cryostat, detector, opto-mechanical system, optics, electronics)
2) Electronics, equipment, and cables to be mounted in up to three PI racks (the PI rack structure itself is Government Furnished Equipment [GFE])
3) Electronics, equipment, and cables to be mounted in up to one counterweight rack (the counterweight rack structure itself is GFE)
4) Interconnect cables between the counterweight rack and the instrument assembly, and the rack and the instrument to the Observatory patch panels
5) Any science instrument specific test equipment needed to calibrate and maintain the instrument
6) Instrument installation cart
7) Any instrument turnover carts or test stand(s) needed to maintain the instrument
8) Spare hardware for items with limited life or risk of failure as determined by the instrument risk management program

Software (applies to facility instrument only)

9) Instrument control software
    - Including executables, source code, APIs, libraries, make files, and other files required to build the executables
10) Software and test scripts required to calibrate or maintain the instrument
11) Instrument data analysis/pipeline software
    - Including executables, source code, APIs, libraries, make files, and other files required to build the executables

Documentation

Programmatic documents

12) Project Management Plan (PMP)
    - Summary: Description of how the project is going to be executed, monitored, and controlled. Should include:
        i. Organization chart
        ii. Plan for requirements management
        iii. Plan for schedule management
        iv. Plan for change control (configuration management)
        v. Plan for risk management
    - Due: Systems Requirements Review

13) Schedule
    - Summary: Instrument development schedule containing sufficient detail for monthly progress tracking
    - Due: Each month under contract
14) Monthly status reports
    - Summary: Description of instrument team's progress over the previous month, including technical status and accomplishments, schedules status, budget status, and photographs and figures of significant accomplishments
    - Due: Each month under contract
15) Yearly funding requirements estimates
    - Summary: Used as inputs to the NASA PPBE process for estimating budgets; includes estimate of funding required for the next five fiscal years
    - Due: Yearly, ~ 1 March

Requirements documents

16) Instrument science and technical performance requirements
    - Summary: Requirements on the instrument scientific performance. May also list goals if desired. Should include a discussion of how the requirements relate to the selected science investigation.
    - Due: Baseline release at SRR with typical updates occurring at PDR and CDR
17) Instrument science and technical performance requirements verification matrix
    - Summary: See section 5.4.3
    - Due: Initial draft at SRR, updated drafts at subsequent reviews, and baseline release at CR or AR
18) Instrument SI System Specification & ICD requirements verification matrix
    - Summary: See section 5.4.3 and 7.4.1.1
    - Due: Initial draft at SRR, updated drafts at subsequent reviews, and baseline release at CR or AR

Airworthiness data package

The following is a list of the airworthiness items to be delivered by the SI Developer to the SOFIA Program. Due date(s) for each airworthiness deliverable item is as listed below and should be submitted to the Program according to the following schedule (unless otherwise noted): 30 days before PDR, 30 days before CDR, and 90 days before Pre-Ship Review. *For example an airworthiness item due at PDR should be delivered by the SI Developer to the SOFIA Program 30 days in advance of PDR.*

19) Drawing Package:
    - Drawing Tree
    - Drawing List
    - Assembly Drawings
    - Critical Safety Item (CSI) Drawings
    - Due: Initial drafts at PDR, baseline releases or final drafts at CDR with all drawings baselined before proceeding to fabrication/assembly, and updated releases reflecting the

as-built system including the approved changes made to the baselined design and drawings which pertain to airworthiness

i. Delivery of drawings with CSI-identified marking is first due at CDR. A number of these assembly drawings will typically still be submitted at PDR but without the formal CSI designation. See section 11.1 for details.

20) Quality Plan
   - Summary: See section 11.2
   - Due: Initial draft at SRR, updated draft at PDR, baseline release at CDR
21) Electrical Systems Report
   - Summary: Power analysis, wiring plan, wiring diagram, wire gauge size, MIL standards for wire insulation type, overcurrent circuit protection. See section 8.5 for details.
   - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system
22) Instrument Assembly Structural Analysis Report
   - See sections 8.3 & 8.4
   - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system
23) Counterweight Rack Report
   - Summary: Drawing showing populated rack configuration, Component description, mass & C.G. of components, structural analysis of components
   - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system
24) PI Rack Report
   - Summary: Drawing showing populated rack configuration, Component description, mass & C.G. of components, structural analysis of components
   - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system
25) System Safety Assessment
   - Summary: See section 8.8 and 11.14
   - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system
26) Pressure Test Plan
   - See section 8.4
   - Due: 60 days prior to test; typically due around CDR
27) Pressure Test Report
   - Due: Pre-Ship Review
28) Certifications
   - Summary: Critical Material Test Reports (CMTRs), pressure relief devices (PRDs), fasteners, welding inspections (post-fabrication and post-test)
   - Due: Pre-Ship Review

Software Assurance Documents

29) Software development plan
   - Summary: See section 11.10
   - Due: Initial draft at SRR, updated draft at PDR, and baseline release at CDR
30) Software requirements document
   - Summary: See section 11.10
   - Due: Baseline release at SRR with typical updates occurring at PDR and CDR

31) Software requirements verification matrix
    - Summary: Compliance matrix containing requirement paragraph identification, requirement text, verification phasing, verification method, verification status, test case/verification compliance artifact, verification remarks/rationale; see section 11.10
    - Due: Initial draft at SRR, updated drafts at subsequent reviews, and baseline release at CR or AR
32) Software architectural design specification
    - Summary: See section 11.10
    - Due: Initial draft at PDR and baseline release at CDR
33) Software users guide (facility instruments only)
    - Summary: See section 11.10
    - Due: Initial draft at PSR and baseline release of final version at AR
34) Software test reports
    - Summary: See section 11.10
    - Due: Following SIL/HIL and Observatory tests; tests may occur before PSR, at AFRC B703 before PIR, or on the aircraft following installation
35) Software version description document
    - Summary: See section 11.10
    - Due: Initial draft at CDR, updated draft at PSR, and baseline release at PIR
36) Software analysis report
    - Summary: See section 11.10
    - Due: As needed
37) Software verification and validation plan
    - Summary: See section 11.10
    - Due: Initial draft at PDR and baseline release at CDR
38) Software verification test procedures
    - Summary: See section 11.10
    - Due: Initial draft at CDR and baseline release at PSR (typical); if software verification test takes place on aircraft, due date for baseline release may be PIR instead (this is at the discretion of the SOFIA Software Test Lead)
39) Instrument to DCS interface control document
    - Summary: See section 11.10
    - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR

Reports, plans, manuals, and other

40) Instrument operations concept
    - Summary: Overview description of how the instrument will operate and interact with the other Observatory subsystems
    - Due: System Requirements Review
41) SI mass and C.G. ICD analysis report
    - Summary: Compliance analysis of the instrument with the mass and center of gravity limits defined in SOF-DA-ICD-SE03-037 (TA_SI_02) and SOF-AR-ICD-SE03-2027

(SI_CWR_01). This analysis pertains to the instrument assembly, Counterweight Rack, and any other SI components mounted to the telescope assembly.

i. *Note the technical content of SOF-DA-ICD-SE03-037 (TA_SI_02, Rev. 1.1) pertaining to instrument mass and c.g. is currently under review by the SOFIA Program; the affected sections of the ICD are Section 4.2.1 (allowable SI assembly c.g. envelopes) and Section 4.2.2 (allowable SI mass change during flight). Consult with your SOFIA Program POC for instrument mass and c.g. design guidance.*

- Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system

42) Instrument ICD envelope analysis report
    - Summary: Compliance analysis of the instrument with the allowable SI dynamic, static, and installation envelopes defined in SOF-DA-ICD-SE03-002 (GLOBAL_09)
    - Due: Initial draft at PDR, updated draft at CDR, and baseline release at PSR reflecting as-built system
43) Instrument cart/stand ICD analysis report(s)
    - Summary: Compliance analysis of instrument cart/stand ground support equipment with the interface requirements defined in SOF-AR-ICD-SE03-205 (SIC_AS_01) and SCI-AR-ICD-SE03-2017 (SIC_SSMO_01)
    - Due: Initial draft at CDR and baseline release at PSR reflecting as-built system
44) Instrument cart/stand structural analysis report(s)
    - Summary: Compliance analysis of instrument cart/stand ground support equipment with the applicable structures safety requirements of SOF-AR-SPE-SE01-2028 (paragraph ID 3.5.2 and subparagraphs).
    - Due: Initial draft at CDR and baseline release at PSR reflecting as-built system
45) Instrument configuration sheet
    - Summary: See section 9.3
    - Due: Pre-Install Review
46) Instrument maintenance logbook
    - Summary: Log of instrument changes following instrument ICD verification and airworthiness approval
    - Due: Acceptance Review (facility instruments only); available for review by the SIAT for other instrument classes
47) Commissioning plan (not required for technology demonstration instruments)
    - Summary: Plan for the commissioning of instrument including a description of laboratory, on-aircraft, and airborne tests that need to be performed to commission all the observing modes of the instrument.
    - Due: Pre-Ship Review
48) Operating manual (facility instruments only)
    - Summary: Manual describing how to operate the instrument on SOFIA. It should include a section on how to address off-nominal conditions such as an ice plug or how the operators should react to a release valve operating.
    - Due: Initial draft at PSR and baseline release of final version at AR

49) Instrument control software manual (facility instruments only)
    - Summary: A user manual for the instrument control software (may be incorporated into the overall instrument operating manual if appropriate)
    - Due: Initial draft at PSR and baseline release of final version at AR
50) Commissioning report (not required for technology demonstration instruments)
    - Summary: Report on the instrument airborne performance characteristics for all user modes of the instrument
    - Due: Acceptance Review (facility instruments) or Commissioning Review (PI instruments)
51) Pipeline developers manual (facility instruments only)
    - Summary: Developers manual for the instrument data reduction pipeline; see *SI Pipeline Acceptance Plan* SCI-US-PLA-SW09-2000, for required content of pipeline developers manual
    - Due: Initial draft at PSR and baseline release of final version at AR
52) Pipeline users manual (facility instruments only)
    - Summary: Users manual for the instrument data reduction pipeline; see *SI Pipeline Acceptance Plan* SCI-US-PLA-SW09-2000, for required content of pipeline users manual
    - Due: Initial draft at PSR and baseline release of final version at AR
53) Maintenance manual (facility instruments only)
    - Summary: Manual describing how to open and close the instrument and perform expected and probable maintenance on the instrument
    - Due: Initial draft at PSR and baseline release of final version at AR
54) Instrument shipping plan (not required for technology demonstration instruments)
    - Summary: Description of how the instrument will be packed and shipped
    - Due: Pre-Ship Review
55) Instrument identification list (facility instruments only)
    - Summary: See section 11.5.2
    - Due: Initial draft at PDR and final release at CDR
56) Action item reports
    - Summary: Statement describing the closer of action items accepted at an instrument review
    - Due: As needed
57) Commissioning data package (applies to non-facility instruments)
    - Summary: See Appendix E – SI Acceptance & Commissioning Data Package Contents
    - Due: Commissioning Review
58) Acceptance data package (facility instruments only)
    - Summary: See Appendix E – SI Acceptance & Commissioning Data Package Contents
    - Due: Acceptance Review

Operating procedures

Instrument operating procedures will be configuration controlled by the SOFIA program. The SOFIA mission operations team is responsible for the proper formatting, shepherding through the SOFIA configuration management process, and long-term maintenance of these documents. Thus the instrument team will be responsible for delivering the first draft of these documents and assisting the SMO with updating these documents as necessary.

59) Instrument installation procedure
    - Summary: Procedure for installing the instrument assembly onto the telescope flange (does not need to include PI rack or counterweight rack installation unless there are special requirements for these racks – there are generic rack installation procedures that cover all instruments)
    - Due: Initial draft at PSR and baseline release at PIR
60) Instrument warm functional check procedure (facility instruments only)
    - Summary: Procedure for checking the instrument's health status while warm that should be performed prior to cooldown
    - Due: Initial draft at PSR and baseline release of final version at AR
61) Instrument cooldown procedure (not required for technology demonstration instruments)
    - Summary: This is a cryogen fill procedure or a cryocooler operating procedure that will enable mission operations crew bring the instrument to operating temperature. This procedure should include a section that details the steps for routine filling of cryogens to maintain the instrument at operating temperature.
    - Due: Initial draft at PSR and baseline release at AR; if this procedure is performed on the aircraft the baseline release is due instead by PIR
62) Instrument cryogen fill procedure
    - Summary: Procedure detailing the steps for routine filling of the cryogens to maintain the instrument at operating temperature. The content of this procedure may be a subsection of the Instrument cooldown procedure.
    - Due: Initial draft at PSR and baseline release at PIR
63) Instrument cold functional check procedure (facility instruments only)
    - Summary: Procedure for checking the instrument's health status while cold prior to line operations testing or flight
    - Due: Initial draft at PSR and baseline release of final version at AR
64) EMI test plan
    - Summary: Plan for testing the instrument to check for electromagnetic interference via a ground test on the aircraft (use an existing instrument EMI test plan as a template)
    - Due: Initial draft at PSR and baseline release at PIR
65) Instrument optical alignment plan (not required for technology demonstration instruments)
    - Summary: Plan for optically aligning the instrument with the telescope
    - Due: Pre-Ship Review
66) Ground test plan
    - Summary: Plan for testing the instrument on the aircraft on the ground, covering both tests that can be accomplished in the hangar as well as tests done on the flight line (observing the sky)
    - Due: Pre-Ship Review

67) Instrument removal procedure
    - Summary: Procedure for removing the instrument assembly flange the telescope flange (does not need to include PI rack or counterweight rack installation unless there are special requirements for these racks – there are generic rack installation procedures that cover all instruments)
    - Due: Initial draft at PSR and baseline release at PIR

Review Chart Packages

68) Systems Requirements Review chart package
    - Summary: See section 7.4.1
    - Due: Systems Requirements Review
69) Preliminary Design Review chart package
    - Summary: See section 7.5.1
    - Due: Preliminary Design Review
70) Critical Design Review chart package
    - Summary: See section 7.6.1
    - Due: Critical Design Review
71) Pre-ship Review chart package
    - Summary: See section 7.6.2
    - Due: Pre-ship Review
72) Commissioning Review chart package (non-facility instruments only)
    - Summary: See section 7.7.5
    - Due: Commissioning Review
73) Acceptance Review chart package (facility instrument only)
    - Summary: See section 7.7.4
    - Due: Acceptance Review

Appendix A.2 – Documentation Delivery Schedule

The table in Appendix A.2 presents the information from Appendix A.1 – Deliverable Items List for document deliverable items, organized by the respective instrument milestone/technical reviews. Note this table only covers document deliverables—Appendix A.1 covers the hardware and software deliverable items which also apply to facility instruments.

This table applies to all the SOFIA science instrument types and explicitly identifies the document deliverable items that are additionally required for facility instruments (denoted by "FSI only"). Successfully completing an instrument technical review will depend on a number of key factors, one of which is timely delivery of documentation by the instrument developer to the SOFIA Program prior to a milestone/technical review; Section 7.4 of this handbook describes in detail the entrance and success criteria for each review.

The deliverable item numbers used in this table correspond to the same numbers in used in Appendix A.1. The instrument developer does not necessarily need to deliver a separate document for each of the itemized deliverables (e.g., separate documents for Instrument control software manual and Operating manual vs. a single document containing both). The itemization scheme of deliverables presented in Appendix A.1 and A.2 is a recommendation, which may additionally facilitate with configuration management of these work products by the instrument developer during development; however it is at discretion of the instrument developer of how particular work products/deliverables will be released as documents as long as it communicated to the SOFIA Program and easily understood which deliverables are contained within which document.

The applicability of the Commissioning Review (CR) and Acceptance Review (AR) columns will depend on the science instrument type: the Commissioning Review will apply to PI and technology demonstration instruments and the Acceptance Review will apply to facility instruments. A legend is provided preceding the table, which defines the technical review acronyms and document status symbols used in the table.

