

ADVANCING SCIENTIFIC DISCOVERY: ASSESSING THE STATUS OF NASA'S SCIENCE MISSION DIRECTORATE

HEARING BEFORE THE SUBCOMMITTEE ON SPACE AND AERONAUTICS OF THE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY OF THE HOUSE OF REPRESENTATIVES ONE HUNDRED EIGHTEENTH CONGRESS

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**ADVANCING SCIENTIFIC DISCOVERY:
ASSESSING THE STATUS OF NASA'S
SCIENCE MISSION DIRECTORATE**

THURSDAY, MARCH 21, 2024

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON SPACE AND AERONAUTICS,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, D.C.

The Subcommittee met, pursuant to notice, at 10:03 a.m., in room 2318 of the Rayburn House Office Building, Hon. Brian Babin [Chairman of the Subcommittee] presiding.

**SPACE AND AERONAUTICS SUBCOMMITTEE****HEARING CHARTER**

“Advancing Scientific Discovery: Assessing the Status of NASA’s Science Mission Directorate”

Thursday, March 21, 2024

10:00 AM

2318 Rayburn House Office Building

Purpose

The purpose of this hearing is to review the National Aeronautics and Space Administration’s current and future activity across the Science Mission Directorate as well as to explore the Agency’s management of these missions. The hearing also provides an opportunity to discuss ongoing challenges to addressing decadal survey priorities.

Witnesses

- **Dr. Nicola Fox**, Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
- **Mr. George A. Scott**, Acting Inspector General, National Aeronautics and Space Administration
- **Dr. Jonathan I. Lunine**, The David C. Duncan Professor in the Physical Sciences, Cornell University
- **Mr. A. Thomas Young**, Former Director, Goddard Space Flight Center and Former President and COO, Martin Marietta Corp.

Overarching Questions

- What is the optimal “balance” for the Science Mission Directorate’s portfolio of programs and projects, including balance between mission types and balance between different Science divisions?

- What lessons has NASA learned from executing major Science Mission Directorate missions in the past, particularly related to cost, schedule, and performance, and how is NASA applying these lessons learned to new and ongoing Directorate activities?
- How can the Science Mission Directorate leverage its diverse network of domestic and international partners to help mitigate the effects of resource constraints on NASA science activities?

Background

NASA's Science Mission Directorate (SMD) seeks to discover the secrets of the Universe, search for life in the Solar System and beyond, and protect and improve life on Earth and in space.¹ Scientific research has been a key tenet of NASA's mission since the Agency's founding. The National Aeronautics and Space Act of 1958 established "the expansion of human knowledge of phenomena in the atmosphere and space" as one of the Agency's eight objectives.² Through the NASA Transition Act of 2017, Congress expanded the scope of NASA's objectives to include "the search for life's origin, evolution, distribution, and future in the universe."³ More recently, in 2023, the Agency stated that "science is the foundation of the agency's Moon to Mars exploration approach," highlighting the centrality of science to NASA's activity and missions.⁴

SMD supports a range of basic and applied research efforts to expand our understanding of naturally occurring space and Earth phenomena, as well as human-induced changes in the Earth system. The directorate also looks farther out into space, studying our galaxy and the universe beyond. SMD primarily focuses on fundamental questions and challenges, but its research also provides insight for other directorate activities and serves as the foundation for future exploration. Not only does SMD research advance space discovery, but it also leads to breakthroughs in fundamental science that have implications for research and technology back on Earth.

SMD strives to maintain a diverse, balanced mission portfolio that includes flight missions, research and analysis, and technology development and applications. Accordingly, SMD utilizes a measured risk-taking approach, allowing NASA to take varying risk postures between missions and foster innovation in a transparent manner. SMD also cultivates entrepreneurialism in its research community. For example, NASA opened the I-Corps program, which works to translate fundamental research into the commercial marketplace, to its research community.⁵

In addition to operating more than 80 spacecraft in locations from low-Earth orbit (LEO) to beyond our solar system, SMD utilizes high-altitude balloons, sounding rockets, and suborbital spacecraft for its research needs. SMD also frequently uses capabilities offered by the International Space Station (ISS), taking advantage of the micro-gravity environment to conduct continuous and interactive research similar to Earth-based laboratories. SMD also uses terrestrial science facilities across the country, including Ames Research Center (Moffett Field, CA);

¹ NASA, *Science 2020-2024: A Vision for Scientific Excellence*, (September 1, 2023), <https://smd-cms.nasa.gov/wp-content/uploads/2023/09/2020-2024-nasa-science-plan-vr-23-update-final.pdf>

² P.L. 85-567

³ P.L. 115-10

⁴ *Id.* at 1

⁵ *Id.* at 1

Armstrong Flight Research Center (Edwards, CA); Glenn Research Center (Cleveland, OH); Goddard Space Flight Center (Greenbelt, MD); and Langley Research Center (Hampton, VA).

Science Mission Directorate Funding

The Fiscal Year 2025 (FY25) President’s Budget Request (PBR) proposes \$7.56 billion for SMD, a decrease of 3 percent, or \$229 million, from FY2024 enacted funding.⁶ This funding enables missions and technology development along with grants which support approximately 10,000 U.S. scientists.⁷ Notably, the PBR states that “SMD uses [the National Academies’ decadal surveys] recommendations to prioritize future flight missions (including space observatories and probes), as well as technology development and proposals for theoretical and suborbital supporting research.”⁸ The NASA funding for SMD between FY20 and FY24 as well as the budget request for FY2025, including the out years, are detailed in appendix A.

Decadal Process

NASA’s scientific priorities are informed by decadal surveys conducted by the National Academies of Science, Engineering, and Medicine (NASEM). Decadal surveys are independent assessments that consider Earth and space science discipline fields and aeronautics research and recommend priorities for research and programmatic areas over the next decade.⁹ The decadal surveys consider inputs from the scientific community, life cycle costs, technical readiness of missions, and more. Appendix B provides a summary of the programs prioritized for each division by its most recent corresponding decadal.

NASEM published the first decadal survey on astronomy in 1964.¹⁰ As of 2023, NASEM has issued decadal surveys relevant to each of the SMD divisions, including the first decadal survey for Biological and Physical Sciences.¹¹ NASA acts as the lead in this process, but NASEM considers inputs from a range of agencies, including the National Science Foundation, the Department of Energy, the National Oceanic and Atmospheric Administration, and the U.S. Geological Survey.

The most recent decadal survey for each SMD division is as follows:

- Earth Science – *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space* (2018).¹²
- Planetary Science – *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* (2022).¹³

⁶ NASA, Fiscal Year 2025 Budget Request, (March 11, 2024), <https://www.nasa.gov/fy-2025-budget-request/>

⁷ NASA, About NASA Science, <https://science.nasa.gov/about-us>

⁸ NASA, FY 2025 Agency Fact Sheet, (March 11, 2024), <https://www.nasa.gov/fy-2025-budget-request/>

⁹ 51 USC § 20305

¹⁰ National Academy of Sciences, *Ground-based Astronomy: A Ten-Year Program*, The National Academies Press, (1964), <https://doi.org/10.17226/13212>

¹¹ Joseph K. Alexander, *Science Advice to NASA: Conflict, Consensus, Partnership, Leadership*, NASA Office of Communications, NASA History Division, Monographs in Aerospace History, No. 57, (2017)

¹² National Research Council, *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*, The National Academies Press, (2018), <https://doi.org/10.17226/24938>

¹³ National Research Council, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*, The National Academies Press, (2023), <https://doi.org/10.17226/26522>

- Astrophysics – *Pathways to Discovery in Astronomy and Astrophysics for the 2020s* (2021).¹⁴
- Heliophysics – *Solar and Space Physics: A Science for a Technological Society* (2013).¹⁵
- Biological and Physical Sciences – *Thriving in Space: Ensuring the Future of Biological and Physical Sciences Research* (2023).¹⁶

Science Mission Directorate Divisions

SMD is comprised of five divisions, as follows: Earth Science; Planetary Science; Astrophysics; Heliophysics; and Biological and Physical Sciences.

Earth Science

The Earth Science Division exists “to advance knowledge of Earth as a system in order to meet the challenges of environmental change and to improve life on our planet.”¹⁷ The Division seeks to understand natural and human influences on the Earth and how they interact with one another. Earth Science studies a range of Earth cycles and processes, such as the water cycle and the movement of heat, to build a more comprehensive understanding of the processes that impact Earth as a system. Earth Science also translates these observations into data that can be used for terrestrial benefit, seeking “to deliver actionable Earth science to decisionmakers at every level.”¹⁸

The Division operates more than 20 spacecraft on-orbit and 7 instruments on the ISS.¹⁹ Earth Science also utilizes airborne and ground-based assets for its activities. Earth Science research falls into one of the following focus areas:

- *Atmospheric Composition* – research on Earth’s atmosphere, including its chemical and physical properties, Earth’s energy budget, and air quality.
- *Weather and Atmospheric Dynamics* – research on the dynamics of the atmosphere to improve our understanding of the fundamental processes that drive weather.
- *Climate Variability and Change* – measures and models Earth’s dynamic systems and how they change over time.
- *Water and Energy Cycle* – research to improve our understanding of the global water cycle.
- *Carbon Cycle and Ecosystems* – detects, explains, and predicts changes in Earth’s ecosystems, biogeochemical cycles, biodiversity, and land cover.
- *Earth Surface and Interior* – research and analysis of solid-Earth processes from crust to core.²⁰

¹⁴ National Research Council, *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, The National Academies Press, (2023), <https://doi.org/10.17226/26141>

¹⁵ National Research Council, *Solar and Space Physics: A Science for a Technological Society*, The National Academies Press, (2013), <https://doi.org/10.17226/13060>

¹⁶ National Research Council, *Thriving in Space: Ensuring the Future of Biological and Physical Sciences Research*, The National Academies Press, (2023), <https://doi.org/10.17226/26750>

¹⁷ NASA, NASA Earth Science, <https://science.nasa.gov/earth-science/>

¹⁸ *Id.* at 1

¹⁹ NASA, Earth Science Missions, <https://science.nasa.gov/earth-science/missions/earth-missions/>

²⁰ *Id.* at 14

Planetary Science

NASA's Planetary Science Division seeks to understand the solar system, and the distribution of life within the solar system, through observation and discovery of complex planetary worlds and objects. Planetary Science missions also support and inform human exploration efforts. More specifically, the Division's "strategic objective is to advance scientific knowledge of the origin and history of the solar system, the potential for life elsewhere, and the hazards and resources present as humans explore space."²¹ Beginning with the launch of Mariner 2 to Venus in 1962, a NASA instrument has visited every planet in our solar system, along with a variety of small space bodies.

Planetary Science divides missions into three categories (Flagship, New Frontiers, and Discovery) based on the mission size. Each mission category operates on a different cadence with distinct cost caps. The guidelines for each mission category are as follows.²²

- *Flagship*: Large missions that address broad, high-priority science objectives. Unlike New Frontiers and Discovery class missions which are led by principal investigators, Flagship missions are managed by a NASA center or office.
- *New Frontiers*: Medium missions intended to bridge the gap between Discovery and Flagship missions. They're intended to launch every 60 months with a \$850 million cost-cap per mission excluding launch vehicle, mission operations, data analysis or partner contributions.
- *Discovery*: Small, rapid cadence missions with limited scope. They're intended to launch every 36 months with a \$450 million cost-cap per mission excluding launch vehicle mission operations, data analysis or partner contributions.

These missions often require complex technologies that regularly push the limits of spacecraft and robotic engineering. For example, in 2023, the Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer (OSIRIS-Rex) mission traveled to an asteroid passing near Earth, collected samples, and returned to Earth for the first time.²³ Presently, the Division operates spacecraft on Mars, Jupiter, and the Moon, as well as the Lucy mission heading for the Trojan asteroids.²⁴

SMD also houses NASA's Planetary Defense Coordination Office,²⁵ which is tasked with providing a better understanding of near-Earth objects (NEOs) by tracking, cataloging, characterizing, and identifying potential hazards. In 2005, Congress directed NASA to evaluate methods for detecting and tracking NEOs, leading to the Near-Earth Object Surveyor Space Telescope (NEO Surveyor) mission.²⁶ Currently under development, the NEO Surveyor will support NASA's planetary defense effort by identifying asteroids, comets, and other objects that

²¹ *Id.* at 1

²² NASA, Unlocking the Mysteries of the Solar System, <https://www.nasa.gov/planetarymissions/planetary-mission-program-overview/>

²³ NASA, Origins, Spectral Interpretation, Resource Identification, and Security – Regolith Explorer (OSIRIS-Rex), <https://science.nasa.gov/mission/osiris-rex/>

²⁴ *Id.* at 1

²⁵ NASA, Planetary Defense Coordination Office, <https://science.nasa.gov/planetary-science/programs/planetarydefense/>

²⁶ NASA, Near-Earth Object Survey and Deflection Analysis of Alternatives, (March 2007), https://www.nasa.gov/wp-content/uploads/2015/01/171331main_NEO_report_march07.pdf

could present a threat to Earth.²⁷ The office also considers mitigations for any potential threat caused by NEOs. In 2022, NASA completed a Double Asteroid Redirection Test (DART) to demonstrate a method for deflecting an asteroid through kinetic impact.²⁸

Astrophysics

Complementing the Planetary Science Division's research within the solar system, the Astrophysics Division concentrates on the universe beyond it. The Astrophysics Division expands humanity's understanding of how the universe began, how the universe works, and how the universe is evolving, as well as whether there are places in the universe which are capable of supporting life.²⁹ The Division contains three science themes: Physics of the Cosmos (PCOS), Cosmic Origins (COR), and Exoplanet Exploration (ExEP).³⁰ There are also two cross-cutting programs, Astrophysics Explorer Program and Astrophysics Research Program, which conduct activities across the three themes.

- *Physics of the Cosmos* – understanding the makeup of energy, space and time, and how they behave in extreme physical conditions through the study of cosmology, high-energy astrophysics, and fundamental physics projects that directly address questions regarding astrophysical phenomena.
- *Cosmic Origins* – understanding the origination and history of the universe, and how stars, galaxies, and planets are formed over time.
- *Exoplanet Exploration* – discovering and characterizing planetary systems and Earth-like planets around nearby stars with the ultimate goal of discovering habitable planets and evidence of life.
- *Astrophysics Explorers* – opportunities for principal-investigator led, small and medium class Astrophysics missions for focused scientific investigations and missions to address scientific gaps not filled by larger missions.
- *Astrophysics Research* – sponsored research programs for theoretical research and applied technology investigations.

SMD operates a fleet of space-based observatories that can look across billions of light years, including the Hubble Space Telescope, the James Webb Space Telescope, and the Fermi Gamma-ray Space Telescope. While these observatories require substantial investment in both time and resources, they provide researchers with cutting edge capabilities. During its first year of operations, James Webb Space Telescope observations challenged the existing ideas regarding the evolution of the universe during its infancy.³¹ Several of these assets have continued to produce high-quality data well beyond their original missions.³² This technological overperformance combined with a budget-constrained environment have created a dilemma for NASA, forcing hard decisions on whether to continue extending the lifespan of older, yet reasonably well-functioning instruments at the cost of new programs, or end the missions and

²⁷ NASA, NEO Surveyor, <https://science.nasa.gov/mission/neo-surveyor/>

²⁸ NASA, Double Asteroid Redirection Test (DART), <https://science.nasa.gov/mission/dart>

²⁹ *Id.* at 1

³⁰ *Id.* at 1

³¹ Tereza Pultarova, *The James Webb Space Telescope discovers enormous distant galaxies that should not exist*, Space.com, (February 22, 2023), <https://www.space.com/james-webb-space-telescope-giant-distant-galaxies-surprise>

³² NASA, NASA Response to the 2022 Astrophysics Senior Review of Operating Missions, (August 5, 2022), https://smd-cms.nasa.gov/wp-content/uploads/2023/04/NASAs_Response_SR2022_Final_Tagged.pdf

fund the next generation of technologies. Smaller Pioneer, Explorer, and Probe missions along with airborne and ground-based assets accompany the large strategic missions.

Heliophysics

NASA's Heliophysics Division studies the nature of the Sun and how it influences space, including the effect of the Sun on planets and technology. The Sun constantly releases particles and energy, resulting in a solar atmosphere that extends well beyond our solar system and on to interstellar space. The Heliophysics Division operates a fleet of spacecraft throughout the heliosphere to observe the near and far-reaching effects of the Sun. For example, the Parker Solar Probe became the first spacecraft to fly through the Sun's upper atmosphere in 2021. The probe progressively moves closer to the sun with each orbit, providing scientists with unprecedented observations and data on the behavior of solar wind.³³

Along with improving our understanding of the Sun, heliophysics research helps protect technology on Earth, as well as astronauts and spacecraft in space. Extreme space weather can damage electronics and interfere with communications, satellites, and power grids.³⁴ Efforts to properly plan for and mitigate the negative effects of space weather rely on research performed by the Heliophysics Division.

Biological and Physical Sciences

SMD's fifth division, Biological and Physical Sciences, was added in 2020 and took over activities previously managed by the Human Exploration Organization Directorate's Space Life and Physical Sciences Research and Applications Division.³⁵ The mission of the new division is "to lead the world in fundamental space-based research, pioneer transformational discoveries, enable sustained human space exploration, and improve life on Earth and in space."³⁶

The Biological and Physical Sciences Division studies phenomena in the spaceflight environment in a way that is not possible on Earth. Division activities include:

- *Space Biology Program* – research using the space environment to understand the impacts of gravity on living organisms and how biological systems react to spaceflight environments.
- *Physical Sciences Program* – research using the space environment to improve understanding of physics and engineering science, and to understand how physical systems respond to space conditions, such as weightlessness and partial gravity.
- *Commercially Enabled Rapid Space Science Project* – collaborative effort with the commercial space industry to develop transformative research capabilities.

The Division uses a range of instruments, including ground-based facilities, and assets in both suborbital and low-Earth orbit locations. The most critical asset is the ISS, which provides the Division with access to a micro-gravity facility that is similar to terrestrial laboratories. For

³³ NASA, Parker Solar Probe, <https://science.nasa.gov/mission/parker-solar-probe/>

³⁴ NASA, NASA Heliophysics, <https://science.nasa.gov/heliophysics>

³⁵ NASA, *A New Home for NASA's Biological and Physical Sciences Research*, (October 15, 2020), <https://science.nasa.gov/science-research/biological-physical-sciences/a-new-home-for-nasa-s-biological-and-physical-sciences-research/>

³⁶ NASA, Biological and Physical Sciences Division Overview, (2023), <https://science.nasa.gov/wp-content/uploads/2020/08/bps-overview-handout-2023-11.pdf?emrc=65e8d384d934d>

example, ISS research addresses human disease and aging, informs the development of quantum technologies, and contributes to the development of novel materials.³⁷ Biological and Physical Division research is critical to enabling the safety and productivity of future long duration human space exploration.

SMD Partnerships

SMD often works in tandem with other departments within NASA, other federal agencies, nongovernmental partners, and international partners to accomplish its many objectives. NASA has taken steps to expand interdisciplinary research opportunities, including between the divisions of SMD. For example, NASA's research coordination network to study planetary habitability, Nexus for Exoplanet System Science (NExSS), has "created a framework for an unprecedented collaboration among the [...] science communities supported by [SMD]."³⁸ Since discoveries in one field often have nexus to the work of other divisions, this collaboration amplifies the impact of any individual research effort.

SMD also engages with other NASA mission directorates. Often, there is overlap between the science objectives SMD seeks to address and the underlying research that must be completed to facilitate objectives in other directorates, and the two directorates are able to collaborate. For example, SMD signed a Memorandum of Understanding (MOU) with NASA's Space Technology Mission Directorate (STMD) to formalize a process for increasing collaboration and avoiding duplication of the directorate's technology programs that are mutually beneficial for both STMD and SMD.³⁹

Outside of NASA, SMD forms partnerships with other federal agencies, foreign governments, and non-governmental entities. Partnerships with other government agencies are critical to avoid duplicative efforts, ensure effective use of limited resources, and support the transfer of knowledge and technology between Federal agencies with different applications. NASA collaborates closely with NSF, NOAA, USGS, FAA and other agencies on a number of projects. Reimbursable agreements facilitate these inter-agency partnerships. For example, NASA's Joint Agency Satellite Division (JASD), located under SMD, facilitates NASA's partnership with NOAA to develop, launch, and operate satellite programs on a reimbursable basis.⁴⁰

Beyond the federal government, international partnerships are involved in two-thirds of SMD missions.⁴¹ SMD is partner to approximately 350 active international agreements across 140 countries and regions. For example, in 2021, SMD issued a Request for Information (RFI) seeking programs that both advanced science while also promoting NASA best practices and values to emerging international partners.⁴² The benefits of these international partnerships are both scientific and diplomatic. International partnerships allow for cost-sharing on mutually beneficial projects and demonstrate the benefits of the American model of space exploration. But notably, they require SMD to accept greater risk owing to the partner's performance.

³⁷ *Id.* at 1

³⁸ NExSS, About NExSS, <https://nexss.info/about/about-nexss/>

³⁹ *Id.* at 1

⁴⁰ NASA, Joint Agency Satellite Division, <https://science.nasa.gov/about-us/smd-programs/joint-agency-satellite-division>

⁴¹ *Id.* at 1

⁴² NASA, *Implementation and Changes to Science Policy Document (SPD)-41: Science Information Policy*, (November 19, 2021), [SPD-41 RFI](#)

Collaboration with the private sector takes on several forms. SMD utilizes traditional contractor relationships and public-private partnerships to advance NASA's science objectives and build on private sector investments. For example, through Venture-Class Acquisition of Dedicated and Rideshare (VADR) missions, SMD "is actively pursuing opportunities to host science instruments on commercial satellites."⁴³ These partnerships also facilitate cooperation on shared challenges, such as orbital debris mitigation.

Mars Sample Return Program

As part of NASA's Mars Sample Return Campaign, the Mars Sample Return (MSR) program plans to retrieve samples collected by the agency's Mars Perseverance rover from the Martian surface and return them to Earth between 2030 and 2031.

The MSR program continues to receive growing attention, particularly as it approaches its Key Decision Point-C (KDP-C) review, planned for March 2024. In 2023, an Independent Review Board (IRB) assessment of the MSR program raised concerns about the program's affordability and schedule.⁴⁴ The IRB report assigned an unofficial cost estimate of \$7.4 billion for the program, over double the cost estimate attached to the program at the time of the review. The NASA Office of Inspector General (OIG) issued its own audit report on the program in February 2024 that highlighted MSR's cost and schedule estimation challenges and warned that the program's actual cost may grow to between \$8 and \$11 billion.⁴⁵

⁴³ *Id.* at 1

⁴⁴ NASA, Mars Sample Return Independent Review Board-2 Final Report, (September 1, 2023), <https://www.nasa.gov/wp-content/uploads/2023/09/msr-irb-report-final-copy-v3.pdf?emrc=65e19c1cd16af>

⁴⁵ NASA OIG, Audit of the Mars Sample Return Program, IG-24-008, (February 28, 2024), <https://oig.nasa.gov/docs/IG-24-008.pdf>

Appendix A

NASA SMD funding for FY20 to FY24

Table 1. NASA Budget Authority, FY2019-FY2024
(in \$ millions)

	FY2019	FY2020	FY2021	FY2022	FY2023	FY2024
Science	\$6,887	\$7,143^a	\$7,291	\$7,611	\$7,792	\$7,334
Earth Science	1,931	1,972	1,997	2,061	2,175	2,195
Planetary Science	2,747	2,713	2,693	3,120	3,217	2,717
Astrophysics	1,191	1,306	1,356	1,394	1,510	1,530
James Webb Space Telescope	305	423	415	175	— ^b	— ^b
Heliophysics	713	725	751	778	805	805
Biological and Physical Sciences ^c	—	5	79	83	85	88

NASA SMD funding request for FY25 to FY29

Budget Authority (\$ in millions)	Fiscal Year						
	Op Plan 2023	CR 2024	Request 2025	2026	2027	2028	2029
Science	7,791.5	7,795.0	7,565.7	7,717.0	7,871.3	8,028.7	8,189.3
Earth Science	2,175.0	—	2,378.7	2,396.3	2,446.1	2,489.7	2,543.4
Planetary Science	3,216.5	—	2,731.5	2,850.5	2,911.6	2,976.8	3,042.5
Astrophysics	1,510.0	—	1,578.1	1,587.0	1,613.6	1,647.1	1,673.4
Heliophysics	805.0	—	786.7	791.9	807.0	820.3	833.4
Biological and Physical Sciences	85.0	—	90.8	91.3	93.0	94.8	96.6

Appendix B

Earth Science Division Decadal Priorities

Program	Notes
Designated Observables	A program element for cost-capped, competed or directed, medium- and large-size missions to address observables essential to the overall program: aerosols; clouds, convection, and precipitation; mass change; surface biology and geology; and surface deformation and change.
Earth System Explorer	A new program element for competitive, cost-capped medium-size instruments and missions targeting: Greenhouse gases, Ice elevation, Ocean surface winds and currents, ozone and trace gases, snow depth and snow water equivalent; and terrestrial ecosystem structure.
Incubation	A new program element focused on investment for capabilities for priority observations: atmospheric winds, planetary boundary layer, and surface topography and vegetation, with an innovation fund to respond to emerging needs
Earth Venture	Add a new “Venture-continuity” component to the existing Earth Venture program element.

Planetary Science Division Decadal Priorities

Large (Flagship) Mission Priorities	
Program	Notes
Uranus Orbiter and Probe (UOP)	Highest-priority new Flagship mission. Optimal launch and cruise times could be achieved with a FY 2024 start of the UOP mission.
Enceladus Orbilander	Viable launch opportunities on existing heavy-lift launch vehicles occur in 2037, 2038, and during the 2040s; these lead to Enceladus landing during favorable south pole illumination and Earth-communication conditions that begin in the early 2050s.
Mars Sample Return (MSR)	The highest scientific priority of NASA’s robotic exploration efforts this decade should be completion of Mars Sample Return as soon as is practicably possible with no increase or decrease in its current scope.
Medium (New Frontiers) Mission Priorities	
New Frontiers-6 (NF-6)	NF-6 candidate missions: Centaur Orbiter and Lander; Ceres Sample Return; Comet Surface Sample Return; Enceladus Multiple Flyby; Lunar Geophysical Network; Saturn Probe; Titan Orbiter; and Venus In-Situ Explorer.
New Frontiers-7 (NF-7)	NF-7 candidate missions: All of the above not selected in NF-6 and Triton Ocean World Surveyor.
Planetary Defense	
Rapid Response, Flyby Reconnaissance Mission	The highest priority planetary defense demonstration mission to follow Double Asteroid Redirection Test (DART) and the Near-Earth Object Surveyor should be a rapid-response, flyby reconnaissance mission targeted to a challenging near-Earth object (NEO) population of objects posing the highest probability of a destructive Earth impact.

Astrophysics Division Decadal Priorities

Program	Notes
Space Based	
Time-Domain Program	A program of competed missions and missions of opportunity to realize and sustain the suite of capabilities required to study transient phenomena and follow up multi-messenger events
Infrared/optical/ultraviolet (IR/O/UV) Large Strategic Mission	IR/O/UV telescope for exoplanet characterization and general astronomy. Mission-specific funding to begin mid to late decade, after mission and technology maturation program.
Ground Based	
Extremely Large Telescope (ELT) Program	Federal investment in the U.S. ELT program for the U.S. community. \$1.7 billion NSF share of \$5.1 billion project.
The Next Generation Very Large Array (ngVLA)	Design, cost trade studies, and prototyping to prepare for construction, which could begin by the end of the decade.

Heliophysics Division Decadal Priorities

Program	Notes
Implement the Diversify, Realize, Integrate, Venture, Educate (DRIVE) Initiative	Includes small satellites, science centers and grant programs, and instrument development.
Accelerate and expand the Heliophysics Explorer Program	Enable Medium Explorer and Mission of Opportunity lines resulting in an increased cadence of one launch every 2-3 years.
Restructure Solar Terrestrial Probes as a moderate-scale, PI-led line	Implement three mid-scale missions meeting the science targets of the following reference missions (priority order): 1. Interstellar Mapping and Acceleration Probe (IMAP) 2. Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) 3. Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI)
Implement a large Living with a Star (LWS) Geospace Dynamics Constellation (GDC)-like mission	

Biological and Physical Sciences Division Decadal Priorities

Program	Notes
Bioregenerative Life Support Systems (BLiSS)	To build and understand the systems that would provide high-quality food, refresh air and water, process waste, and enable the creation of space environments sustainable for long periods of time independent of Earth.
Manufacturing Materials and Processes for Sustainability in Space (MATRICES)	To understand and harness the physical processes by which materials and complex fluids can be repeatably utilized in space, to enable sustainable exploration and circular lifecycles for the built environment on Earth and in space.
Biological and Physical Science Free Flyer (BiPS-Free) vehicle	Addresses current constraints of crew-tended, LEO-limited BPS research, including months-long access by non-human living organisms and engineered materials to the gravitational forces and cosmic ray radiation exposure beyond LEO.

