SOFIA Science Instrument System Specification

Level: 2

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VERIFY THAT THIS IS THE CORRECT VERSION BEFORE USE

SOFIA Science Instrument System Specification

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SOFIA Science Instrument System Specification
Revision History

REV	DATE	DESCRIPTION	APPROVAL
-	4/18/2011	PMB approved baseline release per PRG-CCR-063	PMB
A	7/15/2015	Extensive updates to support AO for 3rd gen. SOFIA SIs per OCCB-CCR-0454. See CCR for detailed FROM: / TO: changes. [Note SE01-2028 and other Level 2 specifications have been pushed down from PMB to OCCB control per PMB-approved PRG-CCR-181, SE01-068 Rev. K.]	OCCB
B	11/4/2015	Updates per OCCB-CCR-0553: • Clarify cryogen reservoir & neck tube pressure test requirements • Acknowledge routine lapses of Observatory power, e.g., during tow-out • Add citation of NESC-RP-15-01017 • Correct traces to SE01-003 parents for several GSE requirements • Correct document titles for several reference docs • Add missing acronyms (and delete duplicates) from Appendix D • Clean-up typographical errors See CCR, briefing charts and detailed FROM: / TO: changes.	OCCB
C	11/8/2017	Updates per OCCB-CCR-1230: • Update front matter to reflect current compliance and reference documents • ParID 1.3, Scope, updated to delete language that keys specific revisions of this specification to the various generations of SOFIA SIs • Section 2, Applicable, Compliance and Reference documents, updated listing of documents to reflect updated requirement language and Notes / Rationale statements • ParID 3.1.2 deleted (replaced by new ParIDs 3.1.6 and 3.11.15) • ParID 3.1.5 deleted to reflect joint SI/SMO development of production data reduction pipelines • ParID 3.2.1 updated Notes and Rationale fields to clarify intent of 20% flux calibration req't • ParID 3.2.2 deleted references to Facility Class SIs (FSIs) • ParID 3.2.4 new requirement added to assure SI capable of collecting ≥8 hours of scientific data per observing flight • Section 3.4 and ParID 3.4.1 new section and requirement to assure SI operability in SOFIA cabin temperature environment • ParID 3.5.3.1 updated Notes field to include supplemental information from SOF-1030 and OP03-2000 to support structural analyses • Section 3.10.3 and ParIDs 3.10.3.1 and 3.10.3.2, new PMP subsection and requirements to specify that welds be certified in accordance w/ AWS D17.1 • ParID 3.11.14 updated to replace SE03-2059 (CRYO_SI_01) ICD w/ SE03-2066 (CRYO_SI_02) ICD to reflect replacement of Phase 1 Cryocooler System w/ Phase 2 Cryocooler System • Appendix A, Table 3.5-2 update Note to correct Fitting Factor from 1.20 to 1.15 • Appendix A, Table 3.5-3 update Note 3 to clarify process for PVS certification of COTS lines and components w/ inadequate CoCs, documentation • Administrative updates (revision level and release date on cover page, running headers, updates to Signature Page to reflect SOFIA staffing changes, document number updates, Appendix C remove defunct support email address, Appendix D glossary updates, etc.) See CCR, briefing charts and detailed FROM: / TO: changes.	OCCB
D	9/5/2018	Updates per OCCB-CCR-1485 (JIRA # SOF-4905): • Updated Section 1.2 to include discussion of new SOF-NASA-SOW-PM91-2094 *SI Dev. Process and Deliverables (P&D) Requirements* document • Added SOF-NASA-SOW-PM91-2094, *SOFIA Science Instrument Development Process and Deliverable (P&D) Requirements* to Section 2.2.2, *SOFIA Specifications and other Compliance Documents* • Added new Section 3.7, *Maintenance,* and new requirement ParID 3.7.1, to ensure that SI designs accommodate Removal & Replacement of spare SI hardware • Appendix A, Updated footnote in Table 3.5-2 to clarify when it is appropriate to apply a Bearing or Fitting Factor, and to clarify that the Fitting Factor is not a Factor of Safety (FS) • Appendix A, Added updated footnote for Table 3.5-2 to Table 3.5-1 • Appendix A, Updated Table 3.5-3 with a new row for Pulse Tube Coolers, defining a Qualification test pressure factor of MNOP x 1.5 (600 psi) and an Acceptance test pressure factor of MNOP x 1.0 (400 psi); also add footnote 6 to this row with additional analysis requirements with defined safety factors based on pulse tube and regenerator tube diameters, and clarifying approach for certifying external rotary valve and associated flex line • Appendix D, Added HIRMES, LSP, PF and PFM to Glossary of Acronyms • Administrative correction of typo "Concensus" to "Consensus" (4 instances)	OCCB

Paragraph Identification (ParID)	Text	Notes / Rationale
1	**Introduction, Overview and Scope**	
1.1	**Introduction** The SOFIA Science Instrument (SI) System Specification is one of three level 2 system specifications in the SOFIA specification tree, along with the Airborne System Specification and the SOFIA Science and Mission Operations (SSMO) Specification (see SOF-DF-SPE-SE01-068, *SOFIA Specification/Product Tree*). The Airborne System Specification contains the requirements on the airborne observatory, including the aircraft, Telescope Assembly (TA), and Mission Controls and Communication System (MCCS) but does not contain requirements on the Science Instruments. The Science and Mission Operations Specification contains the requirements on the Data Cycle System (DCS), Mission Operations, and ground support for Science Instruments. This Science Instrument System Specification contains the generic science instrument requirements for SOFIA science instruments mounted on the telescope assembly. This specification does not contain the science instrument science and technical performance requirements, as those are specific to the instrument type and scientific investigations proposed.	
	For U.S. instruments, the science and technical performance requirements will be contained in an instrument Science and Technical Performance Requirements Document. The performance requirements will be described in the instrument proposals and will be a factor in instrument selection. Prior to the science instrument System Requirements Review (SRR) the instrument teams will release a Science and Technical Performance Requirements Document to the SOFIA Program for acceptance.	
	The parent document of this specification is SOF-DF-SPE-SE01-003, *SOFIA System Specification* .	
	These terms are used in this document: Shall – Mandatory, Verifiable requirement for SI Developer implementation Should – Goal or recommendation for SI Developer implementation (Non-Verifiable) Will – Statement of fact, or signifies intent (e.g., NASA will verify, analyze, etc.)	
	Further information re: the Verification & Validation (V&V) approach may be found within SCI-AR-HBK-OP03-2000, *SOFIA Science Instrument Developers' Handbook* , Section 5.4. Additional detail re: descriptions and phasing of V&V Activities is defined within SOF-NASA-REP-SV05-2057, *SOFIA SI System Specification & ICD Requirements Verification Matrix Template* .	
	The definitions, abbreviations, and acronyms used in this specification are as defined within Appendix D, Glossary of Acronyms & Terms. A more comprehensive listing of SOFIA Program nomenclature may be found within SOF-DF-PD-PD-2009, *SOFIA Lexicon* . The first instance of each abbreviation and acronym in this specification is given as a parenthetical after the complete spelling of the words.	

Paragraph Identification (ParID)	Text	Notes / Rationale
1.2	**Overview** The requirements in this document ensure the science instrument can properly interface with the aircraft systems (i.e. MCCS) and the telescope assembly, as well as meeting the ground safety requirements and airworthiness requirements. This specification includes requirements for compliance with a number of Interface Control Documents (ICDs). This specification, along with those ICDs, SOF-NASA-SOW-PM91-2094, *SOFIA Science Instrument Development Process and Deliverable (P&D) Requirements* , and the instrument specific Science and Technical Performance Requirements, are the complete set of requirements for Science Instruments.	
	The ground safety requirements are the rules necessary for operating in a NASA leased facility in the state of California, and represent a combination of state and federal regulations as well as NASA policies. To ensure the safety of the personnel onboard the aircraft and of the SOFIA observatory, all equipment onboard the aircraft needs to be deemed airworthy before it can be flown. This document contains airworthiness instrument requirements to be verified prior to the issuance of an approval letter by the Science Instrument Airworthiness Team (SIAT). The airworthiness approval and certification criteria for science instruments are enumerated within SOF-NASA-SOW-PM91-2094, *SOFIA Science Instrument Development Process and Deliverable (P&D) Requirements* , Appendix C, *SI Airworthiness Certification Criteria* . SCI-AR-HBK-OP03-2000, *SOFIA Science Instrument Developers' Handbook* , includes additional guidance and narratives surrounding the SI development, V&V, delivery, integration, commissioning and acceptance processes.	
	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; • Systems that monitor, providing warning of, or prevent hazardous conditions; • Anything that affects the aircraft pressure boundaries; • Foreign Object Damage and equipment security; • Pressure systems; • Cryogens; • Toxic substances; and • Radiation, both ionizing and non-ionizing	
1.3	**Scope** This document applies to SOFIA Science Instruments. It includes instruments produced via contract, subcontract, or grant. It includes instruments acquired by NASA or its international partners, except that requirements within agreements between NASA and its international partner will take precedence over this document.	

Paragraph Identification (ParID)	Text	Notes / Rationale
2	**Applicable Compliance and Reference Documents** The latest revisions of the following ICDs, specifications and standards form a part of this requirement to the extent specified herein. Those documents that are cited as sources of mandatory requirements appear in the Compliance Documents section. These are applicable to SI design and development activities performed in-house or outsourced by the SI Developer. Those documents that are cited as sources of recommended guidelines or for reference only appear in the Reference Documents section.	
2.1	**Precedence** In the event of a conflict between the text of this document and the referenced documents cited herein, the text of this document takes precedence. Nothing in this document, however, supercedes the contractual requirements unless a specific exemption has been obtained and approved. As appropriate, reference is made to other project documentation for use as guidance in developing the content of this document and as such forms a basis for requirements to the extent specified herein.	
2.2	**Compliance Documents**	
2.2.1	**Interface Control Documents (ICDs)**	
	SOF-DA-ICD-SE03-002 (GLOBAL_09), *Science Instrument Envelope*	3.11.1
	SOF-DA-ICD-SE03-037 (TA_SI_02), *Telescope Assembly / Science Instrument Mounting Interface*	3.11.2
	SOF-DA-ICD-SE03-2015 (SI_AS_01), *PI Equipment to PI Rack to Aircraft System*	3.11.3
	SOF-DA-ICD-SE03-036 (TA_SI_01), *Cable Load Alleviator Device / Science Instrument Cable Interface*	3.11.4
	SOF-DA-ICD-SE03-051 (TA_SI_05), *SI Equipment Rack / TA Counterweight Interface*	3.11.5
	SCI-AR-ICD-SE03-2027 (SI_CWR_01), *SI Equipment to Counterweight Rack ICD*	3.11.6
	SCI-US-ICD-SE03-2023 (DCS_SI_01), *Data Cycle System (DCS) of the SOFIA Project ICD*	3.11.7
	SOF-AR-ICD-SE03-2029 (MCCS_SI_05), *PI Patch Panel to PI Equipment Rack(s)*	3.11.8
	SOF-DA-ICD-SE03-038 (TA_SI_04), *TA Chopper Processor / Principal Investigator Computer Direct Analog Interface*	3.11.9
	SCI-AR-ICD-SE03-2017 (SIC_SSMO_01), *SI Handling Cart to SSMO Facility Interface*	3.11.10
	SOF-AR-ICD-SE03-205 (SIC_AS_01), *SI Handling Cart to Aircraft System ICD*	3.11.11
	SCI-AR-ICD-SE03-2020 (SSMO_SI_02), *TA Alignment Simulator (TAAS) to Science Instrument ICD*	3.11.12
	SOF-DA-ICD-SE03-2022 (VPS_SI_01), *SI to Aircraft Vacuum Pump*	3.11.13
	SOF-NASA-ICD-SE03-2066 (CRYO_SI_02), *Phase 2 Cryocooler System to Science Instrument ICD*	3.11.14
	SOF-DA-ICD-SE03-052 (MCCS_SI_04), *MCCS to Science Instrument Software Interface (SCL) (Functional)*	3.11.15
2.2.2	**SOFIA Specifications and other Compliance Documents**	
	SOF-NASA-SOW-PM91-2094, *SOFIA Science Instrument Development Process and Deliverable (P&D) Requirements*	1.2
2.2.3	**Standards**	
	NASA-STD-8719.9, *Standard for Lifting Devices and Equipment*, Sections 6, 7, 8, 10, and 13	3.5.2.5
	NASA-STD-8719.17, *NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)*	3.5.3.5
	FAA Advisory Circular (AC) 43.13 Chapter 11, *Aircraft Electrical Systems* , Section 5, *Electrical Wire Rating*	3.5.4.4
	ANSI / AWS D17.1, *Specification for Fusion Welding for Aerospace Applications*	3.10.3.1, 3.10.3.2

