National Aeronautics and Space Administration

OFFICE OF INSPECTOR GENERAL

SOFIA: NASA's Stratospheric Observatory for Infrared Astronomy

OFFICE OF AUDITS

AUDIT REPORT
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Acronyms

DLR	Deutsches Zentrum für Luft- und Raumfahrt
FOC	Full Operational Capability
FY	Fiscal Year
OIG	Office of Inspector General
SOFIA	Stratospheric Observatory for Infrared Astronomy
USRA	Universities Space Research Association

OVERVIEW

SOFIA: NASA'S STRATOSPHERIC OBSERVATORY FOR INFRARED ASTRONOMY

The Issue

In February 2014, NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) reached full operational capability (FOC) after a problematic 23-year development history and a cost of $1.1 billion – more than 300 percent over original estimates (see Figure 1).[1] The SOFIA Program's $3 billion life-cycle cost estimate, which includes a planned 20-year operational life and annual operating costs of approximately $80 million (equating to an annual operating cost of about $104,000 per planned research flight hour), makes it one of the most expensive programs in NASA's science portfolio.[2] While the Program achieved FOC ahead of schedule (per the latest replan) and SOFIA has recently begun to collect science data, maintaining user interest is critical to the Program's viability for the next 20 years.[3] More pressing for the Program is the uncertainty caused by the President's fiscal year (FY) 2015 budget proposal that would place SOFIA in storage for an undefined period unless NASA identifies partners to help subsidize operating costs.[4]

Figure 1. SOFIA in Flight

Source: NASA.

[1] NASA introduced the FOC milestone to represent SOFIA's transition to its operational phase and define the SOFIA Program's capability in terms of the number of operational instruments (four) and the science hours it is capable of performing. A second FOC milestone called FOC+4 represents a point in time 4 years after the Program achieves FOC. According to NASA, by FOC+4, SOFIA should support at least 40 research teams per year and achieve 960 research flight hours per year.

[2] Estimated annual operating cost / planned NASA annual research flight hours = annual operating cost per planned research flight hour ($80 million / 768 = $104,167). NASA operates the SOFIA Program in cooperation with a foreign partner – the Deutsches Zentrum für Luft- und Raumfahrt, the German Aerospace Center. Their planned flight hours and costs are not included in these figures.

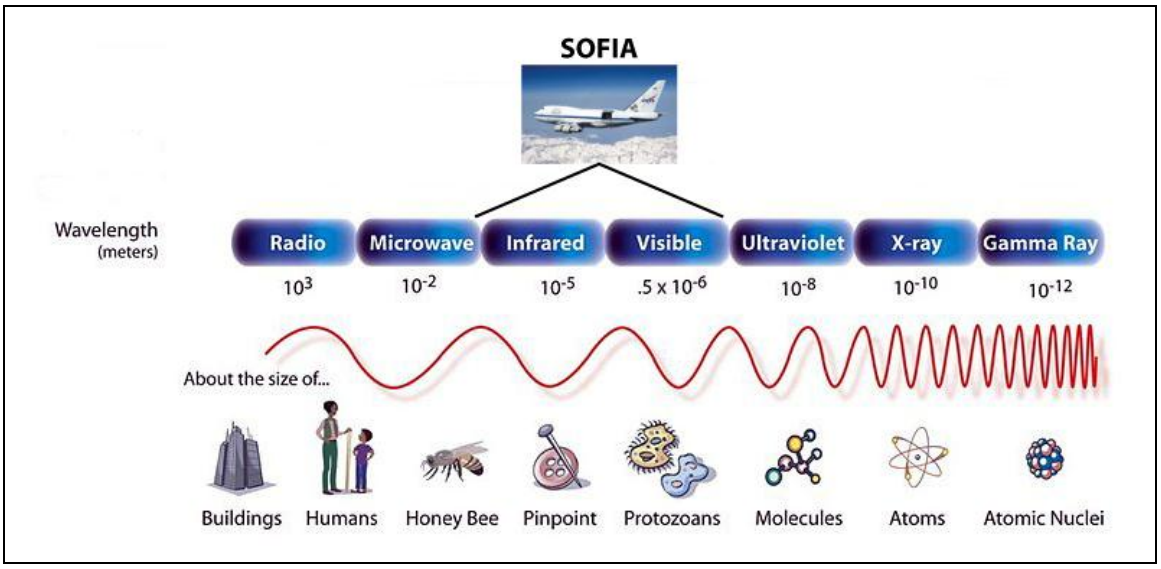
[3] In October 2010, NASA replanned the Program budget and schedule, establishing that FOC would be reached in December 2014 with estimated life-cycle costs of $3.016 billion.

[4] On May 30, 2014, the full House of Representatives approved a FY 2015 funding bill for NASA that provides $70 million to support SOFIA's fixed costs and a base level of scientific observation while NASA seeks partners to supplement the Program's funding. On June 5, 2014, the U.S. Senate Committee on Appropriations passed its version of NASA's FY 2015 spending bill, which included $87 million for the SOFIA Program.

SOFIA is the successor of NASA's Kuiper Airborne Observatory (Kuiper), which flew from 1974 to 1995.[5] Managed by the Science Mission Directorate's Astrophysics Division, the airborne observatory is fitted with a 2.7-meter (approximately 9-foot) telescope mounted onboard a Boeing 747SP that operators expose to the night sky through a uniquely designed cavity door located at the rear of the plane.[6]

NASA designed SOFIA to study the universe in the infrared region of the electromagnetic spectrum, and it can observe both infrared and visible wavelengths from 0.3 to 1,600 microns (see Figure 2).[7] The observatory is particularly well suited for investigating the formation of massive stars and the environment surrounding stars that leads to the formation of planets.

Figure 2. SOFIA's Coverage in the Electromagnetic Spectrum



Source: NASA Office of Inspector General presentation of SOFIA superimposed on NASA's electromagnetic spectrum diagram.

Compared to ground-based observatories, such as the Mauna Kea Observatories in Hawaii that sit about 14,000 feet above sea level, SOFIA can observe from altitudes exceeding 40,000 feet – above 99 percent of water vapor that interferes with ground-based infrared observations. However, unlike space-based observatories, such as NASA's Spitzer Space Telescope, SOFIA's science instruments are interchangeable after

[5] Kuiper was a modified C-141 aircraft and featured a reflecting telescope that was about three times smaller than the telescope installed on SOFIA. Kuiper flew more than 1,400 flights before NASA decommissioned the observatory in the fall of 1995 to make way for SOFIA.

[6] The Boeing 747SP, or "special performance," is a modified version of the Boeing 747 jet airliner. It has a shortened fuselage making it lighter thus permitting longer range and increased speed relative to other 747 configurations.

[7] A micron is a unit of length equal to one millionth of a meter, or 10^{-6} meter. Infrared region is in wavelength between 0.7 micron (7 ten-millionth of a meter, or 0.7 X 10^{-6} meter) and 1,000 micron (one millimeter, or 10^{-3} meter).

each mission.[8] NASA currently has five instruments fully commissioned and plans on commissioning two more by the end of 2015. In addition to its ability to observe a wide-range of the infrared spectrum, SOFIA is a mobile observatory capable of flying on short notice to any part of the globe to achieve optimal viewing of one-time events, such as passing comets. SOFIA can also incorporate newly developed instruments as well as upgrades to existing instruments with relative ease, allowing it to react quickly to advancements in technology.

Given SOFIA's troubled development history and projected $2 billion in operational costs over the next 20 years, we assessed whether NASA is adequately managing the Program to ensure long-term demand for and viability of the observatory. Our audit work included reviewing SOFIA Program policies and procedures, interviewing Program officials, and observing a science flight.[9] We also interviewed scientists who have used SOFIA to conduct research, as well as scientists whose proposals were not selected for a flight. Details of the audit's scope and methodology are in Appendix A.

Results

We found that despite substantial delays in reaching operational capacity, SOFIA remains capable of contributing to the scientific body of knowledge and many in the science community view the observatory as a valuable resource. However, we understand that the SOFIA Program is competing for limited resources and policymakers will have to decide whether other NASA projects are a higher scientific and budgetary priority. If the decision is made to continue the Program, we identified several challenges SOFIA will face going forward. For example, NASA needs to ensure a consistent infusion of new technology, revise the methodology for calculating researcher funding, and re-evaluate the number of research hours SOFIA can fly per year. In addition, we identified organizational and contractual issues that may make it difficult for the SOFIA Program to ensure adequate oversight of its contractor and achieve cost efficiencies. These issues are valid whether SOFIA continues to operate for the next 20 years or is stored and later reactivated.

SOFIA Managers Need to Address Several Issues to Ensure the Best Possible Return on Investment. Based on our analysis of SOFIA information and interviews with Program managers and the research community, we found that SOFIA is capable of adding to the scientific body of knowledge and many in the research community view the observatory as a valuable resource. However, we identified seven issues that could potentially reduce demand for the observatory and ultimately affect its long-term performance:

[8] Launched in August 2003, the Spitzer Space Telescope is an 85 centimeter, space-based infrared telescope studying objects in our solar system and the universe from 3 to 180 microns.

[9] One of the primary targets of the flight was the newly discovered supernova in the M-82 galaxy.

- *More Frequent Infusion of New Technology.* SOFIA's ability to update its technology is one of its unique advantages compared to other observatories, particularly space-based telescopes. This feature provides the observatory with the flexibility to improve its instruments and perform important science throughout its expected 20-year operational life. Accordingly, the Program must ensure frequent technology updates. However, the current funding profile provides for new technology updates approximately every 4 years instead of on a 2-year cycle, which some managers believe is more appropriate to ensure the Program maintains the research community's interest and participation.

- *Lack of a Formal Outreach Plan to Engage Science Community.* The Program does not have a formal plan to manage its scientific outreach efforts, and although it has made efforts to engage the science community, these efforts are ad-hoc and lack a formal mechanism to plan, track, and evaluate outreach activities. A formal outreach plan, similar to those employed by other NASA programs, could help ensure that Program management plans and budgets for a specific amount of outreach each year and monitors its efforts to ensure they are effective and cost efficient.

- *Insufficient Funding to Complete Research Projects.* SOFIA's methodology for calculating research funding results in awards that are not commensurate with the complexity and uniqueness of the observatory. NASA modeled SOFIA's research funding structure on the model used for the Spitzer Space Telescope Program, and all selected proposals receive funding at the same hourly rate. However, unlike Spitzer, SOFIA observations vary greatly in their complexity. Seven of eight science community members that received funding cited insufficient funding as an issue that may prevent them from completing the work necessary to analyze SOFIA-generated data and publish articles in peer-reviewed journals.