Chairman BABIN. Good morning. The Subcommittee on Space and Aeronautics will now come to order. Without objection, the Chair is authorized to declare recesses of the Subcommittee at any time.

And welcome to today's hearing titled "Advancing Scientific Discovery: Assessing the Status of NASA's Science Mission Directorate." I'd like to recognize myself for 5 minutes for an opening statement.

Today's Subcommittee hearing will review the activities of NASA's (National Aeronautics and Space Administration's) Science Mission Directorate, or SMD, and discuss the challenges and opportunities for ensuring success in these activities. Scientific research has been a core function of NASA since the agency's creation. NASA's science missions have helped us to learn more about our planet, discover secrets of the Sun, explore our solar system, and better understand our place in the universe.

SMD has had many recent successes. The Perseverance and Curiosity rovers are adding to our understanding of Mars and enabling us to someday send humans to the Martian surface. The Parker Solar Probe continues to deliver unprecedented observations of the Sun. Just 6 months ago, OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, Security—Regolith Explorer) returned asteroid samples to Earth to be studied at the Johnson Space Center. SMD also carries out some of NASA's most important work by cataloguing and defending our planet from Near-Earth Objects (NEOs).

However, we cannot celebrate these successes without acknowledging the challenges that NASA has faced on missions of all sizes. Just 3 weeks ago, NASA's Office of Inspector General (OIG) released an audit of the Mars Sample Return mission, commonly known as MSR, that NASA hopes to launch in partnership with the European Space Agency before the end of this decade. Anyone who has read prior reports on NASA's science missions from the Inspector General, GAO (Government Accountability Office), or other independent review bodies will see familiar themes in this audit. Project management challenges, including overoptimism on technology development, evolving architectural requirements, and underestimating costs are just a few of the challenges identified by the Inspector General.

This Committee recognizes the immense value of the MSR mission. We continue to hope that these issues will be resolved and that the MSR mission will be successful. However, we cannot ignore this now-familiar pattern of schedule and cost overrun for many NASA programs. When missions are delayed, costs increase as a result. Ripple effects are felt throughout NASA as timelines shift and unrelated programs are delayed or canceled to accommodate the troubled project.

Members of this Committee undoubtedly recall the years of delays and billions of dollars in cost overruns before the James Webb Space Telescope (JWST) was launched. Another mission, the Psyche mission, spacecraft, finally launched in 2023 after more than a year delay, which incurred significant costs, impacted other missions such as the VERITAS (Venus Emissivity, Radio Science,

InSAR, Topography, and Spectroscopy) mission, and we want NASA to engage in bold, daring missions.

But Congress must direct NASA to take on these missions with a clear understanding of the associated costs and risks. Consistent cost overruns and delays can result in other worthy missions being postponed or canceled and can create a reluctance for Congress to provide additional funding or even approve such missions in the future.

Congress has a responsibility to weigh the cost of a mission with its scientific value and cannot simply rationalize cost overruns and schedule delays by stating the end result of these missions will be worthwhile. That is unacceptable to our constituents and should be unacceptable to us all. This Committee has long supported a balanced approach to NASA's scientific missions across discipline and mission type. I expect that that will continue in the future.

At Congress' direction, NASA relies on the decadal process carried out by the National Academy of Science to prioritize its scientific activities. This process seeks a broad range of community input to reach a consensus position on priority missions for the following decade. Recent decadal surveys across disciplines have recommended ambitious missions and optimistic budgets. This Committee recognizes the importance of the decadal process, but must also recognize the current fiscal environment and plan accordingly.

The focus of today's hearing is not to chide NASA, folks, but rather to understand the challenges that NASA faces when fulfilling decadal priorities. We also want to be sure that both Congress and NASA are applying lessons learned from previous missions to facilitate future mission successes.

I thank our distinguished panel of guests this morning and witnesses for joining with us today, and I look forward to a productive discussion.

[The prepared statement of Chairman Babin follows:]

Today's subcommittee hearing will review the activities of NASA's Science Mission Directorate—or SMD—and discuss challenges and opportunities for ensuring success of these activities.

Scientific research has been a core function of NASA since the agency's creation. NASA's science missions have helped us learn more about our planet, discover secrets of the sun, explore our solar system, and better understand our place in the universe.

SMD has had many recent successes. The Perseverance and Curiosity rovers are adding to our understanding of Mars and enabling us to someday send humans to the Martian surface. The Parker Solar Probe continues to deliver unprecedented observations of our sun, and just six months ago OSIRIS-Rex returned asteroid samples to Earth to be studied at the Johnson Space Center.

SMD also carries out some of NASA's most important work by cataloguing and defending our planet from Near-Earth objects.

However, we cannot celebrate these successes without acknowledging the challenges NASA has faced on missions of all sizes.

Just three weeks ago, NASA's Office of Inspector General released an audit of the Mars Sample Return mission—commonly known as MSR—that NASA hopes to launch in partnership with the European Space Agency before the end of the decade.

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This Committee recognizes the immense value of the MSR mission. We continue to hope that these issues will be resolved and that the MSR mission will be successful.

However, we cannot ignore this now-familiar pattern of schedule and cost overruns for many NASA programs. When missions are delayed, costs increase as a result. Ripple effects are felt throughout NASA as timelines shift and unrelated programs are delayed or canceled to accommodate the troubled project.

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We want NASA to engage in bold, daring missions. But Congress must direct NASA to take on these missions with a clear understanding of the associated costs and risks. Consistent cost overruns and delays can result in other worthy missions being postponed or canceled and can create a reluctance for Congress to provide additional funding, or even approve such missions in the future.

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I thank our distinguished panel of witnesses for joining us today and I look forward to a productive discussion.

Chairman BABIN. And I would like to now recognize the Ranking Member for his statement for 5 minutes.

Mr. SORENSEN. Thank you, Chairman. And I join the Chairman in welcoming everyone to today's hearing. We also thank our exceptional panel today of witnesses for being here to share your expertise.

Thanks to the Science Mission Directorate, NASA is conducting reconnaissance of every planet in our solar system, studying the Sun and near-Earth environment, better understanding Earth systems, and probing the evolution of stars, galaxies, and the early universe. As a scientist myself, the only meteorologist in Congress, I'm eager to highlight the importance of NASA's work to our Nation and to my constituents back home in western and northwestern Illinois.

Take, for example, the study of Earth science, a field which NASA's first-of-its-kind Earth observation investigations are helping improve something near and dear to my heart, our Nation's operational weather services. These services inform the study of trends of severe weather and tornadoes, flooding, droughts, which lead to how we use our land. This data can then be used by farmers across the Midwest and around the country, as an example, NASA's heliophysics programs to study the Sun, which help us predict solar storms that can disrupt vital satellite communications and GPS (Global Positioning System) signals.

Speaking of NASA's scientific study of the Sun, communities around the country will soon have an opportunity to learn first-hand about our closest star. On April 8, a total solar eclipse where the Moon passes between the Sun and the Earth, turning day into night for a few short minutes, will be visible in several States, including the southern portion of Illinois. Most of the country, including communities in central and northwestern Illinois, will witness a partial eclipse. And so I would remind everyone, the scientists in Congress, that we advocate you only use one of these when you're taking part in the solar eclipse.

But also, I'd be remiss to say it was one of the greatest parts of my life driving from Illinois to Wyoming to see the last eclipse and the profound impact that it had on me personally.

The opportunities for pursuing important science are vast. However, our fiscal resources are not. The Science Mission Directorate has many projects ongoing, but we do not have unlimited funds. That poses a problem because we need the balance between and among the projects under the Science Mission Directorate to maintain a healthy distribution of funds to small, medium, and large missions. Large high-priority missions with significant resource demands have the potential to upset the balance within and across NASA's science programs.

Today's hearing provides an important opportunity to examine the nature of this balance and how we can pursue ambitious and large missions while maintaining the overall health of the Science Mission Directorate portfolio. I'm eager to find solutions because leaving high-priority science on the chopping block is not the future that I want to see for the next generation and for our country.

I'm proud and excited about what the future holds for NASA's science programs. Answers to so many important challenging and inspiring questions await us. I look forward to working with the Chairman, NASA, and the Administration, as well as stakeholders to ensure a bright and bold future for the space and Earth science programs undertaken by NASA.

And I yield back, Mr. Chairman.

[The prepared statement of Mr. Sorensen follows:]

Good morning.

I join the Chairman in welcoming everyone to today's hearing, "Advancing Scientific Discovery: Assessing the Status of NASA's Science Mission Directorate." We also thank our exceptional panel of witnesses for being here today to share their expertise.

Thanks to the Science Mission Directorate, NASA is conducting reconnaissance of every planet in our solar system, studying the Sun and near-Earth environment, better understanding Earth systems, and probing the evolution of stars, galaxies, and the early Universe.

As a scientist and the only meteorologist in Congress, I'm eager to highlight the importance of NASA's work to our nation and to my constituents in Illinois' 17th District.

Take, for example, the study of Earth science, a field in which NASA's first-of-its-kind Earth observation investigations are helping improve something near and dear to my heart—our nation's operational weather services. These services inform the study of trends in flooding, droughts, and land use. This data can then be used by farmers in Central and Northwestern Illinois and around the country.

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cluding the southern portion of Illinois, while most of the rest of the country, including communities in central and western Illinois will witness a partial eclipse.

I urge everyone to take advantage of this exciting educational moment and find a community or State event across the U.S. to join and experience a total solar eclipse.

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I look forward to working with the Chairman, NASA, and—the Administration, as well as stakeholders, to ensure a bright and bold future for the space and earth science programs undertaken by NASA.

Thank you, and I yield back.

Chairman BABIN. Thank you, Mr. Sorensen. I really appreciate it.

[The prepared statement of Ms. Lofgren follows:]

Good morning, and thank you, Chairman Babin and Ranking Member Sorensen, for holding today's hearing. I also want to welcome our witnesses. We have an incredibly distinguished panel who are very familiar to this Committee and have been the source of much excellent advice in the past, and I am sure today will be no different.

While NASA's science portfolio and budget have enjoyed increases in the recent past, NASA's science programs are facing a perfect storm. The recently enacted appropriations cut NASA's budget, and NASA's science portfolio took an outsized share of the decrease. The guidelines set under the debt ceiling agreement limit further funding growth. Cost and schedule growth on existing projects exacerbate the constraints. The building pressures on the portfolio leave less and less flexibility to accommodate the unexpected and no room for new decadal survey science to get underway. NASA has already had to take the difficult step to delay important missions under development, even ones that are performing well. The FY2025 budget request that Congress just received proposes more delays, descopes, and cancellations, and not just to new missions under development, but to active missions, including to a high-performing Great Observatory.

These decisions are hard, and they have real consequences. NASA's science missions and programs also support an entire ecosystem of scientists, engineers, technicians, professors, students, science communicators, and more. Skilled talent, once lost, may not be easily regained. We must consider the value of ensuring continuity of critical skills and talent.

In addition, we mustn't forget that NASA science is much more than the probes we send into space. It's also the advanced technology, the innovative scientific ideas generated under the research and analysis programs, the theoretical research, the analysis programs that turn mission data into scientific results, and the supporting infrastructure necessary to enable the inspiring and ambitious work that NASA Science Mission Directorate carries out.

We in Congress, and particularly in this Committee, have an important oversight responsibility here. We need to ask hard questions about cost, management, credibility, and scientific return on investment. And NASA needs to give us substantive answers.

But I hope today that we can also talk about how to keep NASA Science whole as we navigate these issues.

Because we need to ensure that we do not lose sight of the big picture. We, as a nation, make the investment in fundamental space and Earth science at NASA because we know the inherent value in doing so. The missions and programs of NASA's Science Mission Directorate are based on the highest-priority science questions identified in the consensus-based decadal survey processes. They help us learn

about the fundamental nature, origins, and evolution of the Earth, Sun, solar system, and universe, and how humanity fits into all of it.

We must preserve and bolster NASA's ability to keep developing the ambitious missions, sustain supporting research capabilities, and pursuing the highest-priority decadal survey science while also finding ways to improve cost and schedule performance and transparency, particularly of the largest missions. It is critical that we get this right.

Thank you, and I yield back.

Chairman BABIN. And now I would like to introduce our distinguished panel of witnesses today. Our first witness today is Dr. Nicky Fox. Dr. Fox serves as the Associate—is the Associate Administrator for NASA's Science Mission Directorate where she oversees the directorate's portfolio of over 100 individual missions. Previously, she served as the Director of the Science Directorate's Heliophysics Division. Prior to joining NASA, Dr. Fox worked as the Chief Scientist for Heliophysics at Johns Hopkins University's Applied Physics Laboratory. During her time at the Applied Physics Lab, Dr. Fox also served as the Project Scientist for NASA's Parker Solar Probe. We're looking forward to hearing from you this morning.

Our next witness is Mr. George Scott, who I'd like to welcome back to the Committee. You did a great job with *Patton* a few years ago, too. I just wanted to let you know. I guess that shows my age. Nobody's seen the movie about George Patton. Mr. Scott serves as the Acting Director General for NASA. He assumed the role in January of this year, having previously served as the Deputy Inspector General. Prior to joining NASA, Mr. Scott spent over three decades at GAO, which included serving as the Managing Director of GAO's Homeland Security and Justice Team. Thank you for being here, sir.

Our third witness is Dr. Jonathan Lunine, who serves as the David C. Duncan Professor in the physical sciences and Chair of the Department of Astronomy at Cornell University. He is also a member of the National Academy of Sciences and has chaired or co-chaired numerous advisory and strategic planning committees at the Academy and also at NASA. This includes chairing the Giant Planet Systems Panel for the 2023 Planetary Science and Astrobiology Decadal Survey. Dr. Lunine is also a co-investigator on NASA's Juno mission and previously served on the Science Working Group of the James Webb Space Telescope.

And our final witness today, no stranger in here, is Mr. Thomas Young, the former Director of NASA's Goddard Space Flight Center. Is also the former COO (Chief Operating Officer) of Martin Marietta and Chairman of SAIC. Mr. Young began his career at NASA's Langley Research Center. Throughout his 20-plus years of service to NASA, Mr. Young has held various roles, including the Deputy Director for NASA Ames Research Center prior to his time at Goddard. He is a member of the National Academy of Engineering and a former member of the NASA Advisory Council.

So I would like to now recognize Dr. Fox for 5 minutes for your opening statement, your testimony. Thank you.

**TESTIMONY OF DR. NICOLA FOX,
ASSOCIATE ADMINISTRATOR,
SCIENCE MISSION DIRECTORATE,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Dr. FOX. Thank you so much. Chairman Babin, Ranking Member Sorensen, and distinguished Members of the Subcommittee, thank you so much for the opportunity to appear here today. It is always great to have a chance to talk about NASA's science program.

NASA's efforts to address fundamental questions about the universe and humanity's place continue to advance the United States' role as a global science leader. As you know, NASA released our Fiscal Year 2025 budget request, which includes \$7.565 billion for the Science Mission Directorate. This request supports over 125 space science missions, including 54 that are preparing to launch in the next few years, and over 70 that are in operation. The request funds U.S. scientists and universities, industry and government labs through more than 4,000 openly competed research awards.

The missions and the science undertaken by NASA are informed by the priorities laid out by the National Academies, but funded by you, of course, the Congress on behalf of the American people. We're grateful for the Congress' continued support of space science, which has produced some stirring successes, and I'm just going to highlight a few because I only have 5 minutes.

As we enter its second year of operation, the James Webb Telescope continues to provide breathtaking results, with each captivating new image leading us closer to unlocking the great secrets of our cosmos. The OSIRIS-REx, as you noted, delivered samples from the asteroid Bennu to the Johnson Space Center, and these pristine samples are more than twice the requirement that was returned are effectively time capsules from the earliest days of our solar system from like 4.5 billion years ago.

NASA is also adding two missions to its Earth science fleet this year. Our first, the PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) mission, to study our atmosphere and oceans and the ecosystem, was successfully launched from Kennedy Space Center on February—in February of this year. And then the second one is NISAR (NASA-ISRO Synthetic Aperture Radar) that is our first joint mission, first joint mission for Earth science with the Indian Space Research Organization. And the—that's going to scan the Earth in kind of minute detail down to about a centimeter resolution with our first-of-a-kind dual band radar.

Our investments in Commercial Lunar Payload Services, or CLPS, are beginning to bear fruit, the first company in the world to make a successful soft landing on the Moon was American. We're very proud of them. And it carried NASA and commercial payloads to the Moon's South Pole region.

This has also been a big year for the Heliophysics Division. We noted two major solar eclipses, the first one very unusual, an annular solar eclipse that occurred in October when you would have needed those glasses for the whole thing. In—coming up from Texas all the way up to Maine, as you noted on April 8, we hope you find a way to join us. Now we've given you glasses, so you're all set to go. Eyes will be well-protected. And if you cannot get

yourself to totality, fear not. NASA science will bring totality to you.

Our Biological and Physical Sciences Division just presented their initial decadal response to the Academy as we drive forward with more and more discoveries about living and thriving in deep space.

Later this year, as you noted, Parker Solar Probe, the coolest, hottest mission under the Sun, will make its closest approach to the Sun. It will do its seventh Venus flyby, and it will go closer to the Sun than any spacecraft has ever come to a star. And we're also approaching solar maximum, which offers science opportunities related to the space weather hazards.

We look forward very much to the launch of Europa Clipper later this year in October. Clipper will search one of Jupiter's moons, the Europa moon, for what we believe is a vast ocean that may hold evidence of life.

We continue our work to protect the planet from asteroids with our NEO Surveyor, which is expected to launch in 2028, and both Clipper and Surveyor are a joint NASA Center and JPL (Jet Propulsion Laboratory) efforts.

Work continues on the Roman Space Telescope, which is a NASA observatory designed to settle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics. And we look forward to maturing the technologies that will be necessary to someday see planets that may harbor life.

There are also challenges to overcome, as you've highlighted, our mission to return samples from the surface of Mars has proven to be more costly than initially expected. In September, an independent review of the Mars Sample Return program provided sobering analysis of the costs and challenges associated with this mission. This spring, NASA will complete an internal assessment of the mission architecture options and will inform the path forward and allow us to provide final details for this—for the planetary science budget.

NASA takes very seriously our responsibility to manage a very diverse portfolio within cost and schedule commitments. We continue to learn from our experiences, and we have instituted new policies to ensure we're constantly improving our ability to manage cost and schedule. It's our willingness to acknowledge these challenges and overcome them to conduct science in ways that have barely been imagined that makes us NASA.

So thank you once again for inviting me to appear before you today, and I'm really looking forward to answering your questions.

[The prepared statement of Dr. Fox follows:]



National Aeronautics and
Space Administration

Hold for Release Until
Presented by Witnesses

March 21, 2024

**Committee on Science, Space,
and Technology**

United States House of Representatives

Statement by:

Dr. Nicola J. Fox, Associate Administrator, Science Mission Directorate

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
March, 21, 2024

**Statement of
Dr. Nicola J. Fox
Associate Administrator, Science Mission Directorate
National Aeronautics and Space Administration
before the
Subcommittee on Space and Aeronautics
Committee on Science, Space, and Technology
United States House of Representatives**

Chairman Babin, Ranking Member Sorensen, and distinguished Members of the Subcommittee, thank you for the opportunity to appear today to discuss NASA's Science program. NASA science programs address fundamental research about the universe and humanity's place in it, and also informs human exploration of the Moon, Mars, and the solar system. NASA's efforts have advanced the United States' role as a global science leader. We hope that the science NASA enables today will inspire our Nation's future engineers and scientists, while also making life better for humanity here on Earth today.

As you know, NASA recently released our fiscal year (FY) 2025 budget request, which includes \$7.565 billion for the Science Mission Directorate. This request supports over 125 space science missions, including 54 that are preparing for launch and over 70 currently in operation. The request funds U.S. scientists in universities, industry, and government labs through more than 4,000 openly competed research awards.

The missions and science undertaken by NASA are informed by the priorities laid out by the National Academies of Science, Engineering, and Medicine but funded through laws passed by you – the Congress – on behalf of the American people. We are grateful for the Congress's continued support of earth and space sciences, which has produced some stirring successes. I would like to highlight a few:

As we enter its second year of operation, the James Webb Space Telescope (JWST) continues to provide breathtaking results, with each captivating new image leading us closer to unlocking the greatest secrets of our cosmos. JWST has discovered galaxies created shortly after the Big Bang, challenging our understanding of how these grand structures are formed.

Recently OSIRIS-Rex delivered samples from the asteroid Bennu to the Johnson Space Center. These pristine samples are effectively time capsules from the earliest days of our solar system, 4.5 billion years ago, and will offer insight into our own planet's history, including whether asteroids colliding with ancient Earth delivered water and other key ingredients for life. Results from this mission may also help further NASA's exploration goals, potentially using asteroids or other solar system objects for future resources.

NASA is adding two missions to its Earth Science fleet this year. First, the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission, to study our atmosphere, oceans, and their ecosystems, was successfully launched from Kennedy Space Center in February 2024. Second, a mission co-developed by NASA's Jet Propulsion Laboratory and our partners at the Indian Space Research Organization (ISRO), the NASA-ISRO Synthetic Aperture Radar (NISAR), is being prepared for launch to scan the Earth in minute detail using a first-of-its kind dual band radar. We hope that the science NASA enables today will inspire our Nation's future engineers and scientists, by meeting our world's needs today and tomorrow with unique, trustworthy, accurate and validated information that enhances knowledge and

directly supports a wide range of actions, decisions, and policymaking across sectors at global, national, regional, and local scales.

Our investments in Commercial Lunar Payload Services (CLPS), which began in 2018, are beginning to bear fruit, as we recently witnessed the first successful lunar soft landing by an American company carrying NASA and commercial payloads to the Moon's South Pole region. We look forward to welcoming additional CLPS providers as they build a commercial ecosystem in which NASA can participate as a customer. The science and technology payloads sent to the Moon's surface as a part of CLPS will help lay the foundation for human missions and create a sustainable human presence on the lunar surface.

This has also been a big year for Heliophysics, as NASA supports education efforts around the country centered on two major solar eclipses: an annular eclipse that crossed from Oregon to Texas last October and a total eclipse expected to be witnessed by millions of Americans from Texas to Maine on April 8. Later this year, the Parker Solar Probe will make its closest approach to the Sun, the closest any spacecraft has ever come to a star. We are also approaching a solar maximum, the peak of the Sun's 11-year activity cycle, which offers opportunities for science that will help us understand better how to protect the Earth from space weather hazards.

We look forward to the launch of Europa Clipper later this year. Clipper will search Jupiter's moon, Europa, for what we believe is a vast ocean that may hold evidence of life. The budget request also continues NASA's important work to protect the planet from asteroids, with funding for NEO Surveyor, which launches in 2028 to detect, track, and characterize asteroids and comets that could impact Earth, and Osiris-APEX, which will visit the asteroid Apophis. Both Europa Clipper and NEO Surveyor include work conducted by NASA Centers and the Jet Propulsion Laboratory in concert.

Work continues at Goddard Space Flight Center on the Roman Space Telescope, a NASA [observatory](#) designed to settle essential questions in the areas of dark energy, exoplanets, and infrared astrophysics, as the top ranked large space mission in the 2010 Astronomy and Astrophysics Decadal Survey.

As NASA works to explore the secrets of the Universe for the benefit of all, we must remain vigilant of the challenges that we will be required to overcome, staying focused on improving operations in order to launch science missions on schedule and on budget. Our current architecture to return samples from the surface of Mars has proven to be more costly than expected. In September, an independent review of the Mars Sample Return (MSR) program provided sobering analyses of the costs and challenges associated with this mission. Given that the Mars Sample Return effort is a major part of NASA's planetary science budget, the budget request enables NASA's internal assessment of mission architecture options to be completed before providing final details for the planetary science budget in FY 2025. This assessment will be used by NASA leadership to inform the determination of a path forward.

The portfolio of missions within NASA's Science Mission Directorate addresses a diverse set of scientific objectives and is implemented with a range of configurations, from large spacecraft to small CubeSats. NASA takes seriously our responsibility to manage these projects within cost and schedule commitments and our obligation to report regularly to our stakeholders on the status of these projects. We perform multiple independent analyses of cost and schedule before deciding to proceed into development and we use these estimates to ensure we have adequate budget and schedule margins to successfully complete development of these technically challenging missions.

Of the last 21 major missions NASA has launched, 11 came in under their development budget commitment. The average cost variance of all these missions was -1%, indicating that overall, we are able to manage risk across a balanced portfolio. We continue to learn from our experiences on these difficult missions and have instituted new policies to ensure we are equipped to manage cost and schedule.

It is our willingness to acknowledge these challenges and overcome them to conduct science in ways that have been barely imagined that makes us NASA. Thank you once again for inviting me to appear before you today. I would be pleased to respond to any questions the Members of the Subcommittee may have.

Dr. Nicola J. Fox, Associate Administrator, Science Mission Directorate, NASA

As the Associate Administrator (AA) for the Science Mission Directorate, Dr. Nicola Fox directs ~100 NASA missions to explore the secrets of the universe—missions that use the view from space to assess questions as practical as hurricane formation, as enticing as the prospect of lunar resources, as amazing as behavior in weightlessness, and as profound as the origin of the universe. She is responsible for fostering an inclusive, welcoming atmosphere and supporting a diverse team of space scientists and engineers around the country. As the AA, Dr. Fox creates a balanced portfolio of carefully chosen missions and research goals to enable a deep scientific understanding of Earth, other planets, the Sun, and the universe. These efforts lay the intellectual foundation for the robotic and human expeditions of the future, while meeting today's needs for scientific information to address national concerns.

Dr. Fox joined NASA in 2018 as SMD's Director of the Heliophysics Division, where she led a world-class team in understanding Earth's most important and life-sustaining star. She oversaw NASA's work to study key space phenomena and improve situational awareness of the very space our astronauts, satellites, and robotic missions travel through as they explore the solar system and beyond. Her portfolio also included NASA's robust space weather research to help the U.S. government better predict space weather, which can interfere with radio communications, affect GPS accuracy, and even—when extreme—affect electrical grids on the ground.

Dr. Fox has authored numerous scientific articles and papers, in addition to delivering science presentations worldwide. She is known for her keen ability to make science accessible to a broad range of audiences, as well as her stellar leadership, creating a sense of purpose and belonging in her teams. In 2021 she was awarded the American Astronautical Society's Carl Sagan Memorial Award for her demonstrated leadership in the field of heliophysics. In 2020 she was awarded NASA's Outstanding Leadership Medal.

Prior to August 2018, Dr. Fox worked at the Applied Physics Lab at the Johns Hopkins University, where she was the chief scientist for heliophysics, as well as the project scientist for NASA's Parker Solar Probe—humanity's first mission to a star. Dr. Fox's extensive project, program, and supervisory experience included serving as the Deputy Project Scientist for the Van Allen Probes and the operations scientist for the International Solar Terrestrial Physics program.

Dr. Fox graduated from The Imperial College of Science, Technology and Medicine in London with a B.S. in Physics. She received an M.S. in Telematics and Satellite Communications from the University of Surrey. She then returned to Imperial College to complete a Ph.D. in Space and Atmospheric Physics.

Chairman BABIN. Yes, ma'am. Thank you very much, Dr. Fox.
And now I'd like to recognize Mr. Scott for 5 minutes for his testimony.

**TESTIMONY OF MR. GEORGE A. SCOTT,
ACTING INSPECTOR GENERAL,
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

Mr. SCOTT. Chairman Babin, Ranking Member Sorensen, and Members of the Subcommittee, thank you for inviting me here today to discuss NASA's Science Mission Directorate. My testimony focuses on key challenges the agency faces in managing its science portfolio, including developing accurate and timely estimates, funding and stability, and workforce capacity issues.

Throughout its history, NASA has been at the forefront of incredible scientific discovery, and the agency continues to do the unexpected. For example, the Mars Ingenuity helicopter, the first aircraft to fly under its own power on another planet, surpassed 2 years of operations and completed 72 flights.

Despite its long history of success, some of NASA's most impressive scientific missions, the Hubble telescope, the Curiosity rover, and the James Webb telescope, all experienced significant cost increases and schedule delays. The extra funding and time needed not only impacted these missions, but also created cascading effects across the agency's science portfolio.

As we have frequently reported, NASA struggles to establish complete, credible, and transparent estimates. This is particularly true when it comes to large, complex missions. NASA's history of setting unrealistic costs and schedule baselines is due in part to the agency's culture of optimism. As we said over a decade ago, a culture of optimism and can-do spirit are essential for realizing groundbreaking scientific achievements and overcoming extraordinary technical challenges. That said, the same optimism may prevent leaders from critically assessing costs, risks, and schedules to determine what can realistically be accomplished within a set budget and timeframe.