Paragraph Identification (ParID)	Text	Notes / Rationale
2.3	**Reference Documents**	
2.3.1	**SOFIA Specifications, ICDs and Manuals**	
	SCI-AR-HBK-OP03-2000, *SOFIA Science Instrument Developers' Handbook*	1.1, 1.2, 3.5.2.9, 3.5.4.1, 3.10.1.1, 3.10.1.2, 3.11
	SOF-DF-SPE-SE01-068, *SOFIA Specification/Product Tree*	1.1
	SOF-DF-SPE-SE01-003, *SOFIA System Specification*	1.1, 3.9.1, SE01-003, *SOFIA System Specification* , is the parent document for SE01-2028. SE01-003 Appendix A Figure 1 & Figure 2 (SI In-Flight Access) referenced in 3.9.1.
	SOF-DF-PD-PD-2009, *SOFIA Lexicon*	1.1, 3.2.4
	SOF-DA-PLA-PM17-2000, *SOFIA Concept of Operations*	3.2.4
	SOF-AR-PLA-PM17-2079, *SOFIA Program Metrics*	3.2.4
	SOF-DF-ICD-SE03-048 (TA_MCCS_P), *Telescope Assembly / Mission Controls and Communications System (MCCS) Physical Interface*	3.5.4.2, References Section 3.3.12 for guidance re: grounding, bonding, signal shielding and power circuit returns
	APP-DF-PRO-OP02-2043, *Procedure for Crossing the TA Barrier during Flight*	3.9.1, Provided as reference for investigator in-flight access to SI equipment on TA / CWR.
	SOF-NASA-REP-SV03-2115, *2016 Cabin Temperature Characterization Results*	3.4.1
	SOF-DA-MAN-OP02-2181, *SOFIA Command Language (SCL) User's Manual (SCLUM)*	3.11.15, Provided as a reference re: SCL syntax and usage
	SOF-NASA-REP-SV05-2057, *SOFIA SI System Specification & ICD Requirements Verification Matrix Template*	1.1, Provided as reference to support definition and phasing of V&V Activities.
2.3.2	**Standards**	
	ANSI / AIAA S-080, *Standard, Space Systems - Metallic Pressure Vessels, Pressurized Structures, and Pressure Components*	3.5.3.2.3, 3.5.3.3.1, Table 3.5-3, Reference Qualification, Acceptance and additional requirements from Section 5.4.2, *Cryostats (or Dewars)* of this standard.
	AFST-8739.4-001, *Aircraft Electrical Systems Standards*	3.10.2.2.1
	ASME Section VIII, Division 2, Alternative Rules for Construction of Pressure Vessels; Parts 4, 5, 7 and 8	3.5.3.3.1, Reference this ASME code for guidance re: hydrostatic test procedures, NDE inspection, combination of stresses and analytical methods for pressure vessels.
	Compressed Gas Association (CGA) E-4, Standard for Gas Pressure Regulators, Appendix A	3.5.3.4, References Appendix A for calculations of flow through a failed regulator based on published Cv
2.3.3	**Other Reference Documents**	
	NASA/TM 2014-218540 - NESC-RP-13-00911, *SOFIA Cryogenic Helium Dewar Heat Flux Evaluation, Maximum Expected Wall Heat Flux and Maximum Pressure after Sudden Loss of Vacuum Insulation on the Stratospheric Obsevatory for Infrared Astronomy (SOFIA) Liquid Helium (LHe) Dewars* , Version 1.1, October 2014	3.5.3.2.2, 3.5.3.2.3, 3.5.3.3.1, Appendix C
	NASA/TM 2015-218810 - NESC-RP-15-01017, *Simplified Methodology to Estimate the Maximum LHe Cryostat Pressure from a Vacuum Jacket Failure* , Version 1.0, September 2015	3.5.3.2.2, 3.5.3.2.3, 3.5.3.3.1, Appendix C

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3	**Requirements**				NVR		
3.1	**Functional**				NVR		
3.1.1	Science Instruments shall be tolerant of unannounced removal, reduction or reapplication of input power with no permanent functional or performance degradation.	**Notes:** 1. Such power transients can have varying characteristics and therefore may need to be addressed by different design implementations. For example: a. Relatively short transients, typically less than 1 second in duration (and often more likely to be on the order of milliseconds), such as those associated with the routine transfer of power from ground to aircraft power (and vice-versa) which must not damage the SI; b. Routine operational periods without Observatory power (e.g., during tow-out of aircraft from hangar to flight line in which the SI is typically without power for 30 - 60 minutes); c. Relatively long power outages (i.e., "blackouts") of up to several hours in duration, which may require an orderly shutdown to "safe" the SI; d. Unannounced application or restoration of power, which may indicate the use of a manually resettable contactor to protect sensitive electronics. 2. For Science Instruments that utilize the Vacuum Pumping System (VPS) or Cryocooler System, developers should also consider the likelihood that a power interruption may impact the nominal operation of these systems. **Rationale:** Unannounced power transients are anticipated and must be tolerated by Science Instruments. While SI equipment that is considered sensitive to power fluctuations should use power from an Uninterruptible Power Supply (UPS), proper function of the SOFIA UPS should not be assumed for the purposes of this requirement, which is intended to ensure that the SI will not suffer *permanent functional or performance degradation* , even in the event of a SOFIA UPS failure.		3.11.1	Analysis & Demonstration	MA	SE&I
3.1.2	*[Deleted]*	*[Editorial Note: Deleted ParID 3.1.2 has been replaced by new ParID 3.1.6 (for the data transfer to the MCCS Archiver) and new ParID 3.11.15 (for the citation of the MCCS_SI_04 ICD)]*			NVR		
3.1.3	SOFIA Science Instruments shall time stamp UTC date and time, with an accuracy of ≤ 50 milliseconds and a precision of ≤ 1 millisecond relative to SOFIA Observatory provided time, for data transferred to the MCCS.	**Note:** UTC reference time from the SOFIA Network Time Protocol (NTP) Server may be obtained via broadcast on the MCCS LAN and/or the coax IRIG-B distribution subsystem. Obtaining time information from MCCS via ASCII text in response to SOFIA Command Language (SCL) command is not sufficiently accurate to meet the 50 millisecond requirement. **Rationale:** Data from dissimilar instruments must be compared for post-flight analysis. Most experiments require a modest level of synchronization compatible with the performance of the standard network time protocol.		3.1.31	Demonstration	MA	SE&I
3.1.4	SOFIA Science Instrument data shall be tagged with position of the observatory.	**Note:** The GPS position reference source may be the SOFIA facility GPS provided via the MCCS, or may be internal to the Science Instrument. **Rationale:** The SI requires access to a time and position reference to time tag data with accuracies and precisions needed for occultations and transit observations. The SI also requires a common time and position reference, such as GPS, that allows synchronization between measurements taken by independent ground-based instruments and airborne measurements taken by SOFIA.		3.1.43	Inspection	MA	SE&I
3.1.5	*[Deleted]*	*[Editorial Note: ParID 3.1.5 has been deleted to reflect joint SI/SMO responsibility for data analysis pipeline development, in which SI developer is responsible for developing data analysis algorithm(s) and providing test data, while SMO is responsible for developing the production data analysis pipeline CSCI]*			NVR		
3.1.6	SOFIA Science Instruments shall transfer stored science data to the MCCS Archiver during the flight.	**Notes:** The MCCS provides a high reliability disk array, the MCCS Archiver Subsystem, for storing observatory data products throughout flights. SIs are expected to transfer stored science data, and may transfer any ancillary data (e.g., housekeeping data), to the MCCS Archiver during the flight. This data transfer is supported via an NFS or Samba mount with a static IP address that will be assigned by the SOFIA Flight Systems group. **Rationale:** The requirement that SIs transfer stored science data during the flight supports the Level 1 requirements that data is to be transferred from the platform to the ground-based data archive after each flight to ensure that no essential data is lost (ref.: SE01-003 ParID 3.1.29), and to provide quick-look access to raw science and housekeeping data from the flight to science investigators within 3 hours after each flight (ref.: SE01-003 ParID 3.2.14).		3.1.29	Demonstration	MA	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.2	**Performance**				NVR		
3.2.1	SOFIA Science Instrument astronomical data shall be flux calibratable to within 20% RMS.	**Notes:** The SOFIA System Specification (SE01-003) requirement parid 3.2.9 states that all astronomical data be calibrated to better than 20% RMS against SOFIA's accepted calibration standards. To this end, the Science Instrument team must demonstrate that the instrument performance characteristics (e.g., noise, non-linearity, stability) are such that this level of calibration can be achieved and that no aspect of the instrument performance will preclude attaining such calibration accuracy. An analysis should be performed incorporating these instrument characteristics to show how, in conjunction with observations of standards and data pipeline post-processing, the data will be calibrated to 20% or better. **Rationale:** Uncalibrated data is difficult to interpret and may be of little scientific value. SOFIA uses accepted flux standards of the astronomical community. Flux calibration of photometric data to within 20% RMS of accepted flux standards is generally acceptable for typical SOFIA science applications (e.g., fitting Spectral Energy Distributions (SEDs)), and is considered to be readily achievable for both ground-based observatories as well as SOFIA and the suite of SIs.		3.2.9	Demonstration & Analysis	MA	SE&I
3.2.2	SOFIA Science Instruments shall provide real-time estimates of cumulative signal-to-noise.	Supports real-time, in-flight decisions about the data acquisition and observing strategy.		3.1.3	Demonstration & Analysis	MA	SE&I
3.2.3	SOFIA Science Instruments shall provide a measurement of the alignment of the SI entrance pupil to the TA exit pupil to within an accuracy as flowed down from the applicable SI-specific throughput performance requirement.	Poorly aligned instruments do not couple effectively to the telescope optics and may suffer from an increased telescope background as a result of this misalignment. This requirement is related to the requirement for efficient observations and the need to achieve some level of successful science hours.		3.1.3	Demonstration or Test	MA	SE&I
3.2.4	SOFIA Science Instruments shall be capable of observing for no fewer than 8 hours per flight.	**Notes:** Research Hours (RH) is defined in SOF-DF-PD-PD-2009, *SOFIA Lexicon* . Detailed descriptions of key top-level operational metrics such as Planned Research Hours (planned RH), Actual Research Hours (actual RH), Science Flight Hours (SFH), and Data Collection Time (DCT) are contained within SOF-AR-PLA-PM17-2079, *SOFIA Program Metrics* . SI ConOps and designs must consider nominal Day of Flight / preflight timelines and operational constraints (e.g., access to aircraft for scheduled cryogen fill operations, power (and cryocooling) interruptions associated with tow-out from hangar, etc.). Additional information regarding such Day of Flight / preflight timelines and constraints may be found within SOF-DA-PLA-PM17-2000, *SOFIA Concept of Operations* , particularly Sections 5.3, *Flight Series Preparation* , and 5.4, *Science Mission Operations (MOPS)* . **Rationale:** Intent is to ensure that instrument ConOps and designs support observations and acquisition of astronomical data once SOFIA is at the desired observing altitude(s). This specified 8 hour minimum observing time for SI corresponds to the higher-level requirement for the overall SOFIA System to provide at least 8 Research Hours per flight during routine science observing and instrument commissioning campaigns. The specific periods of time in which control of the telescope has been granted to the SI during flight are designated as SFHs; this requirement addresses the Program need for instruments to be ready to observe during the overall minimum 8-hour RH period during a flight.		3.2.36	Demonstration	MA	SE&I
3.4	**Environments**				NVR		
3.4.1	SOFIA Science Instruments shall be operable within the SOFIA main cabin with ambient temperatures ranging from 55° F (12.8° C) to 85° F (29.4° C).	**Notes:** As documented within SOF-NASA-REP-SV03-2115, *2016 Cabin Temperature Characterization Results* , the maximum recorded operational temperature within the portion of the cabin where the SI assembly is integrated was 83.7° F during the year 2016. The minimum operational temperature recorded in this area during this same year was 57.0° F. Based on these measurements, the SOFIA program has defined an operational temperature range that envelopes the measured temperature range with some margin for future extremes and anomalies. In the context of this requirement, "operable" means that the SI meets all functional, performance and safety / airworthiness requirements through the entire defined range of ambient temperatures. It should be noted that temperature excursions outside of this required temperature range are possible (e.g., when an unpowered SI is being transported to a remote deployment site in the cargo hold of SOFIA), but while permanent SI degradation or damage to components should be considered for such cases, SI operability (while meeting functional and performance requirements) need not be assured outside of this range. **Rationale:** The Science Instrument, its subsystems and components need to be operable within the range temperature environments anticipated within the portion of the aircraft main cabin where the SI resides.		3.4.1	Analysis	MA	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5	**Safety**				NVR		
3.5.1	**Hardware Containment and Foreign Object Debris / Damage (FOD) Control**				NVR		
3.5.1.1	Screws, bolts, nuts, or other fasteners that are external to the Science Instrument flight hardware, or are used to retain externally mounted components, shall use self-retaining / self-locking features.	**Notes:** The following self-locking features are preferred, and will satisfy this requirement with no need for further review by the SIAT: • Threaded inserts (i.e., Helicoils) with locking features • Locking nuts or nutplates • Lock washers • Castellated nuts with cotter keys • Lead-sealed safety wire (consult with the SIAT for assistance with the proper application of safety wire) KF flange clamps used within the TA INF "tub" (i.e., for Pressure Coupler pumpout ports) should support the use of a positive locking feature, such as safety wire or cotter pins, to ensure that they can not be dislodged and become FOD. In situations where the use of a preferred self-retaining or self-locking feature is deemed impractical (e.g., where frequent assembly / disassembly is needed), alternative fastener retention or locking implementations (e.g., loctite, staking) and/or periodic pre- and/or post-flight inspection methods (e.g., use of torque stripes or tamper-proof seals) may be approved by the SIAT on a case-by-case basis. For components that will be routinely accessed on the SOFIA aircraft (e.g., cryogen fill ports on SI cryostats, access hatches, keyboard and/or monitor tray locking pins, etc.), use of captive fasteners that do not require tools is strongly recommended (e.g., cotter keys tethered with lanyards). 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, the SI developer must clearly identify this to the SIAT early in the design and airworthiness certification review process for assessment of risk and airworthy mitigations. **Rationale:** Science Instrument Airworthiness Team (SIAT) requirement to ensure that such fasteners will not loosen in the vibration environment, leading to unretained / uncontained hardware (i.e., FOD).		3.5.5	Inspection	AW	SIAT