- *Lack of Timely Data.* The SOFIA Program has not met its schedule for delivering data products to researchers. The Program's latest "Call for Proposals" identifies a timetable for delivery for various levels of data. For example, as of January 2014, about 30 percent of collected data was not delivered to researchers within the prescribed timelines. Significant delays in data delivery could negatively impact the Program by frustrating the research community, delaying researchers from conducting follow-up investigations, and dissuading them from pursuing future observations.

- *No Formal Rescheduling Process for Cancelled Observations.* Similar to most major observatories, SOFIA has a relatively strict policy of not rescheduling missed observation flights caused by bad weather, aircraft mechanical issues, or other unforeseen circumstances. Nevertheless, the Program was able to reschedule several flights cancelled due to the October 2013 Federal Government shutdown. An ad-hoc team of scientists – assembled and led by the Program's Science Mission Operations Center Director – made the decision regarding which

flights to reschedule. While this process provided additional opportunities for some observations, we believe development of a formal process would help avoid the perception of preferential treatment when identifying and rescheduling missed flights.

- *Research Flight Hour Requirement May Not Provide Most Efficient Use of the Observatory.* In 1996, NASA established what it believed to be an efficient goal for observation time and based SOFIA's development on an annual operational requirement of 960 research flight hours for the observatory's 20-year lifetime.[10] Our assessment of the assumptions used to establish this requirement indicated the data is outdated, may no longer reflect the most efficient use of NASA resources, and should be reassessed when establishing operational performance expectations. For example, SOFIA is exceeding both its planned science flight hours per flight and the operational reliability percentage used in the original calculations – strong indications that SOFIA has the potential for completing more than 960 research flight hours per year. In light of SOFIA's annual operating cost of approximately $104,000 per planned research flight hour, NASA should establish an optimal operational requirement for observation time that is balanced between quality of science and other competing priorities – such as technology upgrades and researcher funding – to maximize use of the observatory.

- *Periodic Assessments Needed to Assess Cost Efficiency of SOFIA's Science.* The SOFIA Program has no formal process to review SOFIA's cost efficiency in terms of science return during its operations phase. Although SOFIA's Program Plan provides for biannual Program Implementation Reviews, these do not address the amount of "good science" the observatory has collected on a per-dollar basis nor do they compare SOFIA to other operating missions. NASA's Senior Review process occurs every two years and uses this metric for missions that have completed their primary mission requirements and are being considered for an extended mission. However, because of SOFIA's unusually long 20-year operational life cycle and relatively high operating costs, we suggest that NASA not wait to perform a "science per dollar" review similar to a Senior Review.

Organizational Structure May Not Provide Adequate Oversight of Mission Critical Functions. In conjunction with SOFIA's transition to its planned 20-year operational phase, NASA intends to reorganize the Program's management structure and, subsequently, its contract with Universities Space Research Association (USRA). However, the planned organizational structure does not provide adequate management and oversight of the Science Mission Operations Center, which is operated by a

[10] NASA plans for SOFIA to increase the number of flight hours over time and fly 960 research hours – in a typical operation year that does not include heavy maintenance tasks – in years FOC+4 and later.

contractor.[11] Additionally, the current contract does not provide mechanisms to ensure adequate NASA management and oversight of mission critical functions (such as ensuring that a civil servant direct and authorize the contractor's work) as defined by the Office of Federal Procurement Policy. Furthermore, NASA should consider alternatives to the current cost-plus-fixed-fee contract when the USRA contract expires in 2016. Proceeding into the operational phase with an organizational structure and contract type that does not provide management with the proper tools to manage USRA responsibilities may not be the most effective and cost efficient option for the Program going forward.

Uncertainty Surrounding SOFIA's Future Funding has Immediate Ramifications on the Program. The President's FY 2015 budget proposal for NASA would sharply reduce funding for SOFIA and place the observatory in storage unless partners help subsidize NASA's share of the Program's $80 million annual operating costs. In contrast, the full House of Representatives approved $70 million and the Senate Committee on Appropriations proposed $87 million for SOFIA in FY 2015. In this period of uncertainty, the Program must address a series of immediate challenges, including whether and how to plan for a Program shutdown and possible reactivation, how to retain key staff, and whether to move forward with planned research and maintenance activities.

Management Action

In order to ensure long-term demand for and viability of SOFIA if it continues in operation, we recommended the Associate Administrator for the Science Mission Directorate formulate an optimal plan for new instruments and technology and establish a timeline for SOFIA to enter the Senior Review process. We also recommended the Associate Administrator direct SOFIA Program managers to develop plans to conduct outreach to the scientific community, fund research projects based on complexity, and reduce the backload of observational data; implement a formal review process for rescheduling flights; reassess annual research flight hour requirements, the appropriateness of SOFIA's planned organizational restructuring, and the existing contract with USRA; and, in anticipation of the end of the current contract with USRA, consider whether a fixed-price contract would be more appropriate than the current cost-plus-fixed-fee contract.

In response to a draft of our report, the Associate Administrator concurred with our recommendations and proposed corrective actions. We consider the Associate Administrator's proposed corrective actions to be responsive to our recommendations and will close the recommendations upon completion and verification of those actions. We incorporated management's technical comments on our draft into the final report as appropriate and have reprinted the comments in full in Appendix C.

[11] The SOFIA Science Mission Operations Center, located at NASA's Ames Research Center, is responsible for coordinating research activities with the science community.

CONTENTS

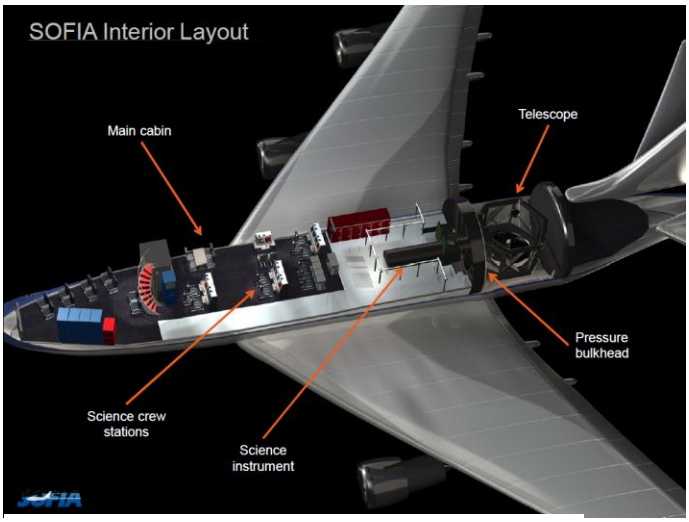
INTRODUCTION

Background

NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) is an airborne-observatory designed to study the universe in the infrared region of the electromagnetic spectrum. SOFIA facilitates research of diverse cosmic environments and collects data to advance understanding of the structure and evolution of the universe. The observatory is particularly well suited for investigating the formation of massive stars and the environment that leads to the formation of planets.

Built within the frame of a Boeing 747SP, SOFIA contains an internally mounted 2.7-meter (approximately 9-foot) telescope that operators expose to the night sky through a uniquely designed cavity door located at the rear of the plane (see Figure 3).[12]

Figure 3. Cutaway Showing SOFIA



Source: NASA.

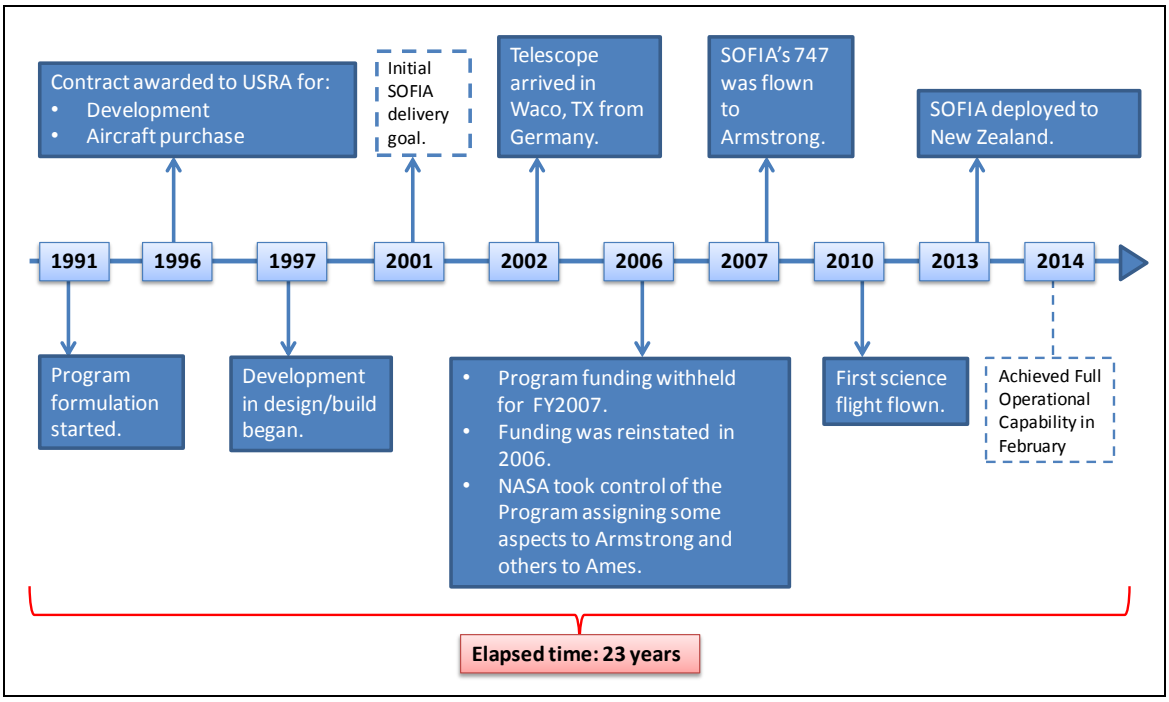
Relative to space and ground-based observatories, SOFIA is mobile and flexible. The observatory can be flown to any part of the world and achieve altitudes exceeding 40,000 feet, allowing SOFIA to avoid water vapor in the lower atmosphere that can interfere with infrared observations from even the highest-altitude ground-based observatories, such as Hawaii's Mauna Kea Observatories located about 14,000 feet above sea level. Moreover, unlike space-based telescopes, SOFIA returns to Earth after each mission enabling researchers to test new instruments and take advantage of new technology as it becomes available.

NASA's Science Mission Directorate manages the overall SOFIA Program from NASA Headquarters. NASA maintains and operates SOFIA from Armstrong Flight Research Center (Armstrong), while all of the Program's science operations, including the office that processes the data obtained during observations, are located at Ames Research Center (Ames).

[12] The Boeing 747SP, or "special performance," is a modified version of the Boeing 747 jet airliner. It has a shortened fuselage making it lighter thus permitting longer range and increased speed relative to other 747 configurations.