To its credit, NASA has taken some actions to address its cost and schedule challenges. For example, in 2020 SMD completed its Large Mission Study that examined how the agency makes critical decisions that impact mission and program success. However, NASA has yet to incorporate the recommendations from the study into its practices and guidance for flagship missions. Also in 2020, the agency established the Chief Program Management Officer position to strengthen oversight and implementation of program management policies and best practices.

Funding instability remains a concern. Unstable funding, whether in terms of the total amount of funds allocated to a project or the timing of when those funds become available, can contribute to poor outcomes. For example, inadequate funding early in a project can decrease management's ability to identify and address key risks early on. In other cases, moving tasks to later in the project may require managers to keep a larger workforce than originally planned, also resulting in increased costs. There's also the instability resulting from appropriations that lock the agency's funding at the previous year's level for extended periods. These uncertain-

ties further compound the difficulties in effectively managing projects.

Workforce capacity remains an issue for NASA. We have identified attracting and retaining a highly skilled and diverse workforce as a top management challenge for the agency. As early as 2018, we highlighted workforce capacity issues at the Jet Propulsion Lab. We are similarly concerned that other centers face the same challenge. For example, the Goddard Space Flight Center faces a heavy workload with large projects that are competing for a limited number of technical workers, even as these missions plan to launch in the next 3 to 5 years.

NASA has repeatedly demonstrated its ability to overcome significant hurdles to accomplish amazing things. However, these achievements have often taken longer and cost much more than planned. Many of the agency's science missions are ambitious endeavors, and they need to be grounded in more realistic assumptions and estimates. Without this, it will be difficult for Congress to make informed decisions about NASA's long-term funding needs. Likewise, the agency will lack information needed to make difficult decisions on how best to allocate limited funds and prioritize future missions.

We will continue to support NASA in achieving its scientific goals, while ensuring transparency and accountability for these efforts. Thank you.

[The prepared statement of Mr. Scott follows:]



Office of Inspector General

Testimony before the House of Representatives
Subcommittee on Space and Aeronautics,
Committee on Science, Space, and Technology

ADVANCING SCIENTIFIC DISCOVERY: ASSESSING THE STATUS OF NASA'S SCIENCE MISSION DIRECTORATE PORTFOLIO

Statement of George A. Scott
Acting Inspector General
National Aeronautics and Space Administration

For Release on Delivery (expected at 10 a.m.)
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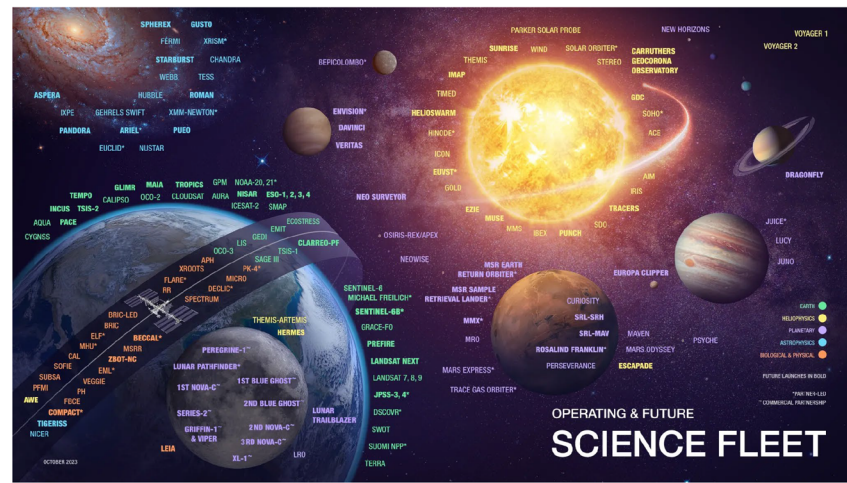
Chairman Babin, Ranking Member Sorensen, and Members of the Subcommittee:

The Office of Inspector General (OIG) is committed to providing independent, objective, and comprehensive oversight of NASA programs and projects. We welcome this opportunity to discuss the Agency's Science Mission Directorate and some of the longstanding challenges it faces.

With direction provided by Congress, Administration priorities, and recommendations of the larger science community, NASA's Science Mission Directorate portfolio consists of approximately 150 individual missions. The portfolio enables scientists to make first-of-their-kind discoveries and contributes tangible benefits to society through technology enhancements and breakthroughs that provide a better understanding of Earth and its environment.

As shown in Figure 1, these missions operate throughout the solar system and beyond. For example, launched in 1977, Voyager 1 and Voyager 2 are NASA's longest continuing missions and are now more than 15 billion and 12 billion miles, respectively, from Earth.

Figure 1: NASA's Operating and Future Science Fleet (as of October 2023)



Source: NASA.

My testimony today is informed largely by the work our office has conducted over the past 5 years (see the Appendix for summaries of relevant reports) and focuses on key challenges NASA faces in managing its science portfolio, including developing accurate and timely cost and schedule estimates, a culture of over optimism, funding instability, and workforce issues.

NASA's Large Science Projects Frequently Take Longer Than Expected and Cost More Than Estimated

NASA's accomplishments in technology development, Earth and space exploration, and scientific discovery continue to demonstrate the Agency's achievements. In fact, NASA's Science Mission Directorate has had many significant accomplishments this past year. For instance, the Mars 2020 Ingenuity helicopter—the first aircraft in history to fly under its own power on another planet—surpassed 2 years of operations and completed 72 flights after only expecting to fly 5 times. And the Parker Solar Probe completed its 18th close approach to the Sun, matching its own distance record of just 4.51 million miles from the solar surface, which it had achieved on its previous close approach just a few months prior.

Despite these successes, we must note that some of NASA's most impressive missions now in operation—Hubble Space Telescope, the Mars Science Laboratory's Curiosity rover, and the James Webb Space Telescope (JWST)—experienced significant cost increases and schedule slippages from what was originally planned. These cost increases and schedule delays have often created cascading effects across the remainder of the portfolio. For example,

- In fiscal year (FY) 2012 NASA moved \$156 million from other Science Mission Directorate projects and accounts to cover JWST cost increases.¹ In addition,
 - What was then named the Wide-Field Infrared Survey Telescope—now Nancy Grace Roman Space Telescope—and several other missions were delayed to make funding available for JWST, and
 - NASA ended an agreement with the European Space Agency on two Mars missions and reevaluated its entire Mars exploration strategy due to limited funding availability.
- In June 2022, the Psyche mission—launched in October 2023 and now on its way to a metal-rich asteroid orbiting the Sun between Mars and Jupiter—was delayed a year, which resulted in about \$132 million increase to its development costs.

Notably, Psyche's problems have now led the Agency to delay the Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS) mission for at least 3 years. Moreover, the Janus spacecraft was consequently put in long-term storage while it awaits future funding and a new launch opportunity.²

We recognize that each project is unique, as are the circumstances that lead to cost increases and schedule delays. However, through our work we have noted that NASA's culture of optimism often results in overly optimistic assumptions about cost, schedule, and the level of effort required to develop new technologies for missions.³ NASA has demonstrated time and again its ability to overcome

¹ JWST was initially baselined in 2009 with a life-cycle cost of about \$5 billion and a launch date in 2014. JWST launched in December 2021 with a life-cycle cost of about \$10 billion.

² Janus was a mission designed to send two small spacecraft to near-Earth asteroids and planned as a rideshare on the Psyche mission. The updated Psyche launch was not favorable to achieving the Janus science requirements.

³ We first reported on this effect in *NASA's Challenges to Meeting Cost, Schedule, and Performance Goals* (IG-12-021, September 27, 2012).

technological and scientific obstacles to accomplish objectives. However, many of the Agency's planned missions are ambitious endeavors that need to be grounded in more realistic cost and schedule commitments. Both the Psyche and Mars Sample Return Independent Review Boards have made this same observation in their recent assessments of these projects.⁴

We have identified funding instability, or inconsistency in funds, as another impediment to NASA's project management success.⁵ Unstable funding, whether in terms of the total amount of funds dedicated to a project or the timing of when those funds are disbursed to the project, can result in inefficient management practices that contribute to poor cost, schedule, and performance outcomes.

For example, inadequate funding in the early phases of a project's life cycle decreases management's ability to identify and address key risks at project inception. In the absence of sufficient funding, project managers may have to defer the development of critical technologies to a time when integration of those technologies may be more difficult or when the costs of material and labor may be greater. In some cases, shifting tasks to later project phases may require managers to sustain a workforce longer than originally planned or add shifts to make up for lost time, both of which can lead to increased costs.

Lastly, there is the funding instability that results from lengthy appropriation continuing resolutions that lock the Agency's funding at the previous fiscal year's level. For example, in November 2023, NASA slowed work on the Mars Sample Return mission because of funding uncertainty. NASA's Jet Propulsion Laboratory (JPL) cited the absence of a new appropriation as a primary cause, necessitating a workforce reduction.

NASA's Cost and Schedule Commitments

NASA's success in managing its major projects begins with proper stewardship of taxpayer funds and the Agency's adherence to cost and schedule commitments it makes to Congress and other stakeholders. NASA does this via an Agency Baseline Commitment (ABC) that establishes and documents an integrated set of project requirements, cost, schedule, and technical content. In turn, the ABC is based on a Joint Cost and Schedule Confidence Level (JCL) to support NASA's commitment to the Office of Management and Budget and Congress.⁶

Our recent work has found instances where the Agency failed to establish ABCs that consider the entirety of the program and project risks. For example, in April 2022 we reported that NASA chose not to conduct a JCL that would encompass the entirety of the mission risks for the Commercial Lunar Payload Services (CLPS) initiative's Volatiles Investigating Polar Exploration Rover (VIPER) mission.⁷

⁴ NASA, [Psyche Independent Review Board Report](#) (November 4, 2022); [Mars Sample Return \(MSR\) Independent Review Board-2 Final Report](#) (September 1, 2023).

⁵ [IG-12-021](#).

⁶ The JCL is an analysis of the probability that cost will be equal to or less than the targeted cost and schedule will be equal to or less than the targeted schedule date. To read more about NASA's JCL process, see our *Audit of NASA's Joint Cost and Schedule Confidence Level Process* ([IG-15-024](#), September 29, 2015).

⁷ NASA OIG, *NASA's Volatiles Investigating Polar Exploration Rover (VIPER) Mission* ([IG-22-010](#), April 6, 2022). VIPER, the most expensive mission in the CLPS portfolio, is a mobile robot intended to land at the South Pole of the Moon in late 2024. We also reported the same lack of transparency and adherence to JCL and ABC principles in the Agency's Artemis campaign as documented in *NASA's Cost Estimating and Reporting Practices for Multi-Mission Programs* ([IG-22-011](#), April 7, 2022) and *NASA's Management of the Mobile Launcher 2 Contract* ([IG-22-012](#), June 9, 2022).

Specifically, NASA excluded the VIPER delivery system—under development by a company that had never demonstrated this capability—from the JCL analysis and the ABC.

In other words, NASA essentially ignored this risk when estimating the mission timeline. Subsequently, the Agency announced the mission would launch in 2024 instead of 2023, VIPER development costs would increase by \$64 million, and \$67.8 million would be added to the cost of the CLPS task order for the contractor, Astrobotic Technologies Inc (Astrobotic), to conduct additional ground tests to reduce risk.

Though the mission is now planned to launch in November 2024, we expect additional cost increases and schedule delays because NASA may require expanded risk mitigation measures in light of Astrobotic's experiences on its first CLPS mission and its Peregrine lander earlier this year.⁸

To its credit, NASA has taken some action to address and attempt to mitigate these challenges. In early 2022, NASA established the Chief Program Management Officer (CPMO) in the Office of the Administrator to strengthen NASA's enterprise-wide oversight, management, and implementation of program management policies and best practices across Headquarters and Centers.

Early Project Estimates Are Routinely Immature and Unreliable

We believe part of the challenge NASA faces can be traced in part to the expectations established in the National Academies of Sciences, Engineering, and Medicine's decadal surveys that guide the Science Mission Directorate in its development of the portfolio. As Congress directed in the NASA Authorization Act of 2008, the NASA

Administrator shall enter into agreements on a periodic basis with the National Academies for independent assessments, also known as decadal surveys, to take stock of the status and opportunities for Earth and space science discipline fields and Aeronautics research and to recommend priorities for research and programmatic areas over the next decade.

Updated approximately every 10 years, the decadal surveys of the Science Mission Directorate's Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, and Planetary Science portfolios identifies what the Academies believe are the most pressing science questions based on input from the wider science community. The law also requires that the surveys provide life-cycle cost estimates for the recommended missions. The challenge for the Academies, and subsequently for NASA, is coming up with missions that are executable within cost and schedule estimates.

This has proven extremely challenging. Many of NASA's missions include first-time efforts and developments, and the cost, time, and effort required to mature these from initial concept to operationally functional may not be well understood and difficult to estimate until the project is further matured in formulation.

For example, the 2023 Planetary Science Decadal laid out a cost and schedule for Mars Sample Return mission that is proving untenable.⁹ Specifically, the 2023 Decadal Survey stated that "the highest

⁸ Astrobotic's Peregrine spacecraft was launched on January 8, 2024, but soon encountered what appeared to be a propellant leak in the lander's propulsion system and was destroyed when it reentered Earth's atmosphere after flying past the Moon's orbit.

⁹ National Academies of Sciences, Engineering, and Medicine, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* (2022).

scientific priority of NASA's robotic exploration efforts this decade should be completion of Mars Sample Return," noting that the mission "is of fundamental strategic importance to NASA, U.S. leadership in planetary science, and international cooperation and should be completed as rapidly as possible." The survey also stated that costs needed to be contained to not undermine the balance of the planetary portfolio. For instance, if costs increased by 20 percent or more above \$5.3 billion or annual budget requests exceeded approximately 35 percent of the total Planetary Science Division budget, then NASA should work with the Administration and Congress to secure additional funding.

In our recent report on the Mars Sample Return Program, we noted several issues with the \$5.3 billion cost estimate.

- It was developed from 2020 to late 2021 and includes an assumption of inflation at 2 percent—far below actual inflation rates in the range of 5 to almost 9 percent from mid-2021 to early 2023.
- The Decadal Survey's estimate also includes a sample receiving facility, which is not included in the Mars Sample Return Program's scope or cost estimates.
- It assumes a European Space Agency-provided Sample Fetch Rover (not included in the Decadal Survey cost), which was descoped in the summer of 2022 and replaced by NASA-developed Sample Recovery Helicopters.
- The \$5.3 billion funding level is not a life-cycle cost estimate as it includes only those costs incurred during the 2023 to 2032 Decadal Survey period and not costs incurred outside this period.

In 2020, the Science Mission Directorate concluded a study of its largest missions to examine how NASA makes critical decisions that either impede or support mission and programmatic success.¹⁰ One of the goals was to help inform leaders to improve decision-making, management, and review processes, with an emphasis on establishing and keeping more achievable commitments. The report made the following observation:

Early [cost and schedule] estimates often show a high degree of precision but have poor accuracy. This creates a false sense of confidence in early numbers and timelines, leading stakeholders to latch onto these inaccurate preliminary estimates, which can unrealistically constrain the project in later phases.

Additional Challenges Affecting Key Priorities of the Science Mission Directorate

In addition to the issues discussed above, NASA also faces challenges with Deep Space Network upgrades, radioisotope power systems development, and workforce capacity. If not adequately addressed, these challenges will affect NASA's ability to successfully execute a range of science missions and priorities.

Deep Space Network (DSN). NASA relies on its DSN to provide communication links that guide and control spacecraft and bring back images and other data from missions. The DSN uses antennas to

¹⁰ NASA Science Mission Directorate, *Large Mission Study Report* (October 2020).

communicate with spacecraft located from between 10,000 miles from Earth to the edge of the solar system and beyond.

As we reported in July 2023, DSN antennas are currently operating at capacity and are oversubscribed—meaning more time is requested by missions than the network’s current capacity can provide—with demand exceeding supply at times by as much as 40 percent.¹¹

The Agency’s Mars Perseverance Rover, James Webb Space Telescope, and upcoming Nancy Grace Roman Space Telescope and Artemis missions will require increasingly higher amounts of bandwidth that will far exceed the network’s ability to meet growing mission demands. Furthermore, as crewed Artemis missions come online and receive priority over uncrewed science missions, DSN time may not be available. As a result, some science missions may not receive the full amount of capacity required for timely navigation and data transfer. In our report, mission managers for the Mars 2020 Perseverance Rover stated that their mission was impacted by DSN oversubscription at least seven times in a 21-month period. These mission managers also said that missed opportunities to send commands delayed the Rover’s progress.

Like many other large NASA projects in development, DSN antenna upgrades are over cost by \$287 million (68 percent) and 5 years behind schedule. But even with needed upgrades, it is possible that NASA may not be able to receive all the future missions’ data that could advance our understanding of the universe and our place in it.

Radioisotope power systems (RPS). As NASA plans for more ambitious exploration of the solar system and beyond, it will need RPS to power longer and more distant missions. However, NASA has not produced a new RPS technology, which uses heat from the natural decay of plutonium-238 (Pu-238) to generate electric power, since establishing the RPS Program in 2010, despite an average investment of \$40 million per year.¹²

NASA’s inability to bring new nuclear power technologies to fruition has negatively impacted its objectives of enabling space-based science outcomes. Exacerbating this challenge is the strained relationship and lack of communication with the Department of Energy (DOE)—the federal agency responsible for plutonium production and its use in nuclear power systems. Restrictions on the level of detail DOE can share with the RPS Program due to national security concerns regarding Pu-238 production affect ongoing mission planning and new mission proposals. Consequently, we are concerned that NASA will not have the power systems needed to support its future, ambitious science mission goals.

Workforce capacity. Our work has shown that NASA faces multiple workforce challenges, including increasing the representation of women and minorities in its civilian and leadership ranks; developing a pipeline of women and minorities in Science, Technology, Engineering, and Mathematics fields; focusing on the fact that a significant percentage of the NASA workforce is retirement eligible; and addressing a shortfall of employees with the right skills in specific technical occupations. As early as 2018 we have highlighted workforce capacity and availability issues at NASA’s JPL, managed by Caltech, and made recommendations for NASA to address them.¹³ In each case, management’s response was limited to

¹¹ NASA OIG, *Audit of NASA’s Deep Space Network* ([IG-23-016](#), July 12, 2023).

¹² NASA OIG, *NASA’s Management of Its Radioisotope Power Systems Program* ([IG-23-010](#), March 20, 2023).

¹³ NASA OIG, *NASA’s Surface Water and Ocean Topography Mission* ([IG-18-011](#), January 17, 2018); *Management of NASA’s Europa Mission* ([IG-19-019](#), May 29, 2019); and *NASA’s Planetary Science Portfolio* ([IG-20-023](#), September 16, 2020).

individual projects but did not address broader workforce capacity issues impacting JPL's ability to complete work in a timely manner. However, the Psyche mission missed its planned launch because of workforce issues as noted by an Independent Review Board.

We are similarly concerned that other Centers face the same workforce challenge. For example, Goddard Space Flight Center faces a heavy workload with large projects such as the On-orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) mission; Roman Space Telescope; and the Capture, Containment, and Return System for the Mars Sample Return mission. All of these missions are competing for a limited technical workforce as each prepares for launch in the next 3 to 5 years—though some of these pressures may be abated by recent NASA decisions to pause work or cancel missions (e.g., OSAM-1). However, any decision that could result in workforce reductions, similar to those at JPL in February 2024, potentially has the unintended secondary effect of making it more difficult to hire personnel with the skills needed for future missions.

Conclusion

While we acknowledge the wide-ranging accomplishments and enormity of tasks the Science Mission Directorate has in managing its portfolio, NASA leadership should continue to establish sustainable budgets and realistic timelines that consider the Agency's overall mission goals and priorities. Given that the Agency is currently anticipated to operate with less than \$8 billion annually for the Science Mission Directorate; absent complete, credible, and transparent cost and schedule commitments, it will be difficult for NASA, Congress, and external stakeholders to make informed decisions about the prioritization of these efforts and the Agency's long-term funding needs.

As discussed in our recent report on the Mars Sample Return Program, characteristics intrinsic to big and complex missions are difficult to quantify in estimates but can drive project costs upwards. These characteristics include less than a full understanding of the mission's complexity and optimal design at inception, over-optimism, and assumptions regarding the project team and contractors' ability to meet requirements.

To this end, we encourage NASA to redouble its efforts to ensure that its science projects are grounded in accurate estimates, while also addressing those additional challenges that can affect the operational performance of these missions.

We look forward to helping NASA achieve its ambitious science exploration goals and plan to continue examining key challenges facing the Agency's Science Mission Directorate and related programs and projects.

APPENDIX

Over the past 5 years, the OIG has issued 15 audit reports that evaluate specific projects within the portfolio, such as Europa Clipper and Mars Sample Return, and Agency-level issues that can affect portfolio operations and goals, such as risks posted by orbital debris and the Agency's technology transfer process. We have also assessed smaller programs within the portfolio, such as the Earth System Science Pathfinder Program and both the Heliophysics Division and Planetary Science Division portfolios. The following is a summary of those reports.

Audit of the Mars Sample Return Program (IG-24-008, February 28, 2024)

The Mars Sample Return (MSR) Program, a partnership between NASA and the European Space Agency (ESA), is part of a four-phase MSR Campaign to collect, retrieve, return, and examine samples from the surface of Mars. It is one of the most technically complex, operationally demanding, and ambitious robotic science missions ever undertaken by NASA. With components currently scheduled to launch in 2027 and 2028, the MSR Program is approaching its next Key Decision Point (KDP) review (KDP-C) at which time NASA will evaluate Program plans, establish cost and schedule baseline commitments, and determine whether it should proceed from formulation to development.

We found that the MSR Program is facing significant obstacles completing its Formulation Phase—specifically, establishing a stable design with realistic cost and schedule estimates—in a timely and effective manner. The MSR Program recently acknowledged it likely cannot meet the life-cycle cost estimate and launch dates established at KDP-B. A delayed Preliminary Design Review for one of the Program's components, due to technical issues and the restructuring of the project's architecture, will add approximately \$200 million to the budget and result in one year of lost schedule. Additionally, the trajectory of the MSR Program's life-cycle cost estimate, which has grown from \$2.5 to \$3 billion in July 2020, to \$6.2 billion at KDP-B in September 2022, to an unofficial estimate of \$7.4 billion as of June 2023 raises questions about the affordability of the Program. Finally, MSR Program formulation is impacted by coordination challenges between NASA and ESA.

The OIG made four recommendations related to program plans to be presented at the KDP-C review and to improve the Agency's pre-formulation guidance.

NASA's Earth System Science Pathfinder Program (IG-23-018, September 5, 2023)

NASA's Earth System Science Pathfinder (ESSP) Program was established to stimulate new scientific understanding of the global Earth system to meet the challenges of climate change and other environmental events such as forest fires and floods by funding small, rapid-development missions. In 2009, NASA introduced the ESSP Earth Venture Class to create low-cost missions focused on developing innovative research and higher risk technologies that ultimately can help communities respond to the changing environment. With an annual budget of \$236 million, ESSP currently supports 22 active

projects. Through the development of orbital and suborbital remote-sensing instruments, these projects produce data to address key Earth science research questions concerning the atmosphere, oceans, land surface, polar ice regions, and solid Earth.

We identified major weaknesses with project management, mission design and operations, and instrument development in several selected projects within the ESSP Program. NASA did not adequately vet principal investigators (PIs) during the solicitation phase to ensure they have appropriate project management and contracting experience as well as sufficient time dedicated to adequately manage their projects. We also found that NASA provided PIs inconsistent and unclear expectations on project reporting requirements during the solicitation process. While the ESSP Program has controlled cost growth and met milestones for 18 of its 22 active projects, as of May 2023 the remaining four of seven unlaunched projects faced cost and schedule challenges primarily related to subcontractor disruptions, access to space costs, and limited experience of PIs managing projects. Finally, we found Earth Venture Class projects are making progress incorporating more societal applications, but the comprehensive incorporation of societal applications remains secondary and underrealized and their requirements are loosely required, poorly understood by proposers, and nominally considered during the selection process.

The OIG made eight recommendations to improve NASA's management of its ESSP Program.

Audit of NASA's Deep Space Network ([IG-23-016](#), July 12, 2023)

NASA relies on its Deep Space Network (DSN) to provide communication links that guide and control spacecraft and relay images and other data from its missions. The DSN consists of three communications facilities located near Goldstone, California; Madrid, Spain; and Canberra, Australia. The complexes use antennas to communicate with spacecraft located from between 10,000 miles from Earth to the edge of the solar system and beyond. In 2010, NASA initiated the Deep Space Network Aperture Enhancement Project (DAEP) to provide upgrades and capacity expansion to ensure continued operation and meet new mission needs.

We found that NASA's DSN is currently oversubscribed and will continue to be overburdened by the demands created by an increasing number of deep space missions. Limitations on the DSN's capacity have already impacted Agency missions' ability to fully meet objectives and achieve full return on investment. In the past 5 years, NASA missions received between 8,500 and 15,000 fewer DSN tracking hours than requested. Internal capacity and loading studies project that demand for DSN support will increase dramatically in the coming decade with excess demand for hours on the DSN reaching about 50 percent by the 2030s. NASA's primary solution to address the DSN's capacity issues is to construct additional antennas and make upgrades to existing infrastructure. Additionally, NASA continues to face challenges in completing DAEP on cost and schedule while working under international agreements and contracts. As NASA pivots toward extended human exploration of the Moon, the Agency may need to give DSN capacity to priority missions in critical phases, such as launches, while other missions make do with limited or no data during those periods.

The OIG made four recommendations to ensure NASA's progress towards upgrading the DSN's ability to support current and future mission requirements.

NASA's Management of Its Radioisotope Power Systems Program ([IG-23-010](#), March 20, 2023)

NASA has used various nuclear power systems for its spacecraft for more than 60 years and continues to develop the technology—generally using plutonium-238 (Pu-238)-based radioisotope power systems (RPS)—to expand solar system exploration capabilities where conventional solar or chemical powered space flight is impractical or impossible. These types of power systems can enhance mission capability by reducing spacecraft size and mass and providing constant power output irrespective of the distance from the Sun. To manage its investments and research in this area, NASA established the RPS Program to ensure the availability of nuclear power systems for space-based scientific mission exploration with the goal of making RPS a low-risk, cost-effective option for the Agency's exploration needs.

We found that NASA has not produced a viable new RPS technology since the Program began in 2010 despite an average investment of \$40 million per year. We also found that NASA lacks a clear resource allocation strategy to ensure completion of its new technology development projects. In addition, the Program's optimistic assumptions about the maturity of nuclear power technologies and its lack of formal assessments of technology readiness, coupled with associated technology maturation risks, contributed to the termination of two technology development projects and portend cost and schedule challenges for current and future RPS developments. The RPS Program's inability to bring new nuclear power technologies to fruition has negatively impacted its core objective of enabling space-based science outcomes because upcoming missions are less likely to propose projects incorporating unproven RPS technologies. Lastly, the RPS Program faces communication challenges with both DOE and internal stakeholders that negatively impact NASA's use of nuclear power system technologies for mission proposals.

The OIG made nine recommendations to ensure the RPS Program effectively and efficiently meets its goals.

NASA's Management of Its Johns Hopkins University Applied Physical Laboratory Portfolio ([IG-22-017](#), September 29, 2022)

The Johns Hopkins University Applied Physics Laboratory (APL) is headquartered in Laurel, Maryland, with six field offices located around the country and has provided important scientific instruments and contributed to space science, spacecraft design and fabrication, and mission operations since its founding in 1942. As of February 2022, NASA activities constituted 19 percent of APL's total work, including the Double Asteroid Redirection Test (DART) mission, testing technologies to defend the Earth against hazardous asteroids, and Dragonfly, which will sample and examine sites around Saturn's moon, Titan. NASA manages two indefinite-delivery, indefinite-quantity (IDIQ) Agency-wide contracts with APL for robotic space missions and supporting research—ARDES I (2006) and ARDES II (2020)—with a combined potential value not to exceed \$3.8 billion.

We found that the Laboratory is appropriately managing its NASA portfolio. Although several projects experienced cost increases or schedule delays, APL was not the primary factor for any cost or schedule performance issues experienced on those projects. For other projects with cost increases or schedule

delays, APL's performance was considered a factor but not the primary cause. However, we found that NASA's decision to move two existing tasks from the ARDES I to ARDES II contract was unnecessary and costly. Specifically, task orders on ARDES I were ended, and the remaining in-scope work was awarded to the ARDES II contract. As a result, rather than the 4.1 percent fixed-fee rate charged for projects under the ARDES I contract, NASA paid the ARDES II rate of 6.5 percent, resulting in cost increases of at least \$3.88 million in ARDES II contract fees for the same scope of work originally covered by the ARDES I contract.