It should be noted that the phasing and delivery of a small number of deliverables may not necessarily be directly coupled with the overall instrument milestone/technical reviews as listed, such as software test procedures. For example, the driving event for development of a software test procedure may be a Test Readiness Review (TRR) before a test; completion of such a procedure and test may roll up into a higher level milestone/technical review such as a Pre-ship Review (PSR). TRRs and tests may occur in different phases of instrument development such as before shipment, at AFRC B703 before installation, and on the aircraft once the instrument has been integrated with the Observatory. NASA SI Development will provide guidance on which deliverables may fall into to this category.

During the course of instrument development an instrument developer may choose to make a modification(s) to the instrument (i.e., design, configuration, operation, mode, etc.) which be a change from a baselined document (e.g., analysis, drawing, plan). In such cases, the instrument developer should deliver an update of the document to the SOFIA Program which reflects the change. The delivery schedule of such documents is not formally shown in the table, with the exception of certain documents that do typically undergo changes following initial baselining of the document (e.g., requirements documents) but that which no update would be required if no changes were made to the baseline release. To reduce risk to the instrument developer and also the SOFIA Program, the instrument developer should communicate any potential changes that concern airworthiness, safety, interfaces with SOFIA, or baselined requirements, to the Program to evaluate the potential impacts of the proposed changes before the developer proceeds with making the change.

Acronym	Definition	Symbol	Definition
SRR	Systems Requirements Review	○	Initial or updated draft release
PDR	Preliminary Design Review	●	Baseline release; typically a final release
CDR	Critical Design Review	▲	Typical updated release following a baseline release (if necessary)
PSR	Pre-Ship Review		
PIR	Pre-Install Review		
CR	Commissioning Review		
AR	Acceptance Review		

Item #	Document	SRR	PDR	CDR	PSR	PIR	CR	AR
12	Project Management Plan	●						
13	Schedule	Update monthly under contract						
14	Monthly status reports	Update monthly under contract						
15	Yearly funding requirements estimates	Update annually						
16	Instrument science and technical performance requirements	●	▲	▲				
17	Instrument science and technical performance verification matrix	○	○	○	○	○	●	●
18	Instrument SI System Specification and ICD requirements verification matrix	○	○	○	○	○	●	●
19	Drawing package		○	●	▲			
20	Quality plan	○	○	●				
21	Electrical systems report		○	○	●			
22	Instrument assembly structural analysis report		○	○	●			
23	Counterweight rack report		○	○	●			
24	PI rack report		○	○	●			
25	System safety assessment		○	○	●			
26	Pressure test plan			●				
27	Pressure test report				●			
28	Certifications				●			
29	Software development plan	○	○	●				
30	Software requirements document	●	▲	▲				
31	Software requirements verification matrix	○	○	○	○	○	●	●
32	Software architectural design specification		○	●				
33	Software users guide *(FSI only)*				○			●
34	Software test reports				●	●		
35	Software version description document			○	○	●		
36	Software analysis report	As needed						
37	Software verification and validation plan		○	●				
38	Software verification test procedures			○	●			
39	Instrument to DCS interface control document		○	○	●			
40	Instrument operations concept	●						
41	Instrument assembly mass and c.g. ICD analysis report		○	○	●			
42	Instrument ICD envelope analysis report		○	○	●			
43	Instrument cart/stand ICD analysis report(s)			○	●			
44	Instrument cart/stand structural analysis report(s)			○	●			
45	Instrument configuration sheet					●		
46	Instrument maintenance logbook *(FSI only)*							●
47	Commissioning plan				●			
48	Operating manual *(FSI only)*				○			●
49	Instrument control software manual *(FSI only)*				○			●
50	Commissioning report						●	●

Item #	Document	SRR	PDR	CDR	PSR	PIR	CR	AR
51	Pipeline developers manual *(FSI only)*				○			●
52	Pipeline users manual *(FSI only)*				○			●
53	Maintenance manual *(FSI only)*				○			●
54	Instrument shipping plan				●			
55	Instrument identification list		○	●				
56	Action item reports	As needed						
57	Commissioning data package *(PSI, TDSI)*						●	
58	Acceptance data package *(FSI only)*							●
59	Instrument installation procedure				○	●		
60	Instrument warm functional check procedure *(FSI only)*				○			●
61	Instrument cooldown procedure				○			●
62	Instrument cryogen fill procedure				○	●		
63	Instrument cold functional check procedure *(FSI only)*				○			●
64	EMI test plan				○	●		
65	Instrument optical alignment plan				●			
66	Ground test plan				●			
67	Instrument removal procedure				○	●		
68	Systems Requirements Review chart package	●						
69	Preliminary Design Review chart package		●					
70	Critical Design Review chart package			●				
71	Pre-ship Review chart package				●			
72	Commissioning Review chart package *(PSI, TDSI)*						●	
73	Acceptance Review chart package *(FSI only)*							●

Appendix B – Acronyms

Acronyms and abbreviations are listed in alphabetical order.

A, I, D, T	Analysis, Inspection, Demonstration, Test
a.k.a.	Also Known As
AC	Alignment Camera
AC	Alternating Current
AFRC	NASA Armstrong Flight Research Center
AFSRB	Airworthiness & Flight Safety Review Board
ANSI	American National Standards Institute
AO	Announcement of Opportunity
AOR	Astronomical Observing Requests
AOT	Astronomical Observing Templates
API	Application Program Interface
APP	Airborne Platform Project
AR	Acceptance Review
ARC	NASA Ames Research Center
arcmin	arc minute
arcsec	arc second
AS	Aircraft System
ASTM	American Society for Testing & Materials
AUX	Auxiliary
AWS	American Welding Society
B703	Building 703 (AFRC)
C	Celsius
CA	California
CAD	Computer Aided Design
CAR	Corrective Action Request
CCC	Closed-Cycle Cryocooler
CDR	Critical Design Review
Cert	Certificate of Conformance or Certification
CFD	Computational Fluid Dynamics
CG	Center of Gravity
cm	centimeter
CMTR	Certified Material Test Report
CoC	Certificate of Conformance
COR	Contracting Officer Representative
COR	Contracting Officer Representative
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
CSCI	Computer Software Configuration Item
CSI	Critical Safety Item
CWP	Counterweight Plate
CWR	Counterweight Rack

DAOF	Dryden Aircraft Operations Facility
dB	decibel
DCS	Data Cycle System
DCS	Direct Current
deg	Degree
DIL	Deliverable Item List
DLR	German Aerospace Center, Deutsches Zentrum für Luft- und Raumfahrt
DOT	Department of Transportation
DFRC	Dryden Flight Research Center (now AFRC)
DSI	Deutsches SOFIA Institut
ECO	Engineering Change Order
EL	Elevation
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPD	Emergency Power Disconnect
EPO	Education & Public Outreach
ESD	Electrostatic Discharge
F	Fahrenheit
FCLS	Focused Chopped Light Source
FFI	Fine Field Imager
FITS	Flexible Image Transport System
FLITECAM	First-Light Infrared Test Experiment Camera (SI)
FMO	Focused Mission of Opportunity
FOD	Foreign Object Debris
FORCAST	Faint Object InfraRed CAmera for the SOFIA Telescope
FPI	Focal Plane Imager
FRR	Flight Readiness Review
FSC	Federal Stock Code
FSI	Facility Science Instrument
ft	Feet
FY	Fiscal Year
GFE	Government Furnished Equipment
GHz	Gigahertz
GI	General Investigator
GIMP	Government Mandatory Inspection Point
GPS	Global Positioning Subsystem
GREAT	German Receiver for Astronomy at Terahertz Frequencies
GSE	Ground Support Equipment
GTO	Guaranteed Time Observation
GUI	Graphical User Interface
GVPP	Gate Valve Pressure Plate
He	Helium Gas
HF	High Frequency
HIL	Hardware-in-the-Loop
HIPO	High Speed Imaging Photometer for Occultations (SI)

HK	Housekeeping
hr	Hour
Hz	Hertz
I&T	Integration & Test
ICD	Interface Control Document
IMF	Instrument Mounting Flange
IMS	Integrated Master Schedule
in	Inch
INF	Instrument Flange
IR	Infrared
IRIG-B	Inter Range Instrumentation Group – B
IRR	Instrument Readiness Room
kHz	kilohertz
ksi	kilopound per square inch
KVA	kilovolt-ampere
L3	L-3 Communications
LCHP	Large Chopped Hot Plate
LFA	Low Frequency Array (GREAT SI)
LHe	Liquid Helium
LN2	Liquid Nitrogen
LOPA	Layout of Personnel Accommodations
LOS	Line Of Sight
MADS	Mission Audio Distribution System
MAN	MAN Technology
MCCS	Mission
mG	milligauss
MHz	Megahertz
MIL	Military Standard
MIL-STD	Military Standard
µm	micrometer; micron
min	Minute
mm	millimeter
MNOP	Maximum Normal Operating Pressure
MOPS	Mission Operations
MOU	Memorandum of Understanding
MS	Military Standard
MS	Margin of Safety
msec	millisecond
N/A	Not Applicable
N2	Nitrogen Gas
NAS	National Aerospace Standards
NASA	National Aeronautics and Space Administration
NASA-STD	NASA Standard
NDE	Non-Destructive Examination
NPR	NASA Procedural Requirement

NSPIRES	NASA Solicitation and Proposal Integrated Review and Evaluation System
OCCB	Observatory Configuration Control Board
PCA	Physical Configuration Audit
PDR	Preliminary Design Review
PDS	Power Distribution System
PEA	Program Element Appendix
PI	Principal Investigator
PIF	Pre-Flight Integration Facility
PIR	Pre-Install Review
PIS	Platform Interface System
PMP	Project Management Plan
PPBE	Planning, Programming, Budgeting, and Execution
PRD	Pressure Review Device
PSD	Power Spectral Density
PSI	Principal Investigator Science Instrument
psi	pounds per square inch
psid	pounds per square inch differential
PSR	Pre-Shipment Review
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
PVS	Pressure Vessel Systems
QA	Quality Assurance
QA	Quality Assurance
Rev	Revision
RFA	Request for Action
RFI	Request for Information
RMS	Root-Mean-Square
S&MA	Safety & Mission Assurance
SAE	Society of Automotive Engineers
SALMON	Stand-Alone Mission of Opportunity Notice
SCHP	Small Chopped Hot Plate
SCL	SOFIA Command Language
SE&I	Systems Engineering & Integration
sec	Second
SI	Science Instrument
SIAT	Science Instrument Airworthiness Team
SIC	Science Instrument Cart
SICCR	Science Instrument Configuration Change Request
SIDAG	Science Instrument Development Advisory Group
SIL	Systems Integration Laboratory
SIS	Superconductor-Insulator-Superconductor
SMA	Secondary Mirror Assembly
SMD	Science Mission Directorate
SMO	Science Mission Operations
SMO	Science Mission Operations

SObRR	SOFIA Observatory Readiness Review
SOFIA	Stratospheric Observatory For Infrared Astronomy
SOW	Statement of Work
SP	Special Performance
SPARC	Scalable Processor Architecture
SPL	Sound Pressure Levels
SRR	System Requirements Review
SSA	System Safety Assessment
SSMO	SOFIA Science and Mission Operations
SSP	SOFIA Science Project
SSWG	System Safety Working Group
STD	Standard
TA	Telescope Assembly
TA	Telescope Assembly
TAAS	Telescope Assembly Alignment Simulator
TAAU	Telescope Assembly Alignment Unit
TAIPS	Telescope Assembly Image Processing Subsystem
TBD	To Be Determined
TBR	To Be Reviewed
TCP/IP	Transmission Control Protocol/Internet Protocol
TDSI	Technology Demonstration Science Instrument
TRR	Test Readiness Review
TTL	Transistor–Transistor Logic
UPS	Uninterruptible Power Supply
US	United States
USRA	Universities Space Research Association
V	Volt
V&V	Verification & Validation
VAC	AC Voltage
VDC	DC Voltage
VDD	Version Description Document
VIS	Vibration Isolation Subsystem
VME	Versa Module-Europe
VPN	Virtual Private Network
VPS	Vacuum Pump System
W	Watts
WBS	Work Breakdown Structure
WFI	Wide Field Imager
XEL	Cross-Elevation
XML	Extensible Markup Language

Appendix C – Rack & Patch Panel Distances

The following graphics are intended to be serve as guidance to SI Developers for approximating and determining lengths of needed cables. It is generally recommended that cables be longer than needed to accommodate the routing and securing of cables to tie-down locations that is performed during instrument hardware and cable installation. SI Developers are encouraged to contact the SOFIA SI Development Team for any specific questions about instrument, rack, and patch panel distances or cable fabrication.

Figure A-1 shows a top view of the three PI rack locations and PI Patch Panel. The direction of aircraft "forward" is the bottom of the graphic. Although not explicitly shown in the graphic, the U401 panel (aircraft portside) is the right side of the PI Patch Panel in the graphic; similarly, the U400 panel (aircraft starboard) is the left side of the PI Patch Panel in the graphic.

Figure A-2 shows a side view of the PI rack locations and PI Patch Panel. The direction of aircraft "forward" is the left side of the graphic. The view is from aircraft portside looking starboard.

Figure A-3 shows three views of the telescope assembly, in respect to the counterweight plate. The features and locations shown are the instrument mounting flange, Counterweight Rack, TA/SI Patch Panels U402 & U403, and chopper junction box. Note not all telescope components are shown in the graphic—only select components to more clearly show the physical SI interface locations. *(The U404 He patch panel was not yet present or installed when this figure was originally generated. The U404 patch panel is installed on SOFIA and information about its position on the telescope assembly can be found in the Cryocooler to Science Instrument CRYO_SI_01 ICD (APP-DA-ICD-SE03-2059). Panel U404 will be included in this graphic when Figure A-3 is next updated.)*