Development History. As illustrated in Figure 4, NASA spent more than 17 years developing SOFIA – 13 years longer than originally planned. The Program experienced significant cost increases and schedule delays during development that resulted in a rebaseline and replan, a major reorganization, geographic relocations, and multiple budget revisions before reaching full operational capability (FOC) in February 2014.

Figure 4. SOFIA Timeline



Note: Universities Space Research Association (USRA)

Source: Office of Inspector General analysis of the SOFIA Program timeline.

Annual operating costs for SOFIA are approximately $80 million, making it the second most expensive operating mission for NASA's Astrophysics Division after the Hubble Space Telescope (Hubble). NASA operates the SOFIA Program in cooperation with a foreign partner – the Deutsches Zentrum für Luft- und Raumfahrt (DLR), the German Aerospace Center. In December 1996, NASA and the DLR entered into a cooperative agreement pursuant to which the DLR received 20 percent of SOFIA observation time in exchange for providing the telescope assembly, aircraft engine upgrades, aircraft repainting, and two science instruments. Now that SOFIA is operational, DLR also provides mission support staff and covers fuel costs for German research flights and 20 percent of overall operating costs.[13]

Also in December 1996, NASA awarded a cost-plus-award-fee contract to Universities Space Research Association (USRA) under which USRA is responsible for all major aspects of the SOFIA Program, including management, development, implementation,

[13] In April 2006, NASA estimated the value of DLR's life-cycle contribution to SOFIA at approximately $323 million; however, the Agency does not have an updated figure.

and operation of the aircraft platform and science functions. The contract included both positive and negative performance incentives that rewarded USRA for being under budget or exceeding standard performance levels, but penalized the company in the event of cost overruns or failure to meet standard performance levels. USRA subcontracted tasks associated with modifying the Boeing 747SP to accommodate the telescope to L-3 Communications Corporation and maintenance of the plane to United Airlines.

As early as 1998 – about 2 years into development – the SOFIA Program began to experience schedule delays, and cost overruns were evident as early as 2000. In November 2004, an Independent Cost, Schedule, and Management Review found NASA lacked sufficient insight into Program development; overlaps among NASA, prime contractor, and subcontractor responsibilities; and a lack of cohesiveness in the systems engineering function. Soon thereafter, in February 2005, NASA issued a stop-work order on the contract due to aircraft maintenance mishaps and quality assurance issues. Work resumed in March 2005 after L-3 Communications Corporation replaced a subcontractor and NASA assumed oversight of the quality assurance process.

By 2006, the SOFIA Program had been in development for 10 years and was about 5 years behind schedule. Contract value for the USRA prime contract was approximately $528 million, or about $217 million over the original contract value. In February of that year, the President released a fiscal year (FY) 2007 budget that withheld funding from the Program and NASA formed an independent team to assess the Program's status and options for moving forward. Following issuance of the team's report, NASA reinstated the SOFIA Program with a reorganized management structure. Specifically, the Agency assumed control of observatory platform development and assigned science operations to Ames and responsibility for aircraft maintenance, quality assurance oversight, and systems engineering to Armstrong. In addition, NASA renegotiated the contract with USRA to cover only the science and operational aspects of the Program and directly contracted with L-3 Communications Corporation to finish development.

NASA rebaselined the SOFIA Program in July 2007, establishing a total life-cycle cost estimate of $2.95 billion – $955 million for formulation and development and $2 billion for 20 years of operations. At that time, the Agency estimated the observatory would reach FOC in December 2013. Pursuant to Program guidelines, FOC occurs when the observatory has four operating science instruments and is capable of conducting observations for 6 hours per flight.[14]

[14] A second FOC milestone called FOC+4 represents a point in time 4 years after the program achieves FOC. According to NASA Headquarters Level 1 requirements, by FOC+4 SOFIA should support at least 40 research teams per year and achieve 960 research flight hours per year. Level 1 requirements are fundamental requirements developed by senior Program management or NASA Headquarters.

In March 2009, the NASA Office of Inspector General (OIG) issued a report that found SOFIA Program management had not completed actions required to address long-term servicing needs of the aircraft, had not requested an independent cost estimate, and lacked an effective process to evaluate the Program's cost efficiency in meeting schedule milestones.[15] The Program implemented the OIG's recommendations for corrective action to address those findings.

Because of delays relating to the cavity door system, in October 2010, NASA increased development cost estimates for the Program to $1.1 billion and delayed FOC to December 2014. Although development costs have exceeded the FY 2007 rebaseline amount by approximately 20 percent, a decrease in expected operations costs have kept total life-cycle cost estimates at about $3 billion or within approximately 0.7 percent of the 2007 estimate.

Unique Capabilities. NASA designed SOFIA to test, use, and serve as a laboratory for a wide range of astronomical instruments – typically cameras and spectrographs – attached to the observatory's telescope.[16] Instruments can be switched out as the objective of each mission changes and, on average, the Program changes instruments every 2 weeks. This capability offers an advantage over space-based telescopes in that SOFIA can incorporate newly developed instruments as well as upgrades to existing instruments with relative ease, react quickly to advancements in technology and new science opportunities, and serve as a test bed for troubleshooting and experimentation. Moreover, its suite of instruments and ability to fly to specific locations at particular times enables SOFIA to execute observations, especially occultations, not possible or practical to conduct from other ground- and space-based observatories.[17] Moreover, unlike space-based observatories SOFIA can return to Earth to resupply cryogen stores when they run low.[18]

SOFIA's long operational life and ability to capture an extensive wavelength range are also unique in the area of infrared spectroscopy. As illustrated in Figure 5, SOFIA is designed to cover a wider range of wavelengths for a longer period than other existing or planned infrared observatories.

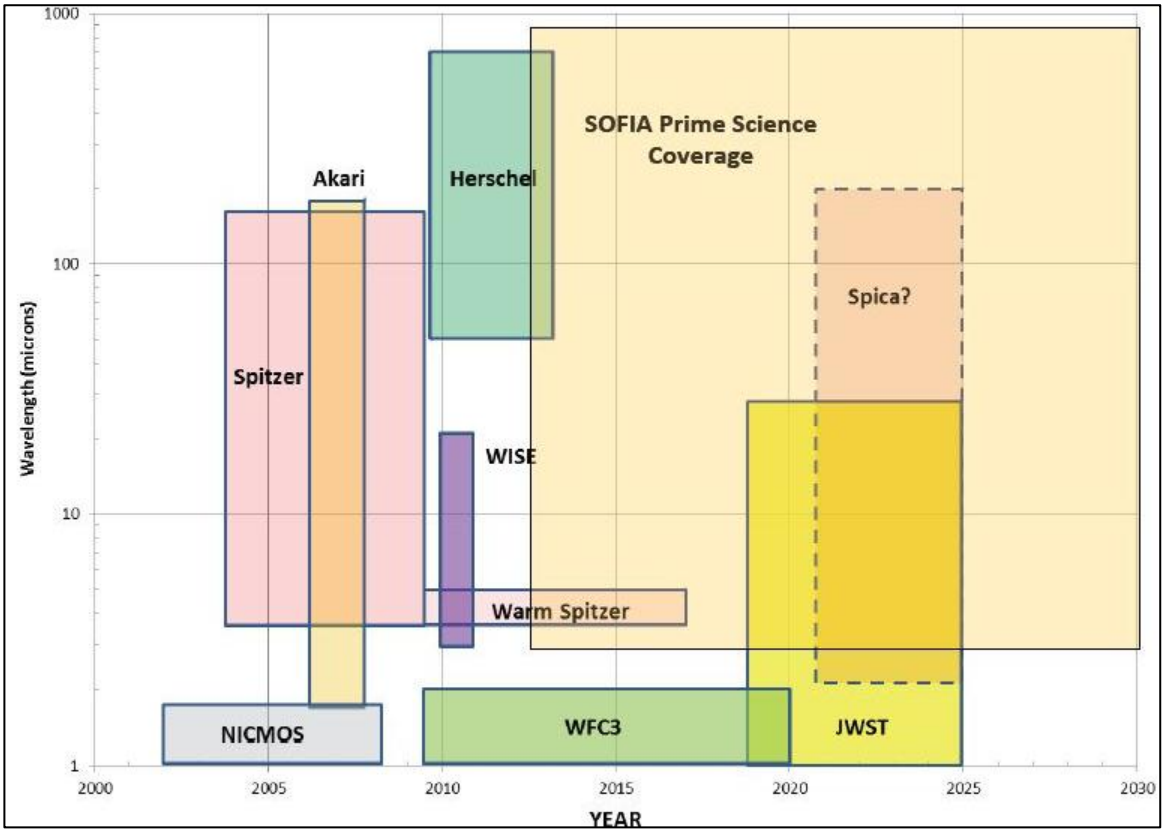
[15] NASA OIG, "Final Memorandum on Audit of the Stratospheric Observatory for Infrared Astronomy (SOFIA) Program Management Effectiveness" (IG-09-013, March 27, 2009).

[16] A spectrograph is an instrument used to disperse light waves into a spectrum for analysis.

[17] An occultation occurs when one object is hidden by another object that passes between it and the observer.

[18] Cryogen is a coolant used to make infrared detectors more sensitive to infrared radiation.

Figure 5. Wavelength Capabilities of Infrared Observatories



Note: NICMOS – Near Infrared Camera and Multi-Object Spectrometer installed on Hubble; WFC3 – Wide Field Camera 3 installed on Hubble; Akari – Japanese telescope whose name translates to "light;" WISE – NASA's Wide-field Infrared Survey Explorer; JWST – NASA's planned James Webb Space Telescope; Spica – Japan's planned Space Infrared Telescope for Cosmology and Astrophysics.

Source: NASA SOFIA Program management.

Observation Proposal and Selection. NASA's process for selecting researchers to use SOFIA begins when the SOFIA Project Scientist (NASA) and the SOFIA Mission Office Center Director (USRA) issue a joint "Call for Proposals."[19] In response, interested researchers submit a science justification, feasibility analysis, and high-level description of their proposed targets and the amount of observation time required. These documents are peer reviewed by a panel comprised of members of the astronomical community, and then the Science Mission Operations Center Director selects proposals that will be considered for scheduling.

Selected proposers provide the Director and the SOFIA instrument team detailed information relating to their planned observations and a budget summary with narrative descriptions. U.S. institutions and U.S. co-investigators on non-U.S. proposals are eligible for a NASA grant to help defray expenses. According to the latest Call for

[19] In coordination with the NASA process, DLR performs a separate selection for scientists affiliated with German institutions.

Proposals, preference is given to researchers who propose substantial investigations that show potential to demonstrate significant scientific impact.