The OIG made one recommendation to ensure NASA does not pay more than required on IDIQ contracts and task orders and one recommendation related to contract modification processes.

NASA's Management of the Earth Science Disasters Program (IG-22-013, June 14, 2022)

NASA's Earth Science Disasters Program (ESDP) is focused on using space- and ground-based observations to provide disaster-related data and information products to domestic and international partners and stakeholders. These products promote global disaster resilience—that is, the ability of nations and communities to prevent, withstand, adapt to, and recover from the harmful impacts of adverse events on people, places, and the natural environment. NASA's Earth Science Division's (ESD) Applied Sciences Program (ASP) initially provided disaster response support on an ad-hoc basis, but in 2016 ESDP was formalized as a program under ASP. NASA is required by the Robert T. Stafford Disaster Relief and Emergency Assistance Act to assist the federal government in responding to disasters, and from 2018 through 2021 ESDP assisted with 204 disasters.

We found that ESDP effectively collects and distributes relevant imagery, data products, and damage assessments to domestic and international partners and stakeholders to predict, prepare for, respond to, and recover from disasters. However, the Program struggles to do so efficiently because ESD and ASP leadership has not created a strategic plan or requirements document to outline the Program's mission, goals, and objectives. Lack of clear and consistent communication from leadership about ESDP's priorities has also created a disconnect regarding Program expectations, goals, and objectives. Guidance for providing disaster support is also incomplete and inconsistently used by ESDP staff. In addition, we found that ESDP's \$6.5 million budget has remained relatively flat for the past 5 years, with a staff consisting of 5 full-time employees and 18 part-time disaster coordinators. As a result, we found ESDP's budget and personnel resources inadequately allocated to scale support, ensure continuity, and maintain sustainable disaster response support.

The OIG made seven recommendations to improve NASA's management of the ESDP.

NASA's Volatiles Investigating Polar Exploration Rover (VIPER) Mission (IG-22-010, April 6, 2022)

The Volatiles Investigating Polar Exploration Rover (VIPER) will survey the Moon's South Pole and its concentration of water ice as a precursor to returning humans to the Moon. The VIPER mission, which includes the rover, four science instruments, launch and delivery of the rover to the Moon by a

commercial vendor, and lunar surface operations, will help determine whether it is practical to use the Moon's water ice to "live off the land," thereby reducing the need for multiple missions to ferry oxygen, food, fuel, and other supplies needed to sustain long-term human exploration on the Moon and potentially missions to Mars.

We found that the VIPER mission carries higher costs, criticality, and schedule risks compared to other current CLPS task orders. Further, NASA's ABC for the VIPER mission includes costs only for development of the rover, science instruments, lunar operations, and applicable cost reserves, and not those associated with a contract to launch and deliver VIPER to the Moon, valued at \$226.5 million when the baseline was completed. Additionally, leading project management tools were not implemented. As a result, NASA and other stakeholders may not have full visibility into the risks and their potential costs to the mission and may not be accurately monitoring mission cost and schedule performance to make timely risk-informed decisions.

The OIG made four recommendations related to enhancing information sharing and policy updates to improve decision-making and implement development best practices for major projects.

NASA's Management of Universities Space Research Association's Cooperative Agreements (IG-21-022, July 14, 2021)

Among the multitude of organizations to whom NASA awards cooperative agreements (as well as grants and contracts) is Universities Space Research Association (USRA)—an independent, nonprofit research corporation established in 1969 to conduct collaborative research in astronomy, astrophysics, lunar science, planetary science, heliophysics, Earth science, and computer science and technology. USRA outsources much of this research to hundreds of universities and nonprofit organizations across the country through subcontracts or grants. Examples of USRA's most significant research for NASA are operation of the Stratospheric Observatory for Infrared Astronomy (SOFIA) program, the Keck Remote Observation Center (operation of Mauna Kea telescopes in Hawaii), and the Goddard Earth Sciences Technology and Research partnership. In addition, NASA has cooperative agreements with USRA to recruit, identify, and place interns across the Agency.

We found that while USRA plays an important role in many NASA science missions, the Agency does not have adequate management or financial oversight of USRA's cooperative agreements. For instance, we found that total funded extensions and augmentations increased the overall value of USRA's 21 agreements from \$200.8 million to \$475.6 million with a lack of information available to support these increases and award decisions. In addition, the financial reports NASA receives from USRA do not contain sufficient information to determine whether funds are being spent appropriately. We identified approximately \$6.8 million in transactions on 17 cooperative agreements that met our keyword search criteria for potential unallowable costs. We also identified that for FYs 2015 through 2020, USRA overcharged the government a total of \$246,060 for its President/Chief Executive Officer's compensation package.

The OIG made 12 recommendations to increase management and financial oversight accountability for cooperative agreements.

COVID-19 Impacts on NASA's Major Programs and Projects (IG-21-016, March 31, 2021)

The COVID-19 pandemic created a health and economic crisis and affected all facets of the federal government. In March 2020, in accordance with Centers for Disease Control and Prevention guidance regarding COVID-19, the President directed federal agencies to modify their operations, including closing facilities and requiring mandatory telework of nonessential federal and contractor workforces. In NASA's case, while maintaining vital operations such as the International Space Station and efforts to launch the first commercial flight of astronauts into space, the Agency altered—essentially overnight—how it conducts business to protect its employees and contractors. By mid-April, 90 percent of the Agency's workforce was working from home; all nonessential travel was canceled; 12 of the Agency's 18 major facilities were closed while the remaining 6 transitioned to in-person support for "mission critical" operations only. To accomplish this dramatic shift in operations, NASA had to make difficult decisions about which missions to prioritize and which to pause or delay. Additionally, NASA received \$60 million under the Coronavirus Aid, Relief, and Economic Security (CARES) Act and the Agency directed the funds across seven broad categories to fund potential mission delays and contractor costs, enhanced information technology infrastructure, facility cleaning, and personal protective equipment.

We provided a snapshot review of the impact the COVID-19 pandemic had on major NASA programs and projects (those with life-cycle costs of at least \$250 million) as estimated at the end of FY 2020, including cost, schedule, performance, and technical challenges. Based on the information provided by project officials, as of October 2020 COVID-19 impacted 56 NASA programs and projects in FY 2020, 30 of which fit the criteria as a major program or project. The estimated cost impact of the COVID-19 pandemic on these 30 major programs and projects was over \$1.6 billion. In addition to cost impact, launch dates for several NASA missions were delayed between 1 and 10 months.

The OIG did not make any formal recommendations but encouraged the Agency to continue collecting accurate and comprehensive information to fully quantify the pandemic's impact and to provide oversight and guidance to ensure reporting of COVID-19 impacts was comparable and consistent across all Directorates.

NASA's Efforts to Mitigate the Risks Posed by Orbital Debris (IG-21-011, January 27, 2021)

Orbital debris is defined as human-made objects in space that no longer serve a useful purpose, such as decommissioned satellites and parts of spacecraft. Millions of pieces of orbital debris exist in low Earth orbit (LEO). Of those pieces, at least 26,000 are the size of a softball or larger that could destroy a satellite on impact; over 500,000 are the size of a marble big enough to cause damage to spacecraft or satellites; and over 100 million are the size of a grain of salt that could puncture a spacesuit. The growing volume of orbital debris threatens the loss of important space-based applications used in daily life, such as weather forecasting, telecommunications, and global positioning systems that are dependent on a stable space environment. At NASA, the Orbital Debris Program Office (ODPO) has

taken the national and international lead in conducting measurements of the debris environment and in developing the technical consensus for adopting mitigation measures.

We found that NASA models of the orbital debris environment lack sufficient data. For objects larger than 3 millimeters, ODPO's data is limited by the decreasing amount of time available on the three radars it uses to detect and statistically estimate debris due to funding, inoperable equipment, and competing priorities from multiple users. In addition, NASA does not have the ability to track debris smaller than 10 centimeters in the range of LEO where the International Space Station resides and plans to rely on the Department of Defense's Space Fence, a ground-based radar system that has not yet reached full operational capability, to track such debris. Finally, we found that Orbital Debris Assessment Reports and End of Mission Plans were not consistently submitted to the Office of Safety and Mission Assurance in a timely manner, and the process used to route the reports for approval was laborious.

The OIG made seven recommendations to better protect spacecraft and maintain the space environment.

NASA's Planetary Science Portfolio (IG-20-023, September 16, 2020)

NASA's Planetary Science Division (PSD) manages a series of high-profile programs such as Lunar Discovery and Exploration, Mars Exploration, Outer Planets and Ocean Worlds, Planetary Defense, and Near-Earth Object Observations. Within those programs, the planetary science portfolio consists of 32 space flight missions in various stages of operation—including orbiters, landers, rovers, and probes—that seek to advance our understanding of the solar system by exploring the Earth's Moon, other planets and their moons, asteroids and comets, and the icy bodies beyond Pluto. We assessed the Agency's management of its planetary science portfolio.

We found that PSD has taken positive steps in response to recommendations and goals outlined by the National Academies of Sciences, Engineering, and Medicine. However, as NASA's planetary science missions become more complex, the life-cycle costs of PSD missions are increasing due to project management challenges and mission complexity. While PSD and NASA Centers are focused on meeting current mission needs, they are at risk of neglecting investments—including technical capabilities, workforce, the Deep Space Network, and technology development—that would help ensure long-term maintenance of NASA's unique planetary science infrastructure. Additionally, in examining discrete planetary science missions, the Lunar Discovery and Exploration Program is accepting higher risk than necessary in the CLPS project, which provides contracts to U.S. commercial entities to develop landers to deliver NASA science instruments and other payloads to the Moon's surface. Finally, Near-Earth Object Observations Program resources were insufficient to meet the program's congressional mandate of cataloging near-Earth objects.

We made 11 recommendations to improve NASA's management of its planetary science portfolio.

NASA's Management of the Stratospheric Observatory for Infrared Astronomy Program (IG-20-022, September 14, 2020)

The Stratospheric Observatory for Infrared Astronomy (SOFIA) was an airborne observatory with a 106-inch telescope mounted onboard a Boeing 747SP that makes observations from between 38,000 and 45,000 feet, putting it above 99 percent of water vapor that interferes with ground-based infrared observations. SOFIA reached full operational capability in 2014 after a problematic 23-year development history and at a cost of \$1.1 billion—more than 300 percent over original estimates.

We found that while SOFIA is responsible for several first-of-its-kind discoveries, a 13-year development delay reduced the Program's ability to produce impactful science in a cost-effective manner, and SOFIA did not fully utilize its unique capabilities to serve as an instrument test bed or to fly anytime, anywhere. In addition, SOFIA experienced operational and technical challenges related to flight operations, observation completion, data processing, contractor award fees, and instrument development. Further, the lack of clear and achievable performance expectations and science output goals reduced productivity and threatened the Program's future viability. Since issuance of our report SOFIA ceased operations and concluded its final science flight on September 29, 2022.

We made 9 recommendations to improve the SOFIA Program's productivity.

Management of NASA's Europa Mission (IG-19-019, May 29, 2019)

Scientists believe that Europa, one of Jupiter's 79 known moons, may have a large liquid ocean, suitable for sustaining life, below its icy surface. In 2011, the National Research Council determined that an orbiter mission to Europa should be NASA's second priority flagship planetary science mission. In response, Congress directed the Agency to plan two separate missions to Europa: (1) a flyby orbiter known as Clipper and (2) a Lander intended to place scientific instruments on the moon's surface. Congress also directed NASA to use the Space Launch System as the launch vehicle for both missions with launch dates of no later than 2023 for the Clipper and 2025 for the Lander.

We found that the Clipper was at risk of not meeting its 2023 launch date due to challenges in developing the Clipper's science instruments, addressing technical workforce gaps, choosing a launch vehicle, and overcoming funding risks that could delay the Clipper or impact other projects in the Agency's planetary science portfolio. Specifically, NASA's aggressive development schedule, a stringent conflict of interest process during instrument selection, and an insufficient evaluation of cost and schedule estimates has increased project integration challenges and led the Agency to accept instrument cost proposals subsequently found to be far too optimistic. Since issuance of our report, NASA missed the 2023 launch date and now has a target launch date of October 2024.

We also found workforce and schedule risks render a 2025 launch date for the Lander unfeasible; requiring the Agency to pursue the Lander at the same time as the Clipper is inconsistent with the National Research Council's (NRC) process of strategically selecting and prioritizing flagship missions and would preclude NASA from producing optimal science. Additionally, the Lander would require substantial and ongoing funding for at least the next 10 years and could adversely affect the Agency's planetary science portfolio.

We made 10 recommendations for the Europa mission to achieve its technical objectives, meet milestones, and control costs.

NASA's Heliophysics Portfolio (IG-19-018, May 7, 2019)

NASA's space missions and much of the U.S. power grid, communications systems, and navigation infrastructure operate in an environment highly susceptible to the Sun. NASA's Heliophysics Division (HPD) and its portfolio of spacecraft, programs, and missions provide observations of solar and geophysical events—also known as “space weather” events—to advance our understanding of the Sun and its interaction with Earth's atmosphere. We assessed the Agency's management of its heliophysics portfolio.

We found that HPD has developed a comprehensive strategy to successfully manage NASA's heliophysics science capabilities and maintain its portfolio of missions. That said, we noted that the Division's 2014 roadmap had not been updated to account for changes in HPD's portfolio and subsequent-year budgets. In addition, although NASA has generally controlled costs for all of its operational HPD missions, the Division's three missions in implementation had missed planned launch dates and collectively incurred almost \$41 million in cost growth. NASA also had not completed 19 of its assigned National Space Weather Action Plan tasks, 1 recommendation from the NRC's 2003 Heliophysics Decadal Survey, and 6 recommendations from NRC's 2013 Heliophysics Decadal Survey. Finally, while NASA had established a successful working relationship with the National Oceanic and Atmospheric Administration, the Agency could more effectively collaborate with the Department of Defense and the commercial space industry on heliophysics-related issues.

We made four recommendations to improve NASA's management of its heliophysics portfolio.

NASA's Technology Transfer Process (IG-19-016, April 15, 2019)

Throughout its existence, NASA has shared its inventions and scientific breakthroughs with the public, academia, and private industry. This transfer of technology—consistent with the legislation that created NASA—can happen in a variety of ways including through the publishing of information and, more formally, through partnerships or licensing of intellectual property.

We found that NASA has made concerted efforts in recent years to improve overall awareness of its Technology Transfer Program through increased communication and outreach, resulting in a considerable increase in the number of New Technology Reports submitted, patent applications filed, and licenses negotiated—effectively increasing the Agency's overall commercialization efforts. However, Goddard Space Flight Center (Goddard) was experiencing poor technology transfer performance outcomes when compared to the other three Centers we reviewed, to include a lower percentage of licenses as well as delays in processing of New Technology Reports and patent applications. Further, we noted that Goddard's technology transfer process was hindered by a lack of adequate controls and poor collaboration between its Technology Transfer Office and the Office of Patent Counsel.

The OIG made four recommendations to improve the effectiveness of the Technology Transfer Program.



Office of Inspector General

George A. Scott



George A. Scott assumed the role of NASA's Acting Inspector General in January 2024, following five years of service as the Deputy Inspector General. He most recently held the position of Interim Executive Director of the Pandemic Response Accountability Committee, overseeing over \$5 trillion in coronavirus-related pandemic relief funds. Prior to joining NASA, Scott accumulated over 30 years of experience at the Government Accountability Office (GAO). During his time there, he served as the Managing Director of GAO's Homeland Security and Justice Team, where he oversaw GAO's efforts in the Department of Homeland Security (DHS) and the Department of Justice. This included initiatives to secure the nation's borders and infrastructure, as well as strengthen emergency preparedness and response capabilities. Scott has extensive oversight experience in DHS management, acquisition, financial management, and human capital issues. He also led oversight efforts on various justice programs and grants.

Scott, a graduate of the University of North Carolina at Chapel Hill, is a Certified Fraud Examiner. He is an accomplished speaker, having testified numerous times before Congress and presented at various conferences and training events.

Chairman BABIN. Thank you, Mr. Scott. And I'd now like to recognize Dr. Lunine for 5 minutes to present his testimony.

**TESTIMONY OF DR. JONATHAN I. LUNINE,
THE DAVID C. DUNCAN PROFESSOR
IN THE PHYSICAL SCIENCES, CORNELL UNIVERSITY**

Dr. LUNINE. Thank you very much. Chairman Babin, Ranking Member Sorensen, and distinguished Members of the Subcommittee, thank you for the opportunity to present my views on the status of NASA's Science Mission Directorate.

It is difficult not to feel passionately patriotic and proud of what our Nation has accomplished in space science. As a scientist and academic whose entire career has been spent working on NASA programs, I am grateful to have participated in the development and execution of some of the greatest space science odysseys ever undertaken: the Voyager flyby of distant Neptune, the Cassini exploration of Saturn, the ongoing Juno mission of Jupiter, the Europa Clipper mission set to launch this October, and the James Webb Space Telescope.

The accomplishments of our Nation's space science program over the past quarter century are too numerous to recount, but we've all tried to list a few of them at least, and I'll try my hand at this as well: the discovery of an ocean capable of sustaining life in two moons in the outer solar system, at least Europa, Jupiter and Enceladus at Saturn; the first exploration of the Sun from inside its atmosphere; the probing of evermore ancient epochs of the universe with Hubble and Webb, and much, much more.

And the investment in space science that the United States has made over the decades is paying off in unexpected ways. For example, the Webb telescope is teaming up with other space telescopes like the Chandra X-ray Observatory to give us unprecedented views of cosmic processes over a vast range of the electromagnetic spectrum from X-rays to the infrared.

I want to turn now to Mars where the Nation's prowess in space technology will be most on display in the coming decade. Two incredibly capable rovers designed and built with American technology by NASA's Jet Propulsion Laboratory have been roaming the Martian surface over the past decade in search of the clues to how Mars went from being a very Earthlike world to one that today is inhospitable. This is a profound question because its answer may well tell us how fragile the habitability of our own planet might be. How did Mars dry up? Exactly when? Did life begin on Mars and then die off?

As articulated by NASA advisory groups in two successive decadal surveys of the National Academy of Sciences, answering these questions will require bringing samples back to Earth. Both planetary science decadal surveys identified Mars Sample Return as their highest priority. Why so? As we learn more about Mars and ask more detailed questions, instruments of increasing sensitivity, resolution, and sophistication are required, eventually exceeding what can be plausibly carried in a spacecraft. In laboratories on Earth, powerful analytic techniques can detect faint clues to the earliest history of Mars and to the possible presence of traces of ancient life.

It is not enough to have these sophisticated geochemical tools in the laboratory. The samples must come from a place on Mars that was once Earthlike. NASA's Perseverance rover is in such a place right now, Jezero Crater. At the crater's western end is a dried-up river channel and an enormous delta-shaped fan of sediments deposited at the time that that river ran. This one complex region holds the potential for answering a host of questions about the geologic and climate evolution of Mars, and Perseverance is collecting samples carefully selected to provide those answers. But to realize that potential requires getting those samples back to Earth.

Mars Sample Return is the most ambitious robotic program ever attempted, bar none. Much of the technology is new and challenging. Having served as a member of the second MSR Independent Review Board (IRB), I am supremely confident that it can and will be done. It can be done because American engineering prowess is up to the task. It will be done because, as a Nation, we surely will not simply walk away from a daring, highly visible, and scientifically important challenge.

In closing, let me point out that more than a half century after the first Moon rocks were returned by the Apollo astronauts, science is still being done on them today by instruments far more capable than those available in 1969 when I was 10 years old. The samples returned from Mars in the coming decade will be analyzed not only by scientists alive today, but by scientists who are not yet born using laboratory techniques that are not yet invented. These precious records of early Mars will be a lasting scientific treasure and the legacy of American technological prowess.

Thank you very much for having me here today.

[The prepared statement of Dr. Lunine follows:]

HOLD FOR RELEASE
UNTIL PRESENTED
BY WITNESS
March 21, 2024

Statement of

Dr. Jonathan I. Lunine
David C. Duncan Professor in the Physical Sciences
Chair, Department of Astronomy
Cornell University

before the
Space and Aeronautics Subcommittee
Committee on Science, Space and Technology
U.S. House of Representatives

Chairman Babin, Ranking Member Sorensen and Members of the subcommittee,

Thank you for the opportunity to present my views on the status of NASA's Science Mission Directorate. When I entered elementary school nearly 60 years ago, I was barely aware of the first tentative steps being taken toward exploring the planets—a time when success was measured by the mere survival of the Mariner 2 Venus flyby mission after 5 months in space, or the 21 blurry images Mariner 4 sent back during the first successful flyby of Mars. With the passing of the decades, the perseverance and ingenuity of this nation's engineering talent paid off, as the United States emerged the unparalleled leader in the scientific exploration of the cosmos: sending probes to all the planets of our solar system and to the outer atmosphere of the Sun, building giant space telescopes that are unveiling the earliest history of the universe, and deploying fleets of spacecraft to monitor the space environment around, and the health of, our home world. Our international partners look to us to enable them to do what they cannot do alone, and our competitors measure their success against the standard established by the United States of America.

It is difficult not to feel passionately patriotic and proud of what our nation has accomplished in space science. As a scientist and academic whose entire career has been spent working on NASA programs, I am grateful to have participated in the development and execution of some of the greatest space science odysseys ever undertaken: the Voyager flyby of distant Neptune and its cryogenic moon Triton, the Cassini exploration of Saturn, the ongoing Juno mission at Jupiter, the Europa Clipper mission set to launch this October to the Jovian moon with a vast underground ocean, and the James Webb Space Telescope, daily making discoveries from our solar system to the edge of the universe.

Before talking about the science of these missions I want to pay homage to the engineers and fabricators who design and build the hardware that make these amazing missions possible. Too often we see the scientist in front of the camera describing the latest discoveries made in a distant galaxy, on the surface of Mars, or in the atmosphere of the Sun. But behind that individual is an army of engineers who overcome enormous technical

challenges to make those discoveries possible. The scientists and their proposed measurements give purpose to, and define, the missions that are then realized by the nation's very best engineers, fabricators, and assemblers. These people exemplify why this nation can do truly extraordinary things.

The accomplishments of the nation's space science program even in just the past twenty years are too numerous to fully recount. A few examples: the Cassini mission revealed vast hydrocarbon seas on the surface of Saturn's giant moon Titan, discovered and then penetrated deep into the icy plume of another Saturnian moon Enceladus, finding salt water and the basic ingredients of life sourced from an underground ocean. The samples that OSIRIS-Rex just returned to Earth are telling us an unexpected story: that the asteroid from which those samples came was once part of a larger world with liquid water. The James Webb Space Telescope has probed deep into the earliest 5% of the history of our universe, finding galaxies that are surprisingly well organized and mature—like walking into a kindergarten class and finding the students already look like adults. Parker Solar Probe has swooped into the intensely hot corona of the Sun—the hot glowing gas you can see in a total solar eclipse. In 1953 Ray Bradbury wrote a short science fiction story about a spaceship scooping up a piece of the Sun—now it's come true.

I want to turn now to Mars, where the nation's prowess in space technology will be most on display in the coming decade. Two incredibly capable rovers, designed and built with American technology by NASA's Jet Propulsion Laboratory, have been roaming the Martian surface over the past decade in search of the answers to how Mars went from being, at least in places, a very Earth-like world, to one that today has an inhospitable, indeed sterilizing, surface. This is a profound question because we are here in this room today thanks to the fact that our planet's environment has remained hospitable to life for over four billion years, despite drastic environmental changes inside and out...changes that are recorded in Earth geology and the record of planetary bodies throughout the solar system. As the only self-aware, technological species on Earth, we might want to find out how planets work, and how things can go wrong on a planet-wide scale. Where can we go to find out?

The answer is Mars. The earlier of the two NASA rovers, Curiosity, following in the stead of preceding missions, has set the stage by documenting extensive geologic evidence that water flowed across an ancient Martian landscape that was warmer and more benign than the Mars of today. And it found traces of organic molecules—the stuff of life-- that appear chemically to be the remnants of a more Earth-world in the distant past. But did life begin on Mars? How did Mars dry up? Exactly when did it dry up? As articulated by NASA advisory groups and two successive Decadal Surveys of the US National Academy of Science, answering these questions will require bringing samples back to the Earth. Indeed, both planetary science Decadal Surveys identified Mars Sample Return as their highest priority¹.

¹ National Research Council. 2011. Vision and Voyages for Planetary Science in the Decade 2013-2022. Washington, DC: NAP. <https://doi.org/10.17226/13117>; National Academies of Sciences, Engineering, and Medicine. 2023. Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032. Washington, DC: NAP. <https://doi.org/10.17226/26522>.

Why so? In science, as one learns more and more about whatever phenomenon is being studied, instruments of increasing sensitivity, resolution and hence sophistication are generally required. In the geological sciences, initial investigations begin in the field, but sooner or later samples have to be brought back to laboratories where instruments that are too large, too power hungry, or even too delicate to bring to the field are located. Geoscience laboratories at universities around the world are equipped with such sophisticated instruments.

And we are now at the stage of Mars exploration where samples must be brought back to these laboratories to answer the questions I've outlined above. In such laboratories chemical clues to the early history of Mars, at concentrations well below what can be detected with onboard instruments, can be measured. Finding evidence of past Martian life, whether chemical or physical, requires very powerful and bulky microprobes, as searches for life in the most ancient sediments on Earth have shown. And to put the chronology of Martian history on an absolute timetable requires precise radiometric dating techniques possible only in a terrestrial laboratory. Such techniques were applied to the samples brought back by astronauts from the Moon, establishing an absolute chronology for the earliest history of the Earth-moon system and tying it to what was happening at the end of planet formation—the most important and a truly profound scientific outcome of the Apollo program.

But it is not enough to have these sophisticated geochemical tools in the lab. The samples themselves must come from the right place on Mars—a place self-evidently once Earthlike. Enter NASA's Perseverance rover, which landed in 2021 in a medium-sized crater named Jezero. At the crater's western end is a river channel and a huge pile of sediments that are like "delta fans" on Earth, deposited where rivers meet the sea. Today Jezero's river channel holds no water and the delta fan sits on a dry and barren crater floor. Perseverance is collecting samples of the crater floor, the delta fan, the hills above it, and soon the rim of the crater, where material from deep in Mars -- excavated by the impact that formed the crater-- may have been deposited. Beyond the crater itself, orbital data suggest that the surrounding area may have once hosted ancient hydrothermal systems, places where water reacted with hot rock. This single complex region on Mars holds the potential for answering a host of questions about geologic and climate evolution of Mars—what happened, and equally importantly, when. But to realize that potential requires getting those tubes off Perseverance and delivering them to Earth. That is the goal of Mars Sample Return, of which the Perseverance mission is step one.

Mars Sample Return is the most ambitious robotic program ever attempted by the United States, and of course by any other nation. It involves multiple NASA centers and the European Space Agency. Much of the technology is new and challenging. Having served as a member of the Standing Review Board, and then the second Independent Review Board last year, I am supremely confident that it can and will be done. It *can* be done because American engineering prowess is up to the task. It *will* be done because as a nation we will not simply walk away from a daring, highly visible, and scientifically important challenge. I understand that there are severe budget pressures, and that choices must be made. But the

benefit of succeeding in bringing back rock and soil from an ancient riverbed on a planet 140 million miles away is that it will tell the world that this nation has the imagination, will and courage to accomplish just about anything. And that message is priceless. To not complete Mars Sample Return—to leave the samples stranded on Mars—would be, as I wrote in a recent op-ed on CNN.com, a national disgrace.

In closing, let me point out that, more than a half century after the first Moon rocks were returned by the Apollo astronauts, science is still being done on them. And the instruments available today are far more capable than those available in 1969, allowing new information to be gleaned. The samples returned from Mars in the coming decade will be analyzed, not only by scientists active today, but by scientists who are not yet born, using laboratory techniques not yet invented. They will be a lasting legacy of American ingenuity.

Thank you.

Biography:

Jonathan I. Lunine is the David C. Duncan Professor in the Physical Sciences and Chair of the Department of Astronomy at Cornell University. He is interested in how planets form and evolve, how they maintain or lose their ability to host life, and whether life exists elsewhere in our solar system and beyond. He pursues these interests through theoretical modeling and participation in spacecraft missions. He was an interdisciplinary scientist on Cassini/Huygens, is co-investigator on the Juno mission, is on MISE (as co-I), gravity science (as team member) on Europa Clipper, and the 3GM gravity experiment on ESA's JUICE mission to Ganymede. He served on the Science Working Group of the James Webb Space Telescope as an Interdisciplinary Scientist, which he is currently using for characterization of extrasolar planets and Kuiper Belt objects. Lunine has contributed to concept studies for solar system and exoplanet characterization missions. Lunine is a member of the National Academy of Sciences and has chaired or co-chaired numerous advisory and strategic planning committees for the Academy and for NASA, including the Giant Planet Systems panel for the Planetary Science and Astrobiology Decadal Survey 2023, and "Pathways to Exploration: Rationales and Approaches for a U.S. Program of Human Space Exploration," which he co-chaired in 2014 with Mitch Daniels. Lunine received a B.S. in Physics and Astronomy from the University of Rochester in 1980 and a Ph.D. from the California Institute of Technology in 1985.