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.2	**Structures**				NVR		
3.5.2.1	The structure of SOFIA Science Instrument flight hardware shall be designed to maintain positive Margins of Safety (MS) for all handling, ground, airborne and emergency landing load conditions.	**Notes:** The Ultimate Load Factors defined in Table 3.5-1, *Ultimate Load Factors* for structural calculations, envelope the Load Factors for ground (taxi), airborne and emergency landing inertial loads, and are to be used for structural calculations. For certain directions, the referenced table defines different Load Factors depending on whether the SI flight hardware is physically mounted to: 1. the Telescope Assembly (TA) Instrument Mounting Flange (IMF) or Counterweight Rack (CWR); or 2. the aircraft cabin / airframe via one of the PI Racks. The applicable Load Factors are to be used for each SI structure, based on the mounting location. The load conditions defined in Table 3.5-1 are prescribed in terms of ultimate loads, therefore a Safety Factor need not be applied in the analysis to show positive Margins of Safety, per Code of Federal Regulations Title 14, Chapter 1, Part 25 (FAR Part 25) Subpart C (Structure) § 25.303, *Factor of Safety* . For internal, mechanically-induced structural loads (i.e., not inertially-induced loads derived from Table 3.5-1), the design / verification must take into account the applicable Factor of Safety (FS) defined in Table 3.5-2, *Factor of Safety* , applied to the limit load. **Rationale:** Science Instrument Airworthiness Team (SIAT) requirement to ensure the structural integrity of SI flight hardware during emergency landing conditions.	Table 3.5-1 Table 3.5-2	3.5.5	Analysis or Analysis & Test	AW	SIAT
3.5.2.2	SI stands and carts to be used at a NASA facility shall be designed to maintain positive Margins of Safety (MS), with a minimum Safety Factor of 2 against deformation or yielding, and a minimum Safety Factor of 3 against collapsing, buckling, exceeding the ultimate load, or failing to support the design load in the vertical/downward direction.	**Notes:** These minimum Safety Factors assume the use of ductile materials. The analysis must take into account all operational scenarios, including those in which the Science Instrument is not being supported by the GSE stand or cart. **Rationale:** Ensure the structural integrity of SI GSE stands and carts to be used aboard the SOFIA aircraft as well as ground-based laboratories, for the safety of personnel and to protect observatory, SI and laboratory assets. This is a recommended requirement for GSE support structures from NASA-STD-5005C, *Standard for the Design and Fabrication of Ground Support Equipment* (section 5.1.2).		3.5.1	Analysis	GS	SE&I
3.5.2.3	SI stands and carts to be used at a NASA facility shall be 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. Though outside the scope of this specification (operational / maintenance vs. design requirement), it should be noted that NASA standards also levy requirements for periodic (annual) inspections, and for stands and carts that include lifting mechanisms, periodic (annual) load testing at 100% rated load. Because the AFRC Lifting Devices & Equipment Manager (LDEM) has declared any lifting of a SOFIA SI at a NASA AFRC facility as a "Critical Lift" operation, such periodic load testing cannot be performed using the SI as the test load. **Rationale:** Ensure the structural integrity of SI GSE stands and carts to be used aboard the SOFIA aircraft as well as ground-based laboratories, for the safety of personnel and to protect observatory, SI and laboratory assets. This is a requirement for structural GSE from NASA-STD-5005C, *Standard for the Design and Fabrication of Ground Support Equipment* (section 4.6.2.1). NASA-STD-8719.9, *Standard for Lifting Devices and Equipment* (section 13.3.1) specifies a proof load test of 120% of rated load (it cites and appears to be a simplified composite of the static and dynamic proof load test conditions of ASME B30.1 section 1-1.4.14.2). We have opted to increase this to 125% of rated capacity to harmonize and merge the requirement with that from NASA-STD-5005C for non-lifting devices.		3.5.1	Test & Inspection	GS	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.2.4	SI installation and lab carts shall be designed to maintain positive Margins of Safety (MS) while sustaining the forward or rear impact of any one wheel of the cart with a 2 inch high curb.	**Notes:** 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 Safety Factor is nececesary for analysis of this off-nominal condition. **Rationale:** This requirement ensures the GSE cart (including the wheel/cart interface, structural braces and gussets, etc.) is sufficiently strong to withstand inadvertent impact with a curb or other low obstacle while the loaded cart is being pushed. The 0.6 m/s (~ 1.3 miles/hour) is believed to be a reasonable "speed limit" for a heavy SI cart being carefully and manually propelled by scientists or technicians in a laboratory setting, and falls within the range established by ISO 3691-5 *Industrial trucks - Safety requirements and verification* - Part 5: *Pedestrian-propelled trucks* (Annex A2.3), which calculates rolling forces for a manually propelled truck based on a speed of 0.5 m/s (+/- 20%). The 2 inch curb height is representative of typical obstacles that may be encountered at AFRC Building 703. 0.1 s is a reasonable impact time per MIL-HDBK-1791, *Designing for Internal Aerial Delivery in Fixed Wing Aircraft* (section 4.2.3.2).		3.5.1	Analysis	GS	SE&I
3.5.2.5	Lifting hardware GSE (e.g. hoists, slings, rigging, chains, spreader bars, etc.) provided by an SI developer for use at a NASA facility, including lifting hardware incorporated into SI carts and stands (e.g., jacks) shall be designed and tested in accordance with the requirements of NASA-STD-8719.9, *Standard for Lifting Devices and Equipment*, Sections 6, 7, 8, 10, and 13, as applicable.	**Notes:** 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 re: the appropriate classification of the lifting devices or the corresponding requirements. For example, consider a Structural Sling: • NASA-STD-8719.9 Sect.10.2.1 Table 10-1 indicates that Structural Slings shall be designed and analyzed to maintain positive margins of safety with a minimum safety factor of 3 against deformation or yielding, and a minimum safety factor of 5 against ultimate failure to support the design load in the vertical/downward direction. • NASA-STD-8719.9 Sect.10.3.1 Table 10-2 indicates Structural Slings shall be proof load tested to 200% of the design load, or 125% of the manufacturer's rated capacity, whichever is higher, for the full length of travel. Though outside the scope of this specification (operational / maintenance vs. design requirement), it should be noted that NASA standards also levy requirements for periodic (annual) load testing at 100% rated load. Because the AFRC Lifting Devices Equipment Manager (LDEM) has declared any lifting of a SOFIA SI at a NASA AFRC facility as a "Critical Lift" operation, such periodic load testing cannot be performed using the SI as the test load. **Rationale:** Requirement to ensure SI lifting hardware is load-certified. NASA-STD-8719.9 presents distinct requirements for design, analysis and proof load testing depending on the specific classification of the lifting device, so we have opted to cite this requirements document, and present specific example design / analysis and proof load testing cases based on one (likely) classification. NASA-STD-5005C, *Standard for the Design and Fabrication of Ground Support Equipment* (Section 4.6.2.1) cites NASA-STD-8719.9, *Standard for Lifting Devices and Equipment for lifting devices and equipment*. Section 10.2.1, *Slings and Rigging*, Table 10-1, *Structural Slings*, specifies these yield and ultimate Safety Factors, which also appear in MSFC-SPEC-1548, *GSE Requirements for MSFC STS Experiments* (section 3.2.4.1.1). Section 10.3.1, *Slings and Rigging*, Table 10-2, *Structural Slings*, specifies these proof load test factors. MSFC-SPEC-1548, *GSE Requirements for MSFC STS Experiments* (section 3.2.4.1.3) also specifies proof testing for lifting equipment at 2 x maximum working load, with inspections.		3.5.1	Analysis, Test & Inspection	GS	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.2.6	SI flight hardware to be hoisted at a NASA facility shall be designed to maintain positive Margins of Safety (MS) with a dynamic load factor of 1.5g in both the upward and downward direction.	Dynamic loads due to hoisting (start – stop loads) per MSFC-SPEC-1548, *GSE Requirements for MSFC STS Experiments* (section 3.2.4.1.2). Because SI flight H/W is designed to higher load factors (e.g., 6g down and 3g up), this requirement is not expected to be a design driver or impact.		3.5.1	Analysis	GS	SE&I
3.5.2.7	SI Ground Support Equipment (GSE) to be hoisted at a NASA facility shall be designed to maintain positive Margins of Safety (MS) with a dynamic load factor of 1.15g in both the upward and downward direction while loaded per the applicable operational scenario.	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).		3.5.1	Analysis	GS	SE&I
3.5.2.8	SI stands and carts shall be designed to ensure that no foot or wheel loses contact with the ground when a load factor of 0.17 or 70 lb-f, whichever is greater, is applied at the highest CG of the combined assembly in any horizontal axis.	GSE cart stability requirement proposed to ensure that the cart will not tip over (to prevent damage the aircraft floor, TA, SI or injury to operator). 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).		3.5.1	Analysis	GS	SE&I
3.5.2.9	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) shall use self-retaining or self-locking features.	**Notes:** Critical design characteristics defined in SCI-AR-HBK-OP03-2000, Science Instrument Developers' Handbook. 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. Ball-Detent pins (a.k.a. "PIP pins") should not be used as load-bearing fasteners. 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.). **Rationale:** Requirement to ensure that vibration environment will not cause fasteners that are part of critical structural load paths and are necessary to maintain positive MS to loosen.		3.5.5	Inspection	AW	SIAT

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.3	**Pressure Vessels and Pressurized Systems (PVS)**				NVR		
3.5.3.1	SOFIA Science Instrument cryogen reservoirs or dewars (inner vessel), cryostats (outer shell), and pressure couplers (where applicable) shall be designed to withstand the worst-case pressure and inertial loads.	**Notes:** The structural analysis must consider and incorporate the material properties at cryogenic temperatures, where applicable. These analyses must include: 1. Stress analysis of the inner vessel due to internal pressure loads (considering the evacuated jacket outside this vessel) 2. Stress analysis of the outer shell, optical window, and pressure coupler (where applicable) due to the (single acting) effects of external pressure and emergency landing (inertial) loads Analyses must show positive Margins of Safety (MS) and are to be provided to the SIAT for airworthiness review. Depending on material properties, thickness and calculated MS, the SIAT may request that optical windows which comprise a portion of the SOFIA cabin pressure boundary (when the TA Gate Valve is open) be proof pressure tested to a 1 atmosphere pressure differential to ensure integrity. Those portions of the SI cryostat that are a portion of the cabin pressure boundary during flight should be designed to withstand the Design Ultimate Pressure Load between the instrument and the cabin which is: 1.5 x 1.33 x Maximum Normal Operating Pressure (MNOP). For a cryostat that is internally under vacuum, the value of the MNOP during flight is 9.4 psi, corresponding to the cabin pressure relief valve setting of the aircraft; during ground operations the value is expected to be 14.7 psi. **Rationale:** To ensure the integrity of pressurized components for safety and airworthiness certification. Failure of an optical window due to the pressure differential could lead to shrapnel damage to TA tertiary mirror or other sensitive hardware in the Nasmyth Tube or cavity.		3.5.5	Analysis or Analysis & Test	AW	SIAT
3.5.3.2	**Cryogen Reservoir Venting Safety**				NVR		
3.5.3.2.1	Each Liquid Helium (LHe) and Liquid Nitrogen (LN2) cryogen reservoirs shall have two (2) independent vent and/or fill "neck" tubes, as follows: 1. Primary vent neck tube for nominal (slow) venting of cryogen evaporate, outfitted with a PRV or equivalent "non-return" device; and 2. Backup (or emergency) vent / fill neck tube, outfitted with a burst disk, code certified to open at a pressure at or below the pressure to which the reservoir has been tested [ref.: ParID 3.5.3.3.1 and Table 3.5-3].	**Notes:** Potentially common failure modes, such as the formation of an ice plug of frozen condensate or debris in the fill/vent tubing, must be considered in the design and the submitted analysis report of the cryogenic reservoir and plumbing systems. One vent neck tube is defined as the primary (or nominal) neck tube, while the other is defined as a backup (or emergency) neck tube. The cracking pressure of the PRV / non-return valve on the primary neck tube will generally establish the Maximum Normal Operating Pressure (MNOP) of the reservoir. If a PRV is included on the backup (emergency) neck tube (i.e., in parallel with the required burst disk), the cracking pressure of the PRVs must be coordinated such that the PRV on the backup (emergency) neck tube will open only in the event of an icing or other venting issue with the primary neck tube. Often, balloons or bags are used on the cabin vent side of the PRV(s), to both act as a "tell-tale" of vent gas flow, and to protect the PRV from condensate and potential icing from ambient humidity. The burst disc must be certified by an applicable National Consensus Codes and Standards (NCS) organization (e.g., ASME). Cryogen reservoir neck tube and vent plumbing designs, and burst disc certifications are to be provided to the SIAT for airworthiness review. Though outside the scope of this specification (operational / maintenance vs. design requirement), SI developers are advised that PRDs must be periodically inspected, recertified and/or replaced in accordance with DCP-S-065 and NASA-STD-8719.17. The associated need for replacement PRVs should be considered in the SI spares plan. **Rationale:** To mitigate the risk of an overpressure situation within a cryogen reservoir that could result from ice plug formation or debris in vent tubes.		3.5.5	Analysis & Inspection	AW	SIAT
3.5.3.2.2	The backup (or emergency) neck tube for Cryogenic Liquid Helium (LHe) reservoirs, with its integrated code certified burst disk, shall be able to safely vent the very rapid LHe boil-off associated with a heat load of 4.0 W/cm^2.	**Notes:** An analysis of the maximum cryostat pressure resulting from a vacuum jacket failure of a liquid Helium reservoir will be conducted prior to CDR by the SOFIA SIAT, based on preliminary cryostat and neck tube design parameters to be provided by the SI developer [ref. NASA/TM 2014-218540 - NESC-RP-13-00911, *SOFIA Cryogenic Helium Dewar Heat Flux Evaluation, Maximum Expected Wall Heat Flux and Maximum Pressure after Sudden Loss of Vacuum Insulation on the Stratospheric Observatory for Infrared Astronomy (SOFIA) Liquid Helium (LHe) Dewars*]. To support conceptual and preliminary designs for cryostats, two approaches for estimating P_{max} are provided as Appendix C, *Simplified Method for Computing System Conceptual Design Maximum Pressure Due to a LOV Event* [ref. NASA/TM 2015-218810 - NESC-RP-15-01017, *Simplified Methodology to Estimate the Maximum LHe Cryostat Pressure from a Vacuum Jacket Failure*]. The LHe cryogen reservoir neck relief tube(s) and high flow burst disk must be sized such that the full flow rate of the rapid LHe boil-off can be safely relieved. The burst disk must be certified by an applicable National Consensus Codes and Standards (NCS) organization (e.g., ASME). Though outside the scope of this specification (operational / maintenance vs. design requirement), SI developers are advised that per DCP-S-065 and NASA-STD-8719.17, PRDs must be periodically inspected. Analyses, cryogen reservoir neck tube and vent plumbing designs, and PRD certifications are to be provided to the SIAT for airworthiness review. **Rationale:** To mitigate the risk of an overpressure situation within a cryogen reservoir that could result from vent tubes or burst disks inadequately sized to vent a rapid boil-off event induced by a Loss Of Vacuum (LOV) of the insulating jacket, or potentially other failure modes that could result in an increased heat load to the LHe within the reservoir.	Appendix C	3.5.5	Analysis & Inspection	AW	SIAT