Science Instrument Classifications and Data Rights. NASA planned a suite of seven research instruments for SOFIA, each with a different capability for varying types of observational targets. All of SOFIA's instruments undergo a commissioning process that entails multiple flights and testing to work out any problems before the Program makes them fully available to the scientific community. The data collected from these instruments is processed and refined using unique software developed by the SOFIA Program's Science Center at Ames. Ames provides the refined data to the researchers, which is generally accessible in a public database after a proprietary period of 12 months. NASA classifies SOFIA's instruments in three categories:

- *Facility-class instruments* are operated and maintained by Science Mission Operations staff at Ames to support research by general investigators.[20] The Program has commissioned two of three planned Facility-class instruments, with the final instrument planned for 2015.

- *Principal Investigator-class instruments* are developed and maintained by an instrument team who operate the instruments for their own use (i.e., as principal investigators). General investigators may also submit proposals to use these instruments. The Program has commissioned two of three planned Principal Investigator-class instruments, with the final instrument planned for 2014.

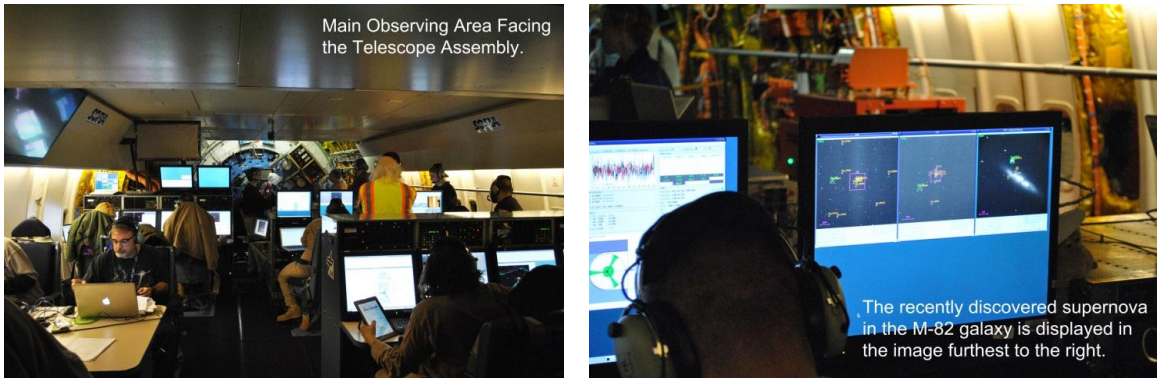
- The Program commissioned one *Special Purpose Principal Investigator-class instrument* in 2013. Special Purpose instruments are designed for observations not practical with the other two classes of instruments. The principal investigator team responsible for development will operate the instrument and accommodate general investigators with approved proposals.

See Appendix B for additional information on SOFIA's instruments.

Current Operational Status. The Program completed its FOC milestone requirements in February 2014 – 9 months ahead of the December 2014 date promised to Congress (see Figure 6). In meeting the FOC criteria, the Program commissioned four of the seven planned science instruments and commissioned the fifth in April 2014. The Program expects to commission the sixth and seventh instruments by the end of 2015.

[20] General investigators are researchers awarded observing time through SOFIA's peer-review process. They are not required to collaborate with the instrument team for Facility-class instruments but are generally required or encouraged to partner with the science instrument team of Principal Investigator-class or Special Purpose Principal Investigator-class instruments.

Figure 6. SOFIA in Operations



Source: OIG flight observation on February 24, 2014.

By March 2014, the Program had completed its first cycle of science observations and was in the middle of its second cycle. Each observation cycle corresponds to a calendar year. During each of the past 2 years, research demand has outstripped SOFIA's capacity.

In 2013 (Observation Cycle-1), the Program completed 25 flights and 175 research flight hours. For that cycle, NASA received research proposals that would have required six times the number of available hours. In 2014 (Observation Cycle-2), the Program has 25 flights and 206 research flight hours planned. For that cycle, proposals surpassed available research hours by a factor of three.

President's 2015 Budget Proposal. On March 4, 2014, the President released his FY 2015 budget and proposed placing SOFIA into storage unless NASA identifies partners to subsidize the observatory's estimated $80 million per year operating costs. The budget submission offered the following explanation for the proposal:

> Due to its high annual operating cost, the Administration greatly reduces funding for the . . . SOFIA project. SOFIA has encountered technical and schedule challenges, and while the observatory will address emerging scientific questions, its contributions to astronomical science will be significantly less than originally envisioned. Funding for SOFIA, which costs almost $80 million per year to operate, can have a larger impact supporting other science missions.

According to senior officials in NASA's Science Mission Directorate and the Office of the Chief Financial Officer, the decision to reduce funding for SOFIA was made because of cuts to the Astrophysics Division budget that resulted in the Directorate prioritizing other science projects ahead of SOFIA. They further explained that Office of Management and Budget direction regarding implementation of proposed reductions in NASA's overall budget was to apply the cuts to a smaller number of lower-priority programs rather than spreading the cuts across a larger number of projects. According to these officials, the $12.3 million funding proposed by the President for FY 2015 is a rough estimate of the cost of labor for that year.

However, the future of the SOFIA Program remains uncertain as the annual appropriations process moves forward. On May 30, 2014, the House of Representatives approved a FY 2015 funding bill for NASA that provides $70 million to support SOFIA's fixed costs as well as a "base level of scientific observation" while NASA seeks partners to supplement the observatory's funding and restore the Program budget to full operational level.[21] In doing so, the House Appropriations Committee expressed the opinion that the observatory is "currently producing good science" and noted that it has not been proposed for termination by NASA's "internal or external scientific review boards." On June 5, 2014, the U.S. Senate Committee on Appropriations passed its version of NASA's FY 2015 spending bill, which included $87 million for the SOFIA Program.[22] In addition, on June 9, 2014, the full House of Representatives passed its version of the 2014 NASA Authorization Act that included language added by the House of Representatives Committee on Science, Space, and Technology that would prohibit NASA from using FY 2014 funds to begin shutting down the SOFIA Program.[23] At the same time, NASA continues to seek partners to share operating costs.

Objectives

Given SOFIA's troubled development history and projected $2 billion in operational costs over the next 20 years, we assessed whether NASA is adequately managing the Program to ensure long-term demand for and viability of the observatory. Our audit work included reviewing Program policies and procedures, interviewing Program officials, and observing a science flight.[24] We also interviewed scientists who have used SOFIA to conduct research, as well as scientists whose proposals were not selected for a flight. See Appendix A for details of the review's scope and methodology, our review of internal controls, and a list of prior coverage.

[21] House of Representatives Committee on Appropriations, "Report on Commerce, Justice, Science, and Related Agencies Appropriations Bill, 2015," May 15, 2014.

[22] Senate Committee on Appropriations, "Report on Departments of Commerce and Justice, and Science, and Related Agencies Appropriations Bill, 2015," June 5, 2015.

[23] House of Representatives Committee on Science, Space, and Technology, "National Aeronautics and Space Administration Authorization Act of 2014, Amendment 02," April 28, 2014.

[24] One of the primary targets of the flight was the newly discovered supernova in the M-82 galaxy.

IF CONTINUED, THE SOFIA PROGRAM FACES CHALLENGES TO ENSURE THE BEST POSSIBLE RETURN ON INVESTMENT

We found that despite substantial delays in reaching operational capacity, SOFIA remains capable of contributing to the body of scientific knowledge and many researchers view the observatory as a valuable resource. However, we understand that the SOFIA Program is competing for limited resources and that policymakers will have to decide whether other NASA projects are a higher scientific and budgetary priority. If the decision is made to continue the Program, we identified several challenges going forward. First, the Program must take steps to ensure that demand for the observatory, particularly from top-tier researchers, continues over SOFIA's planned 20-year life. Second, from a volume of research perspective, SOFIA's Level 1 requirement of 960 annual research hours may be too modest. Finally, the Program lacks procedures to assess science return per dollar invested. Failure by NASA to address these issues could reduce demand for the observatory and affect the quality of its science.

SOFIA's Contributions to Science

We found that despite the 13-year delay in reaching FOC, the science community remains interested in utilizing SOFIA. Although some researchers expressed frustration with the delay, the majority were impressed with the science SOFIA produced and were looking forward to future enhancements. As of May 2014, 45 research papers discussing data collected aboard SOFIA have been published in peer-reviewed journals, including an issue of *The Astrophysical Journal Letters* that featured eight such articles.[25]

Researchers stated that although development delays caused SOFIA to miss opportunities to collaborate with the Hershel and Spitzer observatories, the telescope is still capable of performing observations that build on the work of those observatories. Researchers also told us SOFIA can make observations at wavelengths not covered by the James Webb Space Telescope and that although one of SOFIA's instruments – the Echelon Cross Echelle Spectrograph – was designed to perform observations within Webb's wavelength, SOFIA will do so with a much greater ability to separate wavelengths.

[25] See *The Astrophysical Journal Letters*, 749:2, April 20, 2012, at http://iopscience.iop.org/2041-8205/749/2 (accessed May 8, 2014).

SOFIA Faces Operational Challenges That May Affect the Quality of Science Produced and its Long-Term Viability

During the course of our audit, we identified five concerns regarding SOFIA's long-term outlook: (1) consistent incorporation of new technology into the observatory's suite of instruments; (2) formal and measurable outreach to the scientific community; (3) grant awards that may not be commensurate with the complexity and uniqueness of the observatory; (4) timely availability of observation data; and (5) lack of a formal process for rescheduling cancelled observations. We discuss each of these issues below.

Introduction of New Technology May Be Too Infrequent. SOFIA can observe targets at a range of wavelengths and resolutions attainable by space telescopes; however, unlike space telescopes, SOFIA can be modified relatively easily to add new instruments or accommodate technological upgrades. Indeed, the ability to update SOFIA's technical capabilities is one of the Program's primary advantages and an important justification for its relatively high operating cost. Moreover, we found that current and potential users of SOFIA believe technology updates are vital to its success. We surveyed 18 members of the astronomical community and they identified introduction of new technology as the most important factor in ensuring SOFIA's long-term relevance and success.[26]

NASA plans to introduce technology upgrades for SOFIA on an ongoing basis throughout its operational life. These upgrades can be in the form of a new instrument that offers a completely different capability, a new version of an existing instrument, or the addition of a new feature to an existing instrument. For example, currently under development is an upgraded version of SOFIA's High-resolution Airborne Wideband Camera, which will have the ability to measure magnetic fields in star-forming clouds and galaxies. The Science Mission Directorate is responsible for selecting which instruments to upgrade and allocating required funds. Directorate officials told us they plan to introduce at least one new or revised instrument to SOFIA's research suite approximately every 4 years depending on available budget

However, SOFIA's Science Project team, which is responsible for instrument development and implementation, told us that based on their interactions with the research community they believe new technology should be introduced into SOFIA's instruments suite approximately every 2 years.[27] They believe a 2-year cycle would enhance opportunities to achieve new discovery-level science during observations and therefore encourage greater researcher participation. In addition to the lack of agreement regarding the rate of introducing new technology, we also found that the Program does not have a concrete plan that describes a schedule for implementing new technology or identifying the desired technology upgrade.