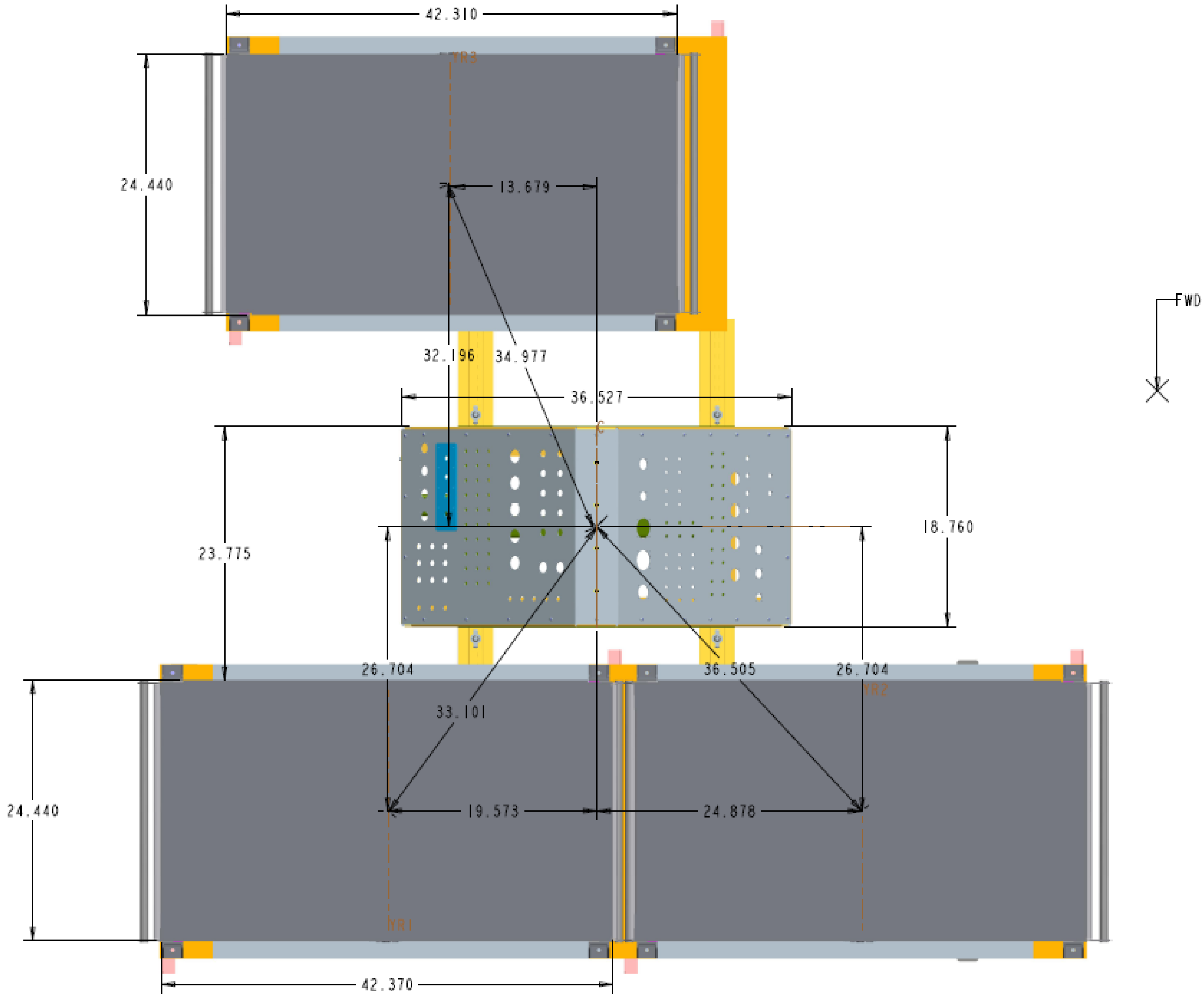

Figure C-1: Top view of PI racks and PI Patch Panel (panels U400 & U401)

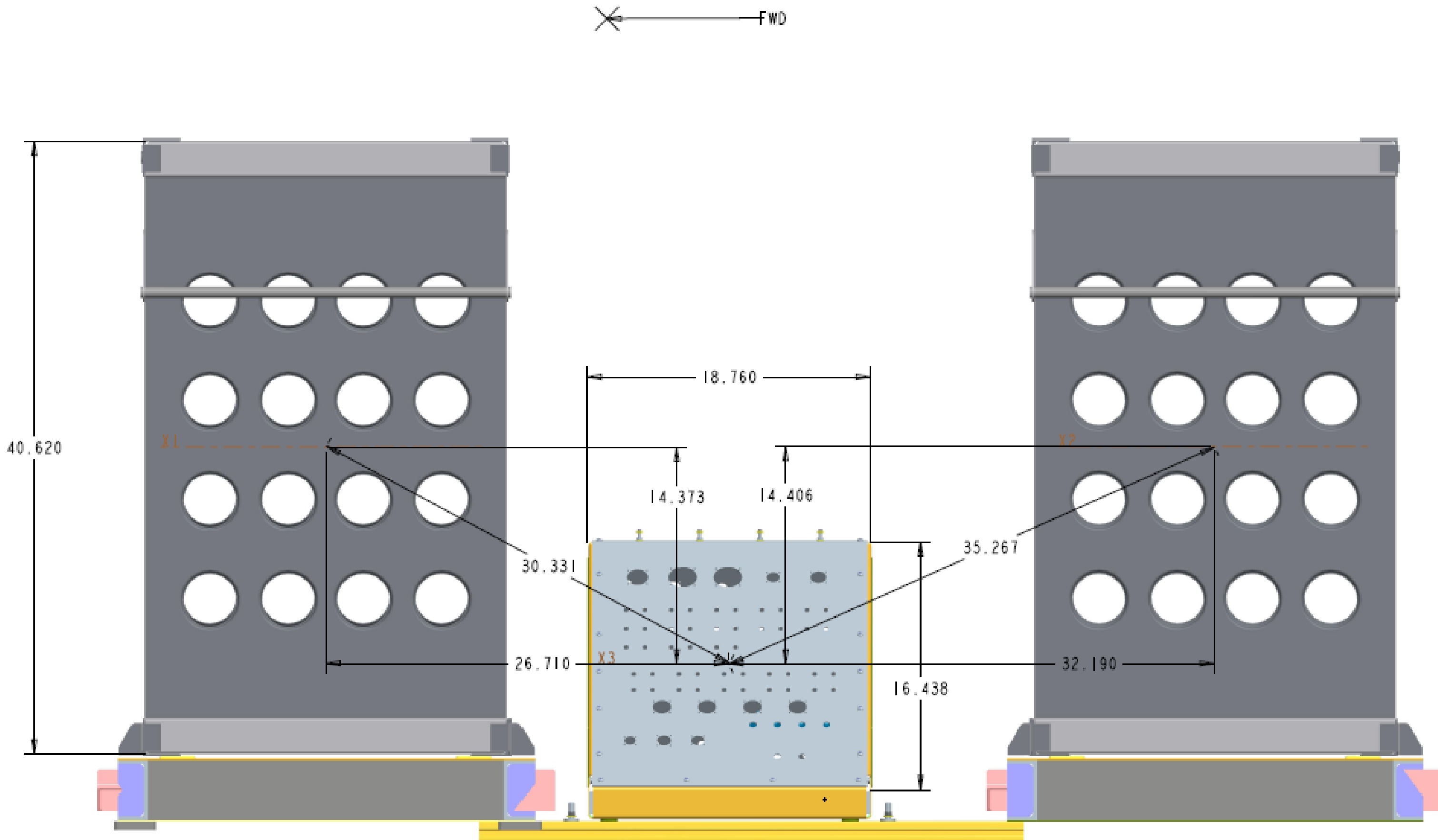

Figure C-2: Side view of PI racks and PI Patch Panel (View looking starboard)

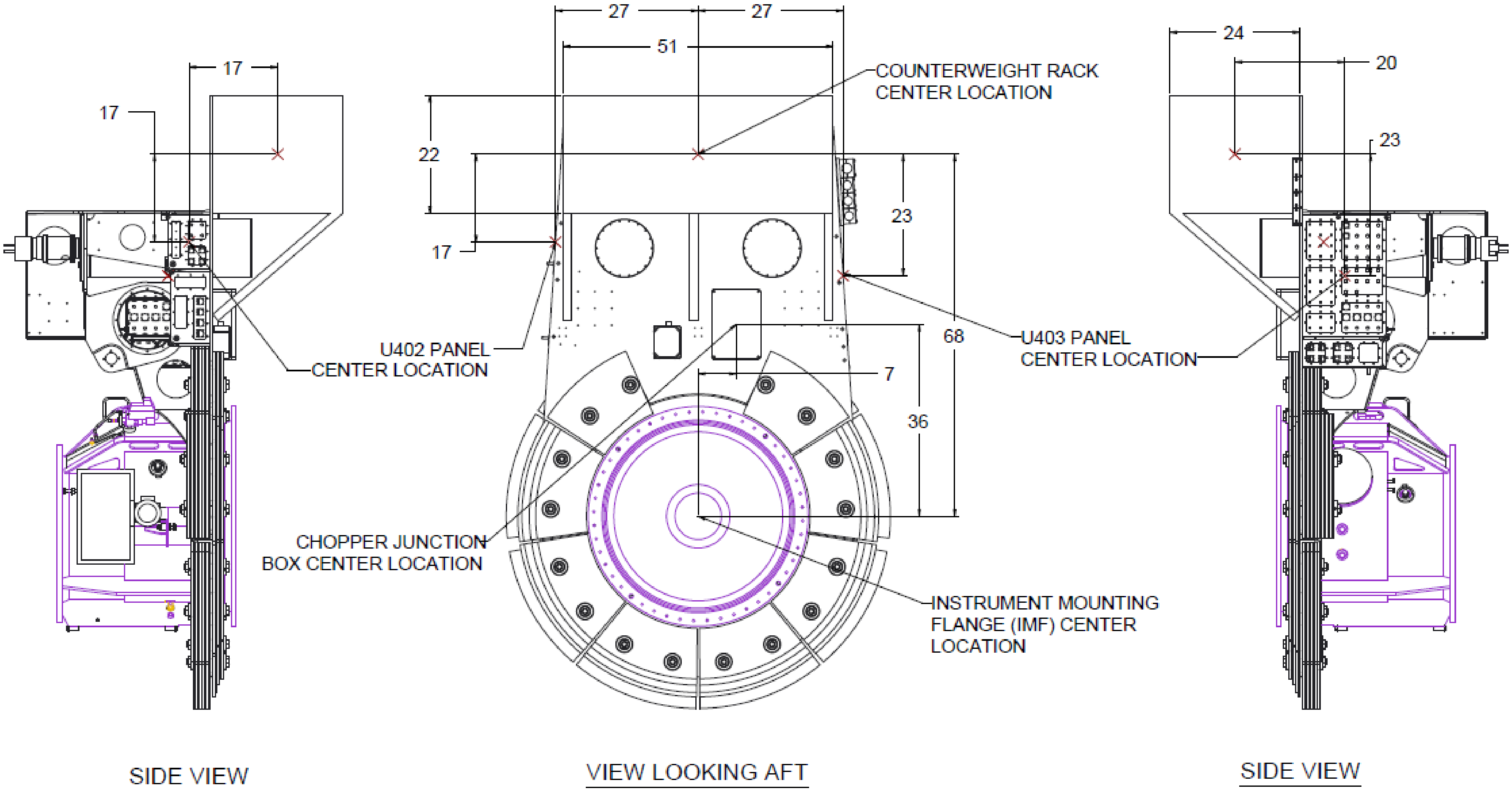

Figure C-3: Views of Telescope Assembly Counterweight Plate and Instrument Mounting Flange

Appendix D – Excerpt from SOFIA SI System Specification & ICD Requirements Verification Matrix Template (SOF-NASA-REP-SV05-2057)

Document	Paragraph Identification (ParID)	Requirement	Verification Method by Development Phase					Verification Activity Description	Compliance / Artifacts	SI Status (Verification status to be filled out by SI Team)					NASA Compliance Authority	NASA Status (Verification status to be filled out by NASA)				
			PDR	CDR	Pre-Ship	At AFRC prior to installation	Installation and checkout			PDR	CDR	Pre-Ship	At AFRC prior to installation	Installation and checkout		PDR	CDR	Pre-Ship	At AFRC prior to installation	Installation and checkout
XXXX	*Y.Y*	*- Each requirement listed separately in this column. - Create additional rows as needed for verification of more than one system with a single requirement (e.g. Installation cart, Lab cart)*	*A, D, I, T or N/A*	*A, D, I, T or N/A*	*A, D, I, T or N/A*	*A, D, I, T or N/A*	*A, D, I, T or N/A*	*Brief description of verification activities.*	*- List each verification compliance reference. - SI Developer to record in this field how SI meets this requirement, providing references to SI compliance artifact documents such as analyses, drawings, etc., as needed. - NASA to record in this field comments, verification results, and references to as-run records, discrepancy reports, deviations, and waivers.*	*In each column, list one of the following:* Complies Does not comply - corrective action planned Does not comply - request waiver Lien Deferred N/A					*SIAT or SSP SE&I*	*In each column, list one of the following:* Pass Fail - corrective action needed Waiver in work Waiver approved More information required Lien Deferred N/A				
General Notes: 1) Any requirement identified to be not applicable to a Science Instrument, should be declared not applicable in the "Compliance / Artifacts" field by the Science Instrument Developer, for review and concurrence by NASA. 2) Abbreviations for methods of verification used in the "Verification Method by Development Phase" columns are: Analysis (A), Demonstration (D), Inspection (I), Test (T).																				
SOF-DA-ICD-SE03-002 (GLOBAL_09) Revision 2: Science Instrument Envelope																				
SE03-002	3.1 a	The SI shall comply with the stay-in Dynamic Envelope defined in Figures 3.1-1A through 3.1-1D.	A	A	A & I	N/A	N/A	(PDR) SI Developer to provide preliminary Dynamic Envelope analysis. A CAD model of the ICD Dynamic Envelope from the SOFIA Program is available upon request by the SI Developer. (CDR) SI Developer to provide updated analysis for instrument CDR design. (Pre-Ship) SI Developer to provide final updated analysis for as-built SI. NASA to inspect hardware.							SSP SE&I					
SOF-DA-ICD-SE03-2015 (SI_AS_01) Revision A: Principal Investigator Equipment to PI Rack to Aircraft System Interface																				
SE03-2015 Rev. A	4.3	The total SI payload loading of the PI rack structure shall be 600 lbs or less.	A	A	A & T	T	N/A	(PDR) SI Developer to provide preliminary PI Rack mass analysis. (CDR) SI Developer to provide updated mass analysis for instrument CDR design. (Pre-Ship) SI Developer to provide final updated payload mass analysis based on reported measured weight of individual rack components. Weight contribution from cables within the rack should be included. It is preferred the team also provide a weight measurement of the fully populated PI Rack (weight of the empty PI Rack is 64 lbs). (At AFRC prior to installation) NASA to measure weight of PI Rack.							SIAT					
SOF-AR-ICD-SE03-2029 (MCCS_SI_05) Revision C: Principal Investigator Patch Panel to Principal Investigator Equipment Rack(s) Interface																				
SE03-2029 Rev. C	3.2.1.1	The power drawn by the SI from Panel U401-J2 (115 VAC, 60 Hz, UPS power) shall not exceed 2 kVA.	A	A	T or A	T	N/A	(PDR) SI Developer to provide preliminary SI power analysis, indicating expected power draw from each SOFIA SI power bus (e.g., J0, J1, J2, J3). (CDR) SI Developer to provide updated power analysis for instrument CDR design. (Pre-Ship) SI Developer to measure and provide power measurement results, or provide a final updated power analysis for the as-built SI. (At AFRC prior to installation) NASA to measure power draw of the SI.							SSP SE&I					

Appendix E – SI Acceptance & Commissioning Data Package Contents

The source of the information in the following table is from the *SOFIA Science Project Data Requirements* (SCI-AR-SOW-PM91-2001):

Item	**Required in Acceptance Data Package**	**Required in Commissioning Data Package**
1. SI Part Number and Revision	Yes	Yes
2. Table of Contents	Yes	Yes
3. Certificate of Acceptance (FSI only)	Yes	No
4. Requirements Verification Compliance Matrix (including traceability of requirements from specifications and ICDs to as-run acceptance procedures or verification analysis reports)	Yes	Yes
5. Drawing Tree	Yes	Yes
6. Drawings	Yes	Yes
7. As-Run Acceptance Procedures and travelers	Yes	Yes
8. Discrepancy Reports	Yes	Yes
9. Comparison with GIDEP Alerts (FSI only)	Yes	No
10. Limited Lift Items List (FSI only)	Yes	No
11. As-Measured Mass Properties Report	Yes	Yes
12. List of loose or separate hardware (FSI only)	Yes	No
13. List of authorized deviations and waivers	Yes	Yes
14. List of any hardware/software modified after start of requirements verification process	Yes	Yes
15. Unsigned DD form 250 or equivalent (FSI only)	Yes	No
16. All airworthiness documentation	Yes	Yes

Note: The items listed in this table are the required contractual content of the Acceptance Data Package (ADP) for USRA-delivered FSIs.

Appendix F – SI Developer's Handbook, Rev. – to A Change Details

Administrative changes:
- Updated cover page and signature page.
- Made global replacements in handbook of Dryden references to Armstrong; DAOF to Armstrong Building 703.
- Removed references to SOFIA Science Project (SSP) and Airborne Platform Project (APP) in handbook.
- Renumbered all figure and table numbers to include specific subsection number.