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.3.2.3	Cryogen reservoir outer vacuum jackets shall include redundant pressure relief capability, each adequately sized to safely relieve the rapid boil-off that would result from the rupture of the internal cryogen reservoir or neck tube, bellows, etc.	**Notes:** "Drop-off plate" relief port(s) to be included on the outer shell to safely vent the vacuum jacket to the cabin environment in the event of a failure of the inner vessel (cryogen reservoir) or neck tube. Typically these are large area openings, outfitted with gasketed plates positioned such that they are held in place solely via the pressure differential between the evacuated vacuum jacket and the surrounding ambient cabin environment. Such plates must be tethered or otherwise captive, to obviate concerns re: loose parts or FOD, and should be opened when practical as a regular maintenance activity to avoid potential gasket material adhesion that might inhibit their intended functionality. Though outside the scope of this specification (operational / maintenance vs. design requirement), SI developers are advised that these relief port drop-off plates must be recertified periodically to Demonstrate proper operation as a normal Operations & Maintenance activity. Initially, the recertification interval is anticipated to be on the order of 2 years or prior to each observing campaign cool-down, in accordance with DCP-S-065 § 11.1 and NASA-STD-8719.17 § 4.10.1.7 and 4.10.1.12. Refer to Appendix C for guidance regarding the analysis of LHe boil-off mass flow rates based on reservoir surface area, outlet area, and an input heat flux of 4.0 W/cm^2 associated with an LOV event (and/or other heat loads, where applicable). Generally speaking, the flow area of each of these redundant drop-off plate relief ports will need to be comparable to that of the backup (or emergency) neck tube and associated burst disk. **Rationale:** Ensures that a failure that results in the rupture of a cryogen reservoir, neck tube, bellows, or other components internal to the cryostat, and ensuing phase change and venting of the liquid cryogen (especially LHe), cannot lead to a catastrophic secondary rupture of the cryostat outer shell / vacuum jacket (ref.: ANSI / AIAA-S-080 ParID 5.3.2.1.5). This also ensures that any frozen air or loading of "getters" within cryostat vacuum jackets resulting from soft leaks will be safely vented when the cryostat is allowed to warm up.	Appendix C	3.5.5	Analysis & Demo	AW	SIAT

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.3.3	**Qualification and Acceptance of Pressure Vessels and Pressurized Systems (PVS)**				NVR		
3.5.3.3.1	Cryogen reservoirs for SOFIA Science Instruments shall be shown to be safe via: 1. An analysis showing positive Margin of Safety (MS) with a Factor of Safety (FS) against yield strength of 2.25 x MNOP for LN2 reservoirs, or 2.25 x P_{max} for LHe reservoirs AND 2. Hydrostatic or pneumatic testing at the Qualification pressure level as defined in Table 3.5-3, *Qualification and Acceptance pressure test levels for cryogen reservoirs, other pressure vessels, lines and components*	**Notes:** MNOP = 14.7 psi + lowest relief valve cracking pressure. For conceptual and preliminary design and planning activities, SI developers are to estimate P_{max} using Appendix C, *Simplified Method for Computing System Conceptual Design Maximum Pressure Due to a LOV Event* [ref. NASA/TM 2015-218810 - NESC-RP-15-01017, *Simplified Methodology to Estimate the Maximum LHe Cryostat Pressure from a Vacuum Jacket Failure*], based on the total surface area of the helium reservoir in cm^2, and a heat flux of 4.0 W/cm^2. By CDR, the SI developer must submit detailed cryostat design information to the SOFIA SIAT, to support a more detailed, higher fidelity Computational Fluid Dynamics (CFD) model [ref. NASA/TM 2014-218540 - NESC-RP-13-00911, *SOFIA Cryogenic Helium Dewar Heat Flux Evaluation, Maximum Expected Wall Heat Flux and Maximum Pressure after Sudden Loss of Vacuum Insulation on the Stratospheric Observatory for Infrared Astronomy (SOFIA) Liquid Helium (LHe) Dewars*], which will be used to refine the P_{max} analysis result, and define the necessary Qualification and Acceptance analysis and test pressure criteria. Where used in lieu of Finite Element Analysis (FEA) methods, hand calculations that incorporate stress concentrations associated with welds and geometric discontinuities, non-hemispherical end caps, etc., are generally acceptable to the SIAT. Refer to ASME Section VIII, Division 2, Parts 4 and 5, for comprehensive guidance re: combination of stresses and analytical methods for pressure vessels. Proto-Flight (PF) Qualification: The ProtoFlight Model (PFM) test article used to qualify the design may undergo established, industry standard Non-Destructive Evaluation (NDE) and be accepted for use in flight hardware if a comparison of pre- and post-test 10x visual inspections performed by a NASA Quality inspector confirm no formation or propagation of cracks at welds and geometric discontinuities. Refer to ASME Section VIII, Division 2, Part 8, Section 8.2, and Part 7, for a comprehensive discussion of suitable hydrostatic test and NDE inspection procedures, respectively. The Proto-Flight Model (PFM) need not also undergo Acceptance pressure testing; the Qualification level pressure test is sufficient for both qualification of the design and acceptance of the PFM reservoir. Acceptance pressure testing is generally only performed for a Prototype Qualification approach, in which a single representative QM is tested to the higher levels to Qualify the design, while all Flight Model (FM) multiples of that design are tested to the lower Acceptance level. Leak testing of each cryogen reservoir conducted after the qualification pressure test must confirm the integrity of the vessel (a comparison of measured leak rates with pre-test baseline levels may be necessary, depending on the leak test methodology). Portions of the cryogen reservoir fill / vent "neck" tubes that are not rated to withstand the prescribed Qualification pressure level (e.g., flexible metal bellows used in neck tube assemblies, often with relatively thin-walls to minimize heat leaks into the cryogen bath) may be excluded from the testing scope of this requirement, including the as-tested configuration. This "hybrid" Proto-Flight / Prototype Qualification and Acceptance approach will require additional testing, including potentially destructive testing of COTS components such as metal bellows assemblies, to establish that representative Qualification Model (QM) test article is able to withstand the Qualification pressure test level without rupture or release of test fluid (yielding of the QM is acceptable). Following successful Qualification testing of individual components (and/or sub-assembly designs), Flight Model (FM) components of the same design and pedigree are integrated into the cryogen reservoir assembly. A leak test of the integrated cryogen reservoir and vent / fill tube assembly at a test pressure of 1.1 x P_{max} must be conducted to establish integrity. All pressure tests (non-COTS items) are to be conducted in accordance with test plans that have been reviewed and approved by the SIAT, and must be witnessed by an SIAT representative or designee. The SIAT and SOFIA SI Development personnel are to be notified as soon as a test date is established and at least 3 weeks in advance of the test date. COTS items may be procured with certified vendor documentation demonstrating proof of burst testing and/or analysis by manufacturer. Test reports and analyses are to be provided to the SIAT for airworthiness review. Cryostat outer housings are not within the scope of this requirement, and need not be tested, though the vacuum annulus of the outer housing, or portions of it, may certainly be included as part of the test setup. **Rationale:** To ensure the integrity of pressurized components for safety and airworthiness certification.	Table 3.5-3, Appendix C	3.5.5	Analysis & Test	AW	SIAT
3.5.3.3.2	Pressure vessels and pressurized lines and components of SOFIA Science Instruments shall be qualified via Analysis, Inspection of CoCs, or Test, and undergo hydrostatic or pneumatic pressure testing to acceptance pressure levels based on the Maximum Normal Operating Pressure (MNOP) of each component and the applicable factor as defined in Table 3.5-3, *Qualification and Acceptance pressure test levels for cryogen reservoirs, other pressure vessels, lines and components* .	**Notes:** Acceptance pressure testing comprises acceptance criteria for pressurized systems to be used in SIs. Such testing is to be conducted once prior to assembly into the SI, and need not be repeated subsequently. All pressure tests (non-COTS items) are to be conducted in accordance with test plans that have been reviewed and approved by the SIAT, and must be witnessed by an SIAT representative or designee. The SIAT and SOFIA SI Development personnel are to be notified as soon as a test date is established and at least 3 weeks in advance of the test date. COTS items may be procured with certified vendor documentation demonstrating proof testing by manufacturer. Test reports, COTS documentation, and analyses are to be provided to the SIAT for airworthiness review. **Rationale:** To ensure the integrity of pressurized components for safety and airworthiness certification.	Table 3.5-3	3.5.5	Analysis, Inspection & Test	AW	SIAT