[26] Our survey population included principal investigators, general investigators, and archival researchers.

[27] SOFIA Program management is divided into a Science Project team located at Ames and a Platform Project team located at Armstrong. The Science Project team coordinates science mission execution and instrument development while the Platform Project team manages and maintains the airplane and associated systems.

The lack of agreement and a clear path forward on new technology infusion could jeopardize SOFIA's ability to perform cutting-edge science and sustain its planned 20-year operational life. As noted above, the user community believes technological adaptability is the most important factor to SOFIA's success. Accordingly, NASA should establish a clear plan for technology upgrades that reassures the user community that SOFIA will continue to provide opportunities to perform discovery-level science.

The Program Does Not Have a Formal Plan to Facilitate and Ensure Effectiveness of Outreach Efforts. Conducting effective and thorough outreach to the science community is vital to SOFIA's long-term success. However, we found that the SOFIA Program has no formal plan to manage its scientific outreach efforts although it has a formal outreach plan for other types of users and has made some efforts to reach out to the scientific community.[28] This contrasts with other science programs, such as in NASA's Earth Science Division, which have formal outreach plans.

According to Program officials, SOFIA's Science Mission Operations Director and other SOFIA staff members meet informally to determine which scientific outreach activities the Program will pursue. Examples of activities in which the Program has engaged include presentations at American Astronomical Society meetings, teleconferences featuring astronomers familiar with SOFIA, and talks at major U.S. research universities. However, the Program does not have a formal plan that specifies which activities the Program is required to perform for the science community. The presence of a formal outreach plan aimed at the science community – the end-users of the observatory – could help ensure the Program plans and budgets for a specific amount of outreach each year and help it track and monitor its outreach efforts to ensure they are effective and cost efficient.[29]

Funding May Not Be Sufficient for Researchers to Complete Projects. Similar to other NASA observatory programs, the SOFIA Program awards grants to researchers whose proposals it selects. For each selected proposal, the Program provides $2,000 to assist in developing an observation plan and an additional $3,000 per awarded research hour. Although some researchers receive outside support in the form of a salary or other funding from sources such as the National Science Foundation, others rely solely on the funding provided by the Program to execute their proposals. Typically, researchers use the NASA grants to hire graduate students to assist with data analysis and pay for travel and other expenses associated with conducting and publishing their research. We found that NASA's current funding level may not be adequate to enable some researchers to complete their work and that the methodology the Program uses to determine award amounts may not reflect the cost and effort associated with SOFIA's unique capabilities and instruments.

[28] In addition to conducting science, the SOFIA Program has an Airborne Astronomy Ambassadors Program that targets teachers and students.

[29] For example, the Program could track such metrics as the number of proposals submitted as a direct result of a particular outreach activity or attendance at events.

Seven of eight researchers we spoke with who had received funding from the Program stated their awards were insufficient to enable them to complete their research. Moreover, by paying the same hourly rate for all proposals the Program's funding formula does not adequately consider the varying levels of effort required to complete different research projects. For example, the Program pays the same hourly rate irrespective of whether the research requires a handful of images or hundreds of images. According to Program managers, they modeled SOFIA's funding formula after the formula used for the Spitzer Space Telescope; however, unlike Spitzer, SOFIA has a multi-instrument suite with varying functionality and capabilities. Accordingly, a funding mechanism that considers the unique aspects and level of effort required on each specific proposal may better ensure that researchers have sufficient funding to complete their projects and publish their findings.

The Program Has Not Fully Met its Data Product Delivery Goals. Data collected during observations is SOFIA's primary output and the information researchers will use to publish papers and add to the body of astronomical knowledge. However, the raw data SOFIA collects needs to be processed and refined before researchers can analyze it. For example, some of the instruments produce data formatted in instrument-specific code that contains superfluous information resulting from instrument attributes and "noise" from cosmic rays or other sources that are not the focus of the research. The process of removing this superfluous information and refining the data is complex and, in many cases, time consuming. In general, contractor staff at Ames is responsible for processing and refining the data.[30] Once processed, the staff distributes the data to the appropriate researchers via SOFIA's online archive. After a period of 12 months, the data is accessible by the general scientific community and the public. The archived data is expected to be refined and processed to the point where a researcher can download a dataset, conduct the analysis, and publish the results.

Although the Program has made some progress in timely delivering observational data to researchers, we found a backlog of data from the previous 10 months waiting to be processed. According to Program officials, as of January 2014, about 30 percent of collected data was not delivered to researchers within the timeframes set by the Program. SOFIA's 2013 Call for Proposals provides the following data delivery goals: Level 1 data will be provided to principal investigators within 24 hours; Level 2 data will be placed in the SOFIA archive within 2 weeks of completion of a flight series; and Level 3 data will be placed in the archive within 4 weeks of completion of a flight series.[31] Program officials told us they have not been able to deliver some data sets in accordance with this timetable because they have yet to resolve technical challenges associated with data calibration.

[30] For non-U.S. Principal Investigator-class instruments, the instrument team is responsible for processing the data.

[31] Level 1 – raw data as provided by SOFIA instruments converted to a standard format. Level 2 – data that is corrected for instrument artifacts (e.g., bad pixels removed). Level 3 – data that is calibrated and made available to the science community in the SOFIA archive.

As SOFIA continues to operate and the observatory platform becomes more functional, the Program will execute more observations and flight hours and the increasing data volume may further delay data delivery. Significant delays could frustrate researchers, delay follow-up investigations, dissuade researchers from proposing future observations, and result in lessened support for the Program in the research community.

The Program Lacks a Formal Procedure for Rescheduling Canceled Flights. Consistent with the practice of most other observatories, current SOFIA Program policy does not allow for rescheduling of observations cancelled due to bad weather, aircraft or instrument technical issues, or other unforeseen circumstances. However, because of SOFIA's flexible maintenance schedule and because the Program already sets aside time to observe newly discovered comets or other objects, Program managers have found they are sometimes able to reschedule missed flights. When possible, Program managers reschedule observations deemed to have a strong probability of collecting cutting-edge science or that need only one additional observation to complete. For example, the Program intends to reschedule several missed flights likely to conduct "good" science cancelled because of the Federal Government shutdown in October 2013.[32] Currently, an ad-hoc team of scientists – assembled and led by the Program's Science Mission Operations Center Director – makes decisions about rescheduling observations, and the Program has no formal methodology that ensures consistency and objectivity in making these decisions. We believe development of a formal process would help avoid preferential treatment or the appearance of such treatment in the rescheduling selection process.

Requirement of 960 Annual Research Flight Hours May Not Provide Most Efficient Use of the Observatory

Evolution of the Annual Operations Requirement. In 1994, when NASA managers first established SOFIA's Level 1 requirements, they set 160 science-producing research flights per year as the initial measure of operational capability but did not specify the number of research hours expected on each flight. In 1996, NASA changed the expectation to an annual hourly requirement of 960 research hours based on 160 flights with 6 research hours per flight.[33] Although this requirement has not changed since 1996, some of the underlying assumptions have, necessitating an assessment to determine whether NASA should increase or decrease the requirement to establish an efficient operating baseline for SOFIA as it enters its operations phase.

[32] The Program's Science Operations team determines the quality of science.

[33] Total flight time, which is currently approximately 10 hours per flight, differs from research flight time because some flight time is needed for taking-off, landing, course adjustments, target acquisition, and instrument or telescope calibration. The 960-hour target applies to years after FOC+4. Before that date, NASA anticipates SOFIA will fly fewer hours due to increased maintenance needs as it builds toward the 960-hour goal.

NASA currently supports the 960-research hour requirement with the following six assumptions:

1. *SOFIA will not fly for three 1-month periods in a typical year.* This is an operational constraint for periodic maintenance of the Boeing 747SP aircraft and observatory systems upgrades.

2. *Research flights will be planned for 4 days per week.* This is a financial constraint based on the cost of having multiple maintenance and operations support crew to support additional flights each week.

3. *The observatory will execute 91 percent of its scheduled flights.* This is an assumed rate for the likelihood that weather or unexpected mechanical problems will prevent flight.

4. *Each flight will yield 8 research hours.* This is an assumption of the actual hours the plane will be at the correct altitude and otherwise ready to conduct research.

5. *Observatory systems are 89 percent reliable.* This is a probability factor derived from the aircraft industry's experience with similar aircraft and includes reliability data from systems similar to those aboard SOFIA. NASA applied the rate to systems design and development requirements for instruments, telescope, and other payload systems.

6. *Fifty-one hours allocated to margin* to allow for unexpected problems.

We summarize NASA's calculation of the 960-hour requirement in the table below.

Table. Basis for 960 Flight Research Hour Requirement

Assumption	Adjustment	Net Availability
Weeks per year	n/a	52 weeks
Maintenance and upgrade time	13 weeks *(52 weeks x 25 percent*)	39 weeks
Flights per week	4 flights per week (*39 weeks x 4 days/week*)	156 flights
Availability factor	91 percent (*156 flights x 0.91*)	142 flights
Research hours per flight	8 hours per flight (*142 flights x 8 hours*)	1,136 hours
Reliability factor	89 percent (*1,137 hours x 0.89*)	1,011 hours
Margin	51 hours (*1,011 hours – 51 hours*)	960 hours[a]

[a] The operational baseline at which SOFIA was developed to perform within established resource constraints is 960 hours. The actual hours per year SOFIA is scheduled to fly varies depending on maintenance requirements and upgrade plans.

Source: NASA OIG evaluation of Program material.

Requirement Assumptions Not Based on Current Data. NASA has not updated the assumptions used to derive the annual 960-hour requirement to reflect SOFIA's actual performance. We found that performance data indicates SOFIA is likely to exceed some of the assumptions on which the requirement is based and therefore may have the capability to exceed the requirement.

Operations Project management expects to reduce the amount of time required for periodic maintenance. NASA assumed 13 weeks for maintenance and upgrades. For purposes of this assumption, maintenance includes required and recommended maintenance, modifications and enhancements, aircraft discrepancies, special inspections, and addressing unexpected issues.[34] Telescope maintenance, such as mirror recoating, will also be performed during this time. Operations Project management told us that 13 weeks was sufficient for them to complete all required tasks. They also pointed out that the assumption was based on performance metrics for commercial crews working on multiple aircraft. However, the SOFIA maintenance crew will work only on the observatory and therefore managers expect the crew to become more efficient over time allowing them to reduce the length of maintenance periods.