Jonathan Lunine,

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 402 Space Sciences Building • Ithaca NY 14853
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Lunine is interested in how planets form and evolve, what processes maintain and establish habitability, and where might life be present in the solar system and beyond. He pursues these interests through theoretical modeling and participation in spacecraft missions. He was an interdisciplinary scientist on Cassini/Huygens, is co-investigator on the Juno mission, is on MISE (as co-I), gravity science (as team member) on Europa Clipper, and 3GM on ESA's JUICE mission to Ganymede. He was an interdisciplinary scientist on the James Webb Space Telescope, which he is currently using for characterization of extrasolar planets and Kuiper Belt objects. Lunine has contributed to concept studies for solar system and exoplanet characterization missions. Lunine is a member of the US National Academy of Sciences and recently chaired the Giant Planet Systems panel for the Planetary Science and Astrobiology Decadal Survey published in 2023.

Education

Ph.D. Planetary Sciences, California Institute of Technology, 1985
 M.S. Planetary Sciences, California Institute of Technology, 1983
 B.S. Physics and Astronomy, *Magna cum Laude*, with Distinction, University of Rochester, 1980

Current Positions

2019–present Chair, Department of Astronomy, Cornell University
 2011–present David C. Duncan Professor in the Physical Sciences, Cornell University
 2007–present David P. Baltimore Distinguished Visiting Scientist, NASA JPL

Selected Honors and Awards

2015 Jean Dominique Cassini Medal European Geosciences Union
 2009 Basic Science Award, International Academy of Astronautics
 2003 Fellow, American Association for the Advancement of Science
 1995 James B. Macelwane Medal, American Geophysical Union
 1990 Zeldovich Award, Commission B, COSPAR, International Council Scientific Unions
 1988 Harold C. Urey Prize, Division for Planetary Sciences, American Astronomical Society

Current and Recent Mission Experience

2015–present Co-investigator, MISE, Team member Gravity Science, Europa Clipper.
 2005–present Co-investigator, Juno New Frontiers Mission
 2002–2022 Interdisciplinary Scientist Astrobiology, JWST
 1990–2018 Interdisciplinary Scientist, Cassini-Huygens

Recent Advisory Experience

2021–2022 Panel chair, Giant Planet Systems, Decadal Survey of Planetary Sci and Astrobio.
 2012–2014 Co-Chair, National Res Council (NRC) Committee on Human Spaceflight

Published papers

420 refereed papers/chapters, 3 books. (List available). Google scholar H-index 111 (career)

Chairman BABIN. Thank you very much for your testimony.
I would now like to recognize Mr. Young for 5 minutes. Thank you.

**TESTIMONY OF MR. A. THOMAS YOUNG, FORMER DIRECTOR,
GODDARD SPACE FLIGHT CENTER AND FORMER PRESIDENT
AND COO, MARTIN MARIETTA CORP.**

Mr. YOUNG. Chairman Babin, Ranking Member Sorensen, Committee Members, I'm pleased to have the opportunity to present my views on NASA's Science Mission Directorate.

Great organizations achieve great accomplishments. NASA's Science Mission Directorate has a legacy of great accomplishments. My examples of great accomplishments by SMD are Viking, Hubble, James Webb Space Telescope, and hopefully, Mars Sample Return. Others might select a different set with equal merit. It would also be a mistake not to recognize the incredible contribution of projects from the sounding rocket and balloon program to projects such as Parker Solar Probe and weather satellites.

What are the characteristics of projects that result in great accomplishments? Today, projects such as JWST and MSR originated from decadal surveys. The National Academies' decadal surveys are comprehensive surveys of a scientific discipline such as astronomy and astrophysics to identify the No. 1 priority project for development by NASA. The surveys provide a mechanism for the scientific community to speak with one voice in identifying the best of the best.

Projects that result in great accomplishments travel extremely difficult development paths. Projects in this category push the boundaries of what is possible. This aggressive approach is necessary to obtain extraordinary scientific results such as JWST results that are being experienced today.

The difficult developmental path these projects follow are populated with incredible engineering, cost, and management challenges. Most, if not all, are threatened by cancellation.

So what are the keys to the success of these projects that must test the limits of what is possible? Clearly, the exceptional people that make up the project organizations in NASA, academia, and industry are key. Superior leaders are required to provide bold and visionary leadership, leadership that recognizes corrective action and not cancellation is necessary to achieve great accomplishments.

The scientists, engineers, and leaders do not simply walk in off the street. They're a result of rigorous hands-on development and being trusted with significant early career responsibilities. NASA has a history of exceptional employee development. This development effort will be even more important as SMD pursues more challenging projects in the future.

Next, I would like to discuss MSR. Today, MSR is in the balance as to whether it will be allowed to follow the path necessary to become an SMD great accomplishment, or will it become a monument to a missed opportunity? I do not want to minimize the technical cost and management problems identified by the Independent Review Board. The problems are significant, as are NASA's and our country's budget challenges.

MSR is identified as the No. 1 priority in the past two planetary decadal surveys. The expectation is clear, that when the samples are analyzed in the highly capable Earth-based laboratories, MSR will join the SMD legacy great accomplishments. Today, the future of MSR is in the hands of NASA, congressional, and Administration leaders. Bold, visionary leadership is needed to put MSR on a path to success.

The future of SMD is populated with incredible opportunities. Many are focused upon civilization's great question: Are we alone? We must continue to improve our project management capabilities to realize the potential that the future holds. My thoughts on some of the required improvements are cost estimating. Better cost estimating of most probable cost and not relying upon lowest credible costs for early decisionmaking is required.

Systems engineering: Improved systems engineering is needed to develop architecture and interfaces that are the simplest possible to achieve project objectives.

Employee development: Developing scientists, engineers, and leaders will continue to grow in importance. Contracts with industries that focus upon buying services as opposed to hardware, systems integration, operations, et cetera, minimize development opportunities.

SMD strategy: A balanced SMD strategy is a worthy objective. However, implementing projects such as Viking, Hubble, JWST, and MSR will likely not be possible without accepting some impact on other activities. This should be acceptable to accomplish great accomplishments.

Project management: Future projects will require the full capabilities of NASA. This includes NASA senior management, the Science Mission Directorate, and the NASA centers, including center directors, project managers, and their respective organizations.

The hallmark of a great organization is the willingness to accept difficult challenges to achieve great accomplishments. I believe SMD is such an organization and that the future of SMD will be bold, exciting, scientifically rewarding, and a source of great national pride.

Thank you very much.

[The prepared statement of Mr. Young follows:]

**TESTIMONY TO THE COMMITTEE
ON
SCIENCE, SPACE AND TECHNOLOGY

SPACE AND AERONAUTICS SUBCOMMITTEE**

MARCH 21, 2024

A. THOMAS YOUNG

Chairman Babin, Ranking Member Sorensen and Committee Members, I am pleased to have the opportunity to present my views on NASA's Science Mission Directorate.

Great organizations achieve great accomplishments. NASA's Science Mission Directorate (SMD) has a legacy of great accomplishments. My examples of great accomplishments by SMD are Viking, Hubble, James Webb Space Telescope and hopefully Mars Sample Return (MSR). Others might select a different set with equal merit. It would also be a mistake not to recognize the incredible contributions of projects from the Sounding Rocket and Balloon Program, to projects such as the Parker Solar Probe and Weather Satellites.

What are the characteristics of projects that result in great accomplishments? Today projects such as JWST and MSR originated from Decadal Surveys. The National Academies Decadal Surveys are comprehensive surveys of a scientific discipline such as Astronomy and Astrophysics to identify the Number 1 priority project for development by NASA. The Surveys provide a mechanism for the scientific community to speak with one voice in identifying the best of the best.

Projects that result in great accomplishments travel extremely difficult development paths. Projects in this

category push the boundaries of what is possible. This aggressive approach is necessary to obtain extraordinary scientific results such as the JWST results that are being experienced today. The difficult development paths these projects follow are populated with incredible engineering, cost and management challenges. Most, if not all, are threatened by cancellation.

So, what are the keys to the success of these projects that must test the limits of what is possible? Clearly, the exceptional people that make up the project organizations in NASA, academia and industry are key. Superior leaders are required to provide bold and visionary leadership. Leadership that recognizes corrective action and not cancellation is necessary to achieve great accomplishments. These scientists, engineers and leaders do not simply walk in off the street. They are the result of rigorous “hands on” development and being trusted with significant early career responsibilities. NASA has a history of exceptional employee development. This development effort will be even more important as SMD pursues more challenging projects in the future.

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it become a monument to a missed opportunity? I do not want to minimize the technical, cost and management problems identified by the Independent Review Board (IRB). The problems are significant, as are NASA's and our country's budget challenges.

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Cost Estimating: Better cost estimating of "Most Probable Cost" and not relying upon "Lowest Credible Cost" for early decision making is required.

Systems Engineering: Improved systems engineering is needed to develop architecture and interfaces that are the “simplest” possible to achieve project objectives.

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SMD Strategy: A balanced SMD strategy is a worthy objective; however, implementing projects such as Viking, Hubble, JWST and MSR will likely not be possible without accepting some impact on other activities. This should be acceptable to achieve great accomplishments.

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The hallmark of a great organization is the willingness to accept difficult challenges to achieve great accomplishments. I believe SMD is such an organization and that the future of SMD will be bold, exciting, scientifically rewarding and a source of great national pride.

A. Thomas Young

A. Thomas Young is the former Director of NASA's Goddard Space Flight Center, President and COO of Martin Marietta and Chairman of SAIC. He retired from Lockheed Martin in July, 1995 and the SAIC Board in 2013. Mr. Young is involved in various advisory and review activities associated with the U.S. Space Program.

Mr. Young began his career with NASA at the Langley Research Center in 1961. He was a member of the Lunar Orbiter Project Team and was Mission Director for Project Viking, which resulted in the successful landing of two spacecraft on the surface of Mars. He became Director of the Planetary Program at NASA Headquarters in 1976 and was appointed Deputy Director of the Ames Research Center in 1978. Mr. Young was Director of the Goddard Space Flight Center from 1979 to 1982. He joined the Martin Marietta Corporation in 1982 and was subsequently President of Baltimore Aerospace and the Electronics and Missiles Group. Mr. Young was President and COO of Martin Marietta from 1990 to 1995.

Mr. Young is a Honorary Fellow of the American Institute of Aeronautics and Astronautics, a Fellow of the American Astronautical Society, a Fellow of the Royal Astronautical Society and a Fellow of the International Academy of Astronautics. He is a member of the National Academy of Engineering and the University of Virginia Raven Society. Mr. Young is a former member of the NASA Advisory Council.

Mr. Young earned a bachelor of aeronautical engineering degree and a bachelor of mechanical engineering degree in 1961 from the University of Virginia. In 1972 he received a masters of management degree from MIT which he attended as a Sloan Fellow. He also holds a honorary doctor of science degree from Salisbury University.

Chairman BABIN. Thank you. I appreciate all of you witnesses for your testimony.

And now I would like to recognize myself for questions for 5 minutes.

Dr. Fox, NASA stood up an internal group to develop a response to the second independent review team's assessment of the Mars Sample Return program. When will NASA be prepared to share the results of this internal review with Congress? We want it to be successful.

Dr. FOX. Thank you so much for the question. We are wrapping up the—putting together the results. They will be available in the spring. And so—but literally, as soon as we can get them to you, we will.

Chairman BABIN. Good. Today, I think, is the first day of spring. You don't have it ready yet, huh?

Dr. FOX. Spring's a lovely term.

Chairman BABIN. All right. All right. Well, thank you.

Congress—also for you, Dr. Fox, Congress directed NASA to discover and characterize at least 90 percent of the Near-Earth Objects, or NEOs, that could cause significant damage if they collide with Earth. NASA is years behind the deadline that Congress set to complete this survey, which is one of really the only—one of the few tasks that NASA is directed by law to complete. The NEO Surveyor mission is an important part of completing this survey. And what is the status of the NEO Surveyor mission?

Dr. FOX. Happy to say that NEO Surveyor is on track. It will launch in 2028, and we really do appreciate the support that we've had to keep that mission funded through even this challenging year. So NEO Surveyor is looking good.

Chairman BABIN. Good deal. Thank you.

Mr. Young, in September 2020, NASA's Office of Inspector General, the OIG, released a report on NASA's planetary science portfolio. The report highlighted NASA's challenges in adhering to Discovery-class mission cost caps. In particular, the report stated that even when excluding launch vehicle and operations costs, none of the Discovery missions are under the \$500 million cost cap. What are the consequences of breaching a cost cap? Does a tolerance for cost-cap breaches have an impact on program discipline for future Discovery-class missions? And how are other non-Discovery-class missions in the pipeline going to be impacted when these cost caps are breached?

Mr. YOUNG. Well, I think you summarized it pretty well. That will happen. It's important to look back as to why the cost breaches. And one of the items is that we continually, for good scientific reasons, select more and more challenging opportunities. And as we do push technological limits, we are in a circumstance where a priori understanding of the precision of the cost is just not there. So I think that, you know, if we wanted to have less testing of the cost or the schedule limits, it really says select projects that are less challenging. The problem with that is they're also less rewarding, and so it's a difficult circumstance, and it's one that that Nicky and her organization have to really balance. But what you described is true. If they're all increasing in cost, they're going to push something else out that's not going to—

Chairman BABIN. That's right.

Mr. YOUNG [continuing]. Be able to fit into the project—into the budget. But—

Chairman BABIN. OK.

Mr. YOUNG [continuing]. On the other hand, testing where you get the best return for the amount of money that is expended is something that deserves an awful lot of scientific analysis and systems engineering analysis before projects are implemented.

Chairman BABIN. Thank you. Mr. Scott, in February 2024 NASA's Office of Inspector General issued a report on the Mars Sample Return, or the MSR program, as we've heard several times today. The report noted that characteristics intrinsic to big and complex missions like the MSR program are hard to quantify in estimates but can drive project costs upwards throughout development. The report stressed that NASA must consider these intrinsic characteristics and cannot attribute past cost growth to inflation, the COVID-19 pandemic, or to supply chain issues. Can you describe these intrinsic characteristics of large missions and their effects on the cost program?

Mr. SCOTT. Thank you, Mr. Chairman.

Chairman BABIN. Or the program costs rather.

Mr. SCOTT. Thank you, Mr. Chairman. Yes, as we've discussed already in the statements, just a number of factors continue to drive the cost increases in large programs like the Mars Sample Return, whether it's the initial baseline estimates either provided by the decadal, which are early on and often lack the complete picture of what some of these missions will cost. You know, there's also workforce issues that can end up driving the cost—increased cost for these missions. The lack of maturity of some of the technology is also a key driver in some of these large, complex missions. That's why we think it's important for NASA to start to implement some of the recommendations from the Large Mission Study to better inform going forward where you put the attention early on in these large projects.

Chairman BABIN. OK. Thank you. And it looks like I'm out of time, so I'd like to recognize the Ranking Member, Mr. Sorensen.

Mr. SORESEN. Thank you, Mr. Chairman.

I'll begin with Dr. Lunine. Last year, I was able to welcome NASA Astronaut Dr. Kate Rubins to my district. And over the course of 2 days' time, we visited numerous schools. And it was really great to hear her explain the importance of what we are learning from the Apollo mission and what we were able to bring back from the lunar surface. Could you please expand on what scientists will be able to learn with the samples that we hope to get back from the Mars surface?

Dr. LUNINE. Sure, thank you very much for the question. The—to answer that question, I will go into my hourlong lecture, but since I don't have that time—

Mr. SORESEN. Four minutes and 10 seconds.

Dr. LUNINE. Yes, I'll give you four points. So, first of all, we do not have a chronology of the early history of Mars that's on an absolute timetable. That is, we know the relative times that events happened but not the absolute times. And for the Earth and the Moon, the Apollo samples gave us that for the Earth-Moon system.

That was one of the most profound scientific accomplishments of Apollo, to know the dates that things happened. And so we'll learn that for Mars from those samples from what's called radiometric dating. And that can be done—really needs to be done in terrestrial laboratories because you have to be able to look at what are called multiple isotopic systems to do that, so I'll leave it at that.

Second, we will learn about the question of whether organic molecules were present with the water and what the nature of those organic molecules were. You can detect some organic molecules on Mars itself, but it's a very faint signature, and to be able to detect molecules that are not well-preserved requires instruments that can detect abundances that are well below what you can bring to Mars.

No. 3, of course, question of life and whether there are—is fossil evidence of life. The experience of geologists on the Earth with very ancient life is that it requires laboratory instruments to find the chemical and physical clues because those clues over billions of years have become very, very faint, and the same for Mars.

And the third is that because the crater that Perseverance is in is formed by an impact, it excavates material from deeper under the crust. And so to be able to sample that material and bring it back to Earth and determine the mineralogy of that material is an outstanding opportunity to know what's underneath the dusty surface of Mars. And I'll leave it at that.

Mr. SORENSEN. Yes. Thank you for sharing. You could probably talk for a long time on this subject.

Dr. LUNINE. I could, yes, that's true. Yes.

Mr. SORENSEN. I do want to go to Dr. Fox. Let's bring this back to our planet. The Landsat satellite system has provided continuous land imagery of our globe for 50 years, not just as a meteorologist have I use this data, but the University of Illinois has utilized this in agriculture. And then also I'd be remiss if—most of us on Capitol Hill are a little bit raspy today because of the fires out in western Virginia or the fires in the western part of the Chairman's State of Texas. How will NASA's development of the next generation of Landsat satellites, Landsat Next, be important for districts like ours?

Dr. FOX. That's a wonderful question. And I, like Jonathan, could give you an hour lecture. But, I mean, Landsat is a critical part of, I mean, our complete Earth monitoring system. And, as you note, you know, wildfires do not follow boundaries. They don't follow State boundaries. We all breathe the same air, as we found last year from the Canadian wildfires.

So a lot of our new missions, Landsat clearly, you know, set to take that next step, next step for Landsat Next. It's really a different generation of Landsat. It—also, I would be remiss if I didn't mention our Surface Biology and Geology Mission that will also just give us these unprecedented views of what—you know what we are doing. We just launched PACE, and that is not only telling us about ocean health, but also about the health of the air that we breathe. So Landsat, clearly a very key part, but it really is in this sort of strength of bringing all of these diverse measurements together to really allow us to do a great job of characterizing our planet.

Mr. SORENSEN. I want to be cognizant of time, so really quickly, Mr. Young, you stated that there are difficult development paths. The projects that result in great accomplishments travel extremely difficult development paths. What do you think we in Congress need to do to consider when we are looking at these projects at?

Mr. YOUNG. Well, I have a quick summary. I would say that we need to look at the difficulties that have occurred and apply lessons learned to the next series that exist. And that is, I think we know that we've got issues in cost estimating. We've got issues in systems engineering. We've got issues in developing the required talent to implement these programs. And we need to very clearly specify them and have a coordinated effort to improve significantly in order to be able to do the challenging things that are in front of us in SMD.

Mr. SORENSEN. Thank you. Learn from the past to make good decisions for the future.

Mr. YOUNG. Absolutely.

Mr. SORENSEN. Thank you, Chairman.

Chairman BABIN. Thank you.

I'd like to recognize the gentleman from Florida, Mr. Posey.

Mr. POSEY. Thank you very much, Chairman Babin. And I want to thank the witnesses for your illuminating testimony today, very, very much appreciated.

Mr. Scott, has the way NASA managed its high-end computer capabilities hampered at all in any way that you know its ability to properly monitor the foreign national accreditation access process?

Mr. SCOTT. Thank you, Mr. Posey. As we recently reported, we did raise issues about the 700-plus foreign nationals that today have been identified accessing the high-end computing capabilities. Again, the issues that came to light were one of the ability to better understand the number of high-end computing—high-end computing systems NASA has running, it's diffuse, spread out across the various centers, and being able to better understand and track and monitor who's actually on the system and ensuring that these diffuse systems have the adequate cybersecurity controls.

Mr. POSEY. Thank you. Do you think the use of NASA's high-end computing by external and foreign national parties is as persuasive as the Inspector General's report might have indicated?

Mr. SCOTT. Again, we've asked NASA to set up a tiger team to look and better understand the number of external users and foreign nationals accessing the system, right? It's a both/and, right? It's important for scientific reasons that folks have access to the high-end computing, and it's equally important that we understand who these folks are, what they're accessing, and being able to track and monitor their use of the systems.

Mr. POSEY. Thank you. Of the more than 700 foreign nationals the IG report says have accessed this system, are you aware of any from any country of concern such as China or the cities of Macao or Hong Kong?

Mr. SCOTT. I'm not aware of any foreign national—from any countries of concern. NASA does have a foreign national accreditation process, and so my understanding is the folks on the system have gone through that process. What we're asking NASA to do is ensuring—to better ensure that the folks responsible for the high-

end computing capabilities are part of the accreditation process and, again, making sure these systems are up-to-date in terms of their cybersecurity controls and we're able to monitor the activity of those on the system.

Mr. POSEY. That's great.

Has NASA expeditiously implemented the recommendations in the Inspector General's report?

Mr. SCOTT. We're awaiting their responses. We believe that their initial responses will address the recommendations we made, but again, we're waiting to see exactly when they're implementing the various recommendations.

Mr. POSEY. OK. Dr. Fox, is NASA working to fully implement the Inspector General's recommendations concerning high-end computer capabilities to restrict access by external and foreign national parties?

Dr. FOX. NASA really appreciates the receipt of the report from the Inspector General's Office, extremely helpful report. We are in the process of implement—of responding to each of the recommendations and putting together the team as requested to actually do this deep-dive study.

Mr. POSEY. OK. Mr. Chairman, I ask unanimous consent to include in the record the March 2024 NASA's Office of Inspector General report.

Chairman BABIN. Without objection, so ordered.

Mr. POSEY. Thank you, Mr. Chairman. I yield back.

Chairman BABIN. Yes, sir. Thank you.

And now I'd like to recognize the gentlewoman from Virginia, Ms. McClellan.

Ms. MCCLELLAN. Thank you, Mr. Chairman.

As the only Member of the Committee from Virginia, I'm particularly proud of the work being done at Langley Research Center, which I've had the opportunity to visit, their work to advance science not only in the Commonwealth, but around the country.

And I have to say that, as a mother to a son who wants to be an astronomer, he's a keen fan of the work that you all do in the Planetary Science and Helioscience Divisions. He has used images from the Hubble and James Webb Space Telescope for school presentations and is a junior volunteer at the Science Museum of Virginia. And those images have sparked an interest in STEM (science, technology, engineering, and mathematics) more than anything that his father and I have ever put in front of him. And I am very hopeful that he will one day be one of those scientists that Dr. Lunine talked about who will be studying samples brought back from Mars.

And thank you very much for the glasses because he told me the other day that we needed special glasses because he's very much looking forward to the eclipse. So you have definitely gotten me some cool points today.

We know that funding stability is essential to maintaining a highly skilled workforce, which enables our continued national leadership in research, innovation, and exploration. And Dr. Fox and Mr. Scott, could you tell us if the President's Fiscal Year '25 budget request sufficiently funds the Science Mission Directorate to

prevent future workforce reductions or some of the challenges you've discussed today?

Dr. FOX. Thank you very much. I'll be happy to yield an extra pair of glasses for your son——

Ms. MCCLELLAN. Thank you.

Dr. FOX [continuing]. To be sure that he's protected, too.

We're very grateful for the President's budget request, the Fiscal Year 2025 President's budget request that does fund NASA at \$7.565 billion for science. That is below the enacted 2023, so it does provide challenges in the portfolio. The bulk of those challenges are in the Planetary Science Division, as you noted, and we are working very closely with our centers, with our teams to try and limit the impact of those reductions.

Ms. MCCLELLAN. And can you tell me what strategies NASA is implementing to prevent attrition and ensure the stability of your workforce?

Dr. FOX. Again, we're working extremely closely with the centers to understand any impacts of the various challenges, obviously, with Mars Sample Return, with the—following the recommendations from the IRB. We did do—we have paused the development of some of the aspects of Mars Sample Return while we look at all of the architecture, the different architecture studies. And so as I know everybody is aware, that did cause some workforce losses at the Jet Propulsion Lab, which, of course, our hearts go out to anyone who has to do that. But that was done as a result of budget limitations there. But we are working extremely closely with all of our centers and, of course, with JPL to try and minimize and, more importantly, to actually sustain the critical workforce that we need to be able to do these amazingly daring missions that we want to succeed with.

Ms. MCCLELLAN. And could you discuss any potential impacts to the Science Mission Directorate projects at Langley specifically if NASA's top-line fund either remains flat or these cuts take place?

Dr. FOX. I don't have a full—so we—let me start again. So for Langley, the biggest impact will be in the Earth Science Division because of some of the delays and the change and the way that we will be implementing some of the Earth science missions, so there will be some impact to Langley there. They also do have critical work with us in Mars Sample Return, and—but they do—also have worked with Dragonfly, which is well-funded, and so we're hoping to be able to balance between some of the missions that have—that are more robustly supported and some that may be a little skinny down in the Fiscal Year 2025 plan.

Ms. MCCLELLAN. OK. And in my remaining time, you may not be able to answer this here, so I'll submit this for the record, but your Bridge Program that develops partnerships between your centers and institutions that are historically under-resourced like minority-serving institutions, community colleges, and tribal colleges, I wonder if you could, for the record, provide an update on the status of the Bridge Program and some of its outcomes?

Dr. FOX. We'd be very happy to provide that for the record. I know the time's done, but I will say we are really, really excited about our Bridge Program for all the reasons that you—it's always nice to be able to offer people opportunities, but to be able to actu-

ally support them to be able to take advantage of those opportunities is what we're doing with our Bridge Program, so thank you for the question.

Ms. MCCLELLAN. Thank you. Mr. Chairman, I yield back.

Chairman BABIN. Yes, ma'am. Thank you very much.

I'd like to recognize the gentleman from California, Mr. Garcia.

Mr. GARCIA. Thank you, Mr. Chairman. Thank you all for being here, to all the witnesses, and your contributions to the country and to science and to our Nation's security.

You won't find a bigger fan on the Hill of NASA and the private-public partnerships that we're enjoying. This is a true space renaissance. And I should say that with all deference, Mr. Chairman, you probably are just as big a fan of NASA and the private partnership as I.

And so, you know, this is not coming from a place of being combative, but trying to be cooperative in the spirit of being successful for these missions, especially the science and national security implications that a lot of these missions carry with them. And while I appreciate the eclipse sunglasses, I would have preferred a set of glasses that would have prevented me from being blindsided by the actions that the Administration has taken over the last few months when it comes to the Mars Sample Recovery program.

Mr. Young said that the fate of MSR is in the hands of NASA, as well as Congress, and I disagree with that. It certainly doesn't feel that way. I think we have a better relationship than what I think you assumed. And you left us in the dark, frankly, with some reprogramming that took place under loopholes during the CR (continuing resolution).

As the authorizer on this Committee and as the appropriator on CJS (Commerce, Justice, Science), I would have really appreciated a heads-up that we were going to lay off close to 600 employees at JPL before that decision was made. I was aware of before it was executed, but not before that decision was made. And we have caused irreparable damage in those decisions. And I understand that the Senate mark was at \$300 million and ours was \$975 million, and we were in the midst of a CR, and there's a lot of uncertainty and ambiguity there. And as a former, you know, program director myself of \$100 million programs, I understand that that uncertainty is not good.

But we could have cooperated, we could have communicated, and we could have landed on a place where maybe we should have preserved those jobs. And what's happening now is those folks that were at JPL aren't just leaving JPL, they're leaving the industry. In many cases, they're leaving the State, and we're losing a cumulative of anywhere between 3,000 years and 5,000 years of corporate knowledge of engineering and design and early development design work expertise that ain't coming back. And so I don't know how we're going to address the workforce issues.

It was a premature decision. It was prior to the IRB Response Team recommendations that we're expecting here in the spring. And I understand you can drive a truck between the \$300 million and the \$975 million or so that the House marked, too, and that's uncertainty. And I definitely have received your message that CR's are bad, but I think you exploited that. I think you exploited loop-

holes in the C.R. language to fund a level that is well below congressional intent and certainly well below executability level.

So I've submitted a letter to the Administration, to Administrator Nelson with 20 colleagues. By the way, I'm the only Republican on this letter, so this is a bipartisan thing from California, requesting that you fund MSR at \$650 for the remaining part of Fiscal Year 2024. I understand that's going to require some reprogramming and different profiles on your cost expenditures. We'd like to see a response to that. But I think we are also asking to not have any other reductions in forces, riffs, or layoffs as a result of the decisions already made so that we can try to salvage what workforce talent we have there as well.