Specific changes (Rev. - paragraph numbers cited below):
1.3: Removed reference to Windchill User's Manual (manual never written). Added reference to Windchill ./Help library.
2: Added information about SOFIA Program transition and dissolution of Science Project and Platform Project. Added reference to SOFIA Concept of Operations (SOF-DA-PLA-PM17-2000).
3: Removed reference to Special Purpose Instrument class—current suite of instrument classes are: Facility, PI, Technology Demonstration. Converted Table 1 image to text.
3.3: Removed Special Purpose Science Instrument section; baseline version of handbook already acknowledged this instrument classification is obsolete.
4.2: Added optional pressure coupler or optical window assembly to system list for instruments. Replaced existing Figure 2 photograph with a new similar photograph showing PI Patch Panel Guard.
4.4: Added Auxiliary (AUX) Rack and Shipping Assembly to Government Furnished Equipment list.
5: Revised ICD count from 14 to 15, accounting for CRYO_SI_01. Removed reference to Synopsis of SOFIA Concept of Operations (SCI-US-PLA-PM17-2016) since it has been by SOFIA ConOps (SOF-DA-PLA-PM17-2000).
5.3.1: Created new Figure 3 ICD context block diagram. Converted Table 2 image to text and added CRYO_SI_01 to the list.
5.3.3: Added vacuum pump system to section.
5.3.4: Added pressure coupler and optical window assembly to section.
5.3.5: Added statement SI Developers will provide their own jumper cables to interface/connect to SOFIA patch panels.
5.3.6: Updated total SI power budget from 5 to 6.5 KVA to reflect current available SI power budget. Added table showing available power types and amounts.
5.3.7: Inserted new section 5.3.7 to address fluidic interface of Phase 1 SOFIA Cryocooler System.
5.3.7.1: Added reference to SOFIA Command Language (SCL) User's Manual (SOF-DA-MAN-OP02-2181). Removed Appendix B SOFIA Command Language Tutorial.
5.3.8: Added more information about specific applicability of cart ICDs to installation vs. lab carts.
5.4.2: Converted Table 3 from image to text.
5.4.3: Revised SI verification section to align with present process used by SE&I and SIAT. Removed out-of-date Table 4.
5.4.4: Added details about deviation and waiver process for SI nonconformance/non-compliance.
(5.4.5.8) Added new section describing Functional & Physical Configuration Audits.
5.4.5.2: Converted Table 4 from image to text and added tier tests to table. Added description of each Tier Test level.

6.2.1: Added cryocooler compressor to Science Lab provisions list. Added statement about cryogen training for SI members participating in cryogen servicing at AFRC.
(6.2.9): Added new section and description about Observatory cryocooler system.
6.2.9: Replaced SOF-DA-ICD-SE03-005 Layout of Personnel Accommodations (LOPA) with APP-DF-DWG-SE02-2924 LOPA. Added new details about workspace on aircraft, including trays in the AUX Rack and two conference tables on the main deck
6.6: Added statement that instrument proposers should include cost of guaranteed time observations (GTO) in proposal budget.
7.1.1: Added statement that this section is out-of-date and will be updated in the next revision of this handbook. Added statement about instrument proposal single-step or two-step selection process.
7.3: Clarified phases referenced in section correspond to NASA project life-cycle phases. Removed Post-Flight Mission Briefs from Figure 8 since these are not performed.
7.4.1.2: Clarified SRR subsections in handbook are guidelines for the content and subject areas to be addressed in the SRR by instrument team.
7.5.1.2: Clarified PDR subsections in handbook are guidelines for the content and subject areas to be addressed in the PDR by instrument team. Added instrument science & technical performance, SOFIA SI System Specification, and SOFIA SI ICD verification matrix deliverables.
7.5.1.7: Changed “waiver” to “deviation” for PDR. Added hazard reports to section.
7.6.1.2: Clarified CDR subsections in handbook are guidelines for the content and subject areas to be addressed in the CDR by instrument team. Added instrument science & technical performance, SOFIA SI System Specification, and SOFIA SI ICD verification matrix deliverables.
7.6.1.2.6: Added hazard reports to section. Added identification of safety critical items.
7.6.1.2.7: Added physical configuration audit (PCA) plan and schedule.
7.6.1.2.9: Change “waivers” to “deviations”. Added applicability of SOFIA SI System Specification to section.
7.6.2.2: Clarified PSR subsections in handbook are guidelines for the content and subject areas to be addressed in the PSR by instrument team. Added instrument science & technical performance, SOFIA SI System Specification, and SOFIA SI ICD verification matrix deliverables.
7.6.2.2.5: Added PCA has been completed. Added certification of proof load tests for instrument carts or stands have been completed. Added certification of pressure relief devices (PRDs) for instrument cryogen vent systems has been completed.
7.7.1: Added details about Pre-Install Review success criteria.
7.7.2: Added entrance and success criteria for Test Readiness Review; section was previously empty.
7.7.3: Changed acronym “SobRR” to “SObRR” for consistency.
7.4.4: Added entrance and success criteria for Acceptance Review.
7.7.5: Added entrance and success criteria for Commissioning Review.
8.1.5: Removed airworthiness deliverables list; it is already contained in Appendix A.
8.3: Removed Quality Assurance section since quality is already covered in detail in section 11, Safety & Mission Assurance.
8.6.1.1.2: Changed polyvinylchloride (PVC) insulation statement from “should be avoided” to “prohibited”.
8.9: Converted Table 7 image to text.
9.4: Added statement specifying delivered CAD models and drawings (facility instruments) should be created from the Professional version of the CAD programs, and not the Student or Academic versions.
11: Revised Figure 19 per input from SOFIA S&MA Lead. Corrected figure title from “S&SM” to “S&MA”.
11.1: Per input from SOFIA S&MA Lead, removed Critical/Major/Minor design characteristics classification from entire section 11 and subsections and replaced it with Critical Safety Item classification. Added list describing design characteristics of CSI items.
11.7: Removed statement that Inspection and Test section “only applies to tests for technology demonstration instruments”.

11.7.3: Removed statement that all calibrated instruments “will be traceable to National Institute of Standards and Technology (NIST)”.
11.8: Removed statement that section does not apply to technology demonstration instruments.
11.9: Deleted Waivers & Deviations section—it will now be covered in section 4 (verification) of the handbook.
11.10: Removed reference to NPR 6000.1 for instruments shipping from instrument developer’s site.
11.10.2: Added statement recommending instrument protect SI flange mating surface with Plexiglas or similar material.
11.14: Added description of asphyxiation and hypoxia risk due to rapid dilution/displacement of oxygen resulting from a rapid cryogen boil-off event, stating mitigations may be defined and implemented depending on amount of liquid cryogens (LHe) contained within an instrument.

Appendix A: Removed statement “This list applies to US Facility Instruments procured under NASA contract”; this statement is redundant as this appendix applies to all classes of instruments and identifies deliverable items specific to facility instruments. Revised Airworthiness Data Package item list and due dates per inputs from SIAT. Changed due date for Instrument Configuration Sheet from PDR to Pre-Install Review to match review specified in section 9.3.

Appendix B: Removed entire SOFIA Command Language tutorial, this has now been replaced by the SOFIA Command Language User’s Manual, which is referenced in Software interface section of this handbook.

Added Appendix C: Added graphics showing distances between interfaces including PI Racks and PI Patch Panel, and telescope assembly instrument mounting flange, Counterweight Rack, TA/SI Patch Panels, and chopper junction box.

Added Appendix D: Added an excerpt from the SOFIA SI System Specification & ICD Requirements Verification Matrix Template.

Added Appendix E: Added a table identifying SI Acceptance/Commissioning Data Package Content.

Added Appendix F: SI Developer’s Handbook OP03-2000, Rev. A Change Log: Changes made to Rev. - (June 2011 version)

Appendix G.1 – Hazard Report: Generic SI and SI-provided GSE Structural Hazards (Sample)

Hazard Report (HR)

Project	Originator	Site	HR Short Title	Test Phase	Date	HR #
SOFIA Science			*Generic SI and SI-provided GSE* Structural Hazards (Rev. 7)	All flight and ground operations (at a NASA facility or when used in conjunction with a NASA aircraft)		

Sub-System	CI No.	Related Documents	Platform	Assigned To	Initial Hazard Categories	
					Human Safety	Loss of Asset/Mission
SI SI, cradle, and SI-provided GSE		SOFIA Science Instrument Specification SOF-AR-SPE-SE01-2028	SOFIA		N/A	N/A

Scenario Based Hazard Description

Science Instrument (SI), cradle, or SI-provided ground support equipment (GSE) structures improperly designed for all nominal and emergency loads conditions or operated improperly resulting in structural failure.

Hazard Cause(s) (Initiating Event, Unsafe Act/Condition)

1. SI flight hardware (all SI components and cradle) structurally fails when exposed to handling, ground, and/or aircraft nominal or emergency load conditions.
2. SI-provided GSE (i.e. carts, stands and lifting equipment) design does not provide positive structural margins of safety or structural materials yield, fatigue or creep during all ground operations (including transfer and installation/de-installation) with the aircraft.

Hazard Effect(s) (Outcome, Potential Mishap)

1. Structural failure of SI fight hardware could result in serious damage to the aircraft and cause serious injury or death to personnel.
2. SI-provides GSE structural failure could result in serious damage to the aircraft or other hardware and cause serious injury of death to personnel.

FINAL HAZARD CATEGORY JUSTIFICATION STATEMENTS

Final Severity Justification

Since Causes 1 & 2 can result in severe personnel injury or death and possible major damage to the SOFIA aircraft, platform and other hardware it deserves a catastrophic ranking for both personnel and assets.

Final Probability Justification

The "design-to" structural requirements found in the 2028 SPEC are rigorous if met by the flight hardware and GSE designs. While extensive ground handling operations can introduce the possibility of operational error into this qualitative assessment, independent safety review of those procedures coupled with independent safety oversight activities as the procedures are run should mitigate the hazard. That being said, there is a separate HR, HR2021A which supplements this hazard report to address ground handling hazards operations for all SI's. For these reasons both causes in this HR receive an Improbable -E ranking. These qualitative likelihood rankings are based on all suggested mitigations being employed and all verifications successfully closed out.

CONFIGURATION CONTROL BOARD (CCB) / SYSTEM SAFETY WORKING GROUP (SSWG) ACTIONS

<table>
<tr><td colspan="6">Assumptions/Status/Remarks/Reason for not opening this HR:</td></tr>
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<tr><td colspan="6">Planned Mitigation Actions Complete and Verified</td></tr>
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</table>

<table>
<tr><td colspan="4">FINAL DISPOSITION</td></tr>
<tr><td rowspan="2">☐ Accepted Risk</td><td rowspan="2">Final Status/Remarks:</td><td colspan="2">Final Hazard Categories</td></tr>
<tr><td>Human Safety
IE</td><td>Loss of Asset/Mission
IE</td></tr>
</table>

Risk Mitigation Actions

Project	HR Short Title	HR #
SOFIA	*Generic SI and SI-provided GSE* Structural Hazards	

Mitigation Number: 1 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 1: (SI structural failure)
1a. Design - SI flight hardware meets 2028 SPEC ultimate load factors for SI components mounted to TA, IMF or CWR with a positive Margin of Safety (MS).
1b. Design - SI flight hardware internal components meets mechanically-induced loads with the appropriate Factor of Safety (FOS) applied (per the 2028 SPEC).
1c. Design - SI flight hardware to be hoisted meets dynamic load factor of 1.5g in both the upward and downward directions, while maintaining a positive margin of safety. *(Note: This is not expected to be a design driver since the flight hardware must meet higher ultimate load factors.)*
1d. Design – Structural fasteners, used in critical structural load paths, are chosen to properly transmit all loads without failing. *(Notes: SI-to-TA bolts/fasteners and centering/load carrying compliance pins are provided by USRA and/or NASA through the SOFIA Platform Project but the selection of the proper number of bolts and pins and selection of TA bolt and pin pattern to adequately transmit all loads must be addressed by the SI organization. While not necessary, should the SI choose a design that meets all loads requirements with a single bolt/fastener "out" or failed please identify those areas in the structural analyses or other documents and revise this control to indicate the presence of this additional mitigation.)*
1e. Design - Screws, nuts, bolts or other threaded fasteners that are part of a Science Instrument flight hardware structural load path for design characteristics classified as Critical and are needed to maintain positive Margins of Safety (MS) utilize self-retaining or self-locking features. *[Notes: Self-locking features such as castellated nuts and cotter keys, lock washers, staking, Loctite, threaded inserts with locking features or safety wiring will satisfy this requirement with no need for further review by the SIAT. In situations where the use of self-retaining or self-locking features is impractical (e.g., where frequent assembly / disassembly is needed, or to assure proper SI function), other approaches, such as the use of torque-striping with inspections, or exceptions may be approved by the SIAT on a case-by-case basis. The use of COTS equipment for SI subsystems is anticipated. While COTS equipment is not exempt from this requirement, in cases where it is deemed impractical to meet this requirement for COTS components, the SI developer must clearly identify this early in the design and airworthiness certification review process for an assessment of risk and possible mitigations (e.g., regular inspections, etc.). This control also meets the Foreign Object Debris (FOD) requirement in the 2028 SPEC.]*
1f. Design - Any metal material used for the fabrication of Science Instrument Flight Hardware design characteristics classified as Critical, including raw material incorporated into threaded fasteners, is accompanied by a Certified Material Test Report (CMTR) obtained from the material distributor.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):
(Check one or more)

Verification Types: ☒ Inspection ☒ Test ☒ Drawing ☒ Report ☐ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

1a1. Drawing – SI flight hardware design data for ultimate loads (To Be Supplied, TBS, by SI)
1a2. Analysis – Structural analyses and reports (TBS)
1b1. Drawing – SI flight design data for mechanically-induced loads (TBS)
1b2. Analysis – Structural analyses and reports (TBS)
1c1. Drawing – SI flight hardware design data for hoisted loads (TBS)
1c2. Analysis – Structural analyses and reports (TBS)
1d1. Design – NASA/USRA-provided TA fastener and pin strength data (TBS by NASA)
1d2. Test – Lot testing of NASA/USRA-provided TA fasteners and pins (TBS by NASA)

1d3. Design – SI-provided flight hardware fastener selection criteria (TBS by SI organization)
1d4. Analysis – Structural analyses depicting adequate transmittal of all loads (including those into the TA) through selected fasteners and reports *(including analysis supporting single bolt/fastener out capability, if claimed)* (TBS)
1d5. Test – Reports of critical SI-provided fastener lot test results (TBS)
1d6. Drawing – Installation drawing specifying fastener types, bolt torques, and fastener back-off protection (TBS)
1d7. Procedure – Installation procedure for the SI (TBS)
1e1. Drawing – SI flight hardware critical fastener back-off prevention data (TBS)
1e2. Inspection – Drawings or reports and/or procedures identifying QA inspections of alternate back-off protection techniques, if required (TBS)
1f1. Analysis – SI-provided hardware criticality analysis (TBS)
1f2. Report – CMTRs for SI-provided hardware deemed critical (TBS)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
SOFIA	*Generic SI and SI-provided GSE* Structural Hazards	