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.3.4	Pressure systems downstream of pressure regulators shall be designed for either the Maximum Normal Operating Pressure (MNOP) of the pressure source or appropriate pressure relief devices (PRDs) to accommodate a full open regulator failure.	**Notes:** To support the analysis to show compliance with this requirement, the flow rate through the regulator is to be calculated using the published flow coefficient (Cv) value for the regulator, with calculations in accordance with the procedure provided in Compressed Gas Association (CGA) E-4, *Standard for Gas Pressure Regulators* , Appendix A. Design and analysis shall anticipate and accommodate any applicable pressure test requirements such that this testing will not be destructive or result in any yield conditions. This requirement is applicable to both ground-based (i.e., GSE) and flight PVS. **Rationale:** This precludes the possibility of the downstream pressure exceeding the MNOP or placard rating of the lowest rated component. For instance, if the pressure vessel system includes a compressed gas cylinder serviced to 2000 psi supplying pressure to an instrument that is rated to 400 psi, even though the pressure is regulated down to below 400 psi via a pressure regulator, the system must have a pressure relief device set no higher than 400 psi downstream of the pressure regulator.		3.5.5	Analysis & Inspection	AW	SE&I
3.5.3.5	All pressurized systems within SOFIA Science Instrument GSE that are being used at any NASA facility shall comply with NASA-STD-8719.17A, *NASA Requirements for Ground-Based Pressure Vessels and Pressurized Systems (PVS)* .	**Notes:** These requirements are applicable to SOFIA SI GSE (e.g., compressed gas cylinders) to be used at AFRC Building 703, and not applicable to flight hardware (e.g., instrument cryostat). The NASA AFRC Pressure Vessels and Pressurized Systems (PVS) Subject Matter Expert and SOFIA Chief Safety Officers (CSOs) have highlighted the following paragraphs from NASA-STD-8719.17A which are likely to be applicable to SOFIA SI GSE, and for which formal verification will be expected: ¶ 4.4.3.1: New pressure vessels, including heat exchangers, shall be ASME Section VIII code stamped as specified within the scope as being used and registered with the National Board (Requirement). [An example stamp for ASME Section VIII Division 1 pressure vessels is shown as Figure 3.5-1] ¶ 4.10.1.11: Pressure safety relief valves shall only be used in accordance with the applicable ASME code of construction (Requirement). ¶ 4.10.2.1.2: Safety-related pressure-indicating devices shall meet an appropriate NCS, such as ASME B40.100, UL-404, or MIL-G-18997 (Requirement). **Rationale:** To ensure the integrity of pressurized GSE components for personnel safety.	Figure 3.5-1	3.5.1	Analysis, Inspection & Test	GS	SE&I
3.5.3.6	Flexible hose ends that could subject personnel to a whipping hazard in the event of end connection failure shall be restrained at each end and at least every six feet.	**Rationale:** Ensure that pressurized hoses will not become a physical hazard in the event of a hose or end fitting failure.		3.5.5	Inspection	AW	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.5.4	**Electrical**				NVR		
3.5.4.1	Wiring to Science Instrument design characteristics classified as Critical shall be routed separately from other wiring.	**Note:** Critical design characteristics defined in SCI-AR-HBK-OP03-2000, Science Instrument Developers' Handbook. Power interface cables and grounding wires or straps between observatory patch panels and SI equipment are not within the scope of this requirement. **Rationale:** Protection against common mode failures within Critical SI subsystems required to maintain safety and control.		3.5.5	Analysis & Inspection	AW	SIAT
3.5.4.2	All electrically conductive external surfaces of each item of powered Science Instrument equipment shall be electrically grounded, with a resistance of no greater than 70 mΩ (0.07 ohm) measured between the Science Instrument equipment conductive surface and the applicable local grounding interface location, as defined in Table 3.5-4, *Local electrical grounding interface locations for SI equipment*.	**Notes:** The Science Instrument assembly (that portion of the Science Instrument mounted to the Telescope Assembly (TA) Instrument Mounting Flange (IMF) will generally be electrically bonded to the TA via its structural / mechanical interface (unless there are features at that interface specifically designed to isolate these assemblies, in which case a provision to ground the SI assembly via a PI-provided grounding wire or strap will be required in accordance with SOF-DA-ICD-SE03-036 (TA_SI_01), *Cable Load Alleviator Device / Science Instrument Cable Interface*, paragraphs 4.1.3.3 through 4.1.3.6). SOF-DF-ICD-SE03-048 (TA_MCCS_P), *Telescope Assembly / Mission Controls and Communications System (MCCS) Physical Interface*, section 3.3.12, Electrical - Bonding and Grounding, provides guidance re: acceptable practices and implementations for meeting these requirements. In particular, section 3.3.12.2, *Grounding in Relation to Power Circuits*, and the referenced Figure 3.3.12.2-1, *Safety (Chassis) Ground Approaches for Consoles, Racks, and Connector Panels*, describe various approaches to acceptable grounding of rack-mounted equipment, depending on the specifics of the equipment. Additionally, other subsections within section 3.3.12 provide guidance re: best practices for equipment grounding and bonding and shielding of AC power and signal cables, for Electromagnetic Interference (EMI) reduction considerations. **Rationale:** Protection of personnel against shock hazards due to electrical faults within SI equipment. Also, keeping all SI equipment referenced to a common, single-point ground (i.e., aircraft structure) is good design practice for EMI/EMC considerations. While 100 mΩ (0.1 ohm) is the typical Class H (Shock and Fault Protection) electrical grounding resistance specification for aerospace applications, Class H specifications are applied end-to-end from equipment to facility / vehicle ground, therefore we have sub-allocated a slightly more stringent 70 mΩ (0.07 ohm) specification for the grounding between the SI equipment to the local grounding interface (i.e., the U402 grounding lug, or the conductive PI Rack / CWR structures), to allow for the additional < 10 mΩ (0.01 ohm) resistance in the grounding path between the TA and the aircraft structure via the Cable Load Alleviator (CLA), per APP-DF-PRO-SV02-2365, *SOFIA SI to Aircraft Ground Path Resistance Characterization*. PI rack(s) and CWR conductive structures will be electrically grounded to aircraft structure with a resistance of no greater than 10 mΩ (0.01 ohm) to nearby grounding provisions via NASA-provided grounding cable assemblies, in accordance with applicable ICD grounding requirements. The referenced ICDs address the verifiable grounding requirement at the applicable interface (i.e., PI Racks to U400/U401, CWR to U402, SI assembly to U402), with the intention that this supports V&V of this specification earlier in the integration flow, before installation on the SOFIA observatory.	Table 3.5-4	3.5.1	Inspection & Test	AW	SE&I
3.5.4.3	Any ground wire, jumper or strap necessary for Science Instrument equipment compliance with the resistance specification of paragraph 3.5.4.2 shall have a conductor sized to accommodate the maximum current that can be provided by the upstream power interface.	**Note:** Generally, the use of the same wire conductor size that is specified for the current carrying conductors in the power interface connector and cable is appropriate and recommended. **Rationale:** Ensures that the grounding provisions have adequate current carrying capacity to accommodate the maximum possible fault current (i.e., a "hard short").		3.5.1	Analysis & Inspection	AW	SE&I
3.5.4.4	All electrical wiring used within or between elements of a Science Instrument installation shall have a wire conductor size that is specified in accordance with FAA Advisory Circular (AC) 43.13 Chapter 11, *Aircraft Electrical Systems*, Section 5, *Electrical Wire Rating*, with a current carrying capacity at least as high as the upstream overcurrent protection device(s), where applicable.	**Notes:** Table 11-9, *Current carrying capacity and resistance of copper wire*, within the cited AC 43.13 document presents the continuous duty current of wires in bundles, groups, harnesses or conduits in aircraft applications. Per the table notes, the values in this table are based on very conservative assumptions with respect to operating altitude, ambient temperature conditions, and bundling. Wires that do not meet these prescriptive criteria may often be shown sufficient using the methods outlined in paragraphs 11-67 through 11-69 and associated figures, based on the rated maximum operating temperature of the wire, the current carrying capacity of a single wire in free air, and specified current derating factors for bundling of wires in harnesses and altitude. This requirement is applicable to all Electrical Ground Support Equipment (EGSE) that is used aboard SOFIA. **Rationale:** Ensures that wiring used in electrical systems is adequately rated to handle the maximum current without overheating and associated smoke and fire hazards.		3.5.1	Analysis & Inspection	AW	SIAT

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.7	**Maintainability**				NVR		
3.7.1	The SI design shall accommodate the removal and replacement of the SI components with spares.	**Note:** In-Flight Maintenance of SI is not required. Compliance based on sparing plan to be developed and delivered in response to SOF-NASA-SOW-PM91-2094, *SOFIA Science Instrument Development Process and Deliverable (P&D) Requirements.* SI developer will determine need and procure the spare parts to complete the Legacy Science Program (LSP) exploitation period based on proposed approach. **Rationale:** No maintenance of specialized parts (e.g., detectors) is required, but maintainability must be considered during design to enable standard servicing and operations.		3.1.18	Analysis & Inspection	MA	SE&I
3.8	**Logistics**				NVR		
3.8.1	Science Instruments with cryostats using expendable cryogens shall meet functional and performance requirements with cryogenic servicing no more frequent than once per 24 hours.	**Rationale:** More frequent cryogen replenishment would drive operational costs.		3.8.3	Analysis & Demonstration	MA	SE&I
3.8.2	The design and operations of SOFIA Science Instruments shall permit removal from the SOFIA aircraft within a 10 hour period.	**Notes:** This time period assumes availability of appropriate staffing, readiness of CWR, tool kits, work orders, and procedures. As a goal, Science Instruments should permit removal from the SOFIA aircraft within a 6 hour period, to allow this operation to be completed during a single standard work shift. **Rationale:** Provides basis for multiple science instruments to be used over the life of the program. Also, a flight series may be considered as little as one flight. The synergy of SOFIA's instrument suite is an important element of the observatory's expected science return. The time spent changing from one instrument to another can also impact the mission's overall science return. These requirements support the transition between flight series and include those portions of the Science Instrument mounted to the Telescope Assembly IMF, as well as the SI counterweight rack, PI rack and Auxiliary PI rack, where applicable.		3.1.8	Analysis	MA	SE&I
3.8.3	The design and operations of SOFIA Science Instruments shall permit installation on the SOFIA aircraft, optical alignment, cryogenic servicing and cold functional check-out of Science Instruments within a 12 hour period.	**Notes:** This time period assumes availability of appropriate staffing, readiness of CWR, tool kits, work orders, and procedures. As a goal, Science Instruments should permit installation on the SOFIA aircraft within an 8 hour period, to allow this operation to be completed during a single standard work shift. **Rationale:** Provides basis for multiple science instruments to be used over the life of the program. Also, a flight series may be considered as little as one flight. The synergy of SOFIA's instrument suite is an important element of the observatory's expected science return. The time spent changing from one instrument to another can also impact the mission's overall science return. These requirements support the transition between flight series and include those portions of the Science Instrument mounted to the Telescope Assembly IMF, as well as the SI counterweight rack, PI rack and Auxiliary PI rack, where applicable.		3.1.8	Analysis	MA	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.9	**Human Factors**				NVR		
3.9.1	The design, operations and in-flight access of SOFIA Science Instruments shall be consistent with the following operational constraints and limitations: 1. Access to the SI Forward Side while the telescope is inertially stabilized and tracking (only those portions accessible with the TA Barrier raised). 2. Access to the SI Top, Port and Starboard Sides to the flange while the TA is braked. 3. Access to the Forward Side of the counterweight rack while the TA is braked at a nominal elevation of 20 degrees. 4. Access to the SI Bottom Side while the TA is braked and caged.	**Notes:** Science Instrument controls and indicators that may require routine access or adjustment during in flight operations should be located in one of the PI racks where possible, and not on those portions of the SI mounted to the TA INF or the CWR. Where such SI controls and indicators must be located in the CWR, note that at elevation angles greater than 20 degrees, some or all of the CWR will likely be inaccessible and/or may have visibility issues. Access to those portions of the SI that are mounted to the TA INF or the CWR which require the TA Barrier to be lowered will require that the TA be braked at a minimum, and also caged where access to the TA itself or the bottom side of the SI are required). Reference SOF-DF-SPE-SE01-003, *SOFIA System Specification* , Appendix A Figure 1 & Figure 2, *SI In-Flight Access* . Reference APP-DF-PRO-OP02-2043, *Procedure for Crossing the TA Barrier during Flight* , for requesting in-flight access to those portions of SI mounted on TA and/or within CWR. **Rationale:** Access to the science instrument must be provided for minor adjustments/repairs, while in flight, in order to alleviate the need to abort a mission and return to base for a minor problem. However, access must be limited to minimize risks associated with this access. Bent Cassegrain is the type of telescope focus this TA has. What is needed is access to instruments in the pressurized cabin forward of the TA focal point forward of the mounting flange and pressure barrier.		3.1.35	Analysis & Demonstration	MA	SE&I
3.10	**Parts, Materials and Processes**				NVR		
3.10.1	**Metal Stock Material Certifications**				NVR		
3.10.1.1	Any metal material used for the fabrication of Science Instrument Flight Hardware design characteristics classified as Critical, including raw material incorporated into threaded fasteners, shall be accompanied by a Certified Material Test Report (CMTR) to be obtained from the material distributor.	**Note:** Critical design characteristics defined in SCI-AR-HBK-OP03-2000, *Science Instrument Developers' Handbook* . **Rationale:** Required for traceability of materials used in the fabrication of safety-critical components and structures.		3.5.5	Inspection	AW	SIAT
3.10.1.2	Any metal material used for the fabrication of Science Instrument GSE design characteristics classified as Critical, including raw material incorporated into threaded fasteners, shall be clearly identified, including heat treatment (or "temper") where applicable, in specifications and drawings.	**Notes:** 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 (M)COTS 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). Critical design characteristics defined in SCI-AR-HBK-OP03-2000, *Science Instrument Developers' Handbook* . **Rationale:** Required for validation of structural analyses and MS results using physical properties and dimensions of materials used in the fabrication of safety-critical components and structures.		3.5.1	Inspection	GS	SE&I
3.10.2	**Electrical Systems**				NVR		
3.10.2.1	**Cable and Connector Labeling**				NVR		
3.10.2.1.1	Each Science Instrument cable shall be labeled at each connector with a unique cable identifier and a unique connector identifier.	**Note:** While considered good practice, intra-SI cables for PI-class SIs (i.e., those routed directly between SI elements with no intervening Observatory patch panel interfaces) are outside the scope of this requirement. **Rationale:** Cables that are bundled, routed and restrained are challenging to trace from end to end. In addition, it is important that cables be clearly identified with self-explanatory labels that uniquely identify each cable and where each end is to be connected, so that they can be accurately and unambiguously referenced within procedures that will be executed by Aircraft Operations and Mission Operations staff.		3.4.1	Inspection	MA	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.10.2.2	**Wire Insulation**				NVR		
3.10.2.2.1	Use of wires coated in polyvinylchloride (PVC) insulation or jacketing shall be prohibited.	**Note:** Reconstruction of PVC components in COTS equipment is recommended if replacement parts that do not use PVC are unavailable, where possible. This is primarily applicable to external cables and connectors. For example, while the power cable for a computer may have a unique connector made of PVC for which a non-PVC replacement is unavailable, the PVC-jacketed and/or insulated cabling between the connectors could be removed and re-fabricated with a Teflon coating. Where reconstruction or replacement of parts that do not use PVC is considered impractical or overly burdensome, the SI developer must clearly identify this early in the design and airworthiness certification review process for assessment of risk and possible airworthy mitigations, possibly including use of shrink tube or other protective sleeving. Further guidance re: selection of preferred aircraft-approved wiring may be found within SCI-AR-HBK-OP03-2000, *SOFIA Science Instrument Developers' Handbook* , section 8.5, *Electrical Systems* , and subsection 8.5.1, *Wires* . **Rationale:** Overheated or burning PVC releases toxic vinyl chloride vapors and is prohibited per AFST-8739.4-001, *Aircraft Electrical Systems Standards* .		3.5.5	Inspection	AW	SIAT
3.10.2.3	**Connectors** The following requirement paragraphs 3.10.2.3.1 through 3.10.2.3.3 are applicable for all connectors mounted on aircraft pressure bulkheads:	**Rationale:** When the TA gate valve is open, portions of the mounted SI become part of the pressure barrier between the pressurized cabin environment and the ambient stratospheric environment in the telescope cavity. These requirements are necessary to ensure that appropriate measures are implemented to preclude gross leaks through connectors on these portions of the SI from the pressurized cabin.			NVR		
3.10.2.3.1	Connectors shall be sealed to prevent leakage through wiring and contact installations.	**Note:** Options for meeting this requirement include the use of hermetic connectors, sealing (potting) of the connectors, or by filling unused contact wire entry holes with appropriate unused contact sealing plugs on both the receptacle and plug sides of the mated connector pair. **Rationale:** Connectors on pressure bulkheads that are not hermetic, sealed (potted) or closed by using sealing plugs or unused contacts can lead to leaks through the connector shell.		3.5.5	Inspection	MA	SIAT
3.10.2.3.2	Connector receptacles installed on aircraft pressure bulkheads shall be mounted and sealed with the connector flange on the pressurized side of the bulkhead.	**Rationale:** Improperly mounted connectors on pressure bulkheads can lead to leaks around the connector shell.		3.5.5	Inspection	MA	SIAT
3.10.2.3.3	A sealing gasket or proper sealing material such as a room temperature vulcanizing (RTV) or aircraft sealant shall be used to prevent pressure leakage at the aircraft bulkhead connector flange.	**Rationale:** Improperly mounted connectors on pressure bulkheads can lead to leaks around the connector shell.		3.5.5	Inspection	MA	SIAT
3.10.3	**Welds**				NVR		
3.10.3.1	Welding for SI cryostats shall comply with AWS D17.1.	**Note:** AWS D17.1 defines welding process, certification, inspection and acceptance requirements based on the weld Classifications (i.e., Class A, Class B, or Class C), which must be declared within the applicable Structural Analysis Report, and marked on the engineering drawings. Consult with the SOFIA Program for definition of weld classifications and clarification of which inspection type is most appropriate for your instrument. **Rationale:** Welds used in the SI system must be certified in accordance with NASA and aerospace industry standards. Weld certification (including classification, analysis, and inspection) must be acceptable to the SIAT.		3.5.5	Analysis, Inspection & Test	AW	SIAT
3.10.3.2	Welding for GSE used to structurally support the SI shall comply with AWS D17.1 Class B *(Nonflight Hardware)* .	**Note:** AWS D17.1 defines welding process, certification, inspection and acceptance requirements based on the weld classification which must be declared within the applicable Structural Analysis Report, and marked on the engineering drawings. **Rationale:** Welds used in GSE that structurally supports the SI must be certified in accordance with NASA and aerospace industry standards. The AFRC Lifting Devices & Equipment Manager (LDEM) has recommended that welds in the structural load path of GSE that supports or lifts the SI be classified as Class B per AWS D17.1.		3.5.1	Analysis & Inspection, or Analysis, Inspection & Test	GS	SE&I