So I guess, Dr. Fox, my question is, will you comply with the direction in the Fiscal Year 2024 spending bill, which hopefully will be executed here shortly, to not further reduce staff on the Mars Sample Return program?

Dr. FOX. So thank you for the question. And as you—really, thank you for your unwavering support of the Mars Sample Return. I really genuinely mean that, and I really do appreciate your support on that.

We did brief Congress a number of times, the appropriations, on the plans for Mars Sample Return. I think I actually had the pleasure of speaking to you myself.

Mr. GARCIA. I appreciate that.

Dr. FOX. And, you know, with the uncertainty, if we had allowed the spending on Mars Sample Return to continue at—or to continue at the 2023 level, we would have reached the *Anti*—

Mr. SCOTT. *Deficiency*.

Dr. FOX [continuing]. *Antideficiency*, thank you, *Antideficiency Act* before February. And of course, we did not want to in any way do that. So we took the measures to limit and to actually follow the recommendations of the Independent Review Board.

Mr. GARCIA. I'm running out of time. I want to ask a question looking forward. Looking forward for the rest of the fiscal year, are you committed to not reducing additional staff? And will you commit to allocating sufficient funding in Fiscal Year 2024 and 2025 to ensure the timely retrieval of samples of Mars? And I want to be very clear. I support you. I support NASA and this program, but it's not unwavering. If we continue to show premature and, in my opinion, reckless behavior patterns at our reprogramming, I will want to do deeper dives into the program and ask even more questions. But if you can answer the questions for the record, you commit to retaining the current staff levels as they are for the rest of year moving forward, and in Fiscal Year 2025, continuing to follow our congressional intent with funding levels to execute the program sufficiently.

Dr. FOX. So we look forward to the results of the Independent Review Team that will be coming out in the spring, and we certainly commit to work closely with JPL to continue to maintain the critical workforce that will be necessary to do these missions.

Mr. GARCIA. OK. I thank you. I'm out of time. I yield back.

Chairman BABIN. Thank you, Mr. Garcia, good questions. I'd like to call on Mr. Strong, my friend from Alabama.

Mr. STRONG. Thank you, Chairman Babin, Ranking Member Sorensen, and our witnesses for their testimony today.

I understand two proposals from Marshall Space Flight Center were not selected in a recent Science Mission Directorate call. These proposals were for concepts called MoonBEAM (Moon Burst Energetics All-sky Monitor) and LEAP (Large Area Burst Polarimeter). MoonBEAM was the highest-rated astrophysics proposal and the only proposal to receive a category one rating, the highest rating possible.

Dr. Fox, Mr. Scott, what is holding NASA back from making these competitive awards?

Dr. FOX. Thank you for the question. There are many factors that go into why a mission—why things are selected and not selected. And for this particular one, we did not have the resources available to be able to support a mission of opportunity.

Mr. STRONG. OK. The Mars Ascent Vehicle also just successfully finished its performance development review and successfully completed wind-tunnel testing at Marshall Space Flight Center. The Mars Ascent Vehicle, a crucial element of Mars Sample Return program, is a top priority within the decadal—I think that's the program they call it—the survey. Dr. Fox, Mr. Scott, what is NASA doing to meet its commitment to the survey's priorities?

Dr. FOX. Yes, as you note, it was the highest priority not only of the current decadal but of the previous decadal to bring our samples back from Mars, as Jonathan also talked about. We are—at the moment, we are reassessing. We had that Independent Review Board that released their findings last October. We are—we have an independent team at NASA that is going through each of those findings.

And so while we're looking at the restructuring that was recommended by that Independent Review Board, we do have some elements of our Sample Return paused because we are being good stewards of taxpayer money, and we don't want to go forward and spend money that would then not be realized. So that is the plan, but stay tuned. In spring, we will roll out the results of that—of the—or the findings of that team and hopefully get Mars Sample Return back on a path to be able to bring those extremely precious samples back from the red planet.

Mr. STRONG. Thank you. We're anxiously awaiting.

Marshall Space Flight Center also hosted ISS (International Space Station) Payload Mission Control Center, which manages many research payloads aboard the ISS. Dr. Fox, how does NASA's plan to ensure that researchers can seamlessly transition their experiments from the ISS to the commercial LEO (low-Earth orbit) destinations as they become available?

Dr. FOX. That's a great question. I could talk for hours about the great stuff that we do on ISS, trust me. But we have—we are investing. We're working with our partner agencies, with NIH (National Institutes of Health), with the FDA (Food and Drug Administration), with the Human Research Program, of course, and with BARDA (Biomedical Advanced Research and Development Authority), our Biological and Physical Sciences Division. I think they have about an \$18 million investment right now in things like tissue chips, so growing organs and sending up—I mean, you could

actually envisage sending up a mini-you on a chip and then looking at how you respond to different medications.

And so being—basically being—planning to do this sort of rapid development and working hand-in-hand with our commercial partners to look at exactly what it would take to transition from this critical science that we do on the ISS and get it ready to enact on whichever of the commercial LEO destinations that we go with. Obviously, they—when they go up—when they put these in space, they want to use them, and so biological and physical sciences is a great customer, and we are ready to do amazing things, whether it's growing plants, looking at yeast and seeds and how they adapt.

Also, I'll just note, you know, already taking advantage of Artemis with flying on Artemis I, flying a biological physical payload there, and getting ready to roll out the science that we're going to do on Artemis II as well, so just excited about the whole thing.

Mr. STRONG. I can tell the excitement in your voice. And I thank each of you for being here today and the role that you play.

Mr. Chairman, I yield back.

Chairman BABIN. Yes, sir. Thank you, Mr. Strong.

And I'd like to call now on our Full Committee Chair, Mr. Lucas.

Chairman LUCAS. Thank you, Mr. Chairman.

And to Mr. Young, when I joined this Committee more than 20 years ago, the James Webb telescope was in the early stages of formulation. And over that period, this Committee engaged in extensive oversight of the development of the program. You led the Independent Review Board that assessed the status of the telescope and testified this—to this Committee about the results. From your vantage point, is NASA integrating lessons learned from the development challenges of James Webb? And it was a challenge.

Mr. YOUNG. And there were challenges, that's no question. In fact, you brought back a lot of interesting memories.

Chairman LUCAS. Oh, absolutely.

Mr. YOUNG. I would say the answer is yes. You know, NASA has put together—and somebody can remind me the name of it—but a group of people that really went about and talked to a lot of people. I was one that spent some time with the group and trying to put together lessons learned. And so, yes, I think there is an effort, you know, to do that.

I think the other thing, though, if I could hitchhike on your question that I need to really emphasize, and you would appreciate this, these missions, the flagship missions that we're talking about that are pushing the boundaries of capability, they are never going to be easy, and they're never going to be free of challenges and difficulties. And I think that we've—you know, the results of James Webb, in my view, maybe doesn't justify all of the issues that you had an opportunity to have a front row seat to, but they really did show with—that the perseverance of trying to get all of the issues under control, particularly those that were technical issues, many of which we found in the IRB that I chaired, came together and really have a system that got—that launched that had 300-and-some single-point failures, any one of which would have been mission-catastrophic. And for all of them to have worked is a credit to NASA and to the engineering capability of a project.

So I'm bouncing around. You're right. I might say, yes, we are learning from it, but I do want to point out that these missions are never going to be easy and free of some of the challenges that exist. We should just get as many of them out of the way as we can in the process.

Chairman LUCAS. And I will remember, Mr. Young, that point in one of the hearings, the discussion that the complexity of the instrument, the complications of the launch, and the fact that we would put it out where we could never go—

Mr. YOUNG. Yes.

Chairman BABIN [continuing]. Put a pair of sunglasses on it, perhaps, the way we'd done Hubble, was very unnerving.

Mr. Scott, your testimony highlights that an issue for many NASA missions is the culture of optimism that results in unrealistic cost and schedule assumptions. Our Committee encourages NASA to pursue bold missions, but how can we encourage NASA to establish more realistic cost and schedule projections for the agency's science missions?

Mr. SCOTT. Thank you, Chairman Lucas. A can-do spirit is helpful and necessary for the things NASA does. That's without question. What we're asking the agency do—to do, though, is continuing to make critical assessments, particularly of these large flagship missions, in terms of costs, schedule, and requirements. And that means asking the hard questions about these missions even if the answers aren't favorable to your project. It's important to balance the sense of optimism and can-do spirit with realism, particularly as it relates to the lack of maturity in some of these technologies, the scientific—balancing that with the scientific value of these missions, but really being able to more fully understand the challenges ahead and try to better balance these cost and schedule issues.

The other issue is the decadal. I'm sort of somewhat sympathetic to NASA. The decadal survey puts out estimates on these projects, but those are early estimates. Those are immature estimates. And yet those become the yardstick by which eventually we start to judge NASA. So I think it's also making sure we better understand what those decadal estimates mean and then holding the agency more accountable as it fully matures and develops these additional estimates.

Chairman LUCAS. Dr. Lunine and Mr. Young, this Committee is working on a NASA authorization bill, and our bill sets NASA policy but does not provide funding for the agency. Recognizing the fiscal environment in which we are operating, how do we set policy for NASA's Science Mission Directorate without creating unrealistic expectations for the agency, which will be difficult to fund? How do we temper our optimism so they can be practical?

Dr. LUNINE. Well, I'm a scientist and not a policy person, Mr. Chairman.

Chairman LUCAS. You're a lucky person.

Dr. LUNINE. Yes, thank you. I know that. I recognize that every day. You know, I would just say that—and this isn't really answering your question, but I feel that the Nation's portfolio of space science projects represents something that, you know, looking back to this time in the future will be seen as one of the remarkable accomplishments of this Nation in terms of what we've done in ex-

ploring the universe and exploring our own Earth, the planets, the Sun. And, you know, being mindful of that, those decisions are very difficult to make. And I—you know, I recognize that, and I hope that those can be made with as much knowledge and perspective as possible.

Mr. YOUNG. If I could add to that, I think one of the things that has to be recognized with the task that you have is that there's a collection of activities that NASA does in the science arena that are probably better understood than something like James Webb Space Telescope is. So I think it's important to have a foundation of programs that advance the scientific understanding but that are not challenging the limits of possibility.

But on the other hand, I think if we look back a decade or two decades from now and we have not been bold in including within the baseline of programs I'm talking about, programs like James Webb, like Mars Sample Return, I think we will collectively be disappointed that we did not pursue the opportunities that were there. And I think, again, what I was saying is pursuing those opportunities is really going to—is what's going to make the road difficult.

I recall, going back to James Webb if I could spend just a minute—and I spent a lot of time up here interacting with—when it was kind of also in the balance. But fundamentally, the—a question I got asked regularly was, was James Webb a step too far? And after I thought about it, bear with me as I answer it, I think the answer is yes. But if we had not taken a step too far, we would not have the incredible results that we have today.

Now, you can't do that with everything, but there are special things like Hubble, like James Webb. And I happen to agree with Jonathan—and like Mars Sample Return, that taking a step a little bit too far is in the best interest of justifying the potential results we come back because it's the flagship missions that are going to kind of provide the James Webb kind of results. And I don't want to minimize the other, but everything can't be done that way. But a program that's absence of those kinds of programs would not be a program that we would be proud of.

Chairman LUCAS. Well put, Mr. Young, and thank you, Mr. Chairman, for indulging me. I yield back.

Chairman BABIN. Yes, sir, good questions. Thank you, Mr. Chairman.

I'd like to call on Mr. McCormick from Georgia for 5 minutes.

Mr. MCCORMICK. Thank you, Dr. Chair. I appreciate you and appreciate the witnesses being here, exciting topic. I will say as a naval aviator, ER doc, and soon-to-be payload specialist, I'm very interested in this topic, especially with NASA and its future activities. I'm worried about some of the things that we need to do to sustain a budget for NASA as we go forward and to be applicable but also accountable simultaneously.

I would be remiss if I did not mention that the Science Mission Directorate seems to be plagued by the same issues as many of NASA's other departments, which constant deadline extensions, flawed cost estimating processes, and poor financial management at times. I hope that today's conversation can lead us to identify key issues and find ways to mitigate these resource constraints.

I'm excited about NASA's successful test of the Double Asteroid Redirection Test, which is DART for most of us others. That program demonstrates the method for deconflicting an asteroid through kinetic impact and the implication it could have as a key to our goal for planetary defense, which I think is kind of cool. We've seen movies on this. I think Bruce Willis had a great depiction of—or maybe it was a documentary, I'm not sure—of how we mitigate that risk in the future because it is a real concern. I mean, we don't know when it's going to be, but we might as well have that capability in the future.

Dr. Fox, now that we have successfully demonstrated the DART program, what's next for this program, and will we create multiple DARTs on standby for possible Near-Earth Objects?

Dr. Fox. What a fabulous question. So the next thing in the planetary defense is the NEO Surveyor, which of course will be critical in characterizing and cataloguing anything that could need us to have sort of DART part 2 if you like. We don't have plans at the moment to have DART in—sort of little DARTs in storage. We don't have the resources in the planetary defense. We are, however, sort of, I think probably recycling maybe is the good way, sustaining, but we are reusing the OSIRIS-REx spacecraft. So after that gave us those precious samples from Bennu, it dropped the capsule and then did a nice maneuver. And eventually, we'll actually rendezvous with Apophis, which is a small asteroid that will come fairly close to the planet, not too close, but fairly close. And so we're using that to go and study close up another asteroid.

Of course, we have our Lucy mission doing flybys of all the Trojan asteroids. We have Psyche on the way to a heavy metal asteroid, giving us all different views. And I just want to paraphrase something that Deputy Melroy said the other day, which was, you know, when she was studying—in her planetary days, she was studying asteroids. We had no idea what they looked like, you know, and now we've had these incredible close-up views. So we're doing such a great job, I think, of categorizing, understanding, and cataloging asteroids that could become problematic, so a very, very vibrant field for us, having survived asteroid autumn last year.

Mr. MCCORMICK. It sounds like you've done your homework, and it sounds like you have a lot of organization. It sounds suspiciously like a heavy metal band.

But with that said, how much do we spend in time coordinating with other nations in these efforts, in sharing information and our like mindedness to survive something like that?

Dr. FOX. Yes, I'm going to actually take that one for the record because I want to get you an accurate response with the actual organizations because I don't remember them now. But we work closely with worldwide—I mean, there are these sort of asteroid watch networks. And again, we will get you all that information.

Mr. MCCORMICK. OK. Yes. More to the point, I think we're all watching space. The question is, how much are we coordinating our efforts to defend against something that could be catastrophic? And then how do we protect our own technologies while at the same time being able to share the information we need in order to protect ourselves? That's the next step, I think, in the evolution of what we're trying to achieve here with DART or whatever—

Dr. FOX. Right.

Mr. McCORMICK [continuing]. The next program is going to be. That's just something I wanted to point out.

Dr. FOX. Yes.

Mr. McCORMICK. Mr. Scott, I'm almost out of time. I got about 1 minute. What is the most concerning issue that you have written a report that has not been addressed by NASA?

Mr. SCOTT. Thank you for that question. I think it's not one issue. Annually, we issue top management challenges for the agency, which really points to the longstanding challenges, whether it's getting humans back to the Moon, addressing the cybersecurity issues. So from what—while NASA is making progress addressing each of those key challenges, I would point you to our top management challenges report, which really summarizes at a high level, we believe, the top issues and challenges NASA is facing across its programs and missions.

Mr. McCORMICK. No. 1, what is it?

Mr. SCOTT. They're all my favorite. I think there's like seven or eight of them, so I don't have a No. 1.

Mr. McCORMICK. You're treating them like kids, huh? You don't want to have a favorite. I get it. OK. Well, I'd say in order for us to be accountable to people, just make sure that we're spending wisely. We budget—and that budget process has to be streamlined a little bit better. Thank you, Mr. Chair.

Chairman BABIN. Absolutely. Thank you. And I think everybody's asked questions, and so we're going to go back through with a second series if that's OK with everyone. And I'm going to call on the Ranking Member, Mr. Sorensen, first.

Mr. SORESENSEN. Thank you, Mr. Chairman. And thank you, again, to our witnesses.

You know, as Congress is tasked here in the wee hours of the morning of a spending package that we will be voting on very—hopefully, very, very shortly, all eyes are on spending. And so I do want to go back to something that—Mr. Young, that you said in your testimony. NASA should look at the most probable cost instead of the lowest credible cost. And so I do want to open this up to a more broader discussion because in 2020, NASA's preliminary estimate, it would cost \$2–3 billion to bring the samples being collected by the Perseverance rover on Mars back to Earth, \$2–3 billion was the estimate.

Last summer, just 3 years later, the Independent Review Board said that a more realistic estimate is \$8–11 billion. And that's still preliminary. How can we, as Members of the Science, Space, and Technology Committee or, more broadly, Members of Congress, continue to justify that this is worth it in the long run? I think, as the Chairman and I are scientists at heart, we understand the value of being bold, Mr. Young, as you had said? How do we continue to do that if the cost overruns keep going up?

Mr. YOUNG. I notice there are no other volunteers. I'm trying to figure out how to do this within reasonable time. When projects are being put together and being—going through various approval processes within NASA, within the Congress, within the OMB (Office of Management and Budget), the thing that is—whether we like it or not, the thing that is encouraged is lowest credible cost.

As Mr. Scott said, in that era, everybody is an optimist. And the difference between lowest credit—there are a lot of data that would support this between a lowest credible cost on a statistical basis I would say is like a 20/80. A most probable cost, there's like an 80/20. Those numbers are at least a factor of two different.

So what I'm really getting around to is that there's got to be some offsetting rule that everybody can't be in the cap—camp of lowest credible cost because we're going to end up with ridiculous numbers as it turned out like \$3 billion.

Now, in a corporation where you're kind of betting a corporation, what do you do, OK? If I go back to my previous life, what we did was we had project people who developed costs, and they were optimists, and we knew they were optimists, and we wanted them to be optimists in—to lead the kind of projects we were talking about. But we did not want to bet the company on their numbers. So we had independent cost estimating capability, people whose job it was to develop the most probable estimate.

So my argument would be in the front end of projects, we need to recognize that many of the numbers we're getting are lowest credible costs, and we need to have an independent capability to work on the objective of being, I'll call it, junkyard dogs, you know, people who are really looking at what this is really going to cost. And then the decisionmakers have got to recognize that these programs are difficult, and—you know, and it's going to take most probable cost. So then we can make judgments against the—more validity in the cost.

So I believe we have capabilities to estimate cost. I think much of the Sample Return problem is not overruns in performance, it's overruns in estimating, and—that we had, you know. That's why I used the terms lowest credible versus most probable.

Mr. SORENSEN. And I look back at what the—what we were doing with respect to space and what it meant for us to get a computer in our hands that is this size and this weight. What is the value of the investment that we made back then? And we can't calculate what that is here today. And that's what I worry here in Congress as we're struggling to meet the needs of what it means to be bold in space. And so I hope that we are able to do the right thing and fund the right parts. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir. Thank you.

I just had a couple of follow up questions. For Mr. Young, you chaired the Independent Review Board for NASA's Psyche mission. Similarly to the OIG's report, the Review Board report noted that delays attributed to COVID-19 may actually be rooted in deeper program issues. I'd like to provide you with an opportunity to discuss the characteristics of large missions that contribute to delays and cost increases if you don't mind.

Mr. YOUNG. Psyche is an interesting example, and it was done during the COVID time period. So there's no question but what COVID had an adverse impact on Psyche and projects because project management is a team sport. And what I mean by that is people really need to be face-to-face and—to work it out. But it would be wrong to blame even a majority of Psyche's problems on COVID. It was certainly a factor.

But Psyche clearly had some—started as some software development problems in the guidance and control of software that were poorly communicated throughout the organization, were not recognized until it was too late to have corrective action that would have allowed the project to go on schedule.

The other thing I would say with that is to JPL's credit, when we interacted with them from the IRB standpoint, we really push hard on this issue of hybrid work vis-à-vis in-person work. And they put together a concept that recognized employees' maybe cultural differences but necessary to make the project work.

I guess the other thing I would say was that the IRB really stayed with JPL hand-in-hand all the way through the process, and they developed a path forward, that when we first reviewed it, we said you need to go back and there's some other things you need to do. And they did. So, I mean, JPL and NASA's response to that, they accepted every recommendation we had. They responded to them. And Nicky probably remembers, but she came out to get a preliminary assessment of what we were doing, and my comment was at that time, which is true, that we had high expectations for what they were going to do, and they exceeded them. And so I think that really is—in my view, that is a textbook way to when you have a problem like that, you know, that you go about solving it. And what NASA and JPL did in responding to our recommendations was—we applauded quite significantly.

And it's always rewarding—back to James Webb where I chaired the IRB there—and I don't want to make this sound like taking credit, but it's always pretty nice, and you can then sit back and watch like Psyche. It then launched on the revised schedule, and it's on the way to the asteroid Psyche and is performing extraordinarily well.

Chairman BABIN. OK. Thank you. And then also to follow up, Science Mission Directorate periodically conducts reviews of its operating missions known as senior reviews. The reviews provide a valuable opportunity for NASA to leverage its investments by extending the operations of spacecraft that continue to provide useful data beyond their planned lifetime. And while a useful tool, I'm interested in ensuring that NASA allocates its funding in the most efficient manner possible. In particular, recent senior reviews across SMD's divisions have recommended extending the majority of programs being considered. Does the senior review process assess how continued operations of a mission would impact NASA's budget? And how does NASA weigh whether extension of an existing mission is worth potentially diverting funds from a future mission? Mr. Young?

Mr. YOUNG. Yes, I'm not the person really to—

Chairman BABIN. OK.

Mr. YOUNG [continuing]. Comment on the—on that process.

Chairman BABIN. Then I bet it's Dr. Fox.

Dr. FOX. Yes, happy to talk about that.

Chairman BABIN. OK.

Dr. FOX. So—and we really value the senior review process because if we do have to make tough decisions, it does give us that ranking. Of course, nobody ever wants their mission turned off, and why would you? I wouldn't want mine turned off. So—but it is chal-

lenging because we—as—when we talk about the balanced portfolio across the Science Mission Directorate, we really do mean in terms of our legacy missions with the new, exciting missions.

I will—I do want to sort of highlight how the Earth Science Division has recently used their senior review. You know, they got a recommendation to maintain all of their operating missions. They did not have the resources to do it, so what they actually did was give a very challenging budget scenario to each of those operating missions, and, boy, did they deliver. So they are cutting those—the actual budget to—you know, finding creative, efficient ways to keep operating the missions. Maybe you can't do it in the way you've always done it before in prime mission, but there are efficiencies you can make to extend the missions, and we've seen that across the portfolio where, you know—so we find that the senior review process is very, very valuable. We do like it when they give us the ranking of the missions because it does make it easier when we have to make those hard decisions.

Chairman BABIN. OK. Thank you very much. And I'm out of time.

I'd like to call on gentleman from California once again.

Mr. GARCIA. Thank you, Mr. Chairman.

Chairman BABIN. Yes, sir.

Mr. GARCIA. I want to follow up on the Mars Sample Return discussion that we were having. I'm a dog with a bone on this one because it's so important to us, and the damage here is tremendous, not to just my district, but to all of southern California, to all of, frankly, the NASA workforce industrial base and the implications of this bad behavior are far-reaching.

This was premature, pre-decisional based on pre-decisional conversations in Congress that were happening real-time between both the House and the Senate, very shortsighted, and has caused irreparable damage. I describe this as nothing short of a bag job against the good folks at JPL, people who are now unemployed, looking for other industries, looking for other jobs, almost 600 folks as a result of this bad decision. It's a slap in the face to Congress, both the authorizers and the appropriators.

So you mentioned, Dr. Fox, the *Antideficiency Act*. The *Antideficiency Act* is meant to be a way to ensure that agencies aren't spending more than what they are appropriated to. Your Fiscal Year 2023 appropriations number was \$818 million, \$818.8—I believe, to be exact—million. OK? You made the decision for the layoffs on February 6, which is about roughly 35 percent through the fiscal year, so 35 percent of \$818 million is about \$286 million. So you were either—this program—and I don't want to say you. This program was either burning hot at a rate of 3X and you were therefore looking at an *Antideficiency Act* to breach, or the remaining money, the delta between \$818 million, which is what you were last appropriated, and \$286 million, which would have been your sort of SPI (schedule performance index) for a 35 percent profile through the Fiscal Year 2023, was reprogrammed to another program.

So this argument that you made these decisions based on an *Antideficiency Act* actually is technically and legally not true unless you were burning at a 3X rate or you did reprogram money to an-

other program from MSR to something else that we weren't notified for. And I would actually submit that the appearance of what has been done here is not an *Antideficiency Act* violation or an attempt to prevent an *Antideficiency Act* violation, but it looks more like an *Impoundment Act* violation to me, which is where you don't execute the money that has been allocated to you with a specific purpose through congressional appropriations process.

So I don't—out of deference to you, I don't want you to answer that question here, right now, but I would like a deeper dive into why you are asserting and your staff is asserting that the rationale for these layoffs was an *Antideficiency Act* because it, frankly, technically, legally, numerically, programmatically, it cannot hold water unless you were burning at 3X, which I don't think you were. I understand you're in the midst of an IRB. There was confusion about the technical solutions moving forward. I understand there was confusion about the timelines and schedules that would be derived from those technical solutions. And I also understand Congress was doing you a disservice with a CR But to baseline against a \$300 million number that came out of the Senate markups is not what you anchor to when you start talking about *Antideficiency Act* conversations. OK? You anchor to your previously appropriated number, which was \$818 million.

So happy to let you comment on that right now if you want to. If you would prefer to answer for the record later with the actual numbers and your SPI and your actual burn rates and show us where money was being reallocated before February 6 to substantiate the layoffs, you can also do that, but I'll defer to you.

I want to make sure—a lot of these jobs are already lost. A lot of these people are already gone, so I don't know how we do MSR correctly without that workforce. We're already challenged, and there's already—you know, there's an unprecedented level of competition right now between primes to go hire these people when they're getting scooped up. But I'll defer to you, Ms.—Dr. Fox, if you want to respond.

Dr. FOX. I'm happy to take it for the record so we can get you all—I mean, you are asking some—for some very deep numbers that, of course, I don't have at the tip of my tongue, so we're happy to take it for the record. Obviously, again, we have—you know, we do not direct JPL on their workforce. We did provide them financial guidance that was based on what we thought was going to be available and having been given the information—or, you know, with the *Fiscal Responsibility Act* coming out at the—no higher than the 2023 and a cut below that.

I will just note that the cut to Planetary is nearly half a billion dollars against the 2023 enacted, and it is \$666 million against the President's budget request for 2024, so it is a very big cut to Planetary.

Mr. GARCIA. Yes, but from an *Antideficiency Act*—and I'm out of time—that is not what you should have been anchoring to. We were allowed and we were able to continue to fight for the higher dollar levels. And so we can continue this conversation, but I just—I'm scared. I'm scared. I'm worried about the workforce. And it's not my district, it's southern California, and we'll be looking for responses to the letters from the delegates from the area.

Thank you. I yield back.

Chairman BABIN. Thank you, Mr. Garcia, appreciate it.

Well, this concludes our hearing today, but I want to thank each one of you witnesses for being here and your valuable testimony for us to be able to have proper oversight and know what's going on with our programs.

The record will remain open for 10 days for additional comments and also for written questions from Members.

This hearing is now adjourned.

[Whereupon, at 11:40 a.m., the Subcommittee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

*Responses by Dr. Nicola Fox*U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY*“Advancing Scientific Discovery: Assessing the Status of NASA's Science Mission Directorate”*Dr. Nicola Fox, Associate Administrator, Science Mission Directorate, National Aeronautics and
Space AdministrationQuestions submitted by Chairman Brian Babin

1. NASA's Fiscal Year 2025 budget justification includes a summary of the 2024 Major Program Annual Report, which identifies three Science Mission Directorate, or SMD, major programs with cost and schedule changes since the 2023 report. The projected development cost of the NASA-Indian Space Research Organisation Synthetic Aperture Radar mission decreased by 2% with no change in the expected launch date. The development cost of the Plankton, Aerosol, Cloud, ocean Ecosystem mission decreased by 3% with no change in the launch date. The projected development cost of the Sentinel-6 mission decreased by 10% with no change in the expected spacecraft B launch date. How did SMD accomplish the development cost reductions achieved by these three missions? Further, what lessons has SMD learned from those cost reductions, and from the success at keeping the missions on schedule, that could be applied to other missions?

Most missions in the NASA Science portfolio are novel, and the causes of cost or schedule overruns are unique to each project. Since the establishment of the 70% Joint Cost and Schedule Confidence Level (JCL) requirement for major missions in 2009, SMD has confirmed and launched 39 missions. Including James Webb Space Telescope (JWST), these missions have overrun their Phase C/D commitments by a net 4.5% and excluding JWST, these missions have underrun their Phase C/D budget commitments by a net 0.5%. 19 of the 39 missions completed development under their cost commitment.