Mitigation Number: 2 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 2: (structural failure of GSE)
2a. Design – SI-provided GSE will not deform or yield with a minimum FOS of 2 and will not collapse, buckle, exceed ultimate load or fail to support the design load in the vertical/downward direction with a FOS of 3. *(Note: These minimum FOS assume use of ductile materials. The analyses used to demonstrate these FOS must take into account all operational scenarios, including those in which the SI is not being supported by the GSE stand or cart.)*
2b. Design - SI-provided stands and carts are proof load tested to 125% of the anticipated maximum design load in the vertical/downward direction. *(Note: For stands and carts that include integral jacks for lifting or leveling applications, this requirement is applicable for the full length of travel.)*
2c. Design - SI-provided carts maintain positive margins of safety while sustaining the forward or rear impact of any one wheel of the cart with a 2 inch high curb. *(Note: Analysis should assume the cart is fully loaded and is brought to rest from a velocity of 2 ft/s (0.6 m/s) in 0.1 s. No FOS needs to be maintained in this analysis for this off-nominal condition.)*
2d. Design - SI-provided lifting GSE (e.g. hoists, slings, rigging, chains, SSP SE&I spreader bars, etc.) meets NASA-STD-8719.9, Standard for Lifting Devices and Equipment, Sections 6,7,8,10, and 13, as applicable. *(Note: NASA-STD-8719.9 presents distinct requirements for design, analysis and proof load testing depending on the specific classification of the lifting device, as well as the service class or duty cycle; SI developers should contact NASA for guidance if there are questions.)*
2e. Design - SI-provided GSE to be hoisted designed with a dynamic load factor of 1.15g in both the upward and downward direction when loaded per the applicable operational scenario, while maintaining a positive margin of safety. *[Note: Dynamic loads due to hoisting (start – stop loads) per MSFC-SPEC-1548, GSE.]*
Requirements for MSFC STS Experiments (section 3.2.4.1.2). A lower dynamic load factor of 1.15g (up and down) applies for SI GSE (i.e., SI carts), which are designed and analyzed to maintain positive margins with safety factors of 2 (yield) and 3 (ultimate).]
2f. Design - SI-provided carts designed such that no wheel loses contact with the ground when a load factor of 0.17 or 70 lb-f, whichever is greater, is applies to the highest CG of the combined SI and cart in any horizontal axis. *[Note: MIL-STD-1472F, Human Engineering (Table XVIII) and FAA HF-STD-001, Human Factors Design Standard (section 14.5.3, Exhibit 14.5.3.1), referenced by NASA-STD-5005C, Standard for the Design and Fabrication of Ground Support Equipment (section 5.9). For a short time, one person can exert 70 lb-f, so this is considered a lower limit. However, stability should also consider the effects of a sloped surface and even accidents (e.g., where a person trips and falls hard against the cart). The lateral load factor of 0.17 is consistent with a 1:9 slope with a factor of 1.5, which should be sufficient to avoid having to perform tilt table stability testing on the carts, as indicated by DIN EN 1915-2, Aircraft ground support equipment - General requirements -Part 2: Stability and strength requirements, calculations and test methods (includes Amendment A1:2009) (section 7.1).]*
2g. Design - Any metal material used for the fabrication of Science Instrument GSE with design characteristics classified as Critical, including raw material incorporated into threaded fasteners, is clearly identified, including heat treatment (or "temper") where applicable, in specifications and drawings. *[Note: For use in GSE hardware, it is generally acceptable to procure metal stock and fasteners from a reputable vendor with source and lot traceability records. The use of Commercial-Off-The-Shelf (COTS) and Modified COTS (MCOTS) hardware is anticipated for Science Instrument GSE. Those portions of GSE that comprise MCOTS are not exempt from this requirement; all reasonable efforts must be made to obtain material specifications and dimensions to validate the stress analyses and calculated Margins of Safety (MS).]*

(Note: Above mitigations taken directly from SI SPEC-2028 requirements for SI-provided GSE design and test.)

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective
(Check one or more)
Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI and SI-provided GSE Structural Hazards	

Mitigation Number: 2 (continued) ☐ Complete ☐ Repetitive

Verification Types: ☒ Inspection ☒ Test ☒ Drawing ☒ Report ☒ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**
Final Verification General Description:

2a1. Drawing - Depicting all SI-provided GSE (TBS)
2a2. Analysis - Analyses and reports showing the SI-provided GSE meets all required FOS (TBS)
2b1. Test - Proof load tests and reports for all SI-provided GSE (TBS)
2c1. Analysis - Analyses and reports showing that the SI-provided GSE meets curb impact loads (TBS)
2d1. Drawing- Depicting all SI-provided GSE lifting hardware (TBS)
2d2. Analysis – Analyses and reports showing the SI-provided GSE lifting hardware meets NASA Standards FOS (TBS)
2d3. Test – Proof load tests for all SI-provided GSE lifting hardware (TBS)
2d4. Procedure – All SI-provided GSE lifting hardware operated in accordance with approved procedure (TBS)
2e1. Analysis – Analyses and reports showing that SI-provided GSE requiring lift meets dynamic load factor (TBS)
2f1. Analysis – Analyses and reports showing that SI-provided GSE cart wheels will not lose contact with the ground (TBS)
2f2. Procedure – All SI-provided GSE operated in accordance with approved procedure (TBS)
2g1. Drawing – Depicting locations of all critical materials in SI-provided GSE (TBS)
2g2. Inspection – Of all metal structure containing critical materials (QA MIP) (TBS by NASA)

RISK MITIGATION SUMMARY
Design:
Safety Interlocks/Controls/Software Assurance:
Warning/Caution/Protective Devices:
Procedures/Training/PPE/Mission Rule/Operating Limit:
Placards/Other:

Appendix G.2 – Hazard Report: Generic SI Cryostat Overpressure and Habitable Atmosphere Hazards (Sample)

Hazard Report (HR)

Project	Originator	Site	HR Short Title	Test Phase	Date	HR #
SOFIA Science		AFRC	*Generic SI* Cryostat Overpressure and Habitable Atmosphere Hazards (Rev. 9)	Any time dewars contain liquid cryogens (flight & ground ops)		

Sub-System	CI No.	Related Documents	Platform	Assigned To	Initial Hazard Categories	
					Human Safety	Loss of Asset/Mission
Dewar tank and vent system(s)		SOFIA Science Instrument Specification SOF-AR-SPE-SE01-2028	SOFIA		N/A	N/A

Scenario Based Hazard Description

Science Instrument (SI) dewar tank and vent system improperly designed or manufactured, tank pressure relief devices fail to function or operate properly, or vents become blocked with ice or debris resulting in dewar tank overpressure (Note: Cryostat dewars are "actively safe" as the liquid cryogens will boil-off and the vent system must work to relieve internal tank pressures.). Also, the SI-provided vacuum line could become entangled as the TA rotates causing the vent stack tube to become crimped closed resulting in dewar tank overpressure (for SIs utilizing VPS only). Worst case loss of cryostat vacuum and/or magnet quenching *(if applicable)* scenarios (*both* design cases) can result in rapid heat transfer to cryostat dewar fluids resulting in very rapid liquid cryogen boil-off and tank pressure rise. Worst case, if the "must work" vent system fails to relieve pressure properly the tank(s) can explode resulting in the release of high velocity shrapnel. Note: SOFIA SI dewar tanks are not required to demonstrate a leak-before-burst design and outer annulus of cryostat is not required to be certified to contain the resultant overpressure or shrapnel from a tank explosion event. Rapid boil-off and venting of cryogens can also result in reducing local cabin Oxygen concentrations to below acceptable levels and potentially cause injury/incapacitation of personnel. Note: It has been concluded that venting cryogens, even in a loss of vacuum (LOV) scenario pose no unique hazards to nearby personnel such that special PPE would have to be worn during SI operations where open exposure to these fluids is not nominally expected. However, the sudden rapid release of high velocity fluids from vent stacks from a LOV event could slightly increase the likelihood of personnel slipping/falling in their haste to get away from the rapidly venting fluids. There are no unique mitigations or precautions being put in place to reduce the likelihood of a slip, trip or fall for this scenario.

Hazard Cause(s) (Initiating Event, Unsafe Act/Condition)

1. Dewar tank vent system not properly designed to handle nominal operating pressure rise.
2. Dewar tank and vent system not properly designed or manufactured to handle worst case, off nominal, tank pressure rise and mass flow rate due to loss of cryostat annulus vacuum (LOV) or magnet quench (if applicable).
3. Dewar tank vent becomes blocked with debris or "ice" (water ice or solidified air).
4. Dewar tank vent tube crimped shut or venting capability seriously degraded due to vacuum line (for SIs using VPS) snagging on external equipment when TA rotates.
4. Dewar tank vent tube crimped shut or crushed when SI tips over or there is a "loss of load" when not installed on the TA.
5. Cabin habitable atmosphere degrades due to boil-off of cryogen liquids.
6. Cryostat optical window breaks due to flaw in design or inability to handle differential pressure.

Hazard Effect(s) (Outcome, Potential Mishap)

1. Loss of science when pressure rises to the point where the one time rupture pin device or burst disk operates or valve opens.
2. Tank explosion creates shrapnel that causes personnel injury or death and potential catastrophic damage to SOFIA aircraft and platform.
3. Blocked vent results in tank explosion creating shrapnel that causes personnel injury or death and potential catastrophic damage to SOFIA aircraft and platform.
4. Blocked vents results in tank explosion creating shrapnel that causes personnel injury or death and potential catastrophic damage to SOFIA aircraft and platform.
5. Low O2 concentrations could result in personnel injury or death.
6. A failed cryostat optical window would result in a LOV event. Nominally, assuming that the liquid helium dewar tank(s) and vent system is designed properly, a LOV event would only result in loss of science and/or damage to the SI.

FINAL HAZARD CATEGORY JUSTIFICATION STATEMENTS

Final Severity Justification

Cause 1 results in loss of science so it has a critical asset ranking only. While it could be argued that Cause 2, by itself, would only result in loss of SI (no external release of shrapnel), in lieu of any definitive containment analysis or leak-before-burst analysis, with the SI in a quiescent state (mounted to the TA or in a stable condition mounted on a laboratory stand), this is hard to prove. Furthermore Cause 2 could still happen as a result of a serious ground handling mishap in which not only a LOV occurs but there is significant structural damage to the outer vacuum annulus case, which would expose ground personnel to the potential of being hit by shrapnel from a now unprotected rupturing SI liquid Helium dewar tank(s). Cause 3 could be given a critical asset ranking (SI damage or loss of science only) since most likely it would be the smaller vent associated with the SI bleed valves that might get blocked by ice or debris, however since there is currently no Program requirement to use a burst disk on the high flow vent, generically we must assume that the primary flow vent could get blocked. Furthermore, most SIs utilize the high flow vent to conduct fill operations and something could go wrong during the fill operation leaving the primary vent partially or totally blocked. Since Causes 2, 3 and 4 can result in severe personnel injury or death and possible major damage to the SI, SOFIA aircraft and platform, and/or AFRC Building 703 laboratories it deserves a catastrophic ranking for both personnel and assets. For Causes 2, 3 and 4 the catastrophic ranking applies to lab ops, ground ops and flight ops although "asset damage" could either be SI and laboratory or SI and aircraft platform depending on operational phase. The ranking for Cause 5 is dependent on how much gas is released into the main cabin or laboratory but worst case could result in a catastrophic hazard to personnel immediately present. Since, worst case, Cause 6 results in loss of science and/or damage to SI only it receives a critical damage to assets ranking.

Final Probability Justification

(Use the following as a starting point for determining HR final probability. Include separate probability rankings for lab, ground and flight operations, if there is rationale for different rankings.)

These cryogen SIs are "actively safe" thereby requiring that the "must work" vent systems perform properly. The super cold liquid cryogens will boil-off and the "normally closed" pressure relief devices must open to relieve the pressure. If a big enough opening were created in the vacuum annulus inrushing air would cause near instantaneous pressure rise in the tank dewars. This would more likely happen during ground handling operations (significant damage to cryostat housing) but a seal gapping/failure or other problem causing a loss of vacuum during routine flight operations is also possible (although a small leak of outside air into the vacuum annulus can result in a significantly lower heat input to the dewars due to the cryo pumping effect). These SIs are fully serviced in the lab before being brought out to the aircraft initially and will still have some cryo load left before removal from the aircraft for final de-servicing (typically SIs will be continually topped off in the aircraft on the ground, not in flight, but not be fully de-serviced in the aircraft). Final qualitative likelihood rankings are based on all suggested mitigations being employed and all verifications successfully closed out. Since we are assuming that the worst case heat load into the cryo fluids are design cases the likelihood of having those events happen in the first place do not have to factor into these qualitative risk rankings.

CONFIGURATION CONTROL BOARD (CCB) / SYSTEM SAFETY WORKING GROUP (SSWG) ACTIONS

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<tr><td colspan="6">FINAL DISPOSITION</td></tr>
<tr><td rowspan="2">☐ Accepted Risk</td><td rowspan="2" colspan="3">Final Status/Remarks:</td><td colspan="2">Final Hazard Categories</td></tr>
<tr><td>Human Safety
IE – lab
IE – ground
IE - flight</td><td>Loss of Asset/Mission
IE – lab
IE-ground
IE-flight</td></tr>
</table>

Risk Mitigation Actions

Project	HR Short Title	HR #
SOFIA	*Generic* Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 1 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 1: (dewar tank vent system improperly designed to handle pressure rise due to nominal boil-off of gases)

1a. Design - Pressure relief valves (PRVs) are properly designed and certified *(certification of PRVs desired but not mandatory assuming that a certified burst disk/rupture pin device is employed in the design)* to relieve pressure from nominal liquid cryogen boil-off *(address for each LHe and LN2 in the SI). (If no certified burst disk/rupture pin device is utilized in the design to relieve tank pressure, contact AFRC Safety for advice on how to fill out this mitigation.)*
1b. Design – Nominal and back-up vent system properly designed (materials compatibility assessment) to handle venting cryogenic gases *(address for each LHe and LN2 dewar in the SI).*

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective
(Check one or more)
Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☒ Inspection ☐ Test ☒ Drawing ☐ Report ☐ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description: *(address for each LHe and LN2 dewar in the SI).*

1a1. Drawing - PRV design data (To Be Supplied, TBS, by SI)
1a2. Inspection - PRV hardware certification data (AFRC PRV test data may also be cited) (TBS)
1b1. Drawing – Vent design component data/materials list (TBS)
1b2. Inspection - Vent system hardware certification data (TBS)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
SOFIA	*Generic* Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 2 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 2: (dewar tank vent system improperly designed to handle worst case pressure rise due to a LOV or other event that would result in a very rapid pressure rise internal to the tank)

2a. Design – Dewar tank, seals and vents designed to handle worst case pressure (Pmax) and mass flow rates due to worst case heat input into liquid cryogens (loss of cryostat vacuum or magnet quench , if applicable). Note: Pmax and worst case mass flow rate are to be calculated based on back-up (high flow) vent area only and be generated from one of the Program-approved JSC thermal analysis products *(address for each LHe and LN2 dewar in the SI).*
2b. Design – Dewar tank, seals and vents properly designed (materials compatibility) to handle cryogenic fluids and gases *(address for each LHe and LN2 dewar in the SI).*
2c. Training – Tank built utilizing certified welders *(address for each LHe and LN2 dewar in the SI).*

(Note: The reason for this mitigation is that it is desired to always have these dewar tanks relieving through their vent systems to keep the verifications simple and consistent with the SI design specification. A mitigation depicting venting or relieving into the cryostat annulus would require certification that the dewar tanks are leak-before-burst via a test to destruction, proof testing of the cryostat housing, and verification of cryostat annulus pressure relief devices via test. That is a more expensive and difficult approach.)