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.11	**Interface**	**Notes:** SOFIA Science Instrument interfaces are described SCI-AR-HBK-OP03-2000, *SOFIA Science Instrument Developers' Handbook* , Section 5.3, *Interfaces*, Figure 5.3.1-1, *SOFIA Science Instrument Interfaces Block Diagram* , and Table 5.3.1-1, *Table describing Science Instrument ICDs* . Further information re: the Verification & Validation (V&V) approach may be found within OP03-2000, Section 5.4. Details regarding V&V Methodologies and Review & Approval Authority, as well as descriptions and phasing of V&V Activities are defined within SOF-NASA-REP-SV05-2057, *SOFIA SI System Specification & ICD Requirements Verification Matrix Template* . **Rationale:** OP03-2000 Figure 5.3.1-1 provides a very helpful pictorial reference depicting the SOFIA interfaces applicable to Science Instruments, and the corresponding ICDs.			NVR		
3.11.1	SOFIA Science Instruments shall comply with the installation, static, and dynamic envelopes as defined within SOF-DA-ICD-SE03-002 (ICD Global_09), *Science Instrument Envelope* .	**Note:** Science Instruments may be brought aboard the SOFIA aircraft in sections for reassembly once on board.		3.11.1			
3.11.2	SOFIA Science Instruments shall comply with the interface requirements of SOF-DA-ICD-SE03-037 (TA_SI_02), *Telescope Assembly / Science Instrument Mounting Interface* .			3.11.1			
3.11.3	SOFIA Science Instruments shall comply with the interface requirements of SOF-DA-ICD-SE03-2015 (SI_AS_01), *PI Equipment to PI Rack to Aircraft System* .			3.11.1			
3.11.4	SOFIA Science Instruments shall comply with the interface requirements of SOF-DA-ICD-SE03-036 (TA_SI_01), *Cable Load Alleviator Device / Science Instrument Cable Interface* .			3.11.1			
3.11.5	SOFIA Science Instruments that utilize the Counterweight Rack (CWR) on the TA for electronic equipment shall comply with the interface requirements of SOF-DA-ICD-SE03-051 (TA_SI_05), *SI Equipment Rack / TA Counterweight Interface* .			3.11.1			
3.11.6	SOFIA Science Instruments that utilize the Counterweight Rack (CWR) on the TA for electronic equipment shall comply with the interface requirements of SCI-AR-ICD-SE03-2027 (SI_CWR_01), *SI Equipment to Counterweight Rack ICD* .			3.11.1			
3.11.7	SOFIA Science Instruments shall store all imaging and spectroscopic data (for in-flight and post-flight analysis) in Flexible Image Transport System (FITS) format files that adhere to the FITS Standard (v3.0, 10 July 2008) and the SOFIA keyword list as documented within SCI-US-ICD-SE03-2023 (DCS_SI_01), *Data Cycle System (DCS) of the SOFIA Project ICD* .	**Note:** Science Instrument data to be stored and transferred to MCCS will include SOFIA subsystem housekeeping parameters as specified within the SOFIA keyword list. **Rationale:** The FITS standard was developed for the migration of astronomical data across databases and archives. The standard has many incarnations. The SOFIA program must select a FITS compatible format for it's data. Data from all the Airborne Observatory imagers needs to be stored in this format as well as the data from the science instruments. The SOFIA observatory needs to collect housekeeping data from various subsystems and redistribute those data to other subsystems (i.e. TA and SIs) to facilitate the performance of those subsystems during flight and enable the post-flight processing of the science data.		3.1.32			

Paragraph Identification (ParID)	Requirement Text	Notes / Rationale	Applicable Figures for Requirement	Trace to Parent (SE01-003)	V&V Method(s) (multiple)	Requirement Classification	V&V Review & Approval Authority
3.11.8	SOFIA Science Instruments shall comply with the physical interface requirements for connectivity with the Mission Controls and Communications System (MCCS) as defined within SOF-AR-ICD-SE03-2029 (MCCS_SI_05), *PI Patch Panel to PI Equipment Rack(s)* .	**Notes:** Section 3.2.1.1, Power Interface, within this ICD defines the maximum power (KVA for Frequency Converter and UPS supplied AC power and Amps for DC power) available to SI equipment on a per interface connector basis.		3.11.1			
3.11.9	SOFIA Science Instruments that make use of the Telescope Assembly's secondary mirror chopping shall support synchronization with the chopping secondary mechanism via SI-provided synchronization signal or TA-provided synchronization signal as defined within SOF-DA-ICD-SE03-038 (TA_SI_04), *TA Chopper Processor / Principal Investigator Computer Direct Analog Interface* .	Science instruments that use chopping must be synchronized with the secondary mirror motions. Typically the instrument provides the synchronization signal and therefore an external reference is provided by the instrument. Some instruments can use the internal synchronization signal provided by the TA.		3.1.27			
3.11.10	SOFIA Science Instrument carts and stands to be used within the SOFIA Science and Mission Operations (SSMO) Facility shall comply with the requirements of SCI-AR-ICD-SE03-2017 (SIC_SSMO_01), *SI Handling Cart to SSMO Facility Interface* .			3.11.1			
3.11.11	SOFIA Science Instrument carts and stands to be used within the SOFIA aircraft shall comply with the requirements of SOF-AR-ICD-SE03-205 (SIC_AS_01), *SI Handling Cart to Aircraft System ICD* .			3.11.1			
3.11.12	SOFIA Science Instruments that utilize the TA Alignment Simulator (TAAS) for optical alignment and checkout shall comply with the interface requirements of SCI-AR-ICD-SE03-2020 (SSMO_SI_02), *TA Alignment Simulator (TAAS) to Science Instrument ICD* .			3.11.1			
3.11.13	SOFIA Science Instruments that make use of the SOFIA Vacuum Pump System (VPS) shall comply with the interface requirements of SOF-DA-ICD-SE03-2022 (VPS_SI_01), *SI to Aircraft Vacuum Pump* .			3.11.1			
3.11.14	SOFIA Science Instruments that utilize the Cryocooler System shall comply with the interface requirements of SOF-NASA-ICD-SE03-2066 (CRYO_SI_02), *Phase 2 Cryocooler System to Science Instrument ICD* .			3.11.1			
3.11.15	SOFIA Science Instruments shall comply with the software interface requirements of SOF-DA-ICD-SE03-052 (MCCS_SI_04), *MCCS to Science Instrument Software Interface (Functional)* .	**Notes:** MCCS provides command, control and data transfer functionality between SIs and SOFIA subsystems including the TA, DCS, SOFIA Command Language (SCL), etc. SE03-052 (MCCS_SI_04) is the ICD that defines the functional requirements for this SI interface. Further information re: SCL syntax and usage may be found within SOF-DA-MAN-OP02-2181, *SOFIA Command Language (SCL) User's Manual (SCLUM)* .		3.11.1			

APPENDIX A - Figures & Tables

	Ultimate Load Factors (Gs) for equipment mounted to:	
Direction	**Telescope Assembly**	**Cabin / Airframe**
Forward	9.0	9.0
Down	6.0	6.0
Up	3.0	3.0
Lateral	6.0	3.0
Aft	1.5	1.5
Note:	A Bearing or Fitting Factor not less than 1.15 is to be used on fastened joints and fittings where failure of one fastener, pin, or lug could result in loss of a component or any major portion thereof	

Table 3.5-1: Ultimate Load Factors for structural calculations (ref.: paragraph 3.5.2.1)

Load Condition	Primary structure material	Factor of Safety (FS)	Verification Methodology
Ultimate load factor	Metallic or Composite	N/A	Analysis only
Non-inertial limit loads	Metallic	2.250	Analysis only
Non-inertial limit loads	Composite	3.000	Analysis only
Non-inertial limit loads	Metallic or Composite	1.875	Proof load testing to 120% of flight limit loads
Non-inertial limit loads	Metallic or Composite (using well-established composite processes and materials)	1.500	Proof load testing to 100% of design limit load (DLL) in each of the various design cases with no yielding, and when subsequently loaded without failure to 150% DLL using the most critical load case
Note:	An additional Bearing or Fitting Factor not less than 1.15 is to be used on fastened joints and fittings where failure of one fastener, pin, or lug could result in loss of a component or any major portion thereof		

Table 3.5-2: Factor of Safety (ref.: paragraph 3.5.2.1)

	Pressure (psi)	
PVS Element	**Qualification**	**Acceptance**
LN2 Reservoirs	MNOP x 2.0	MNOP x 1.5 [Note 4]
LHe Reservoirs [Note 2]	P_{max} x 2.0	P_{max} x 1.5 [Note 4]
Vessels [Note 5]	MNOP x 3.0	MNOP x 1.5
Lines and Components [Note 3]	MNOP x 3.0	MNOP x 2.0
Flexible Lines [Note 3]	MNOP x 4.0	MNOP x 2.0
Pulse Tube Coolers [Note 6]	MNOP x 1.5 (600 psi)	MNOP x 1.0 (400 psi)

Notes:

1. MNOP = Maximum pressure which the pressurized hardware is expected to experience during its service life, in association with its applicable operating environments; or 14.7 psi + lowest relief valve cracking pressure for LN2 reservoirs.

2. P_{max} analysis result from Appendix C, *Simplified Method for Computing System Conceptual Design Maximum Pressure Due to a LOV Event* . is to be used only during conceptual / preliminary design phases to provide a conservative estimate; see Notes for ParID 3.5.3.3.1 re: methodology for refining P_{max} to establish applicable test pressure levels for LHe reservoirs.

3. Lines and components must undergo acceptance pressure testing if the qualification test is omitted and/or information within the Certifications of Conformance (CoC), relevant technical specifications, or test information is unsatisfactory to ensure product conformance with listed test requirements.

4. For cryogen reservoirs that are qualified using the Proto-Flight (PF) qualification approach (as defined in paragraph 3.5.3.3.1), the Proto-Flight Model (PFM) need not also undergo acceptance pressure testing; the qualification level pressure test is sufficient for both qualification of the design and acceptance of the PFM reservoir.

5. Pressure Vessels that are code stamped to National Consensus Codes and Standards (NCS), e.g., ASME, DOT, etc., do not need to be tested to Qualification or Acceptance levels prior to installation and service, as long as the application is within the rated service conditions.

6. Certification of Pulse Tube Coolers via this approach must be accompanied by a stress analysis of each of the pulse and regenerator tubes, showing positive Margins of Safety (MS) based on Cryocooler System MNOP of 400 psi and using the appropriate Factor of Safety (FS) value specified below for each tube diameter (ref. AIAA S-080-1998 Table 2):
   a. 4.0 if diameter < 38 mm (1.5 in)
   b. 2.5 if diameter ≥ 38 mm (1.5 in)

Pulse Tube rotary valves that are not integral to the cold head assembly are to be certified via the pressure testing prescribed for Lines and Components, and associated pressurized He flexible lines are to be certified via the pressure testing prescribed for Flexible Lines.

Table 3.5-3: Qualification and Acceptance pressure test levels for cryogen reservoirs, other pressure vessels, lines and components (ref.: paragraphs 3.5.3.3.1, 3.5.3.3.2)

SI Equipment Location	Applicable local grounding Interface Location
SI Assembly	SI assembly grounding lug / test point
CWR	CWR conductive structure
PI Rack(s)	PI Rack conductive structure

Table 3.5-4: Local electrical grounding interface locations for SI equipment (ref.: paragraph 3.5.4.2)

Figure 3.5-1: Example stamp for ASME Section VIII Division 1 pressure vessel (ref.: paragraph 3.5.3.5)

APPENDIX B - Open Issues

Open Issue #	SE01-2028 Paragraph	Action Plan	Actionee	Action ECD

TBD To Be Determined
TBR To Be Reviewed
TBS To Be Supplied

APPENDIX C - Simplified Method for Computing System Conceptual Design Maximum Pressure Due To A LOV Event

Appropriate care for personnel and aircraft safety requires careful cryostat design, especially as pertains to pressure relief. For those science instruments using liquid helium as a refrigerant, additional caution is required to ensure adequate venting in the event of a sudden loss of cryostat vacuum. Such an event produces a step increase in heat input to the tank and rapid helium boil-off. If the evolving helium gas can't exit via the vent stack quickly, in-tank pressures can rise to dangerous levels and a poorly designed system could suffer a catastrophic rupture. SIs must demonstrate the ability to accommodate a total heat flux of 4.0 W/cm^2 and the resulting pressure rise in the system due to a loss of vacuum event

To safeguard against this concern, the SOFIA Program requires analysis of proposed tank/vent system designs prior to the start of fabrication, and follows up with pressure testing of the hardware that is eventually built.