SMD continues to refine its ability to execute missions within cost commitments by implementing improved management techniques (particularly on large strategic missions) and the use of independent review boards and cost estimates, including JCL estimates.

SMD's approach to managing risk involves providing appropriate levels of unallocated future expenses, which are informed by rigorous risk assessments and cost and schedule reviews at key milestones. We continue to monitor risk and other programmatic changes for each project as well as at the portfolio level.

Questions submitted by Ranking Member Eric Sorensen

1. The President's Fiscal Year (FY) 2025 budget request for NASA proposes a restructuring of the Earth System Observatory, a set of Earth-focused missions under development that are designed to advance scientific understanding of the Earth's systems and provide key applied science information to guide efforts related

to climate change, disaster mitigation, fighting forest fires, and improving real-time agricultural processes. At a March 13 NASA Earth Science townhall, NASA administrators noted that the strategy for the Earth System Observatory is to “decouple, partner, and compete.”

a. Please elaborate on what the “decouple, partner, and compete” strategy means and how it compares to the existing plans for the Earth System Observatory.

The former architectures of both the Atmosphere Observing System (AOS) and Surface Biology and Geology (SBG) missions within the Earth System Observatory (ESO) featured a tightly-coupled approach combining measurements made from a small number of large satellites, each with multiple instruments. We had also planned to launch all of these satellites within a constrained time window, to maximize overlapping observations on orbit. AOS and SBG were each to be managed as single missions, with multiple components. The large satellites with multiple instruments carried significant risk and concentrated development costs over a small number of years, which drove the need for increased reserves and high annual budget requirements.

“Decouple, partner, and compete” is the philosophy we are executing to adapt to available funding levels while retaining as much mission content in the ESO as possible. “Decouple” means we will now disaggregate both AOS and SBG into smaller projects to be executed independently. This approach reduces cost and schedule risk and annual funding needs, with the trade-off being reduced on-orbit overlap. “Partner” means we will affirm the international partnerships we have already established and pursue new ones to cost-effectively implement science content defined in the original mission architectures. “Compete” means we will accomplish one component of the new AOS architecture as a cost-capped competed mission opportunity to ensure that we acquire the best observation quality within the available budget.

b. Will any of the Earth System Observatory missions be delayed or scaled back in scope from what had previously been planned and announced?

Yes. For AOS, the backscatter lidar capability in the inclined orbit has been removed from the architecture. The radar in the Polar orbit will be the “best available” within the cost cap (competed). The AOS remains largely on schedule. For SBG, the scope is retained but the Visible and Short-Wave Infrared (VSWIR) capability is delayed. The reduced scope, while reducing some science capability, increases the likelihood that the EOS missions will be implemented in the near term, as opposed to indefinitely delayed due to funding constraints.

c. What would be the impacts to Earth science and applications decadal survey priorities?

Throughout the process of aligning ESO mission content with evolving resource targets, NASA has worked to preserve the highest priority science from the “Designated Observables” from the Decadal, while maintaining the competed missions in the Venture and Explorer lines (also a Decadal priority) and protecting partner contributions and commitments.

d. The National Academies is currently conducting the mid-decade assessment of progress on the decadal survey recommendations from the current decadal survey for Earth science and applications from space. Has NASA fully informed the study committee of these changes to the Earth System Observatory?

Yes. NASA has kept the National Academies, international partners, and community stakeholders as informed as possible, within the constraints of the budget process, as our strategy to execute these missions continues to evolve during formulation. The mid-decade assessment was nearly complete at the time of the FY 2025 budget request roll-out, so the full impacts of these adjustments may not be reflected in the mid-term report. However, NASA briefed the National Academies Committee on Earth Science and Applications from Space on the NASA Earth Science FY25 budget request, including these changes to the ESO.

e. How will NASA implement the new strategy for the Earth System Observatory, including the approach and timeline?

NASA met the budget target by reducing synchronization, to maintain the majority of the technical content. The updated timelines for the decoupled missions are as follows:

- GRACE-Continuity continues unaffected with a planned LRD of December 2028
- SBG-TIR – Deliver to ASI partner November 2027, LRD FY 2029
- SBG-VSWIR – LRD NET FY 2032
- AOS-Sky – directed mission, passive instrument suite, LRD NET 2030
- HAWCsat – CSA partner, planned co-manifest with AOS-Sky
- AOS-Cloud (New competed radar mission), Community Announcement released on April 19, 2024, anticipated launch FY 2031
- PMM – JAXA partner, LRD 2029
- AOS-Storm – Smallsat to host CNES Radiometer, planned co-manifest with PMM
- CALIGOLA – ASI LIDAR mission, NASA detector suite, LRD NET 2029

These timelines are contingent on full funding of the FY 2025 President’s Budget request for Earth Science Systematic Missions.

2. **The explanatory statement accompanying the FY2024 minibuss appropriations law allocated \$10 million for NASA to set up a project office at NASA Goddard and begin work maturing the technologies and concept for the next astrophysics great observatory, which has been called the Habitable Worlds Observatory. What will NASA accomplish on the Habitable Worlds Observatory in FY2024, and what will be accomplished in FY2025 under the requested budget?**

In FY 2024, NASA will make progress in maturing technologies relevant to a potential future Habitable Worlds Observatory (HWO) mission, including the following steps:

1. Create a Project Office at the Goddard Space Flight Center, with the initial goal of consolidating and developing a technology investment roadmap.
2. Continue work with Science, Technology, Architecture Review Team (START) and its working groups to conduct science trades that will inform the goals and objectives for a potential future HWO.
3. Initiate development of the software models (i.e., integrated modeling) to predict system level performance of the Observatory at the picometer level of precision.
4. Begin developing the government technology testbeds to provide our academic and commercial partners a gold standard to test their technologies.
5. Develop a mentorship program for early-career scientists and engineers to increase access to careers and fields that are relevant to the study of habitable worlds.
6. Issue calls for precursor science & technology that must be developed for a potential future HWO mission to succeed.
7. Initiate a solicitation to industry for technology development.

In addition to continuation of the above activities, the major objective for FY 2025 is to initiate significant industry participation in technology maturation activities in support of a potential future Habitable Worlds Observatory. This will be achieved via a Research Opportunities in Space and Earth Science (ROSES) Announcement of Opportunity call initiated in FY 2024, with awards to be made in FY 2025.

3. **The NASA Authorization Act of 2022, enacted as part of the CHIPS and Science law, set a goal for NASA to dedicate at least 10% of the funding for each of NASA's science divisions to research and analysis programs by FY2025. Does NASA's FY2025 budget request meet this goal?**

NASA's Science Mission Directorate's budget request for FY 2025 exceeds 10% of funding for research and analysis programs. Each NASA science division's budget for research and analysis programs, as a percentage of division budget, is:

- Earth Science Division 15%
- Planetary Science Division 11%
- Astrophysics Division 16%
- Heliophysics Division 19%
- Biological and Physical Science Division 11%

Additionally, our FY 2025 budget calls for consistent investments in research and analysis programs through FY 2029.

- 4. The President’s FY2025 budget request for NASA proposes the cancellation of the development of the Geospace Dynamics Constellation (GDC), a mission under development and a priority recommendation of the last decadal survey in heliophysics. GDC is going to provide crucial measurements of the extreme variability of conditions in near-Earth space, which will improve our space weather and space situational awareness models. In 2022, NASA charged an independent review board to assess the scientific, technical, and management plans for GDC.**

a. Did the 2022 IRB recommend cancellation of GDC?

The 2022 IRB did not recommend cancellation of GDC. Please note that the GDC IRB was not tasked to provide a recommendation on whether the project should be cancelled, nor was the GDC IRB tasked with prioritization of GDC within current budgets. It was chartered to assess the programmatic readiness, management approach, and structure of the science team to maximize the science return.

b. Did the 2022 IRB find that GDC would satisfy the science priorities recommended by the decadal survey for the mission?

Yes, the IRB concluded that NASA’s planned implementation of GDC addresses the primary recommendations from the 2013-2022 Decadal Survey for Solar and Space Physics.

c. What will be the scientific impact, if Congress were to accept NASA’s proposal to cancel GDC?

The proposed cancellation of GDC enables support for other priority science missions that would likely need to be canceled or delayed if GDC were implemented. The cancellation of GDC would, however, prevent NASA from making advances in our scientific understanding of Earth’s upper atmosphere and its interaction with the local space environment, as recommended by the 2013-2022 Decadal Survey.

d. In the last two budget requests, NASA proposed significant cuts to GDC to implement a “pause” in the mission’s development. What is the rationale for cancelling the mission as proposed in the FY2025 budget proposal?

The GDC IRB found that the FY2023 budget profile did not support the current Launch Readiness Date (LRD) and that delays to 2032 or later would “expose NASA to uncertainty and risks” that are likely to require additional funds. The combination of increased costs and decreasing budgets led to the conclusion that GDC should be proposed for cancellation. The

tightly constrained budget environment due in part to the Fiscal Responsibility Act of 2023 made it infeasible to continue funding the mission.

- e. NASA also stated in the last two budget requests that the reductions to GDC were to accommodate other priorities, including Mars Sample Return. How does NASA make choices among high-priority decadal missions in its different disciplines?**

SMD strives to maintain balance between all divisions and science disciplines to ensure that each division makes progress against their respective Decadal Surveys within budgetary constraints. NASA does not consider any one division to be higher priority than any other. Programmatic factors specific to individual missions and the specifics of budgetary constraints will influence the choices made during the budget process. Significant budget constraints required NASA to make difficult choices across the entirety of SMD including to Mars Sample Return.

- 5. Mr. Scott states in his prepared testimony that “[Deep Space Network] antennas are currently operating at capacity and are oversubscribed—meaning more time is requested by missions than the network’s current capacity can provide—with demand exceeding supply at times by as much as 40 percent” and also that, “even with needed upgrades, it is possible that NASA may not be able to receive all the future missions’ data that could advance our understanding of the universe and our place in it.”**

- a. How do the constraints on the DSN impact the scientific return of NASA’s deep space missions?**

NASA provides operational communications and navigation (C&N) services to an array of science and exploration missions which depend on those services to be successful. NASA missions can be designed to last ten or more years, and often are extended beyond their planned operational mission period in order to continue to return invaluable science data and capitalize on investment. For example, missions such as Voyager 1 and 2 and the Hubble Space Telescope are tremendous science assets utilized by the scientific community and revered by the public. Further, NASA must actively understand the landscape of future science and exploration missions to determine the C&N capabilities that will be required and plan appropriately to meet those needs. Future missions are expected to produce much higher amounts of data while employing novel mission designs, such as swarms of collaborating spacecraft. These demands will change how services are delivered to meet the overall set of mission C&N requirements.

As reported by the NASA Inspector General, demand for DSN support to NASA science missions has increased faster than the capacity of the network. The DSN team has established a strong working relationship with NASA’s mission teams that has enabled NASA to ensure that critical science mandatory for achievement of mission objectives is fully supported in the nominal network schedule. Demand projections developed in 2023 suggested an exceedance of the DSN capacity by as much as 40 percent at times during the next four to five years (the “contention period” mentioned in the OIG report).

Based on these projections and lessons learned from Artemis I, NASA has embarked on several activities to address the capacity and reliability challenges for DSN. In addition to completing upgrades to the DSN, implementing Lunar Exploration Ground Sites (LEGS), and exploring

options to offload demand from DSN, the Space Communications and Navigation (SCaN) Program has created a DSN prioritization working group that is specifically focused on ensuring science return concurrent with Artemis mission operations. Efforts of this team, which includes members from Exploration Systems Development Mission Directorate (ESDMD), Science Mission Directorate (SMD), and Space Operations Mission Directorate (SOMD), have already resulted in an improved understanding of the Artemis mission requirements and proposed approaches to scheduling during nominal and contingency operations intended to protect NASA science and exploration needs. The work from this team is ongoing and NASA will iterate DSN demand projections to assess the recommendations from the DSN prioritization working group.

b. How does NASA ensure that the requirements of the science missions are well-understood and taken into account by the Space Operations Mission Directorate when planning for future DSN services?

NASA's SMD and SOMD have a common interest in ensuring the provision of SCaN Program C&N services meets mission needs now and into the future. Coordination occurs between SMD and SOMD's SCaN, such that each party has a common understanding of the objectives, outcomes, and mechanisms of that coordination, as well as a common understanding of the services being provisioned to missions and the associated cost implications.

SMD and SCaN independently conduct respective long-range planning for this purpose. SMD strategic planning is tied to science objectives and guiding documentation such as the SMD Science Plan, the advice provided through the various advisory bodies within NASA and the National Academies, and the Decadal Surveys. SCaN has responsibility for the management and operation of the existing networks and the evolution of the C&N architecture and services over time. Communication between the two organizations ensures that the SCaN network roadmap is responsive to mission needs.

The primary mechanisms for the exchange of requirements, technology needs and development, as well as network implementation and status are through the SCaN Board of Directors (BOD), and technical working groups as needed. SMD provides to SCaN appropriate information on mission forecasts, upcoming announcements of opportunity, and insight into mission requirements that are relevant to C&N (e.g., data rate capability, unique navigation requirements). Implementation solutions for C&N service are determined by SCaN, which provides to SMD appropriate information on the network roadmap and time-phased capability of the networks. SCaN also keeps SMD apprised of trends in radio frequency (RF) spectrum policy that have the potential to impact NASA missions.

c. What is the maturity level of deep space optical communications capabilities under development by NASA, and what are NASA's plans and timelines regarding the potential future use of optical communications technologies to meet some or all of the demands that only the DSN can meet today?

For the Deep Space Optical Communications (DSOC) experiment, NASA expects to reach Technology Readiness Level (TRL) 7 maturity level in the fall of 2024, pending successful completion of DSOC's final Level 1 requirement of its first year of operations. On April 8, 2024, DSOC successfully demonstrated optical downlinks of 6.25 Megabits per second (Mbps),

20.8 Mbps, and 25 Mbps from a distance of more than 1.5 Astronomical Units (1 AU, an Astronomical Unit, is the distance from the Sun to Earth's orbit, or about 93 million miles), including receiving 30 Megabytes of Psyche spacecraft telemetry. The 25 Mbps link at >1.5 AU substantially exceeds the Level 1 requirement target, and meets the third of four Level 1 mission requirements. The remaining Level 1 requirement of the first year of operation is currently expected to be met in October 2024.

NASA is exploring the possible future use of optical communications technologies to support deep space missions, though this technology is still in the demonstration phase, at this point.

Questions submitted by Full Committee Ranking Member Zoe Lofgren

1. **The President's Fiscal Year (FY) 2025 budget request for NASA proposes a \$27.2 million (40%) cut to the budget for the operations of the Chandra X-ray Observatory and to begin shutting down the mission. Chandra is the most powerful X-ray telescope in space right now, and it has enabled us to answer fundamental questions about the origins and evolution of the universe. NASA's 2022 Senior Review ranked Chandra, along with the Hubble Space Telescope, in the top tier of operating astrophysics missions for its continued scientific value, and NASA approved Chandra for extended operations through FY2025 and for participation in the 2025 Senior Review.**

- a. **What is the rationale for reversing the decisions based on the recommendations of the 2022 Senior Review and ending Chandra early?**

The primary rationale is that Chandra mission operations cannot be sustained at the previous level of funding in light of FY 2025 budget constraints. These reductions are required to maintain a balanced Astrophysics portfolio. Chandra has been operating for twenty-five years and reliance on its continued performance represents an increased risk moving forward. FY 2025 budget constraints are such that the recommendations made in the last Senior Review, during a different budget climate, cannot be followed beyond FY 2024.

- b. **Has NASA sought independent scientific input to inform its proposal to end Chandra operations sooner than planned?**

A Mini-Senior Review will be commissioned during FY 2024 to solicit community input on alternative operational scenarios for Chandra and Hubble that could provide more cost-effective science operation models for each mission. With a combined operational cost of \$188M, the Mini-Senior Review will address potential cost savings that could be achieved via consolidation of Hubble and Webb science operations. The Mini-Senior Review will investigate options for a streamlined operational model for Chandra.

- c. **What are the research questions in astrophysics that can only be addressed by Chandra?**

Chandra is a large area X-ray telescope, so it primarily addresses Astrophysics problems that require deep x-ray imaging capabilities and high angular resolution.

- d. **Is NASA currently pursuing development of a mission that would match or exceed Chandra's capabilities to address the gap that would be left, were the agency's proposal to end the mission be accepted?**

The Budget proposes to start orderly mission drawdown to minimal operations, not to end the mission. The agency is attempting to identify a lower-cost operations concept for the current stage of Chandra's extended mission.

Additionally, NASA is currently reviewing proposals for a Probe-Class (\$1B) mission recommended by the Decadal Review. The Probe mission proposals are for X-Ray or Far-Infrared missions. In addition, a Medium-Class Explorers (MIDEX) call in FY 2027 also presents the opportunity to propose a mission that would meet or exceed the current capabilities of Chandra. NASA is partnering with the European Space Agency to develop an X-ray mission known as NewAthena that could exceed the capabilities of Chandra.

e. Are international space agencies operating, or pursuing the development of, a mission that would match or exceed Chandra's capabilities?

NASA is partnering with the European Space Agency to develop an X-ray mission known as NewAthena that could exceed the capabilities of Chandra. This mission will be adopted by ESA in 2027 and NASA will initiate Phase A development once adoption has occurred. NASA has already developed an X-ray sensor for this mission.

f. What would be the impact on the U.S. x-ray astrophysics and astronomy research community should the Chandra mission end early? How many U.S. researchers would be affected?

NASA is attempting to identify an alternative operations concept for the Chandra mission that would allow research to continue at this stage of the extended mission.

It should be noted that the Agency also operates the following operational x-ray missions: IXPE, NICER, XMM, XRISM, NuSTAR and SWIFT. Science funding for these missions, combined with other Research Opportunities in Space and Earth Science (ROSES) research programs provide a total of ~\$28M.

g. What would be the implications for the United States' global standing in x-ray astronomy should the proposal to end the Chandra mission be adopted?

The Agency is attempting to identify a lower-cost alternative for Chandra's continued operation, consistent with the reduced funding for Chandra proposed in the President's Budget, while also maintaining a balanced Astrophysics portfolio.

It should be noted that the Agency also operates the following operational x-ray missions: IXPE, NICER, XMM, XRISM, NuSTAR and SWIFT. Science funding for these missions, combined with other ROSES research programs provide a total of ~\$28M. The U.S. X-ray community

remains well-funded and has access to numerous X-ray science missions, together with opportunities for new missions in the future.

Questions submitted by Rep. Mike Garcia

- 1. During the hearing you asserted that had NASA continued to spend at FY23 levels for the Mars Sample Return program, such spending would have resulted in an Antideficiency Act violation, and you committed to providing detailed evidence to support that claim. Please provide any relevant information for the record.**

In July 2023, the Senate Appropriations Committee marked up and reported, S. 2321, the FY 2024 Commerce, Justice, Science Appropriations bill, and accompanying report (Senate Report 118-62). Senate Report 118-62 included language funding the Mars Sample Return (MSR) Program at not less than \$300.0 million, \$522.0 million below the FY 2023 enacted level and \$649.3 million below the President's Budget Request (PBR).

The table below shows the monthly costs for MSR during FY 2023. This shows that the project was costing an average of \$82.0 million per month during the last quarter of FY 2023. Had this level been sustained during FY 2024, the project would have costed \$984.0 million during FY 2024. The project had \$327.0M of uncosted funding from prior years available as of October 1, 2023. Therefore, MSR would have required over \$650 million in FY 2024 funding to support monthly costs at this rate and appropriate carryover into FY 2025, exceeding the Senate mark of not less than \$300.0 million by at least \$350.0 million.

FY 2023	Monthly Cost
October	\$ 60,076,798
November	\$ 48,051,908
December	\$ 60,530,612
January	\$ 61,139,578
February	\$ 51,080,567
March	\$ 22,126,940
April	\$ 104,630,254
May	\$ 78,782,653
June	\$ 82,599,805
July	\$ 77,526,697
August	\$ 81,568,111
September	\$ 87,652,544

During the period of the extended FY 2024 Continuing Resolution (CR), NASA planned available funding prudently to the most conservative funding level within the anticipated FY

2024 constraints as related in the Joint Explanatory Statement for the Consolidated Appropriations Act, 2024 (P.L. 118-42), including the not less than \$300.0 million level for MSR stipulated in Senate Report 118-62.

If NASA had expended more on MSR during the period of the FY 2024 CR than the level ultimately specified in an enacted FY 2024 appropriation, NASA would have been required to deobligate funds in excess of the amount appropriated for MSR or reduce an equivalent amount from other Planetary Science projects, causing significant damage and programmatic disruption to projects such as Europa Clipper, NEO Surveyor, and Dragonfly. In order to protect against such an outcome, SMD directed the MSR project to plan to a not less than \$300.0 million FY 2024 budget during the period of the extended FY 2024 CR. NASA believes this to have been the most responsible path forward for MSR, given the uncertainty in both the MSR mission architecture and FY 2024 funding constraints.

2. In NASA's FY21 budget request, the Dragonfly mission was estimated to launch NET April 2026 with a projected FY25 request of \$208.9 million. Yet your FY25 budget request asks for \$434.6 million and a new launch date of NET July 2028. Why has the cost of this project more than doubled and experienced continued delays? Will NASA implement an Independent Review Board?

On April 16, 2024, NASA confirmed the Dragonfly mission with a total lifecycle cost of \$3.35 billion and a launch date of July 2028. This reflects a cost increase of about two times the proposed formulation and development cost and a delay of more than two years from when the mission was originally selected in 2019.

The New Frontiers Announcement of Opportunity under which Dragonfly was selected set a cost cap of \$850 million in FY 2015 dollars, and covered Phases A-D of the life cycle (i.e., excluding operations) and excluded the costs of the launch vehicle and associated nuclear services as well as mission directorate held cost reserves. As proposed, the Dragonfly mission met this cost cap requirement and had an initial cost for Phases A-D of approximately \$1 billion in real year dollars. The current estimate for those phases within the \$3.35 billion Agency Baseline Commitment is approximately \$2.1 billion. That is the basis for the statement that the cost is twice what it was at selection.

Since mission selection in 2019, NASA has changed the targeted launch date several times due to budgetary constraints. The cumulative impact of these early NASA-directed replans, and another after the Preliminary Design Review (PDR), are responsible for nearly two thirds of the increase in Phase A-D costs. The Dragonfly project also conducted an in-depth design iteration prior to PDR. The increased costs of that, combined with COVID-driven increases in labor rates and the costs of parts and materials, are responsible for the balance of the increase in Phase A-D costs.

Separate from the Phase A-D costs, NASA also provided additional funding to support the acquisition of a heavy-lift launch vehicle. The greater energy provided by such a vehicle enables

a shorter cruise phase to Titan, offsetting the schedule impacts of prior launch delays and allowing the science to be returned in the timeframe originally proposed.

An Independent Review Board (IRB) will not be needed given that the mission successfully passed all of the success criteria of its Preliminary Design Review in early 2023 and has a credible path forward.

Questions submitted by Rep. Jennifer McClellan

- 1. The Science Mission Directorate Bridge Program aims to develop partnerships between NASA Centers and institutions that have been historically under-resourced—including Minority Serving Institutions, Community Colleges, and Tribal Colleges and Universities. Dr. Fox, could you provide an update on the status of the Bridge Program and some of its outcomes?**

A call for seed funding proposals to develop new partnerships between NASA Centers and under-resourced institutions was included in NASA Science Mission Directorate's annual omnibus solicitation for basic and applied research, Research Opportunities in Space and Earth Science (ROSES) 2023. A total of 86 proposals were received by this year's closing date of March 29, 2024, the first 40 of which have been peer reviewed. The other 46 proposals are currently undergoing review, with anticipated selections to be made in late June 2024.

Thus far, a total of 24 partnerships have been selected for two-year funding awards with a total contract value of \$7.6M. Additional funding is planned for the final selectees later this year. All selected proposals were led by investigators at under-resourced institutions, and seven NASA Centers are involved in new Bridge Program partnerships these institutions. Cohort-building and mentor training activities are underway for faculty and NASA partners, and student research experiences are planned to begin in summer 2024.

Questions submitted by Rep. Summer Lee

- 1. NASA's CLPS program has moved forward with two missions so far this year. The agency assumed risk in moving forward with new contracting methods and enabling new companies to participate in our nation's space program, and I applaud the efforts made to date. I look forward to future CLPS missions, including the one to deliver the VIPER rover which will demonstrate ground-breaking science that could change the economics of future space science and exploration. In light of cuts made to the Planetary Science portfolio within the Science Mission Directorate in the final FY24 appropriations act, can you please update us on NASA's progress and plans for the VIPER mission, including its method of delivery to Moon via a CLPS delivery service contract?**

Since a 2023 replan, VIPER has continued to face technical and supply chain challenges that have consumed funded cost and schedule, including late delivery of subsystems and hardware by vendors; out-of-specification printed wiring board and connectors; and failures in the drill engineering unit during testing. The CLPS-provided lunar delivery of VIPER also has increased

schedule uncertainty in the wake of Astrobotic's Peregrine Mission 1 failure to land on the Moon. As a result of ongoing technical and supply chain challenges, NASA requested the VIPER project to provide a plan for a potential 2025 IOC. The project has estimated that the associated costs of this delay could result in exceeding the original ABC development cost estimate by more than 30 percent, requiring a rebaseline of the project. To assess the viability of the project given these likely cost and schedule increases and impacts on upcoming CLPS deliveries and other areas of the LDEP portfolio, NASA is finalizing the results of a Continuation/Termination Review for VIPER.

Following Astrobotic Technology's Peregrine Mission-1 (PM-1), Astrobotic conducted a Failure Review Board (FRB) on Peregrine and will soon brief NASA on the results. NASA expects Astrobotic to apply corrective actions from the PM-1 Failure Review Board to the Griffin lander. After incorporating any necessary actions, along the findings of the Continuation/Termination review, NASA will inform Congress with an update and plans for both VIPER and the Griffin lander.

Responses by Mr. George A. Scott

Question submitted by Chairman Brian Babin

1. The Science Mission Directorate, or SMD, frequently contributes to activities in other NASA Directorates. When directorates collaborate, how does NASA ensure that one directorate's funding isn't diverted from its intended purpose to support another's priority?

RESPONSE: Other than Section 505(7) of the Consolidated Appropriations Act, 2024, that prohibits the reprogramming of funds that augments any existing program, project, or activity in excess \$500,000 or 10 percent, whichever is less, we are unaware of any additional limitations. We believe that NASA is best positioned to respond to this question.

Question submitted by Ranking Member Eric Sorensen

1. NASA is developing the Dragonfly mission, a large, principle-investigator, or PI-led mission that will send a rotorcraft to Saturn's moon, Titan. In November 2023, NASA announced that it was approving the Dragonfly project to proceed with work on final mission design and fabrication – known as Phase C — but postponed setting the agency's baseline cost and schedule commitment for the mission until at least mid-2024.

a. To what extent is NASA's decision to postpone setting an agency baseline cost and schedule commitment consistent with NASA's policies and applicable federal laws for missions under development?

b. What are the risks of moving forward with final design and fabrication of mission hardware without a confirmed understanding of the cost and schedule commitments??

RESPONSE: NASA Procedural Requirements 7120.5F states "...the Decision Authority determines the readiness of a program or project to progress to the next phase of the life cycle and establishes the content, cost, and schedule commitments for the ensuing phase(s)." Further, 51 U.S.C. § 30104 states that the Agency shall not enter into a contract for development of a major program, where development is defined as approval to proceed to implementation—which occurs after KDP-C—unless technical, cost, and schedule risks of the program are clearly identified. Because Dragonfly had not been approved to proceed to implementation and only limited funding has been provided until KDP-C, the Agency's decision to postpone establishing a baseline cost and schedule commitment was consistent with NASA policy and federal law.

In our view, transparency and accountability can be achieved best through valid, reasonable, and timely cost and schedule commitments. Without an established Agency Baseline Commitment, the ability to effectively monitor and manage the cost and schedule of a project can be significantly hindered. By delaying implementation, NASA had not established a basis to identify cost and schedule breaches for the Dragonfly mission, nor was the Agency required to notify Congress in accordance with 51 U.S. Code § 30104.

On April 16, 2024, NASA confirmed the Dragonfly mission with a baseline cost of \$3.35 billion and anticipated launch date of July 2028 – reflecting a cost increase of about two times the initial proposed cost and a delay of more than 2 years from when the mission was originally selected in 2019. The mission can now complete its final design, followed by the construction and testing of the entire spacecraft and science instruments.