Actual flights indicate the Program can accomplish more than 8 research hours per flight. Over the span of Cycle 1 and Cycle 2 flights, the SOFIA Program has collected detailed performance data that reflects an average of 8.4 viable research hours per flight. The Program expects this figure to increase as staff builds knowledge and expertise in operating SOFIA's systems.

The 91 percent factor to account for weather and unexpected mechanical problems does not appear applicable to SOFIA's actual operational environment. NASA developed this factor before deciding SOFIA would operate out of the desert environment of Palmdale, California. Operations Project management indicated that weather events that would prevent a flight are not a significant concern at the Palmdale airport. Moreover, although it is possible that weather could affect flight paths, preflight planning would most likely mitigate this risk. In addition, the risk of unexpected mechanical problems appears to be accounted for in the Program's maintenance and reliability assumptions.

The Program is likely to surpass the 89 percent reliability factor. NASA based this rate on a 1998 study that used commercial aircraft metrics to establish a combined reliability target of all SOFIA components.[35] Operations Project management stated that they are on target to meet this goal and are confident that SOFIA will exceed it as systems mature. To support their contention, they noted NASA included this reliability goal in the design of the aircraft components and that SOFIA's systems and subsystems are performing better than expected, made of high-quality components that exceed commercial grade

[34] The observatory also requires significant maintenance every 5 to 7 years, time that is not accounted for in the 13 weeks. Rather, NASA adjusts the 960-hour requirement downward during heavy maintenance years.

[35] Raytheon Corporation, "Allocation of Requirements for Reliability, Availability & Maintainability to the SOFIA System," February 1998.

specifications, and subject to an increase in overall reliability as maintenance and support crews gain knowledge of the aircraft's systems and subsystems.

The margin applied does not appear to be necessary. Generally, margin allows programs and projects flexibility to address unknown and unexpected problems. However, there does not appear to be a need to apply a margin factor to SOFIA's operational performance because some of the other assumptions have a built-in margin. For example, the maintenance period includes time for unknown problems and the reliability factor addresses unexpected issues.

Based on our assessment of NASA's assumptions, as well as discussions with SOFIA Program staff regarding actual observatory performance, it appears the Program is capable of more than 960 research flight hours per year. Given an estimated life-cycle cost of approximately $209,000 per planned research flight hour (annual operating costs of about $104,000 per planned research flight hour), establishing an optimal operational requirement for observation time that is properly balanced with quality of science and other competing priorities – such as technology upgrades, outreach activities, and researcher funding – is key to maximizing use of the observatory.[36]

The Program Lacks Procedures to Assess Science Return Output Over SOFIA's 20-Year Expected Life

Typically, NASA does not assess programs and projects for return on investment during their operations phase, but rather when they have completed their prime mission and are seeking to continue operating beyond that point (known as extended operations). However, with a planned operating life of 20 years and relatively high life-cycle operating costs of $1.9 billion, SOFIA is not a typical NASA program. For example, Spitzer had a planned operational life of 2.5 to 5 years and budgeted operating costs of approximately $70 million per year. Although SOFIA's program plan provides for a biannual Program Implementation Review, that review will not address the value of the science obtained by the observatory relative to NASA's investment or in the context of NASA's overall science portfolio in the same way these factors are considered for extended missions.

NASA reviews extended missions every 2 years through a process known as the Senior Review, which consists of panel members with scientific and technical expertise related to the mission they are tasked with reviewing. The primary purpose of the Senior Review is to determine the value of extending mission operations with the intent to maximize scientific returns within a constrained budget environment. The factors Senior Review panels consider include the number of papers produced by the researchers directly performing the observations, the amount of data accessed by other researchers,

[36] Life-cycle cost per planned research flight hour = estimated life-cycle cost / planned NASA life-cycle research flight hours ($3.016 billion / 14,416 = $209,212). Annual operating cost per planned research flight hour = estimated annual operating cost / planned NASA annual research flight hours ($80 million / 768 = $104,167). DLR planned flight hours and costs are not included in these figures.

and how often ensuing research products cited its data. Given the unusually long duration of SOFIA's initial operations phase, we believe NASA should subject the Program to Senior Review or a similar process during that phase.

Recommendations, Management's Response, and Evaluation of Management's Response

If SOFIA continues in operation, we recommended the Associate Administrator for the Science Mission Directorate:

Recommendation 1. Formulate an optimal plan for technology upgrades that will be adequate to encourage researcher participation over SOFIA's planned operational life cycle.

Management's Response. The Associate Administrator concurred with our recommendation, stating that NASA will develop an Instrumentation Development Plan by December 31, 2014, to formalize the Program's approach to integration of new technologies and capabilities.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 2. Establish a timeline for SOFIA to be evaluated within the Senior Review or a similar process during its primary operational phase.

Management's Response. The Associate Administrator concurred with our recommendation, stating that by October 31, 2014, NASA will establish a plan for conducting a Senior Review of the SOFIA Program.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

We further recommended the Associate Administrator direct SOFIA Program managers to:

Recommendation 3. Develop a formal plan for conducting outreach to the science community.

Management's Response. The Associate Administrator concurred with our recommendation, stating NASA will direct USRA to develop a formal Science Community Outreach Plan by October 31, 2014.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 4. Develop a plan to fund research projects based on their complexity.

Management's Response. The Associate Administrator concurred with our recommendation, stating that NASA will re-evaluate its approach for allocating funding and weigh any potential changes against other Program priorities. Any revisions to the funding algorithm will be made prior to NASA's Call for Proposals in the spring of 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 5. Develop a plan to reduce the backload of undelivered data and implement a plan to improve data delivery times.

Management's Response. The Associate Administrator concurred with our recommendation, stating that NASA will direct USRA to provide a report on SOFIA data processing performance and, if necessary, direct USRA to provide corrective action by November 30, 2014.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 6. Implement a formal process governing rescheduling of flights.

Management's Response. The Associate Administrator concurred with our recommendation, stating that the Project Scientist will develop and put in place a new policy by January 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 7. Reassess the 960 research flight hours per year requirement.

Management's Response. The Associate Administrator concurred with our recommendation, stating that a reassessment may result in an annual research hour requirement that is less than, greater than, or equal to the current 960 hour requirement after all Program priorities are taken into account. By December 31, 2014, NASA will formalize any changes to the annual research hour requirement in the Program Commitment Agreement.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

ORGANIZATIONAL STRUCTURE DOES NOT PROVIDE ADEQUATE OVERSIGHT OF MISSION CRITICAL FUNCTIONS

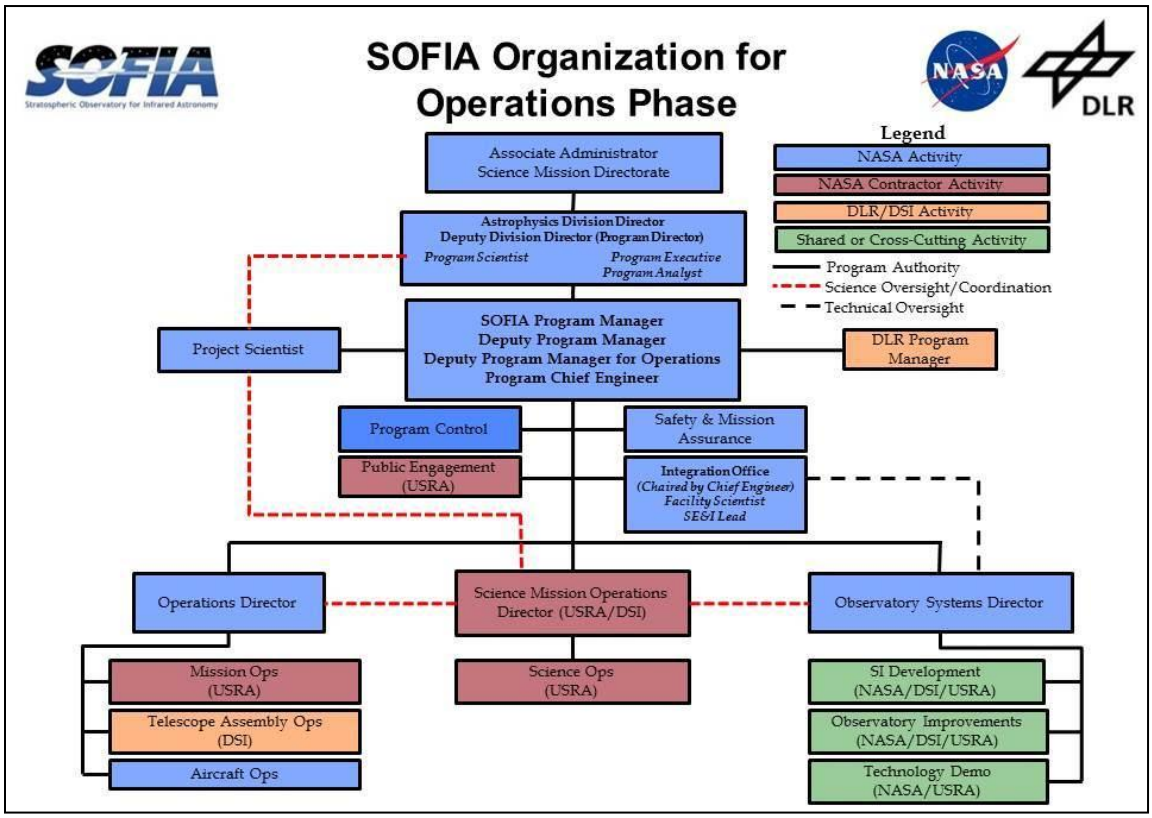
NASA plans to reorganize SOFIA's management structure for its operational phase and will have the opportunity to re-examine its current cost-plus-fixed-fee contract with USRA that expires in 2016. We found that the organizational structure NASA plans for the Program will not provide adequate Agency management and oversight of SOFIA's science operations, the current contract does not provide for adequate management oversight of mission critical functions, and a cost-plus-fixed-fee model may not be the most cost efficient option for the Program going forward.

The Organization Structure for SOFIA's Operations Phase Does Not Provide Adequate Agency Oversight of Science Functions

Since the Program has achieved its FOC milestone, NASA is planning to move the SOFIA Program Office to Ames and divide its functions into three sections: Observatory Operations, Observatory Systems, and Science Mission Operations. Under the plan, civil servants will manage the first two sections and a USRA contract employee the third in the role of Director of the Science Mission Operations Center. The Director will oversee a team of USRA employees and his or her responsibilities will include evaluating, selecting, and awarding observation time; establishing a users group; conducting science research; scheduling and coordinating observation flights; and processing and archiving science data.[37] The Director will report to the SOFIA Program Manager, with no intermediate management oversight by a civil servant (see Figure 7).