Pressure levels to be used in these tests will be calculated by SOFIA staff using a detailed numerical finite-element analysis using dimensional data provided by the SI team prior to the Critical Design Review. This analysis requires specialized software and expertise that is not likely to be available to SI teams, and thus can't be practically carried out in the early design phase of SI development.

The guidance below is intended to help SI developers to judge in advance whether their tank / vent design will ultimately pass muster against the finite-element model, while still in a relatively early stage in the development process. This guidance provides estimates only. It remains the responsibility of the SI team to ensure that the hardware fabricated can withstand the numerical model-prescribed test pressures, *including required safety margins* as indicated in the SOFIA Science Instrument System Specification, SOF-AR-SPE-SE01-2028, paragraph 3.5.3 and subparagraphs.

We include two tools for estimating P_{max} , the maximum pressure a tank/vent system might experience in an LOV event. When considering these two options keep in mind that the “One-line Estimate” approach presented in C.1, while based on real data run through the full up thermal desktop model, could result in lower – or even negative – design margin for the new SI when the full up model is run to support the CDR entrance criteria. Conversely, the “Simplified Iterative Analysis” approach presented in C.2 will provide a result that includes additional design margin and thus the selected design is perhaps more likely to pass the full up thermal desktop model at CDR.

C.1 One-line Estimate:

Based on examination of the existing suite of SOFIA science instruments, the predominant correlating factor in relation to the P_{max} value returned by the numerical model is the ratio of tank surface area (*At*) to vent neck tube cross sectional area (*An*). For each of the first-gen SIs, the P_{max} value returned by the detailed model can be approximated by:

$$P_{max} = 0.15*(At/An) + 208 \text{ (units of kPa)}$$

The simple estimate is plotted below, along with the existing test case results of the detailed model to show the quality of the linefit. We stress that *this simple expression provides an approximation only*, and designers are cautioned that if they are outside of or near the limits of the empirically-established range of *At/An*, or if their vent design follows a complex path through the instrument, the approximation might be quite rough. It should be adequate for a 'sanity check' analysis.

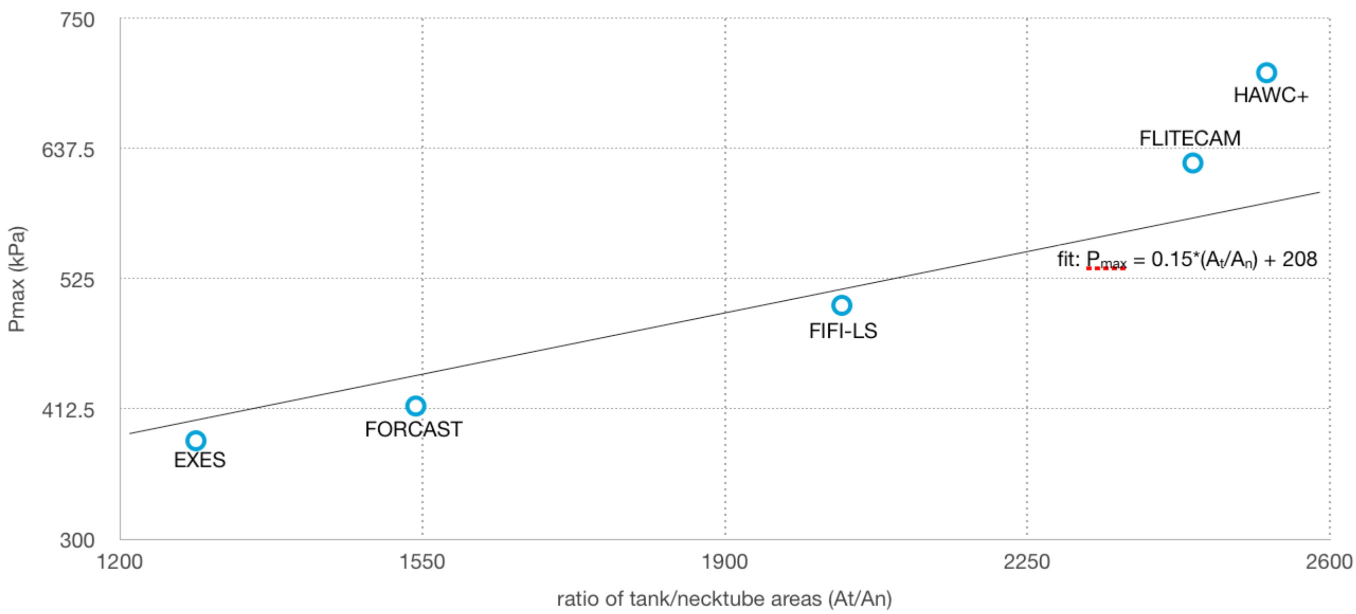

Figure C-1: Comparison of one-line estimate to existing SOFIA SI test cases

C.2 Simplified Iterative Analysis:

As designs mature, developers may consider use of an alternative analysis using a more involved tool, described below. This method is based on some of the methodology of the detailed numerical analysis, but uses ideal gas assumptions to simplify the calculation. We note that supercritical fluids near the critical point cannot be represented accurately as ideal gasses, so this method also yields only an approximation.

In this analysis dimensional data on a candidate design are gathered, and a series of guesses at P_{max} are evaluated iteratively pressures and approximates the heat input to the surface of the helium tank. At the end of each iteration the computed heat flux is compared to a limit of 4.0 W/cm^2. P_{max} is taken to be the lowest pressure estimate that yields a flux at or above this limit. The process is illustrated in a flow chart diagram is shown below with the specific detailed computations below the chart. A reasonable starting guess for P_{max} might be the result of the one-line estimate from C.1.

A step-by-step explanation of the calculation follows (ref. Figure C-2 for a flow chart representation of this iterative computation method):

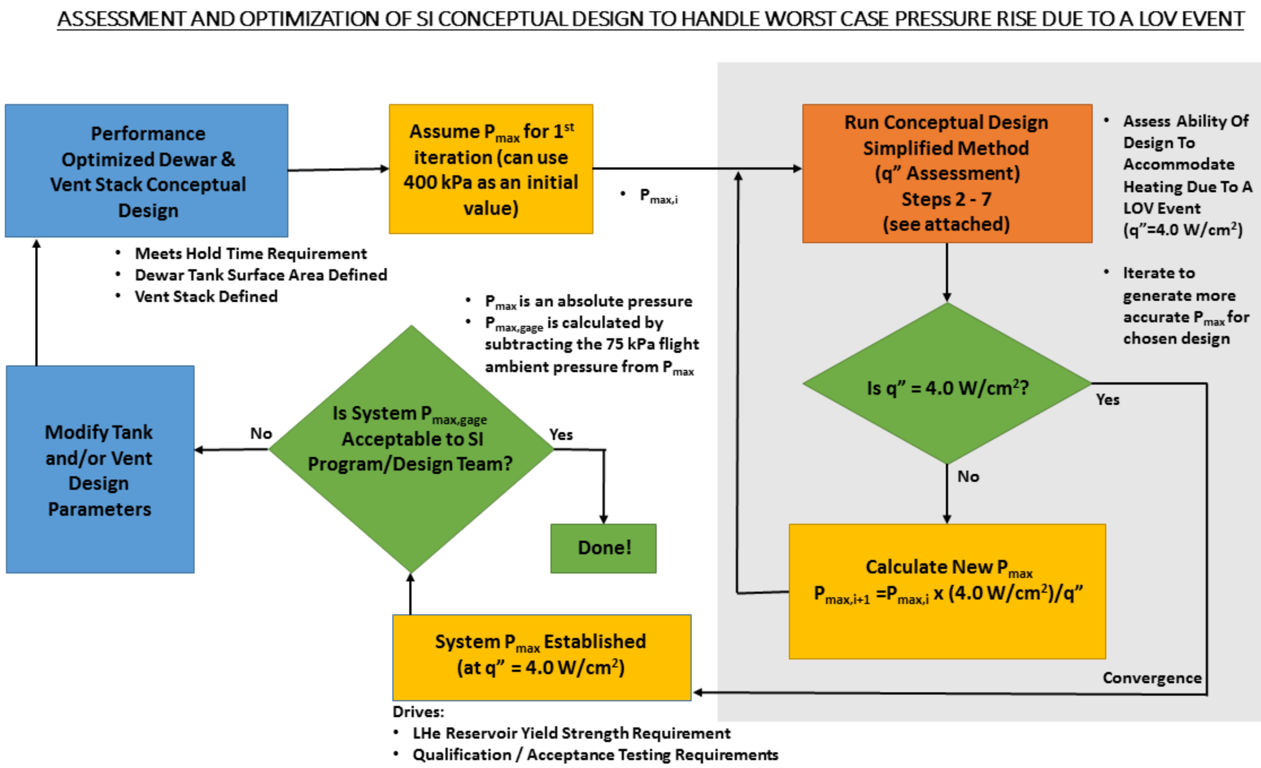

Figure C-2: Flow Chart for Assessment and Optimization of SI Conceptual Design to Handle Worst Case Pressure Rise Due to a LOV Event

1) **Choose a P_{max} for the first iteration (from C.1, or ~400 kPa)**

Note: This initial value is a nominal average from flown SOFIA SIs to date. Choosing this value as an initial guess should result in rapid convergence.

2) **Verify Acceptability of Vent Stack Geometry** for Simplified Method

2.1) Calculate the hydraulic diameter (d_{hyd}) for each section of the vent

For a circular tube, d_{hyd} = tube diameter
For a non-circular tube, d_{hyd}= 4 A_{CS}/p
where
A_{CS} is the Cross-Sectional Area (A_{CS}) (ref. Appendix C, 4.2)
p is wetted perimeter
Note: for an annular path, $d_{hyd} = (d_{outer\ diameter}^2 – d_{inner\ diameter}^2)/(d_{outer\ diameter} + d_{inner\ diameter})$

Note 1: Each section of the vent stack that has a unique equivalent hydraulic diameter, d_{hyd}, is calculated separately.

Note 2: The backup (or emergency) vent path is used in this analysis, the primary (or nominal) vent path is neglected (ref. ParID 3.5.3.2.1).

2.2) Calculate the equivalent length (l_e) of each section of the vent

Equivalent length (l_e)= Sum of equivalent length of each part [l_e=l_e(1) +l_e(2)+l_e(3)+...]
l_e(straight tube) = length of tube
l_e(elbow) = 20 * d_{hyd}(elbow)
l_e(tee) = 20 * d_{hyd}(tee)
l_e(bellow) = 2 * length of bellows

2.3) Calculate Diameter Ratio (l_e/d_{hyd}) of each section of the vent

2.4) Plot Diameter Ratio (l_e/d_{hyd}) and P_{max} on the chart shown as Figure C-3 to ensure that it is in the acceptable area for <u>each</u> vent section.

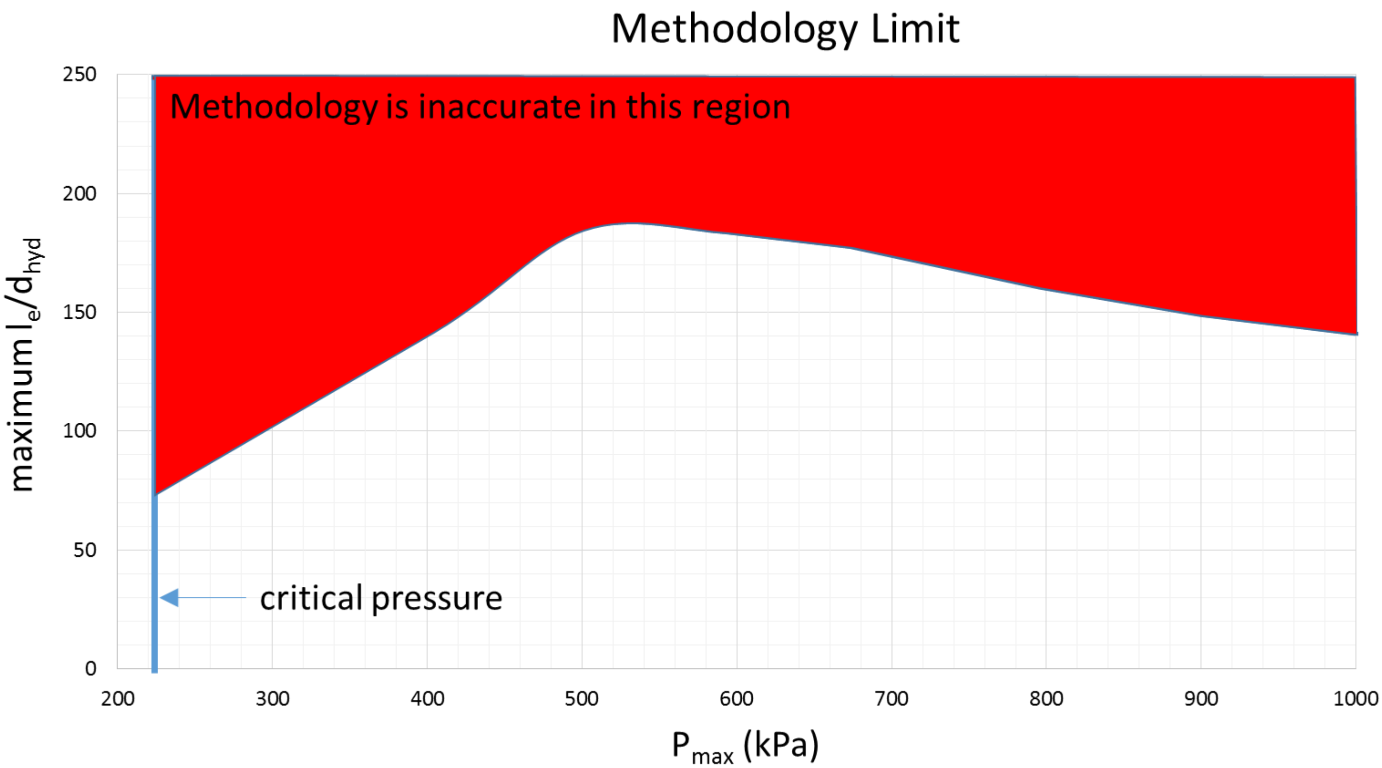

Figure C-3: Diameter Ratio vs. P_{max} Acceptable Region Chart

If any vent section falls outside acceptable area (i.e. red area right of blue line), redesign vent stack to decrease the diameter ratio. Then restart analysis from beginning.