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☒ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):
(Check one or more)

Verification Types: ☒ Inspection ☒ Test ☒ Drawing ☒ Report ☐ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description: *(address for each LHe and LN2 in the SI).*

2a1. Drawing – Dewar tank and vent system design data (TBS)
2a2 & 2b1. Inspection – As-flown tank and vent system built to specified drawings (configuration data, including vent areas and tank/vent design data, are required for independent worst case pressure rise and mass flow rate design capability analysis calculation (performed by JSC Engineering Crew and Thermal System Division personnel) for a Q = 4.0 W/sq cm. (TBS by NASA)
2a3. Report – Official submittal of dewar and tank data to support an enhanced analysis to determine if the SI design can withstand worst case heat flux due to a LOV, or other, event. (TBS, and attach to this HR)
2a4. Analysis - Loss of cryostat vacuum (or other worst case thermal) SI-specific analysis to determine if Pmax and worst case mass flow rate can be accommodated by dewar tank and vent design (conducted in accordance with SOF-AR-SPE-SE01-2028). (TBS by NASA)
2a5. Test – Proof pressure test of the dewar tank with vent neck(s) installed (to a value higher than Pmax). (TBS)
2a6. Report – Tank proof pressure test plan and test results reviewed and approved by NASA. (TBS by NASA)
2a7. Inspection – NDE of the dewar tank welds after proof test (QA MIP). (TBS by NASA QA)
2b2. Drawing – Tank design data/materials list (TBD) (TBS)
2c1. Inspection – Certifications of tank welders (QA MIP). (TBS by NASA QA)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
SOFIA	*Generic* Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 3 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 3: (dewar tank vent becomes blocked with debris or ice)

3a. Design – Dewar tank has redundant vent/pressure relief paths *(address for each LHe and LN2 dewar in the SI).*
3b. Design – List design controls (PRV design specifics or other controls) to prevent water condensate from entering dewar vent system potentially causing water ice formation and vent blockage. Also, for SIs utilizing the VPS system list design mitigations preventing warm moist air from entering the vent during pressure equalization should the vacuum vent line come off or open up *(address for each LHe and LN2 and vent in the SI).*
3c. Design – List design controls (seals, bellows, or other controls) to prevent outside air from entering dewar vent system potentially causing the formation of air or N2 ice formation and vent blockage *(address for each LHe and LN2 and vent in the SI).*
3d. Design – Removable vent tube/fill neck fittings and hardware sized so that they cannot fall into or lodge in the vent during SI cryo servicing/de-servicing operations *(address for each LHe and LN2 and vent in the SI).*
3e. Procedure/Training - During laboratory operations the liquid helium vent necks on the SI are sometimes removed. During these operations a lightweight "puck" or a "blind flange" (not clamped to vent stack) is placed over or installed on the vent neck. These devices are intended to quickly release/pop off should there be a rapid pressure release from the internal cryogen dewars. These temporary covers also prevent loose parts from falling into the cryostat dewars during lab ops. Following initial cryo dewar chill down or servicing/top-off operations the vent system is reattached to obtain the flight configuration as soon as practical.

(Note: Because there are no specific SI requirements specifications, other than having dual vents, to control water or air ice blockage in the vent systems this mitigation is written more generically. Typically SIs will choose PRVs that are normally spring loaded closed and/or have some other control to prevent condensed water or ice on the outside of the PRV and vent neck from ever entering the vent system. Similarly SIs will employ various types of seals and expansion bellows to prevent outside air from entering the vent system. However, there are other possible acceptable design controls as well Continuously boiling off cryogens will ensure a positive flow out the vent stack.)

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective
(Check one or more)
Devices ☒ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☐Inspection ☒Test ☒ Drawing ☐ Report ☒Procedure ☒Other (explain): Training
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description: *(address for each LHe and LN2 dewar in the SI).*

3a1. Drawing – Dewar tank venting design (TBS)
3b1. Drawing - List location of data and operation of design controls. (TBS)
3b2. Test - List tests performed to show that design controls are effective. (TBS)
3b3. Test – PRV operation independently tested by NASA lab. (TBS by NASA)
3c1. Drawing - List location of data for design controls. (TBS)
3c2. Test - List tests performed to show that design controls are effective. (TBS)
3d1. Drawing – Show fitting capture/captive devices, sizes of loose parts relative to open vent neck area, etc. associated with cryo servicing/de-servicing operations. (TBS)
3d2. Procedure – Cryo fluid servicing procedure depicting warnings/cautions when handling small loose items above an open vent. (TBS)
3e1. Training - While no specific procedure exists for "interim vent configurations" only trained personnel are permitted to perform these operations. Nominally, the cryostat is returned to the flight configuration as soon as practical. (TBD if true)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 4 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Causes 2 & 3: (tank and vent unable to handle worst case pressure rise; tank vent blocked by ice)

4a. Design – Certified rupture pin/burst disk (high flow, high quality "must work" design pressure relieve device) installed on high flow vent port *(address for each LHe and LN2 dewar in the SI).*
4b. Design – Rupture pin/burst disk device selected to relieve at required pressure (Pmax or lower pressure) regardless of any mechanical friction/stiction inherent in the design *(address for each LHe and LN2 dewar in the SI).*
4c. Design – Rupture pin/burst disk device will operate with cryogenic fluids and gases and in the aircraft and ground operational environment (loads, vibrations, mechanical shock, thermal, etc.) *(Address for each LHe and LN2 dewar in the SI).*
4d. Training – During certain laboratory cryo operations (notably after initial dewar chill down and when SI optics are still warm) personnel perform necessary actions to prevent or remove frost/ice on the vent stack that could potentially impede pressure relief operation *(address for each LHe and LN2 dewar in the SI).*

(Note: This mitigation is probably the most important control in this HR. The rupture pin/burst disk is a "must work" device to relieve rapidly rising dewar tank pressures. It must be simple and extremely reliable device (like a fixed membrane pushing against a knife edge). The PRVs on the nominal vent are typically not sized to handle the high mass flow rates associated with a worst case thermal input into the cryogenic fluids. The reason why Cause 3 is included in this mitigation is because it is the primary vent, with its cycling PRVs and smaller flow area, which has the greatest potential for having an issue with ice blockage. Should the primary vent have an ice blockage the pressure will slowly build up until the rupture pin/burst disk opens thereby controlling the hazard. Maximum pressure relief for the rupture pin/burst disks must be kept below 25 bar for the liquid helium dewar to avoid the possibility of a Helium freeze/thaw hazard.)

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective
(Check one or more)
Devices ☒ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☒ Inspection ☒ Test ☒ Drawing ☒ Report ☐ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**
Final Verification General Description: *(address for each LHe and LN2 dewar in the SI).*

4a1. Drawing – Vent system drawing depicting rupture pin/burst disk location. (TBS)
4a2. Inspection – Rupture pin/burst disk certification data. (TBS by NASA)
4a3. Report – NASA review and approval of selected rupture pin/burst disk design. (TBS by NASA)
4a4. Inspection – As-flown vent system contains the correct rupture pin/burst disk devices correctly installed on the proper vent ports per specified drawings. (TBS by NASA)
4b1. Drawing – Rupture pin/burst disk design data. (TBS)
4b2. Analysis – Supporting rupture pin/burst disk selection (pressure relief will occur at or before system Pmax with any inherent friction/stiction in the device). (TBS)
4c1. Drawing – Burst disk/rupture pin design performance and operational envelope data (TBS).
4d1. Training – Specify procedure (if it exists) or personnel training associated with removal of frost/ice build-up on vent stack.

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 5 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 5: (degraded cabin atmosphere due to liquid cryogen boil off)

5a. Design – Worst case, instantaneous total expulsion of all SI cryogenic fluids (as a result of a thermal event) does not reduce cabin atmosphere below acceptable O2 concentration levels with aircraft PACs operating properly. *(Note: An analysis, see attached, must be done to verify this control. If this control is found to be valid then this hazard cause no longer carries a catastrophic or critical severity rating. If this control is found to be invalid it must be removed from this HR. For this case the catastrophic severity rating is retained.)*
5b. Procedures/Training – Personnel trained to recognize rapid expulsion of cryogenic fluids from SI.
5c. Protective Devices – Upon notification of a SI thermal event causing rapid expulsion of cryogenic fluids by Mission Operations, the airplane pilot can deploy the O2 masks in the main cabin and start the flow of oxygen.
5d. Mission Rule/Operating Limit – When operating above 40,000 feet at least one of the pilots will be on oxygen at all times (FAA requirement).
5e. Design – During all ground operations in closed environments (such as a SI laboratory) additional air circulation, mixing, and replenishment will be provided to maintain O2 levels within the acceptable range for a worst case LOV event.
5f. Procedures/Training – Ground Operations personnel trained to recognize rapid expulsion of cryogenic fluids from SI. Ground procedures require air circulation equipment to be available and operating whenever SIs contain a significant amount of cryo fluids and facility air mixing equipment (aircraft PACs or laboratory air handlers) are not operating or available.

(Note: For a loss of cryostat annulus vacuum LHe will boil-off almost instantaneously through the vent system. LN2, if present in the SI, will boil-off within minutes. The localized air concentrations around the SI could exceed OSHA limits before the aircraft PACs can mix and replenish the air to an acceptable O2 concentration level. Typically Mission Operations personnel are located at some distance from the SI vents; however LHe and LN2 gases are not vented overboard. Potentially, with SIs containing a large volume of LHe the entire main cabin atmosphere could drop below acceptable OSHA O2 limits. Aircraft PACs will eventually be able to return cabin environment to acceptable O2 concentrations with the time-to-effect being dependent on how much SI gas is vented into the main cabin. During ground operations air mixing capability may not be as good as the in-flight cabin without use of fans and air mixers.)

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective Devices ☒ Procedures/Training ☒ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☒ Inspection ☐ Test ☒ Drawing ☒ Report ☒ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

5a1. Report – Listing maximum quantities of liquid cryogens onboard the SI. (TBS)
5a2. Analysis – To determine worst case O2 concentration level thereby establishing hazard severity (see attached – TBS by NASA).
5b1. Procedure - Pilot notification when a mass expulsion of cryogen gases has occurred. (TBS)
5b2. Inspection – Mission operators trained and certified to recognize hazard. (TBS)
5c1. Procedure – Pilot deployment of O2 masks and starting flow of main cabin O2. (TBS by NASA)
5d1. Procedure – Pilot donning of O2 mask when operating above 40,000 feet altitude. (TBS by NASA)
5e1. Analysis – To determine worst case O2 concentration levels for confined spaces such that adequate air circulation, mixing, and replenishment can be calculated. (TBS)
5e2. Drawing – List air circulation and air mixing devices for all “closed” environments during ground operations. (TBS by

NASA)
5f1. Procedure – To verify that air circulation and mixing devices are installed, operational, and running when personnel are present. (TBS by NASA)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 6 ☐ Complete ☐ Repetitive

(Note: This mitigation only applies to SIs utilizing the VPS system).

Planned Mitigation General Description:

Pertinent to Cause 4: (damaged vent)

6a. Procedures - Approved SI lifting, handling and ground transportation procedures are utilized inside the SI laboratory and during SI installation with and uninstallation from the aircraft.
6b. Training - Emergency rapid egress of all personnel from the area should it be determined that the vent stack has been damaged and is not properly venting following tip over of the SI or as a result of a loss of load situation.
6c. Analysis – Performed to ascertain necessary vacuum line length and necessary standoff and tie down provisions to prevent vacuum line from becoming entangled or snared on equipment during worst case TA rotation –during both operational and maintenance rotations *(address for each LHe dewar in the SI using VPS).*
6d. Design – Vacuum vent line contains adequate length/strain relief to accommodate TA rotation to maximum position *(address for each LHe dewar in the SI using VPS).*
6e. Design – Vacuum vent line utilizes sufficient standoffs and tie downs to prevent entanglement snaring on equipment *(address for each LHe dewar in the SI using VPS).*

(Note: While it is possible for a SI to utilize some sort of quick release should vacuum line strain force become too high due to entanglement/snaring the analysis and testing to prove that design will always work to mitigate a catastrophic hazard is more complex. In addition, loss of VPS pumping, even for a few minutes can result in losing the superfluid helium condition in the dewar and would result in loss of science to recover the superfluid state. Therefore it is probably best to approach mitigation as suggested.)

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☒ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):
(Check one or more)

Verification Types: ☒Inspection ☐Test ☒ Drawing ☐ Report ☒Procedure ☒Other (explain): Analysis & Training
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description: *(address for each LHe dewar in the SI using VPS).*

6a1. Procedure – List all SI lifting, handling and ground transportation procedures. (TBS)
6b1. Training – Specify how vent neck damage will be evaluated in real time and what follow-on actions will occur. (TBS by SI and NASA)
6c1. Analysis – Specify source of data and how analysis is performed. (TBS)
6c2. Drawing – Specify drawing showing vacuum line length to VPS interface and location of all strain relief, standoffs and tie down provisions. (TBS)
6d1. Procedure – Installation of vacuum line. (TBS)
6e1. Procedure – Installation of vacuum line standoffs and tie downs. (TBS)
6e2. Inspection – NASA QA inspection of final vacuum line routing and tie down on SI. (TBS by NASA)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI Cryostat Overpressure and Habitable Atmosphere Hazards	

Mitigation Number: 7 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 6: (cryostat optical window breaks)

7a. Design - Cryostat optical window and attachment fixture is designed to take maximum pressure differential with a safety margin applied.
7b. Design – Cryostat optical window has been tested to the maximum pressure differential to rule out any cracks or flaws in the optical glass.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective
(Check one or more)
Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☐ Inspection ☒ Test ☐ Drawing ☐ Report ☐ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

7a1. Analysis – Showing that optical window can take differential pressure loading.
7b1. Test – Demonstrating that the optical window can take differential pressure loading.

RISK MITIGATION SUMMARY
Design:
Safety Interlocks/Controls/Software Assurance:
Warning/Caution/Protective Devices:
Procedures/Training/PPE/Mission Rule/Operating Limit:
Placards/Other:

Attachment 1 – How to perform a proper O2 cabin depletion analysis for vented cryogens. (TBS by NASA)

Appendix G.3 – Hazard Report: Generic SI - Aircraft Platform Pressure Boundary Hazards (Sample)

Hazard Report (HR)

Project	Originator	Site	HR Short Title	Test Phase	Date	HR #
SOFIA Science			*Generic SI* - Aircraft Platform Pressure Boundary Hazards (Rev. 7)	All flight operations (in conjunction with a NASA aircraft)		

Sub-System	CI No.	Related Documents	Platform	Assigned To	Initial Hazard Categories	
					Human Safety	Loss of Asset/Mission
SI and SI cradle		SOFIA Science Instrument Specification SOF-AR-SPE-SE01-2028	SOFIA		N/A	N/A

Scenario Based Hazard Description

Science Instrument (SI) or cradle components (that are part of the aircraft pressure boundary), including electrical connectors and receptacles, are improperly designed or improperly sealed or fail causing a leak or hole in the aircraft pressure boundary potentially resulting in the aircraft having to perform emergency operations. Debris could also enter the telescope cavity damaging the telescope and/or ruin the telescope's delicate mirror and other optical equipment.

Hazard Cause(s) (Initiating Event, Unsafe Act/Condition)

1. SI dedicated pressure bulkhead- mounted connectors and/or receptacles leak.
2. SI-to-TA seal or TA cavity pressure coupler gaps or leaks.
3. SI hardware fails or an observation window that is part of the pressure boundary breaks resulting in a large breach of the aircraft pressure boundary.

(Note: Not all SIs will have observation window(s) as part of the pressure boundary, but even if so, Cause 3 is valid as all SIs provide for some seal of the pressure boundary.)

Hazard Effect(s) (Outcome, Potential Mishap)

1. Aircraft systems will be able to compensate for small leaks to maintain the cabin atmosphere within acceptable limits.
2. Aircraft systems may not be able to compensate for a larger leak or sustain feeding a larger leak without dropping to a lower altitude.
3. Aircraft systems may not be able to compensate for a larger leak without taking emergency action (dropping to a lower altitude).
4. Debris from broken window or other failed hardware can enter telescope cavity possibly impeding the closing of the gate valve and potentially damaging the telescope and/or the telescope's sensitive optics.

FINAL HAZARD CATEGORY JUSTIFICATION STATEMENTS

Final Severity Justification

In a worst case scenario it is possible that serious personnel injuries could occur should the aircraft have to perform an emergency descent to a lower altitude. For this reason the human safety severity rating for this HR is critical - II. The damage to assets rating for this HR is mostly driven by Cause 3 and, worst case, that damage to the telescope could exceed $2M placing the asset severity at catastrophic -I.