[37] The SOFIA Users Group is comprised of active astronomers that meet at least once a year to advise the SOFIA Science Mission Operations Director on technical and operational matters relating to the scientific performance and health of the Observatory. In addition to representing outside scientists, the SOFIA Users Group represents the needs of SOFIA users and works closely with the observatory technical staff to provide technical and scientific advice and consultation for correcting problems and input on planning and implementing upgrades.

Figure 7. SOFIA's Planned Management Structure after Full Operational Capability



Source: NASA SOFIA Program.

Although NASA plans to move the Program Manager from Armstrong to Ames where the USRA staff will be located beginning in FY 2015, in our judgment, the planned structure will not provide adequate Agency management and oversight of SOFIA's science operations. Specifically, we do not believe it is reasonable to expect the Program Manager to monitor the operational decisions of the science operation functions adequately while simultaneously managing the geographically dispersed Program and day-to-day programmatic decisions.

Current Contract Does Not Include Adequate Management and Oversight of Mission Critical Functions

As discussed above, USRA employees will manage, direct, monitor, and control a majority of SOFIA's science operations as the Program continues in its operational phase. We believe that under Office of Federal Procurement Policy guidelines, these

functions are "necessary to [NASA] being able to effectively perform and maintain control of its mission and operations" and therefore "critical."[38] Office guidelines require agencies to

> ensure that Federal employees perform and/or manage critical functions to the extent necessary for the agency to operate effectively and maintain control of its mission and operations; …when work need not be reserved for Federal performance and contractor performance is appropriate, agencies shall take steps to employ and train an adequate number of government personnel to administer contracts and protect the public interest through the active and informed management and oversight of contractor performance, especially where contracts have been awarded for the performance of critical functions.

Furthermore, of the five challenges we identified, four are contracted functions: science community outreach, research grant funding, data delivery, and observation rescheduling.

In our judgment, NASA's contract with USRA lacks the appropriate controls to ensure compliance with Office of Federal Procurement Policy guidelines. We compared the USRA contract with the Space Telescope Science Institute's contract for operating Hubble. In contrast to the USRA contract, the statement of work for the Hubble contract includes specific steps to preserve Agency control over mission critical functions, including (1) having civil servants direct and authorize the contractor's work, (2) training a civil servant on back-up systems operation, and (3) requiring independent performance assessments. In contrast, SOFIA's contract with USRA does not provide for a civil servant under the Program Manager to direct and authorize the contractor's work, appropriate back-up operation training for a civil servant, or an independent performance assessment.

Cost-Plus-Fixed-Fee May Not Be the Most Cost Efficient Contract Option Going Forward

NASA's current cost-plus-fixed-fee contract with USRA, in place since January 2007 and expiring in 2016, may not be the most cost efficient contract type for the Program's operational phase. The Federal Acquisition Regulation provides that contract type is a function of risk, with the Government assuming more risk in the form of cost-type contracts when requirements are complex, such as for research and development projects, and the risk shifting to the contractor in the form of fixed-price contracts when requirements recur or production begins.[39] The Regulation states that agencies should use cost-reimbursement contracts only when they cannot sufficiently define requirements or uncertainties make it too difficult to estimate costs for a fixed-price contract and warns that cost-type contracts "provide the contractor only a minimum incentive to control costs."[40] By 2016, SOFIA will have been operating at FOC for 2 years and the Program

[38] Office of Federal Procurement Policy 11-01, October 12, 2011.

[39] Federal Acquisition Regulation §16.104 "Factors in selecting contract types" para (d).

[40] Federal Acquisition Regulation §16.306 "Cost-plus-fixed-fee contracts" para (a) and §16.301-2 "Application."

will have gained significant information about the level of effort needed to run its Science Mission Operations. Accordingly, we believe NASA should examine whether moving to a fixed-price contact would be appropriate.

Recommendations, Management's Response, and Evaluation of Management's Response

The Associate Administrator for the Science Mission Directorate should:

Recommendation 8. Reassess SOFIA's organizational structure to ensure it provides an appropriate level of Government oversight of USRA.

Management's Response. The Associate Administrator concurred with our recommendation, stating that in addition to the Program Manager, the Project Scientist and the Contracting Officer's Technical Representative maintain direct insight and oversight of the Science Management Office's daily operations. However, by September 30, 2014, NASA will reassess the organizational structure to ensure an appropriate level of Government oversight of USRA.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 9. Reassess the existing contract with USRA to ensure that contracted functions determined to be critical for SOFIA to operate effectively are managed according to OFFP guidelines.

Management's Response. The Associate Administrator concurred with our recommendation, stating that as part of reassessing the SOFIA organizational structure, NASA will consult the Headquarters' Offices of Procurement and General Counsel to assess SOFIA's compliance with Office of Procurement Policy guidelines by September 30, 2014. In addition, NASA will evaluate the differences between the USRA's SOFIA contract and the Space Telescope Science Institute's Hubble Space Telescope contract and expeditiously implement any required corrective action.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

Recommendation 10. In anticipation of the end of the current contract with USRA in 2016, consider whether a fixed-price contract would be more appropriate than the current cost-plus-fixed-fee contract.

Management's Response. The Associate Administrator concurred with our recommendation, noting that the current contract with USRA was written during a different phase in the life of the Program. Therefore, NASA will evaluate all potential mechanisms for the follow-on contract and define a new procurement strategy by June 30, 2015.

Evaluation of Management's Response. Management's comments are responsive; therefore, the recommendation is resolved and will be closed upon verification and completion of the proposed corrective actions.

UNCERTAINTY SURROUNDING SOFIA'S FUTURE FUNDING HAS IMMEDIATE RAMIFICATIONS ON THE PROGRAM

The President's FY 2015 budget proposal would sharply reduce funding for SOFIA and place the observatory in storage unless partners assume NASA's share of the Program's $80 million annual operating costs. In contrast, the full House of Representatives approved $70 million and the U.S. Senate Committee on Appropriations proposed $87 million for SOFIA in FY 2015. Consequently, the Program must address a series of immediate challenges in this period of uncertainty, including whether and how to plan for a Program shutdown and possible reactivation or whether to continue moving forward with SOFIA's planned research and maintenance activities.

Challenges to the Program's Operational Continuity

The SOFIA Program faces challenges in FYs 2014 and 2015 because of the proposed budget cuts, including finding partners to assume NASA's share of costs, the possible loss of key personnel during this period of uncertainty, and delay of planned aircraft maintenance. As of July 2014, SOFIA Program management had not identified additional partners and was planning for and attempting to manage the impact of the proposed funding cuts. Program management also expressed the view that the proposed budget of $12.3 million was insufficient even to shut down the Program.

NASA Has Not Identified Additional Partners. Program management has approached DLR about increasing its financial commitment to SOFIA, but to date DLR has declined to do so. In addition, on April 1, 2014, NASA issued a Request for Information soliciting potential partners interested in using SOFIA for scientific or other uses. According to Program management, the effort required to solicit and negotiate a serious partnership would take 1 to 2 years. As of July 2014, no organization has expressed interest in assuming any portion of NASA's cost or in purchasing observation time aboard SOFIA.

Risk of Losing Key Personnel. According to Program management, SOFIA staff – some of whom have highly specialized skills – will likely begin leaving the Program as early as May 2014 when planned science operations are completed before the aircraft's scheduled heavy maintenance. Most jobs for astronomers and astrophysicists are with universities and the hiring cycle for these institutions coincides with the academic year. Therefore, SOFIA science team members and technical staff, who are primarily contractors, are likely to start looking for new positions immediately because waiting until the end of the fiscal year would limit their options. Moreover, the President's FY 2015 budget proposal of $12.3 million only covers NASA civil service personnel costs and does not provide funding for contracted personnel.

The loss of mission critical science team staff could affect the Program's ability to complete the remaining science flights scheduled for calendar year 2014. Moreover, the loss of mission critical staff could affect the Program's ability to continue operations and meet science objectives for FY 2015, even if partners are identified to assume NASA's share of operating costs or if Congress and the President reach an agreement to continue funding SOFIA at operational levels in FY 2015.

Scheduled Heavy Maintenance Delayed. NASA planned to fly SOFIA to Germany to undergo approximately 5 months of heavy maintenance in June 2014; however, the certainty of the original plan was in question given the President's budget proposal. DLR decided to delay the heavy maintenance by 1 month to allow congressional review of the President's budget proposal. Subsequently, NASA flew SOFIA to Germany at the end of June and began undergoing heavy maintenance in July 2014.

Insufficient Funding to Execute Storage Option in FY 2015. Under the President's proposed budget, NASA will have $12.3 million to develop and execute plans to store SOFIA if the Agency cannot find partners to assume their share of the operating costs. Program management stated that the proposal has insufficient schedule and budget to execute any options going forward. Specifically, SOFIA Program officials said the $12.3 million will only cover civil servant labor and associated expenses for the year and not disposition costs, such as the hangar lease, contract labor for aircraft storage support, building operating costs, servicing of life support systems, and ground support equipment upkeep.

Challenges in Storing SOFIA

Placing SOFIA in storage will entail extra expenses for maintenance and replacement of aged parts if the Program is reactivated. These costs will vary depending on how SOFIA is stored and for how long.

Cost of Cold Storage Option. If SOFIA goes into cold storage with little maintenance and operational readiness upkeep, NASA will incur lower storage costs but higher reactivation costs as aircraft parts and components degrade. Replacement parts will be more difficult to acquire because they are becoming obsolete as time passes. SOFIA's 747SP aircraft started flying in 1977 and Boeing built the last of this model in 1987. Currently, only 18 747SPs remain in operation, and those aircraft compete for a decreasing supply of replacement parts. While NASA Operations management feels confident that it has acquired sufficient critical replacement parts for SOFIA's current planned 20-year operational life, this could change based on how long the aircraft is stored.

Cost of Operational-Readiness Storage Option. Conversely, if SOFIA is maintained in a state of operational readiness, the costs incurred during the storage period will be higher with lower reactivation costs. Nonetheless, NASA has not made a determination of how and for how long the observatory will be stored nor has it performed corresponding cost analyses.

Cost of Training and Replacing Personnel. NASA will eliminate nonessential civil servant positions if it places SOFIA in storage. Consequently, the Agency will incur additional costs to train new staff if the plane is taken out of storage and the Program is reactivated. More importantly, some of the positions currently staffed by contractors, such as telescope operators and science team members, are highly skilled and difficult to replace. Recruiting and training new staff for these positions will be costly and challenging.