3) **Determine Analysis Temperature (T) at Maximum Pressure (P_{max})**

$T = 7.2162E\text{-}09 * P_{max}^3 - 1.5782E\text{-}05 * P_{max}^2 + 1.5065E\text{-}02 * P_{max} + 2.5670$

where

P_{max} = Maximum Pressure (units are in kPa)

T = Temperature (units are in Kelvin (K))

4) **Determine the Limiting Equivalent Flow Area ($CC * A_{CS})_{min}$**

Since Contraction Coefficient (CC) and A_{CS} are the only variables that change from section to section of the vent stack, we can determine the limiting section by determining which CC * A_{CS} product is the lowest.

4.1) Determine the Contraction Coefficient (CC) for each section of the vent stack (ref. Figure C-4).

re-entrant, CC=0.75
flush entrance, CC=0.82
annular entrance, CC=0.91
orifice, CC=0.60
burst disk, CC=1.0

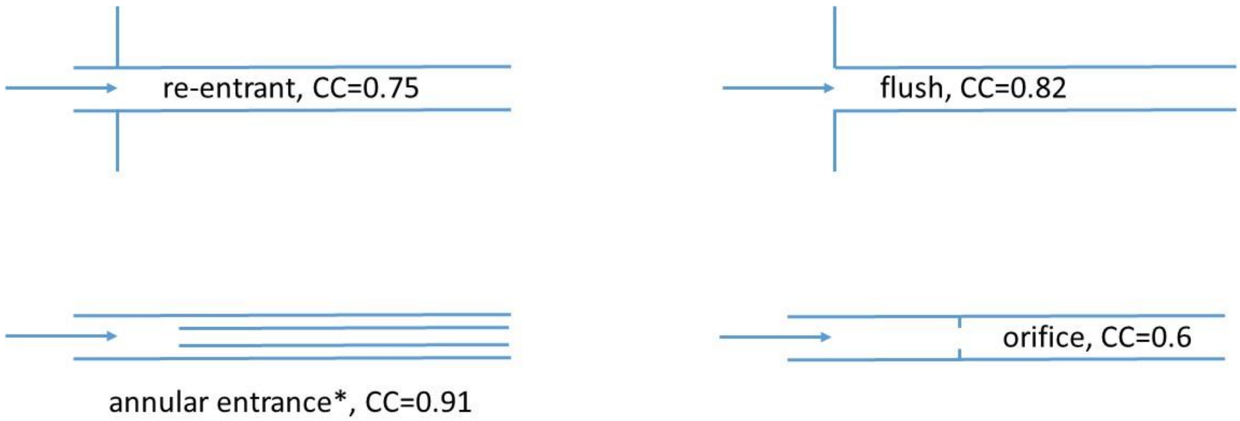

Figure C-4: Types of Neck Tube Entrance Configurations and Associated Values of Contraction Coefficient (CC)

4.2) Determine the Flow Cross-Sectional Area (A_{CS}) of each section of the vent stack.

A_{CS} = Flow Cross-Sectional Area (units in mm^2)

4.3) Determine which CC * A_{CS} is the minimum, $(CC * A_{CS})_{min}$.

5) **Determine the Mass Flow Rate ($\dot{m}$) at P_{max} and analysis T**

5.1) Determine Acoustic Velocity of the Helium (a)

$$a = \sqrt{\gamma\, RT}$$

where
γ = Ratio of Specific Heat for Helium = 1.67 (no units)
R = Ideal Gas Constant for Helium = 2077 J/kg K
T = Analysis Temperature at Maximum Pressure (P_{max}) (units are in K)
a = Acoustic Velocity of the Helium (units are in m/s)
Note: to get a into the correct units, multiply by 1 kg m^2/J s^2

5.2) Determine density of the Helium (ρ)

ρ = P/RT
where
P = Maximum Pressure, P_{max} (units in kPa)
R = Ideal Gas Constant for Helium = 2077 J/kg K
ρ = density of the Helium (units in kg/m^3)
Note: to get ρ into the correct units, multiply by 1000 N/m^2 kPa * 1 J/N m

5.3) Determine Mass Flow Rate ($\dot{m}$)

$\dot{m} = \rho * a * FC * (CC*A_{CS})_{min}$
where
ρ = density of the Helium = P/RT (kg/m^3)
a = Acoustic Velocity of the Helium $= \sqrt{\gamma\ \mathrm{RT}}$ (units are in m/s)
FC = Compressible Flow Coefficient for Helium = 0.562 (no units)
CC = Contraction Coefficient (no units)
A_{CS} = Equivalent Minimum Flow Cross-Sectional Area (units are in mm^2)
Note: to get $\dot{m}$ into the correct units, multiply by $1/1000^2$ m^2/mm^2
$\dot{m}$ = Mass Flow Rate (units are in kg/s)

6) **Calculate the Dewar Heat Load (Q)**

6.1) Calculate the Pseudo-Latent Heat (h^*_{fg}) at P_{max} and analysis T

$h^*_{fg} = -5.6218E-10*P_{max}^3 - 8.0722E-06*P_{max}^2 + 4.2593E-02*P_{max} + 4.8249$
where
P_{max} = Maximum Pressure (units are in kPa).
h^*_{fg} = Pseudo-Latent Heat (units are in kJ/kg)

6.2) Calculate the Dewar Heat Load (Q) for Mass Flow Rate

$Q = h^*_{fg} * \dot{m}$
where
h^*_{fg} = Pseudo-Latent Heat (units are in kJ/kg)
$\dot{m}$ = Mass Flow Rate (units are in kg/s)
Q = Dewar Heat Load (units in kW)

7) **Determine the Dewar Heat Flux (q'') at P_{max}**

7.1) Calculate the Dewar Heat Flux (q'')

$q'' = Q / A_{surface}$
where
Q = Dewar Heat Load (units in kW)

$A_{surface}$ = Dewar surface area (units are in cm^2). This is the surface area of the outside of the helium dewar.
q'' = Wall Heat Flux (units are in W/cm^2)
Note: to get q'' into the correct units, multiply by 1000 W/kW

8) **Update P_{max} if necessary**

8.1) If q'' = 4.0 W/cm^2 (i.e., 4.0 W/cm^2 < q'' < 4.05 W/cm^2), go to step 9

8.2) If $q'' \neq 4.0$ W/cm^2 (i.e., not within the range defined above in 8.1), adjust P_{max}

$$P_{max,new} = P_{max,old} \text{ x } \frac{4.0}{q''}$$

And return to step 2.4

9) **Determine if Dewar passes Design Requirement**

9.1) Calculate Maximum Gage Pressure

If P_{max} is less than 227 kPa, set it to 227 kPa, which is the lower limit of the simplified method.

$P_{max,gage} = P_{max} - 75$ kPa

Flight is the limiting case for the gage pressure. 75 kPa is flight ambient pressure.

10) **Assessment of $P_{max,gage}$ vs. Dewar Structural Capabilities**

If $P_{max,\ gage}$ is not within the expected chosen dewar structural limits or is otherwise unsatisfactory to the SI Program or SI design team, modify design.

Based on experience with first generation instruments, this iterative process may return P_{max} estimates that are ~25% higher than the detailed model provides, depending on design details. Using this more conservative P_{max} estimate will reduce the likelihood of surprises when the detailed model is run, at the potential expense of increased parasitic heat to be expected of more conservative designs. Designers are reminded that the SI must meet minimum hold time requirements, and that there are practical limits to how much LHe can be carried in the available SI volume.

Summary

The tools provided in this appendix are intended to help SI designers build safe science instruments that meet the necessary operational constraints of the SOFIA environment without unduly compromising instrument performance. Whether these tools are used or not, the eventual test pressure will be independently verified by the Airworthiness Team before the fabrication process begins.

Please contact the SOFIA Program for help with these calculations.

APPENDIX D - Glossary of Acronyms & Terms

Acronyms:

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
AIAA	American Institute of Aeronautics and Astronautics
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
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing & Materials
AUX	Auxiliary
AW	Airworthiness
AWS	American Welding Society
B703	Building 703 (AFRC)
C	Celsius
CA	California
CAD	Computer Aided Design
CAR	Corrective Action Request
CC	Contraction Coefficient
CCC	Closed-Cycle Cryocooler
CCR	Configuration Change Request
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
COTS	Commercial Off-The-Shelf
CPU	Central Processing Unit
CR	Commissioning Review
CSCI	Computer Software Configuration Item
CSI	Critical Safety Item
CWP	Counterweight Plate
CWR	Counterweight Rack
DAOF	Dryden Aircraft Operations Facility
dB	decibel
DC	Direct Current
DCP	Dryden Centerwide Procedure
DCS	Data Cycle System
DCT	Data Collection Time
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
EXES	Echelon-Cross-Echelle Spectrograph
F	Fahrenheit
FCLS	Focused Chopped Light Source
FEA	Finite Element Analysis
FFI	Fine Field Imager
FIFI-LS	Field-Imaging Far-Infrared Line Spectrometer
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 (SI)
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
GMIP	Government Mandatory Inspection Point
GPS	Global Positioning Subsystem
GREAT	German Receiver for Astronomy at Terahertz Frequencies (SI)
GS	Ground Safety
GSE	Ground Support Equipment
GTO	Guaranteed Time Observation
GUI	Graphical User Interface
GVPP	Gate Valve Pressure Plate
HAWC+	High-resolution Airborne Wideband Camera (2nd gen. SI upgrade)
He	Helium Gas
HF	High Frequency
HIL	Hardware-in-the-Loop
HIPO	High Speed Imaging Photometer for Occultations (SI)
HIRMES	HIgh Resolution Mid-infrarEd Spectrometer
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 (now Science Support Laboratory)
K	Kelvin
kHz	kilohertz
ksi	kilopound per square inch
kVA	kilovolt-ampere

kW	kilowatt
L3	L-3 Communications
LCHP	Large Chopped Hot Plate
LDEM	Lifting Devices & Equipment Manager
LFA	Low Frequency Array (GREAT SI)
LHe	Liquid Helium
LN2	Liquid Nitrogen
LOPA	Layout of Personnel Accommodations
LOS	Line Of Sight
LOV	Loss of Vacuum
LSP	Legacy Science Program
MA	Mission Assurance
MADS	Mission Audio Distribution System
MAN	MAN Technology
MCCS	Mission Controls and Communications System
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
NCS	National Consensus Codes and Standards
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
PF	Proto-Flight
PFM	Proto-Flight Model
PI	Principal Investigator
PIF	Pre-Flight Integration Facility
PIR	Pre-Install Review
PIS	Platform Interface System
P_{max}	Maximum Pressure in LHe reservoir resulting from a LOV event
PMP	Project Management Plan
PPBE	Planning, Programming, Budgeting, and Execution
PRD	Pressure Relief Device
PRV	Pressure Relief Valve
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 Vessels and Pressurized Systems
QA	Quality Assurance
Rev	Revision
RFA	Request for Action
RFI	Request for Information
RH	Research Hour
RMS	Root-Mean-Square
ROSES	Research Opportunities in Space and Earth Sciences
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
SCLUM	SCL User's Manual
SE&I	Systems Engineering & Integration
sec	Second
SED	Spectral Energy Distribution
SFH	Science Flight Hour
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
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
SSL	Science Support Laboratory (formerly Instrument Readiness Room)
SSMO	SOFIA Science and Mission Operations
SSP	SOFIA Science Project
SSWG	System Safety Working Group
STD	Standard
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

Terms:

Acceptance Tests	The required formal tests conducted on the flight hardware to ascertain that the materials, manufacturing processes, and workmanship meet specifications and that the hardware is acceptable for intended usage.
Flexible Lines	A non-rigid piping component excluding bellows expansion joints.
Maximum Normal Operating Pressure (MNOP)	Maximum pressure which the pressurized hardware is expected to experience during its service life, in association with its applicable operating environments. In the specific case of cryogen reservoirs, this pressure is generally set by the Pressure Relief Valve (PRV) with the lowest cracking pressure.
P_{max}	Maximum Pressure in LHe reservoir resulting from a LOV event
Qualification Tests	The required formal contractual tests used to demonstrate that the design, manufacturing, and assembly have resulted in hardware designs conforming to specification requirements.