Final Probability Justification

The controls to prevent leakage are reasonably robust. The aircraft also has the capability to feed small leaks to extend the mission, if necessary. Again, the probability rating for this HR is driven mostly by Cause 3. With a properly done structural analysis of the hardware making up the pressure boundary and testing of optical windows to the worst case pressure differential to make sure that minor flaws that might be present in the window do not cause the window to break under load, it is felt that the probability ranking for both human safety and assets should be improbable - E. Final qualitative likelihood rankings are based on all suggested mitigations being employed and all verifications successfully closed out.

CONFIGURATION CONTROL BOARD (CCB) / SYSTEM SAFETY WORKING GROUP (SSWG) ACTIONS

Assumptions/Status/Remarks/Reason for not opening this HR:

Hazard Report Officially Opened

SSWG Chair Signature	Date	Project Manager Signature	Date	Pilot/Crew Chief Signature	Date

Planned Mitigation Actions Complete and Verified

SSWG Chair Signature	Date	Project Manager Signature	Date	Pilot/Crew Chief Signature	Date

FINAL DISPOSITION

		Final Hazard Categories	
☐ Accepted Risk	Final Status/Remarks:	Human Safety IIE	Loss of Asset/Mission IE

Risk Mitigation Actions

Project	HR Short Title	HR #
SOFIA	*Generic SI* - Aircraft Platform Pressure Boundary Hazards	

Mitigation Number: 1 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause1: (leakage of SI dedicated pressure bulkhead-mounted connectors and/or receptacles)
1a. Design - SI incorporates hermetic connectors, sealing (potting) of the connectors, or filling of unused contact wire entry holes with appropriate unused contact sealing plugs on both the receptacle and plug sides of the mated connector pair for connectors installed through the SI pressure boundary.
1b. Design - Connector receptacles installed through SI pressure boundary are mounted and sealed with the connector flange on the pressurized side of the bulkhead.
1c. Design - A sealing gasket or proper sealing material such as a room temperature vulcanizing (RTV) or aircraft sealant is used to prevent pressure leakage at the aircraft bulkhead connector flange for connectors/receptacles through SI pressure boundary.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☒ Inspection ☐ Test ☒ Drawing ☐ Report ☒ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

1a1. Drawing – Electrical connector drawing for connectors that penetrate the pressure bulkhead (To Be Supplied, TBS, by SI)
1b1. Drawing - Electrical connector drawing for connector receptacles that penetrate the pressure bulkhead (TBS)
1c1. Drawing - Electrical connector drawing depicting sealing materials around connector flanges that penetrate the pressure bulkhead (TBS)
1a2, 1b2, 1c2. Drawing - Installation drawing for all connectors and receptacles (TBS)
1a3, 1b3, 1c3. Procedure - Connector and receptacle installation procedure (TBS)
1a4, 1b4, 1c4. Inspection - QA inspection of final connector and receptacle installation (TBS by NASA)

Risk Mitigation Actions

Project	HR Short Title	HR #
SOFIA	*Generic SI* - Aircraft Platform Pressure Boundary Hazards	

Mitigation Number: 2 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 2: (SI-to-TA main seal or cavity pressure coupler leaks)
2a. Design - SI-to-TA seals/O-rings are properly sized to not gap, bunch up, or tear. Seals/O-rings are coated with lubricant to help them "set" as the mounting bolts are torqued. *(Note: Specify whether the SI utilizes the standard SOFIA-supplied O-ring, or utilizes a SI-provided pressure coupler or some other seal arrangement.)*
2b. Design - SI-to-TA pressure coupler is built to very tight tolerances and can be adjusted to form a good seal inside the Nasmyth tube. *(Note: This control is only valid for SI designs that employ a pressure coupler.)*
2c. Mission Rule/Operating Limit - If cabin pressure cannot be maintained as necessary to provide a safe environment for passengers the gate valve will be closed and, if necessary, crew oxygen masks will be deployed and the aircraft will descend to a lower altitude.
2d. Procedures/Training - Platform pilot and crew are trained to recognize cabin leaks, attempt to compensate for increased leakage, close the gate valve, and perform an emergency descent procedure, if necessary.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☒ Procedures/Training ☒ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☒ Inspection ☒ Test ☒ Drawing ☐ Report ☒ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

2a1. Drawing – Data depicting SI-to-TA seal layout and lubrication requirements (TBS by NASA if SOFIA-supplied O-ring is used; TBS by SI if some other sealing interface is utilized)
2a2. Procedure - SI-to-TA seal installation and bolt torqueing approach procedure (TBS)
2a3. Inspection - QA inspection of installed seals final configuration, QA MIP (TBS by NASA)
2b1. Drawing - Data showing pressure coupler design details showing sealing interfaces with Nasmyth tube (TBS)
2b2. Test - Pressure coupler sealing test with TA/Nasmyth tube mock-up in DAOF lab, if performed (TBS)
2b3. Inspection - QA inspection of installed SI in aircraft (TBS by NASA)
2c1. Procedure - Acceptable cabin leak rate limits are established in pilot procedures (TBS by NASA)
2d1. Inspection - Pilots are fully certified to recognize cabin leaks and take the appropriate actions

Risk Mitigation Actions (continued)

Project	HR Short Title *Generic SI* - Aircraft Platform Pressure Boundary Hazards	HR #

Mitigation Number: 3 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause3: (large breach of aircraft pressure boundary due to failed observation window or some other SI hardware failure)
3a. Design – All SI hardware, exposed to the aircraft pressure boundary pressure differential, is built to withstand the worst case delta pressure with adequate structural safety margins.
3b. Design - Special optical or observing windows will be shown via test that they won't shatter or otherwise fail when exposed to the worst case pressure differential. *(Note: State whether window is part of SI pressure boundary. This control is not applicable to SI's that do not employ external optical windows as part of their pressure boundary.)*
3c. Mission Rule/Operating Limit - If cabin pressure cannot be maintained as necessary to provide a safe environment for passengers the gate valve will be closed and, if necessary, crew oxygen masks will be deployed and the aircraft will descend to a lower altitude.
3d. Procedures/Training - Platform pilot and crew are trained to recognize cabin leaks, attempt to compensate for increased leakage, attempt to close the gate valve, and perform an emergency descent procedure, if necessary.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☒ Procedures/Training ☒ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):
(Check one or more)

Verification Types: ☒ Inspection ☒ Test ☒ Drawing ☒ Report ☒ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

3a1. Analysis - Structural analysis and report that shows positive margins of safety for pressure loads (TBS)
3b1. Test - Test showing that the window(s) will not shatter or unseat when exposed to the worst case pressure differential (TBS)
3b2. Inspection - QA inspection of test and/or test results as a QA MIP (TBS by NASA)
3c1. Procedure - Acceptable cabin leak rate limits are established in pilot procedures (TBS by NASA)
3d1. Inspection - Pilots are fully certified to recognize cabin leaks and take the appropriate actions

RISK MITIGATION SUMMARY
Design:
Safety Interlocks/Controls/Software Assurance:
Warning/Caution/Protective Devices:
Procedures/Training/PPE/Mission Rule/Operating Limit:
Placards/Other:

Appendix G.4 – Hazard Report: Generic SI and SI-provided EGSE Electrical Hazards (Sample)

Hazard Report (HR)

Project	Originator	Site	HR Short Title	Test Phase	Date	HR #
SOFIA Science			*Generic SI and SI-provided EGSE* Electrical Hazards (Rev. 9)	All flight and ground operations (at a NASA facility or when used in conjunction with a NASA aircraft)		

Sub-System	CI No.	Related Documents	Platform	Assigned To	Initial Hazard Categories	
					Human Safety	Loss of Asset/Mission
SI SI, and SI-provided EGSE		SOFIA Science Instrument Specification SOF-AR-SPE-SE01-2028 *(Note: Additional typical and "best practices" prudent electrical safety design requirements were taken from other sources and utilized for this analysis.)*	SOFIA		N/A	N/A

Scenario Based Hazard Description

Science Instrument (SI) electrical equipment (including software) or SI-provided electrical ground support equipment (EGSE), improperly designed, suffers internal faults, or is installed or operated incorrectly resulting in electrical shock to personnel, generates fire/smoke in the aircraft cabin, creates electromagnetic interference (EMI) with aircraft systems, or causes damage to SOFIA aircraft/platform or laboratory facilities.

Hazard Cause(s) (Initiating Event, Unsafe Act/Condition)

1. SI electrical systems improperly designed, grounded or operated or electrical faults occur inside equipment.
2. SI wiring improperly designed resulting in fire/smoke in aircraft cabin or other confined spaces.
3. SI electrical systems improperly designed resulting in excess current draw.
4. SI systems generate excessive electro-magnetic interference (EMI).
5. SI component or software failures.
6. SI-provided EGSE electrical systems improperly designed, grounded or operated or electrical faults occur inside equipment.
7. SI-provided EGSE wiring improperly designed resulting in fire/smoke in aircraft cabin or other confined spaces.

(Note: This hazard analysis presupposes that SI-provided EGSE does not contain high energy storage batteries – only facility power and/or UPS sources are used in conjunction with use of EGSE.)

Hazard Effect(s) (Outcome, Potential Mishap)

1. Electrical shock to flight or ground personnel.
2. Personnel burned or ingest toxic smoke and fumes.
3. Excessive current draw could damage SOFIA aircraft/platform electrical system.
4. EMI can interfere with critical aircraft systems.
5. Loss of control over SI systems.
6. Electrical shock to ground personnel.
7. Personnel burned or ingest toxic smoke and fumes.

FINAL HAZARD CATEGORY JUSTIFICATION STATEMENTS

a. Final Severity Justification

Since Causes 1, 2 (should fire expand to adjacent materials), 3, 6, & 7 can result in severe personnel injury or death and possible major damage to the SOFIA aircraft, platform and other hardware this hazard report deserves a catastrophic ranking for both personnel and assets. For Cause 4, should interference with critical aircraft systems be observed, the SI can be powered down resulting in a critical ranking for loss of science. For Cause 5 it is assumed for the purposes of this HR that loss of SI control does not represent a hazard to personnel or the aircraft platform and therefore deserves a criticality ranking for loss of science.

b. Final Probability Justification

Unfortunately there are minimal “design-to” electrical safety requirements found in the 2028 SPEC for the developers of the SI electrical systems and EGSE to utilize. An attempt has been made in this HR to pull on “best practices” electrical design requirements to provide some enhanced measure of safety as “necessary and sufficient controls”. It is anticipated that much of the external SI support equipment (such as power supplies, signal conditioning equipment, computers and monitors) will be unmodified COTS hardware that has been built to some electrical standard or code even though this requirement is not in the 2028 SPEC. This hazard report (HR) focusses on meeting standard SI design and operational requirements. Based largely on this enhanced set of hazard controls, the catastrophic causes of this HR receive an Improbable -E ranking. These qualitative likelihood rankings are based on all suggested mitigations being employed and all verifications successfully closed out.

CONFIGURATION CONTROL BOARD (CCB) / SYSTEM SAFETY WORKING GROUP (SSWG) ACTIONS					
Assumptions/Status/Remarks/Reason for not opening this HR:					
Hazard Report Officially Opened					
SSWG Chair Signature	Date	Project Manager Signature	Date	Pilot/Crew Chief Signature	Date
Planned Mitigation Actions Complete and Verified					
SSWG Chair Signature	Date	Project Manager Signature	Date	Pilot/Crew Chief Signature	Date

FINAL DISPOSITION			
☐ Accepted Risk	Final Status/Remarks:	Final Hazard Categories	
		Human Safety IE	Loss of Asset/Mission IE

Risk Mitigation Actions

Project	HR Short Title	HR #
SOFIA	*Generic SI and SI-provided EGSE* Electrical Hazards	

Mitigation Number: 1 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 1 (electrical shock - SI):
1a. Design – Exposed high voltage terminals are covered with protected caps, guards, shields or insulation.
1b. Procedure - SI is powered off at MCCS power panel when mating certain connectors or when performing electrical servicing or troubleshooting operations. *(Note: Some procedures may be considered hazardous and require additional "lock-out/tag-out" procedural steps.)*
1c. Design - COTS electrical equipment has not been modified.
1d. Design - All exposed metal surfaces are electrically tied to facility ground. SI (including SI hardware in SI and TA racks) is grounded to TA/aircraft ground with resistance to ground measured at less than or equal to 0.01 ohm per procedure.
1e. Design - Any ground wire, jumper or strap necessary for SI equipment compliance with the grounding resistance specification has a conductor sized to accommodate the maximum current that can be provided by the upstream power interface.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective Devices ☒ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☒ Inspection ☐ Test ☒ Drawing ☐ Report ☒ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

1a1. Drawing – Electrical drawing specifying exposed high voltage terminal protection (To Be Supplied, TBS, by SI)
1a2. Inspection – Assessment that protective measures are in place before energizing high voltage devices (QA MIP) (TBS by NASA QA)
1b1. Procedure – Installation procedure for SI wiring hook-up or troubleshooting circuits (TBS)
1c1. Drawing - Data or statement that COTS equipment has not been modified (TBS)
1d1. Drawing – Electrical drawing depicting grounding scheme (TBS)
1d2. Procedure – Grounding procedure (TBS)
1d3. Inspection – Assessment that grounds were properly made (QA MIP) (TBS by NASA QA)
1e1. Drawing – Electrical drawing depicting grounding interfaces (TBS)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI and SI-provided EGSE Electrical Hazards	

Mitigation Number: 2 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 2 (fire/smoke - SI):
2a. Design – Wires are sized properly to handle worst case current draw (wire derating criteria).
2b. Design - Wire selection and design is per aircraft standards (wire insulation selection).
2c. Design - Circuit interruption protection exists against excessive current draw (SI provided and platform provided).
2d. Design – SI dedicated Universal Power Supply (UPS) can be powered off remotely should there be a need to rapidly and completely power down the aircraft.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☐ Inspection ☐ Test ☒ Drawing ☒ Report ☒ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

2a1. Report – Depicting wire size/derating criteria utilized in selecting wire conductor gages (TBS)
2b1. Report – Specifying criteria utilized in selecting wire insulation (TBS)
2b2. Inspection – Performed as part of SIAT Inspection Procedure, APP-DF-PRO-SV02-2351 (TBS by NASA)
2c1. Drawing – Electrical drawing depicting SI-provided circuit interrupt provisions (TBS)
2c2. Drawing – Electrical drawing depicting platform-provided circuit interrupt provisions (TBS by NASA)
2d1. Drawing – Electrical drawing depicting remote UPS power switches (TBS)
2d2. Procedure – Emergency SI power down procedure (TBS)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI and SI-provided EGSE Electrical Hazards	

Mitigation Number: 3 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 3 (excessive current draw):
3a. Design – SI contains redundant TBS number of fuses circuit breakers, or other current limiting devices to protect aircraft platform from an excessive current/power draw.
3b. Design – Aircraft platform has dedicated circuit breakers to limit possible current/power draw from SI.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☐ Inspection ☐ ☐ Test ☒ Drawing ☐ Report ☐ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

3a1. Drawing – Electrical drawing depicting SI-provided circuit interruption devices and their trip ratings (TBS)
3b1. Drawing – Electrical drawing depicting platform-provided circuit breakers and their trip ratings (TBS by NASA)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI and SI-provided EGSE Electrical Hazards	

Mitigation Number: 4 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 4 (SI generated EMI):
4a. Design – SI electronics are chosen to minimize interference with sensitive SI science equipment and the aircraft platform electronics.
4b. Design – SI internal electronics are properly grounded.
4c. Design – SI (including SI hardware in SI and TA racks) is properly grounded to TA/aircraft ground with resistance to ground measured at less than or equal to 0.01 ohm per procedure.
4d. Test – EMI test with fully powered on aircraft platform and SI after SI fully integrated and prior to first flight.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☒ Other (explain): Test
(Check one or more)