APPENDIX A

Scope and Methodology

We performed this audit from July 2013 through June 2014 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

We performed work at NASA Headquarters, Ames Research Center, and Armstrong Flight Research Center. We conducted interviews across multiple levels of Program and Directorate management at Headquarters and each Center, and observed an operational science flight to gain an understanding of Program practices and status. We interviewed science community members to assess their interest in the observatory and identify operational concerns. We also reviewed NASA contract NAS2-97001 to determine contractual requirements for USRA operations. Finally, we obtained and reviewed copies of the Program Implementation Review Report, and monthly and quarterly status reports.

Use of Computer-Processed Data. We used computer-processed data to perform this audit. We obtained and reviewed Earned Value Management reports and research proposal lists. We did not test the general or application controls for the systems that generated either of these reports.

Review of Internal Controls

We reviewed and evaluated the internal controls associated with NASA's management of the SOFIA Program and its operations. We noted concerns as discussed in the report. Our recommendations, if implemented, should address the concerns.

Prior Coverage

During the last 5 years, the NASA Office of Inspector General (OIG) and the Government Accountability Office (GAO) have issued six reports of particular relevance to the subject of this report. Unrestricted reports can be accessed over the Internet at http://oig.nasa.gov/audits/reports/FY14 and http://www.gao.gov, respectively.

NASA Office of Inspector General

"Final Memorandum on Audit of the Stratospheric Observatory for Infrared Astronomy (SOFIA) Program Management Effectiveness" (IG-09-013, March 27, 2009)

Government Accountability Office

"NASA: Assessments of Selected Large-Scale Projects" (GAO-14-338SP, April 15, 2014)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-13-276SP, April 17, 2013)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-12-207SP, March 1, 2012)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-11-239SP, March 3, 2011)

"NASA: Assessments of Selected Large-Scale Projects" (GAO-10-227SP, February 1, 2010)

SOFIA'S INSTRUMENT SUITE

Science Instrument	Acronym	Class	Developing Institution	Instrument Type	Wavelength Coverage	Year Commissioned
Faint Object Infrared Camera for the SOFIA Telescope	FORCAST	Facility	Cornell University	Mid/Far-IR Camera	5 - 40 microns	2013
German Receiver for Astronomy at THz Frequencies	GREAT	Principal Investigator	Max Planck Institute, Bonn (Germany)	IR Heterodyne Spectrometer	60 - 200 microns	2013
High-speed Imaging Photometer for Occultation	HIPO	Special Purpose Principal Investigator	Lowell Observatory	High-speed Imaging Photometer	0.3 - 1.1 microns	2013
First-Light Infrared Test Experiment Camera	FLITECAM	Facility	University of California – Los Angeles	Near-IR Test Camera	1 - 5 microns	2014
Field-Imaging Far-Infrared Line Spectrometer	FIFI-LS	Principal Investigator	University of Stuttgart (Germany)	Imaging Spectrometer	50 - 200 microns	2014
Echelon Cross Echelle Spectrograph	EXES	Principal Investigator	University of California – Davis	Echelon Spectrograph	4.5 - 28.3 microns	2014 (Planned)
High-resolution Airborne Wideband Camera	HAWC+	Facility	Jet Propulsion Laboratory	Far-IR Bolometer Camera and Polarimeter	50 - 240 microns	2015 (Planned)

Note: IR – Infrared; THz – Terahertz.

Source: NASA OIG evaluation of Program data.

MANAGEMENT COMMENTS

National Aeronautics and Space Administration
Headquarters
Washington, DC 20546-0001

JUL -3 2014

Reply to Attn of: Science Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator for Science Mission Directorate

SUBJECT: Response to OIG Draft Report, "SOFIA: NASA's Stratospheric Observatory for Infrared Astronomy" (Assignment A-13-015-00)

The Science Mission Directorate (SMD) appreciates the opportunity to review your draft report entitled "SOFIA: NASA's Stratospheric Observatory for Infrared Astronomy" (Assignment A-13-015-00), dated June 6, 2014.

As reflected in the OIG report, there is current uncertainty regarding the SOFIA budget beyond FY 2014. The President's Budget Request for FY 2015 states, "Unless partners are able to support the U.S. portion of SOFIA costs, NASA will place the aircraft into storage by FY 2015." The Appropriations Committees in the Congress, on the other hand, have proposed funding to continue SOFIA science operations in FY15. Additionally, the Memorandum of Understanding between NASA and DLR regarding the SOFIA program expires in 2016. SMD continues to work closely with our German partner to assess program risks and to define the optimum path forward.

In its assessment of SOFIA, the OIG assumed that SOFIA would continue with a budget that supports science operations in FY 2015 and beyond, and under similar partnership terms beyond 2016. NASA's response to the OIG report will make the same assumptions, although NASA's ability to implement fully all of the OIG's recommendations will depend on the final enacted budget and any changes in the MOU with DLR after 2016.

In the report, the OIG makes ten recommendations related to NASA's Stratospheric Observatory for Infrared Astronomy (SOFIA) Program. NASA's response to the recommendations outlined in the report, including planned corrective actions, follows:

The OIG recommends that, if SOFIA continues in operation, the Associate Administrator for the Science Mission Directorate should:

Recommendation 1: Formulate an optimal plan for technology upgrades that will be adequate to encourage researcher participation over SOFIA's planned operational life cycle.

Management's Response: Concur. NASA will develop an *Instrumentation Development Plan* to formalize the Program's approach to integration of new technologies and capabilities. The plan will describe NASA's approach to developing new Facility Science Instruments, upgrading existing instruments, and accommodating technology demonstrations. Community input on the plan will be solicited through the Program's existing advisory structure. The cadence of new capability infusion will be discussed both through the Program advisory structure and as part of the annual Planning, Programming, Budgeting, and Execution (PPBE) process. This recommendation cannot be implemented separately from #4 and #7 below, since expenditures on new instrumentation must be optimally balanced against other program elements such as research hours and General Observer (GO) funding. The initial Instrumentation Development Plan will be completed by December 31, 2014.

Recommendation 2: Establish a timeline for SOFIA to be evaluated within the Senior Review or a similar process during its primary operational phase.

Management's Response: Concur. NASA will establish a plan for conducting a Senior Review of SOFIA, including the most likely timeframe for the review. In establishing this plan NASA will utilize feedback from community scientists. This plan will be established on or before October 31, 2014.

The Associate Administrator for the Science Mission Directorate should direct SOFIA Program managers to:

Recommendation 3: Develop a formal plan for conducting outreach to the science community.

Management's Response: Concur. NASA will direct its prime SOFIA science contractor, Universities Space Research Association (USRA), to develop a formal *Science Community Outreach Plan*. The plan must be approved by the Project Scientist and Program Scientist prior to implementation. This will be completed on or before October 31, 2014.

Recommendation 4: Develop a plan to fund research projects based on their complexity.

Management's Response: Concur. NASA will reevaluate its approach to allocating funding for data analysis by SOFIA General Observers (GOs). However, any solution that increases the Program's total annual GO budget would have to be weighed against all other Program priorities. This recommendation cannot be implemented separately from #1 above and #7 below, since expenditures on GO grants must be optimally balanced against other program elements such as new instrumentation and research hours. Any changes to the GO funding algorithm will be established prior to NASA issuing the SOFIA Cycle 4 Call for Proposals in the spring of 2015.

Recommendation 5: Develop a plan to reduce the backload of undelivered data and implement a plan to improve data delivery times.

Management's Response: Concur. NASA will direct USRA to provide a report to NASA on SOFIA data processing performance through July 31, 2014, with monthly updates thereafter. If necessary, NASA will further direct USRA to provide a corrective action plan on or before November 30, 2014.

Recommendation 6: Implement a formal process governing rescheduling of flights.

Management's Response: Concur. The Project Scientist will develop and document the policy and submit it for concurrence by the SMD Astrophysics Division. The new policy will be put in place before the start of Cycle 3 in January 2015.

Recommendation 7: Reassess the 960 research flight hours per year requirement.

Management's Response: Concur. NASA understands that the OIG recommendation allows for this reassessment to result in an annual research hour requirement that is either less than, greater than, or equal to the current figure of 960 hours. This recommendation cannot be implemented separately from #1 and #4 above, since expenditures on research hours must be optimally balanced against other program elements such as new instrumentation and GO funding. NASA will formalize any change to the annual research hour requirement in a revision to the Program Commitment Agreement (PCA), which contains the current requirement. NASA plans to do this by December 31, 2014.

The Associate Administrator for the Science Mission Directorate should:

Recommendation 8: Reassess SOFIA's organizational structure to ensure it provides an appropriate level of Government oversight of Universities Space Research Association (USRA).

Management's Response: Concur. Per the existing SOFIA organizational structure, in addition to the Program Manager there are at least two civil servants in the Program Office who maintain direct insight and oversight of Science Management Office (SMO) functions on a daily basis: The Project Scientist and the Contracting Officer's Technical Representative (COTR). However, in order to ensure that NASA provides an appropriate level of Government oversight of USRA, NASA will reassess this organizational structure. The reassessment will be done by September 30, 2014. If any corrective action is required, NASA will undertake such actions as expeditiously as possible.

Recommendation 9: Reassess the existing contract with USRA to ensure that contracted functions determined to be critical for SOFIA to operate effectively are managed according to Office of Federal Procurement Policy (OFFP) guidelines.

Management's Response: Concur. NASA's civil servant oversight of USRA is outlined in the response to Recommendation #8. As part of reassessing the SOFIA organizational structure as described above, NASA will consult the Headquarters Office of Procurement and Office of General Counsel to assess SOFIA's compliance with the OFPP guidelines cited by OIG. NASA will also evaluate OIG's findings with respect to differences between the USRA SOFIA contract and the Space Telescope Science Institute Hubble Space Telescope (STScI HST) contract. This assessment will be done by September 30, 2014. If any corrective action is required, NASA will undertake such actions as expeditiously as possible.

Recommendation 10: In anticipation of the end of the current contract with USRA in 2016, consider whether a fixed-price contract would be more appropriate than the current cost-plus-fixed-fee contract.

Management's Response: Concur. NASA recognizes that the current contract with USRA was written during a very different phase in the life of the Program. NASA will evaluate all potential mechanisms for the follow-on contract to ensure that NASA maintains proper oversight, incentivizes the contractor appropriately, and achieves an optimal balance of risk between the government and the contactor. NASA will define the procurement strategy for the follow-on contract by June 30, 2015.

We have reviewed the draft report for information that we believe should not be publicly released and have provided our concerns regarding public release of that information to the OIG.

Again, thank you for the opportunity to review and comment on the subject draft report. If you have any questions or require additional information regarding this response, please contact Peter Meister at (202) 358-1557.

Charles J Kay

FOR Dr. John M. Grunsfeld

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