Verification Types: ☐ Inspection ☐ Test ☒ Drawing ☒ Report ☐ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

4a1. Report – Data substantiating that SI electronics will not produce excessive amounts of EMI (TBS)
4b1. Drawing – Electrical drawing depicting internal grounding scheme (TBS)
4c1. Drawing – Electrical drawing depicting SI grounding scheme (TBS)
4d1. Report – Test results of integrated platform/SI EMI test (TBS by NASA)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI and SI-provided EGSE Electrical Hazards	

Mitigation Number: 5 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 5 (loss of SI control):
5a. Design – Total loss of external power to SI will not cause a personnel safety or platform damage concern. *(Note: Since purely mechanical relief valves and burst disk/rupture pin devices are used to control all forms of pressure rise internal to the cryostat, the SI is safe without the need for power from any source).*
5b. Design – Loss of MCCS command and control will not cause a personnel safety or platform damage concern. The SI is safe without any services.
5c. Design – Worst case SI internal software failure will not cause a personnel safety or platform damage concern. *(Note: Failure to meet this control will result in the software being declared "safety critical" and additional controls will need to be specified.)*
5d. Design – Failure of SI power supplies or any SI electrical, internal mechanical, or science detector components will not cause a personal safety or platform damage concern.
.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective
(Check one or more)
Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☐ Inspection ☐ Test ☐ Drawing ☐ Report ☐ Procedure ☒ Other (explain): Analysis
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

5a1. Analysis – Hazard analysis for total loss of power as documented in the SI Systems Safety Analysis (SSA) (TBD)
5b1. Analysis – Hazard analysis for loss of MCCs command and control as documented in the SI SSA (TBD)
5c1. Analysis – Hazard analysis for worst case SI software failure as documented in the SI SSA (TBD)
5d1. Analysis – Hazard analysis for SI electrical, mechanical, and science components as documented in the SI SSA (TBD)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
SOFIA	*Generic SI and SI-provided EGSE* Electrical Hazards	

Mitigation Number: 6 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 6 (electrical shock - EGSE):
6a. Design – Exposed high voltage terminals are covered with protected caps, guards, shields or insulation.
6b. Procedure – Power is removed when mating certain connectors or when performing electrical servicing or troubleshooting operations. *(Note: Some procedures may be considered hazardous and require additional "lock-out/tag-out" procedural steps.)*
6c. Design - COTS electrical equipment has not been modified.
6d. Design - All power connectors will be 3-prong or have dedicated chassis ground connector (or grounded by some other means).
6e. Design - Any ground wire, jumper or strap necessary for EGSE grounding has a conductor sized to accommodate the maximum current that can be provided by the upstream power interface.
6f. AFRC Procedure: EGSE is limited to lab use only and is only permitted on-board the aircraft if reviewed and approved by NASA.

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☒ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☒ Other (explain): DCP-001

Verification Types: ☒ Inspection ☐ Test ☒ Drawing ☐ Report ☒ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

6a1. Drawing – EGSE electrical drawing specifying exposed high voltage terminal protection (TBS)
6a2. Inspection – Assessment that protective measures are in place before energizing high voltage devices (QA MIP) (TBS by NASA QA)
6b1. Procedure – Operational procedure for EGSE/SI wiring hook-up or troubleshooting circuits (TBS)
6c1. Drawing – Data or statement that COTS equipment has not been modified (TBS)
6d1. Drawing – EGSE electrical drawing or other data depicting grounding scheme to facility ground (TBS)
6e1. Drawing – EGSE electrical drawing depicting grounding interfaces (TBS)
6f1. Procedure - EGSE procedures contain notations that EGSE are not to be brought onboard the aircraft without NASA approval (TBS)

Risk Mitigation Actions (continued)

Project	HR Short Title	HR #
	Generic SI and SI-provided EGSE Electrical Hazards	

Mitigation Number: 7 ☐ Complete ☐ Repetitive

Planned Mitigation General Description:

Pertinent to Cause 7 (fire/smoke - EGSE):
7a. Design – COTS electrical equipment meets a recognized electrical standard or code, has not been modified, and will be used in accordance with the manufacturer's recommendations.
7b. Design – SI unique EGSE is designed, tested and certified to a recognized electrical standard or code. *(Note: Make a statement listing all SI unique EGSE and the intended use of each piece of equipment. If there is no unique SI EGSE specify "N/A for this SI".)*

Mitigation Types: ☒ Design ☐ Safety Interlocks/Controls ☐ Software Assurance ☐ Warning/Caution Devices ☐ Protective Devices ☐ Procedures/Training ☐ Mission Rule/Operating Limit ☐ Placards ☐ Other (explain):

Verification Types: ☐ Inspection ☐ Test ☒ Drawing ☐ Report ☐ Procedure ☐ Other (explain):
(Check one or more)

Assigned to: **Date last Modified:** **Date completed:**

Final Verification General Description:

7a1. Drawing – Drawing depicting COTS items in the EGSE design (TBS)
7a2. Drawing - Data or statement that COTS equipment has not been modified (TBS)
7b1. Drawing – Depicting all SI unique EGSE to be utilized, if applicable (TBS)
7b2. Report – List of design, test and certification standards for all SI unique EGSE, if applicable (TBS)
7b3. Test – List testing done for all SI unique EGSE, if applicable (TBS)
7b4. Report – Provide certification paper for all SI unique EGSE, if applicable (TBS)

RISK MITIGATION SUMMARY
Design:
Safety Interlocks/Controls/Software Assurance:
Warning/Caution/Protective Devices:
Procedures/Training/PPE/Mission Rule/Operating Limit:
Placards/Other:

Appendix H – SI Developer's Handbook, Rev. A to B Change Details

Administrative changes:
- Updated signature page.
- Made global editorial revisions throughout document; correcting typos and making minor changes to style and grammar usage to improve readability.

Specific changes (Rev. A paragraph numbers cited below):
1.1: Added DLR to first introductory sentence. Added OP03-001 document number to SOFIA Experimenter's Handbook reference. Added USRA-DAL-SSMOC-SCIN-PLAN-4100 document number to Guidelines for SOFIA SI Integration and Commissioning Plans reference.
2: Added USRA-DAL-SSMOC-SCIN-REP-1018 document number to Science Vision for the Stratospheric Observatory for Infrared Astronomy reference.
4.1 & 4.2: Consolidated these sections into one section to eliminate redundancy. The remaining 4.x subsections were renumbered to reflect this change (e.g., "Other equipment" subsection 4.3 has been renumbered to 4.2).
Figure 5.3.1-1: Added data interface type to figure; pertaining to the DCS_SI_01 interface.
Table 5.3.1-1: Corrected scope description within table for SI_CWR_01 and SI_AS_01 ICDs; changed description from "guidelines" to "requirements". Clarified that scope of SIC_SSMO_01 ICD covers both instrument lab carts and stands.
5.3.2: Added details about the various methods for driving the chopper.
5.3.6: Added U401 panel reference designator to description—the panel at which MCCS supplies power to science instruments.
5.3.7: Added references to Phase 1 SOFIA (upGREAT) Cryocooler System Specification APP-DA-SPE-SE01-2076 and (upGREAT) Cryocooler Concept of Operation APP-DA-PLA-PM17-2076.
5.3.8.3: Added summary description of the Level 1-4 data product levels. Added reference to SCI-US-PLA-SW09-2000 SI Pipeline Acceptance Plan.
5.3.9: Added clarifying statement that initial certification and periodic recertification of the SOFIA PI Rack dollies and CWR carts is performed by NASA.
5.4 & 5.4.x subsections: Updated the number of major verification phases to align with the verification process defined in the SOFIA Science Instrument System Specification and ICD Requirements Verification Matrix Template (SOF-NASA-REP-SV05-2057) approved by the OCCB 4 Nov 2015, which defines the five major verification phases of instrument development: PDR, CDR, Pre-Ship, At AFRC prior to installation, and Installation and checkout.
5.4.2: Added pipeline software requirements to the list of approved requirements (documents) to be verified for instruments.
5.4.4: Added clarifying statement that the parts or elements of the instrument which receive an approved deviation or waiver against a SOFIA requirement will still undergo verification—but will be performed against the design element which received the approved deviation/waiver (e.g., design drawing) to verify the as-built part conforms with the design.
5.4.5.1: Changed section title from "Pre-CDR Verification Activities" to "PDR Verification Activities".
- Added new section "CDR Verification Activities"; subsequent 5.4.5.x sections have been renumbered to reflect the newly added/inserted section (e.g., Pre-Ship Verification Activities section number changed from 5.4.5.2 to 5.4.5.3).
5.4.5.2: Pre-Ship Verification Activities section number changed from 5.4.5.2 to 5.4.5.3.
- Added new 5.4.5.3.1 Airworthiness Inspections section describing the airworthiness verification inspection process.

- Added new 5.4.5.3.2 SE&I Verification (Non-Software) section describing the roles and scope of SE&I verification activities.
- Added new 5.4.5.3.3 Instrument Software-MCCS Testing section describing the roles and scope of SI-MCCS Tier tests. The tier test cases are defined in the 5.4.5.3.3.x subsections.
- Added new 5.4.5.3.4 Instrument Data Product-DCS Testing section describing the roles and scope of SI-DCS testing.
- Added new 5.4.5.3.5 Instrument Data Reduction Pipeline-DPS Testing section describing the roles and scope of SI-DPS testing.

5.4.5.3: Post-Ship Verification Activities section number changed to 5.4.5.4.
5.4.5.4: EMI test section number changed to 5.4.5.5.
5.4.5.5: Line Operations section number changed to 5.4.5.6.
5.4.5.6: Instrument Commissioning Flight Series section number changed to 5.4.5.7.
5.4.5.7: Instrument Modifications and Upgrades section number changed to 5.4.5.8.
5.4.5.8: Functional & Physical Configuration Audit section number changed to 5.4.5.9.
6.2.7: Added citation to Vacuum Pump System Concept of Operations, APP-DA-PLA-PM17-2074.
6.8: Added citation to Software Architectural Design Document for the Data Processing System (DPS) of the SOFIA Project (SCI-US-SPE-SW02-2019).
7.4.1: Inserted and added new SRR Entrance Criteria section before SRR Success Criteria section; the entrance criteria section becoming the new 7.4.1.2 section. All existing 7.4.1.2.x subsections have been renumbered to 7.4.1.3.x.
7.5.1: Inserted and added new PDR Entrance Criteria section before PDR Success Criteria section; the entrance criteria section becoming the new 7.5.1.2 section. All existing 7.5.1.2.x subsections have been renumbered to 7.5.1.3.x.
7.5.1.11: Removed text "Transportation container requirements have been identified."
7.6.1: Inserted and added new CDR Entrance Criteria section before CDR Success Criteria section; the entrance criteria section becoming the new 7.6.1.2 section. All existing 7.6.1.2.x subsections have been renumbered to 7.6.1.3.x.
7.6.2: Inserted and added new PSR Entrance Criteria section before PSR Success Criteria section; the entrance criteria section becoming the new 7.6.2.2 section. The criteria was adapted from the SOFIA SE&I Technical Review Entrance and Success Criteria Confluence page which has been vetted by the SOFIA Integration Office. All existing 7.6.2.2.x subsections have been renumbered to 7.6.2.3.x.
7.7.1: Added details about delta airworthiness and ICD verification process for subsequent installations of an instrument on SOFIA.

- Added new 7.7.1.1 PIR Entrance Criteria section; criteria was adapted from the SOFIA SE&I Technical Review Entrance and Success Criteria Confluence page which has been vetted by the SOFIA Integration Office.
- Added new 7.7.1.2 PIR Success Criteria section.

7.7.2: Added general reference to TRR checklist used to determine readiness of a project to start formal test.
7.7.4: Removed redundant statement about applicability of Acceptance Review to only facility instruments.
7.7.4.1: Made correction clarifying AR Entrance Criteria for pipeline is not only the data reduction pipeline algorithms but are all the deliverables defined in the SI Pipeline Acceptance Plan SCI-US-PLA-SW09-2000

- Added new 7.7.4.3 SI Acceptance Process section describing the instrument acceptance process, including participant stakeholders and action timeline.

7.7.5.1: Corrected CR Entrance Criteria for pipeline, pertaining applicable PI instruments for which delivery of a pipeline is required, is not only the data reduction pipeline algorithms but are all the deliverables defined in the SI Pipeline Acceptance Plan SCI-US-PLA-SW09-2000.

8.2: Revised System Safety section per inputs received from SOFIA Safety. Introduces use of hazard reports and hazard action matrices to identify hazards, establish mitigations, and characterize residual risk.
8.4.2.1: Revised description of cryostat internal pressure structural analysis to align with pressure requirements of SOFIA Science Instrument System Specification SOF-AR-SPE-SE01-2028 Rev. A, which was approved 15 July 2015.
10.3: Made minor revisions to vibration description pertaining to caging and braking of the telescope. Revised in-flight acceleration value to 1.7g in Z (normal) based on feedback from DSI.
11.2: Added guidance reference to SOFIA Quality Plan, SOF-NASA-PLA-PM21-2090.
11.10: Replaced Software Assurance guidance statements from: “1. Reviewing the SOFIA Science Project Software Management Plan, SCI-AR-PLA-PM20-2004 first,” to “1. Reviewing the SOF-DA-PLA-PM20-201, SOFIA Software Management Plan (SMP) first,”; and “2. Reviewing the SOFIA Science Project Software Assurance Plan, SCI-AR-PLA-PM21-2014,” to “2.Reviewing the SOF-NASA-PLA-PM21-2091, SOFIA Software Assurance Plan (SSAP),”.
Table 11.10-1: Reconstructed software assurance deliverables table to be editable.
11.12: Added guidance reference to SOFIA Program Mishap Preparedness and Contingency Plan, SOF-DF-PLA-OP05-2000.
11.14: Revised System Safety section pertaining to oxygen deprivation/asphyxiation hazard per inputs from SOFIA Safety. Added guidance reference to SOFIA Safety Plan, SOF-NASA-PLA-PM21-2089.
Table 11.14-1: Reconstructed hazard severity classification table to be editable.
Table 11.14-2: Reconstructed hazards probability classifications table to be editable; an issue with not all text being visible (rows for Class A & C) with the previous table has been corrected in this new version.
Table 11.14-3: Reconstructed hazards action matrix table to be editable; typos that existed within the previous table has been corrected in this new version.
Appendix A: Appendix renamed to “Appendix A.1 Deliverable Items List”. Formalized the following items as deliverables: Software requirements verification matrix, SI mass and C.G. ICD analysis report, Instrument ICD envelope analysis report, Instrument cart/stand ICD analysis report(s), Instrument cart/stand structural analysis report(s), Cryogen fill procedure. Renumbered deliverable items to account for the new entries added to the list. Revised deliverable due dates to align with proposed Appendix A.2 Documentation Delivery Schedule.
- Added Appendix A.2 Documentation Delivery Schedule summarizing document deliverables due by milestone/technical review.
Appendix D: Added document number SOF-NASA-REP-SV05-2057 to appendix title. Replaced previous matrix template excerpt with layout/format established in the recently approved and baselined SOF-NASA-REP-SV05-2057.
Appendix E: Added informational statement content of table originates from SOFIA Science Project Data Requirements, SCI-AR-SOW-PM91-2001. Added annotations for items which apply to “FSI only”.
- Added Appendix G.1 Hazard Report: Generic SI and SI-provided GSE Structural Hazards.
- Added Appendix G.2 Hazard Report: Generic SI Cryostat Overpressure and Habitable Atmosphere Hazards.
- Added Appendix G.3 Hazard Report: Generic SI - Aircraft Platform Pressure Boundary Hazards.
- Added Appendix G.4 Hazard Report: Generic SI and SI-provided EGSE Electrical Hazards.
- Added Appendix H SI Developer’s Handbook OP03-2000, Rev. B Change Log: Changes made to Rev. A (June 2015 version).