Responses by Mr. A. Thomas Young

The NASA Science Program has contributed enormously to our knowledge of Earth, our Solar System, and the Universe. These accomplishments have been realized from projects that range from small to flagship missions. The flagship missions have ranged from moderate risk to missions that have pushed the boundaries of what is possible. All have made positive contributions to our knowledge. Many small missions have exceeded our expectations. Missions that have pushed the boundaries of what is possible have overcome technical, schedule, and cost challenges that were considered to be impossible. Examples of such missions are Viking, Hubble, and James Webb Space Telescope (JWST). All at one time in their development were candidates for cancellation. The reason for going forward with these high risk missions was that the risk was required to achieve the extraordinary potential these missions promised. A striking characteristic of these extremely high risk missions is that NASA, Congressional, and Administration leadership proved support when the challenges seemed most insurmountable. This support was as important to their ultimate success as was the project management, engineering, and scientific capabilities of those responsible for project implementation.

Today there is much discussion of the need for a balanced science program. A balanced program certainly has merit. A critical question is the time frame over which a science program is judged to be balanced. If judgment of balance is done each year flagship missions will be deemphasized. This would result in a significant loss of incredible scientific accomplishment that can only be realized by flagship and high risk flagship missions. A more credible time frame to assess balance is a decade or more. Looking back over the time from Viking to today, one can argue that NASA has done an exceptional job of implementing a balanced program. There have times when small missions were emphasized and there have been times when programs such as JWST have consumed a large amount of the available resources.

Looking to the future, Decadal Surveys are a remarkable resource to establish scientific and mission priorities. Budget realities represent boundaries that must be respected. The challenge of leadership is to construct a cadence of missions that when viewed from a perspective of decades in the future maximize the scientific return for the available resources. This will undoubtedly will be a mixture of small, medium, flagship, and extremely high risk flagship missions.

Clearly many flagship missions have had significant cost and schedule growth. Looking to the future we can and must do

better. Prior to entering development flagship missions should be subjected to an independent, external review of the technical, schedule, cost, and management requirements. This affords NASA an opportunity to assure that all requirements are consistent with available resources. At this point any issues can be resolved before the start of development. Strong systems engineering evaluation of candidate missions is necessary to eliminate technical and management complexities that can result in unnecessary cost, schedule, and risk growth.

Determining the cost and schedule for flagship missions will always be challenging. Better cost and schedule determinations can be made if we recognize that most, if not all, advocates for the mission are searching for the lowest credible cost and earliest possible schedule. Historically this has been necessary to achieve approval. If significant cost and schedule growth is to be avoided, the emphasis must change from "lowest credible" to "most probable." This will require that "most probable" becomes the criteria for a mission to move into development. It will also require an independent cost estimating capability to be charged with developing the most probable cost and schedule for the proposed mission. This will assure that a mission starts with a much more credible cost and schedule.

NASA's Science Program can be even more awesome in the future if it continues to focus on a balance of small, medium, flagship, and high risk flagship missions where balance is achieved over a decade or more baseline. An independent, external review before development, strong systems engineering assessment of technical and management complexity, and independent determination of most probable cost and schedule will all add to increase credibility of future missions.

Appendix II

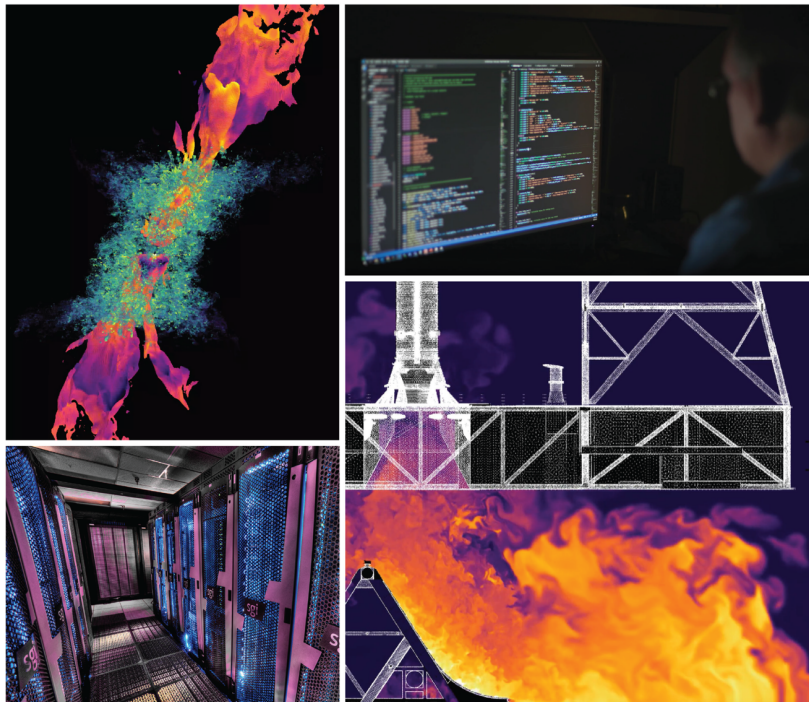
ADDITIONAL MATERIAL FOR THE RECORD

NASA

Office of Inspector General



Audit of NASA's High-End Computing Capabilities



March 14, 2024

IG-24-009



Office of Inspector General

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To suggest ideas or request future audits, contact the Assistant Inspector General for Audits at <https://oig.nasa.gov/aboutAll.html>.

COVER IMAGES

Top Left—A computer simulation of jets of particles and radiation, moving at near light speed, created by supermassive black holes.
Top Right— A NASA astrophysicist works on computer code to create the black hole simulations using NASA supercomputers.
Bottom Left—Two rows of Discover supercomputer racks at the NASA Center for Climate Simulation.
Bottom Right—A simulation of Space Launch System launch ignition NASA Kennedy Space Center's Launch Complex 39B.

RESULTS IN BRIEF

Audit of NASA's High-End Computing Capabilities

March 14, 2024

IG-24-009



WHY WE PERFORMED THIS AUDIT

Since its inception, NASA has pioneered many high-end computing (HEC) technologies and techniques that have become standard. HEC, or supercomputing, provides the critical processing power and time-saving capabilities that allow NASA to gain insight from large amounts of data that would take normal computers much longer to assess. A broad spectrum of employees, researchers, partners, external collaborators, and NASA Mission Directorates use the Agency's HEC capabilities. For example, NASA is currently using HEC capabilities to model the Agency's planned human landing on Mars, as well as to process and analyze the physics and environmental data critical to a successful landing. NASA's two main HEC facilities are the NASA Center for Climate Simulation at Goddard Space Flight Center and the NASA Advanced Supercomputing facility at Ames Research Center, but—thanks to remote access and cloud computing—NASA's HEC resources are used across NASA Centers and by authorized external partners around the world.

NASA manages HEC systems differently than its other computer systems. As one of five capability portfolios—a collection of functionally similar, site-specific capability components—NASA policy calls for HEC to be managed in an integrated manner and within budget constraints to meet certain requirements and strategic needs. Although HEC resource requirements are overseen by the Science Mission Directorate (SMD), each Mission Directorate has the autonomy to manage their own data and user access based on their individual requirements. Further, securing HEC systems is challenging due to their size; performance requirements; complex hardware, software, and applications; varying security requirements; and the nature of shared cyber resources.

In this audit, we assessed NASA's overall management of its HEC capabilities. Specifically, we focused on relevant policies, processes and controls, capacity planning, stakeholder engagement, and cybersecurity. We reviewed applicable policies and criteria; interviewed key officials, personnel, and stakeholders; evaluated capacity planning and success metrics; and reviewed techniques to identify and mitigate HEC cybersecurity risks. We met with officials and stakeholders from Headquarters and NASA Centers and benchmarked best practices with the Department of Energy and National Oceanic and Atmospheric Administration. We also participated in the National Institute of Standards and Technology (NIST) HEC security working group meetings to increase our comprehension of supercomputing technical architecture and cybersecurity techniques.

WHAT WE FOUND

Despite a history of innovation in HEC, NASA needs a renewed commitment and sustained leadership attention to reinvigorate its HEC efforts. Without key changes, the Agency's HEC is likely to constrain future mission priorities and goals. NASA's HEC is not managed as a program or centralized Agency strategic service; instead, resources are managed within the Earth Science Research Program within SMD, and this organizational placement hinders NASA's HEC efforts. One scientist within that Program is responsible for HEC capabilities at both HEC facilities, in addition to their Earth science responsibilities. This disjointed organization and management of HEC resources exacerbates several issues, including oversight, monitoring, and the foreign national accreditation access process. Although NASA has identified HEC as a capability portfolio, we found that key guiding documents and frameworks are absent, such as a management plan—an agreement detailing how the portfolio will be managed—and a commitment agreement designed to engage all relevant stakeholders and identify HEC as a strategic activity. Furthermore, while the Office of the Chief Information Officer (OCIO) has some oversight of HEC, it is not directly engaged in HEC activities or governance. Lastly, NASA is not

keeping up with technological developments and advanced research computing requirements, in part due to these organizational and funding constraints.

NASA's HEC resources are oversubscribed and overburdened—in other words, Mission Directorates are requesting more computing time than existing capacity can provide. This scarcity drives schedule delays and often leads to NASA teams purchasing their own HEC resources to meet deadlines. For example, the Space Launch System team invests about \$250,000 annually to purchase and locally manage their own HEC clusters rather than waiting for existing HEC resource availability. Agency officials told us that, except for Goddard Space Flight Center and Stennis Space Center, there are independent HEC assets installed at almost every NASA Center. NASA also lacks a comprehensive strategy for when to use HEC assets on the premises versus when to utilize cloud computing options—or a widespread understanding of the cost implications for each choice. Stakeholders told us that while they know NASA has HEC cloud computing options, they were hesitant to use them due to unknown scheduling practices or assumed higher costs.

NASA's decentralized HEC management also raises cybersecurity concerns. In addition to teams building their own HEC assets, OCIO-mandated cybersecurity controls are sometimes ignored or bypassed by Mission Directorates that view them as too stringent. OCIO's limited involvement with HEC system management can also result in duplicate spending (such as for software that OCIO already licenses) and difficulty in identifying and controlling access to HEC systems that are not included in OCIO's asset inventory tools. We also identified extensive use of NASA's HEC assets by external and foreign national parties without adequate user activity monitoring or a review process by security personnel for gaining access to HEC systems. Finally, we found that individual Center HEC asset users are not steadily monitored, and there are no evaluations conducted to verify rights and accesses granted to international partners. Without an integrated HEC strategy and a more focused, security management approach, the Agency's trailblazing science and technology research will continue to be unnecessarily limited by NASA's disjointed HEC efforts.

WHAT WE RECOMMENDED

To establish executive leadership and strategically position NASA's HEC to meet the Agency's specialized needs, we recommended NASA's Associate Administrator (1) appoint executive leadership to determine the appropriate definition, scope, ownership, organizational placement, and structure for NASA's HEC. Additionally, we recommended that the Associate Administrator establish a tiger team to collaborate and strategize on HEC issues, including: (2) develop enterprise-wide stakeholder requirements to validate commitment agreements as required by policy; (3) identify technology gaps essential for meeting current and future needs and strategic technological and scientific requirements; (4) develop a strategy to improve prioritization and allocation of HEC assets, including on-premises versus cloud resources; (5) evaluate cyber risks to determine oversight and monitoring requirements; (6) implement an HEC classification designation for identifying HEC assets; (7) develop an inventory of enterprise-wide HEC assets; (8) document risk impact, classification, and categorization for all HEC jobs; and (9) identify and mitigate gaps in the foreign national accreditation access process.

We provided a draft of this report to NASA management who concurred with Recommendation 1 and partially concurred with Recommendations 2 through 9. NASA described planned actions to address Recommendation 1 and stated that a tiger team will be established to collaborate and strategize on HEC issues; subsequently, the tiger team will determine the implementation of Recommendations 2 through 9. While we consider management's comments responsive, OIG requests regular updates to understand the planned actions and timeline for implementation and to monitor progress towards implementation of Recommendations 2 through 9. The recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions.

For more information on the NASA Office of Inspector General and to view this and other reports visit <https://oig.nasa.gov/>.

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Acronyms

AI	artificial intelligence
ARMD	Aeronautics Research Mission Directorate
AWS	Amazon Web Services
CFD	Computational Fluid Dynamics
CP	capability portfolio
CPU	central processing unit
DOE	Department of Energy
ESDMD	Exploration Systems Development Mission Directorate
FLOPS	floating point operations per second
GAO	Government Accountability Office
GPU	graphics processing unit
HEC	high-end computing
IT	information technology
NAS	NASA Advanced Supercomputing
NCCS	NASA Center for Climate Simulation
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NPR	NASA Procedural Requirements
NSCI	National Strategic Computing Initiative
OCIO	Office of the Chief Information Officer
OIG	Office of Inspector General
RISCS	Risk Information Security Compliance System
SLS	Space Launch System
SMCE	Science Managed Cloud Environment
SMD	Science Mission Directorate
TCP/IP	Transmission Control Protocol/Internet Protocol

INTRODUCTION

Serving a broad spectrum of employees, customers, researchers, partners, and external collaborators, NASA's high-end computing (HEC) capability—previously known as “supercomputers”—provides a comprehensive set of resources and services for the Agency's Mission Directorates as well as the NASA Engineering and Safety Center.¹ Because HEC environments differ from traditional information technology (IT) systems, it is more difficult to strike the right balance between scientific and engineering requirements and cybersecurity protections.

Analyzing immense amounts of data would be impossible without HEC capabilities—a typical computer simply cannot process data rapidly enough to meet Agency scientific and engineering demands. For example, HEC capabilities enabled NASA to ingest and analyze months of Kepler observation data to more quickly identify evidence pointing to the existence of exoplanets—many located in the habitable zone.² Currently, NASA is using HEC capabilities to model the Agency's planned human landing on Mars, as well as to process and analyze the physics and environmental data critical to a successful atmospheric entry and landing on the Martian surface.

Because HEC systems transfer user data into the HEC environment, the system owner is responsible for ensuring the confidentiality, integrity, and availability of that data by employing effective cybersecurity controls.³ However, traditional cybersecurity tools can be either incompatible or overly disruptive in an HEC environment. As a result, cybersecurity considerations may take a back seat to the processing speed and system capabilities needed for scientific research.

Defining High-end Computing

Broadly Defined

High-end computing, also known as high-performance computing or supercomputing, is the ability to process large amounts of data and perform complex calculations at high speeds for solving large-scale technical and scientific problems.

Source: NASA

¹ For this report, we broadly define high-end computing, also known as high-performance computing or supercomputing, as the ability to process large amounts of data and perform complex calculations at high speeds for solving large-scale technical and scientific problems. In this document, we will use the term HEC throughout.

² The Kepler Mission, launched on March 6, 2009, was the first space mission dedicated to the search for Earth-sized and smaller planets in the habitable zone of other stars in our neighborhood of the galaxy. An exoplanet is any planet beyond our solar system. A habitable zone is the distance from a star at which liquid water could exist on orbiting planets' surfaces. Analyses typically take about 3 days to run on HEC versus more than a month on Kepler Science Operations Center computers.

³ An HEC environment is a system that connects scientific computing users, data, applications software, and middleware and integrates them into a single research environment. Data transfer is the process of using computing techniques to move data from one computer to another. A cybersecurity control is a safeguard or countermeasure designed to protect the confidentiality, integrity, and availability of information and to meet defined security requirements.

In this audit, we assessed NASA's overall management of its HEC capabilities. Specifically, we focused on relevant policies, processes and controls, capacity planning, stakeholder engagement, and cybersecurity. See Appendix A for details on the audit's scope and methodology.

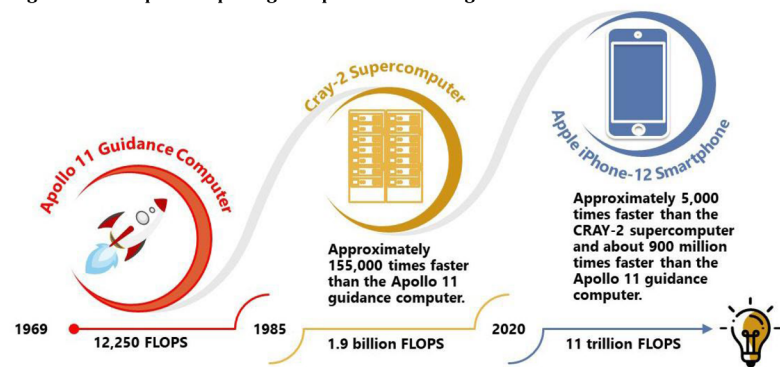
Background

In a complex, rapidly changing world, government agencies increasingly rely on HEC to manage and process massive volumes of data to solve mission-critical challenges. With the ability to process large amounts of data and perform calculations at high speeds, HEC helps solve large-scale technical and scientific problems, enabling researchers to study subjects that would otherwise be impractical, or impossible, to investigate due to their complexity or the danger they pose. In recent years, HEC has helped the federal government develop treatments for COVID-19, advance scientific research and discovery, and conduct high fidelity operational simulations.

Designed in 1964 by Seymour Cray—known as the “father of supercomputing”—the Control Data Corporation 6600 is considered the first high-end computer. Today, the 6600 is dwarfed when compared to the computing power of common smartphones.

Assessing computing power is highly complex. To simplify for illustration and ease of understanding: the computer's processor clock speed determines how quickly the central processing unit can retrieve and interpret instructions. Today, mobile devices have more computing power than HEC assets through the turn of the 21st century—including the computational ability of the Apollo 11 Guidance Computer that helped put astronauts on the Moon more than half a century ago. See Figure 1 for an illustration comparing processing power through the years and Appendix B for additional information.

Figure 1: Example Comparing Computer Processing Power



Source: NASA Office of Inspector General (OIG) presentation of Adobe information.

Note: "FLOPS" stands for floating point operations per second.

However, while interesting, this comparison is not precise. It's like comparing the first airplanes designed by the Wright Brothers and a fighter jet—both could fly, but the two are, technologically, worlds apart. Making a side-by-side comparison of computing power is difficult because there are many

ways to measure computational performance, such as the speed at which a system calculates floating point operations per second, known as FLOPS, or the speed at which a system can run graphics-intensive applications. Performance also depends on several other factors, such as the amount and speed of memory, network performance, and how well the computer code utilizes the system hardware.

In 1991, when the Federal High-Performance Computing and Communications initiative began ramping up, NASA was tasked with conducting basic and applied research in networking and information technology, particularly in the field of computational science, with emphasis on aerospace sciences, Earth and space sciences, and remote exploration and experimentation.⁴

In 2015, an Executive Order established the National Strategic Computing Initiative (NSCI) and a whole-of-government HEC strategy.⁵ The NSCI, in collaboration with industry and academia, led to the creation of a cohesive, multi-agency vision and federal investment to maximize the benefits of HEC for the United States. As such, NASA was established as a deployment agency—meaning that NASA, along with other deployment agencies, participates in the co-design process to integrate the special requirements of its missions and to influence the early design stages for new HEC systems, software, and applications.⁶

In 2021, the Government Accountability Office (GAO) conducted a review of agencies charged with HEC responsibilities in the NSCI Executive Order.⁷ Although GAO noted that NASA and the other agencies made advances in HEC research, development, and deployment activities, stakeholders cited ongoing challenges related to the uncertainty over how to meet future funding needs, cloud utilization, and software maintenance.

Since the NSCI was established, the use of HEC for modeling, simulation, and artificial intelligence (AI) has grown substantially.⁸ NASA, for example, uses a combination of high-end computers, AI, and satellite data to process extremely large volumes of imagery transmitted by the Transiting Exoplanet Survey Satellite.⁹ Once the high-end computer processes the raw data, the data is used to investigate vast regions of space for valuable scientific data hidden within multiple star systems. As more agencies rely on HEC to process their data, these systems become high-profile targets for attackers. To protect information, the *Executive Order on Improving the Nation's Cybersecurity* mandates that data be encrypted in transit and at rest.¹⁰

⁴ Public Law 102-194, *High-Performance Computing Act of 1991* (December 9, 1991).

⁵ Executive Order 13702, *Creating a National Strategic Computing Initiative* (July 29, 2015).

⁶ The Department of Defense, Department of Energy, and the National Science Foundation are NSCI lead agencies in developing the next generation of integrated HEC hardware and software capability, as well as workforce development. In addition to NASA, the other four NSCI deployment agencies are the Federal Bureau of Investigation, the National Institutes of Health, the Department of Homeland Security, and the National Oceanic and Atmospheric Administration.

⁷ GAO, *High-Performance Computing Advances Made Towards Implementing the National Strategy, But Better Reporting and a More Detailed Plan Are Needed* ([GAO 21-104500](#), September 2021).

⁸ AI is generally thought of as the capability of a machine to imitate intelligent human behavior.

⁹ The Transiting Exoplanet Survey Satellite is a NASA mission to discover Earth-size worlds around nearby stars.

¹⁰ Executive Order 14028, *Improving the Nation's Cybersecurity* (May 12, 2021). Encryption, at its most basic level, is the process of protecting information or data by using mathematical models to scramble it in such a way that only the parties who have the key can unscramble it. As the name implies, data in transit is data moving from one location to another. Data at rest refers to inactive data, meaning it is not moving between devices or networks.

Cybersecurity Versus Performance is a Constant Struggle

As the global cyberthreat environment grows, protecting critical systems and sensitive information from digital attacks can overwhelm even the most sophisticated cybersecurity professionals. This is equally true in HEC environments, especially those providing a user front end (computer interface) that is exposed to the internet and its common threats of vulnerabilities and attacks. Securing HEC systems is challenging due to their size; performance requirements; diverse and complex hardware, software, and applications; varying security requirements; and the nature of shared cyber resources.

Mirroring the commercial industry, government HEC threats break down into four themes: exploiting humans, exploiting software, exploiting protocols, and insecure design. Exploiting humans includes issues like phishing attacks and insider threats.¹¹ Exploiting software includes taking advantage of bugs that, if exploited, can lead to memory being overwritten to redirect the flow of a program or information to an attacker. Exploiting protocols includes things such as brute-force password cracking attacks.¹² HEC users often consider cybersecurity valuable only as long as it does not significantly slow down system performance and impede research.

Underscoring the importance of HEC cybersecurity, in February 2023, the National Institute of Standards and Technology (NIST) released inaugural draft guidance to standardize and facilitate the sharing of HEC security information and knowledge through the development of an HEC system reference model.¹³ The reference model divides an HEC system into four function zones: high-performance computing, data storage, access, and management. Because the NIST draft guidance is currently under review, the lack of standards contributes to the challenges of consistently applying cybersecurity in an HEC environment.

HEC Is Key to NASA's Mission Success

For over three decades, NASA's use of HEC resources has been a major and growing factor in the effectiveness and execution of its missions. For example, in October 2004 NASA's high-end computer Columbia, located at Ames Research Center (Ames), gained worldwide recognition as the most powerful computer in the world at the time. The combined speed and productivity increased the Agency's HEC capability tenfold for missions in aeronautics, space exploration, and Earth and space sciences. Notably, Columbia—named to honor the crew of the Space Shuttle Columbia STS-107, lost in 2003—was critical to NASA's post-Columbia return to flight effort and for near-real-time simulations that contributed to the safety of subsequent shuttle missions. The HEC Columbia remained active until early 2013 when it was phased out to make way for newer, upgraded HEC assets. See Appendix C for additional information on how various NASA missions use HEC to assist their work.

In a recent publication NASA described five uses of HEC related to mission success:

¹¹ Phishing is an attempt by an individual or group to solicit personal information from unsuspecting users by employing social engineering techniques. Phishing emails are crafted to appear as if they have been sent from a legitimate organization or known individual and entice users to click on a link that will take them to a fraudulent website that also appears legitimate. Cybersecurity threats posed by an organization's employees and contractors are commonly referred to as insider threats.

¹² A protocol is a set of rules or procedures for transmitting data between electronic devices, such as computers.

¹³ NIST Special Publication 800-223, Draft, *High-Performance Computing (HPC) Security* (February 2023).

1. Designing safe, efficient air taxis, such as the Urban Air Mobility tiltwing single-main rotor concept vehicle, by simulating aerodynamic performance.¹⁴
2. Keeping planetary rovers safe during risky landings by simulating and analyzing various scenarios of supersonic parachute inflation.
3. Modeling spacecraft heat shield materials at the microscale to generate high-resolution 3D images.
4. Predicting weather and climate to keep humans safe by simulating weather and climate events.
5. Exploring the past, present, and future of planets inside and outside of our solar system by simulating the climates of planets.

NASA's HEC Helps Battle COVID-19

In March 2020, as the world came to a standstill due to the COVID-19 pandemic, HEC gained recognition for its role in helping accelerate science, therapeutics development, and COVID-19-related patient care. Recognizing the potential of HEC to accelerate progress in developing a vaccine for COVID-19, the HEC community—including NASA—created a public-private consortium between government, industry, and academia to aggregate compute time and resources on consortium member's HEC assets and to make them available to assist in researching the virus. Acting as a single point of access, the COVID-19 High-Performance Computing Consortium provided scientists state-of-the-art HEC resources to accelerate and enable pandemic research and response.¹⁵

As a consortium member, NASA assessed research proposals for technical feasibility and benefits, then matched approved proposals to resource providers based in part on HEC requirements. For example, using computing resources at the Ames facility, scientists from around the United States conducted research to understand the virus and develop treatments and vaccines. Running computationally intensive data derived from COVID-19 patient samples, NASA HEC assets identified potential biomarkers indicative of disease severity.¹⁶ The results of this analysis allowed for identification of unique human sequence variation associated with high risk of morbidity for COVID-19 patients. Likewise, NASA HEC assets were used for COVID-19 environmental impact studies. As part of Earth science pandemic research efforts, one such study involved analyzing air pollution reduction due to a decrease in airline flights.

NASA Pioneered Many HEC Firsts

NASA builds its HEC systems differently than its counterparts at national labs and research universities by playing the long game and adding performance over time. Instead of commissioning a monolithic machine with a defined operational period, NASA uses a modular strategy, gradually adding additional computing capacity. For example, the HEC Aitken has been upgraded yearly since 2019, including

¹⁴ Urban Air Mobility vehicles support vertical lift research aimed at capabilities and technologies that will eliminate barriers for quiet, safe, efficient, autonomous vehicles operating in both urban and rural environments. Using NASA's powerful supercomputers, researchers are simulating the aerodynamic performance to understand complex airflow around aircraft components.

¹⁵ NASA, along with the Office of Science and Technology Policy, Department of Energy, National Science Foundation, IBM, Massachusetts Institute of Technology, Rensselaer Polytechnic Institute, Amazon Web Services, Hewlett Packard Enterprise, Google, and Microsoft joined the High-Performance Computing Consortium as founding members.

¹⁶ A biomarker is a biological molecule found in blood, other body fluids, or tissues that is a sign of a normal or abnormal process, or of a condition or disease. It may be used to see how well the body responds to a treatment for a disease or condition.

recently in November 2023. By upgrading its HEC assets over time, NASA attempts to keep pace with the technology needed to tackle complex subjects such as Artemis missions and simulating weather on Mars.¹⁷

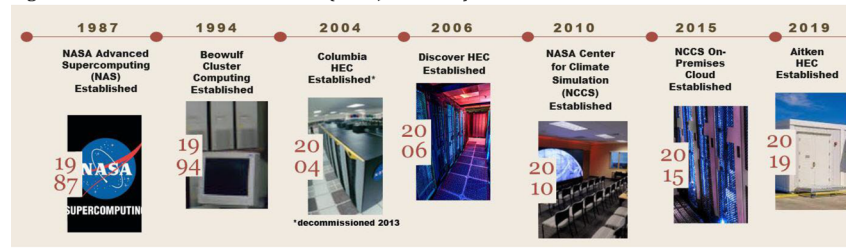
Since its inception, NASA has pioneered many technologies and techniques that have become standards within the HEC ecosystem.¹⁸ For instance, in 1994 the first Beowulf Linux commodity cluster was constructed at NASA's Goddard Space Flight Center (Goddard) with its origins part of HEC folklore.¹⁹ Beowulf linked personal computers, Linux, ethernet, and network drivers into a supercomputer that accelerated the global scientific community's move away from expensive, proprietary supercomputer systems and toward the adoption of computer clusters and open-source software. This method of building HEC clusters continues today. Currently, most of the world's top 500 computer systems use NASA's Beowulf approach. Significantly, in April 2022 Beowulf cluster computing was inducted into the Space Technology Hall of Fame.

NASA's architectural and operational models also led the world in a series of firsts, such as:

- First to put the UNIX operating system on HEC.
- First to implement TCP/IP networking in HEC environment.²⁰
- First to link HEC hardware and workstations together to distribute computation and visualization (what is now known as client/server).
- Developed Aeronet, the first high-speed wide-area network connecting HEC resources to remote customer sites.
- Developed the first UNIX-based hierarchical mass storage system.

Figure 2 highlights select milestones in NASA's HEC evolution over more than 30 years.

Figure 2: Select NASA HEC Milestones (as of June 2023)



Source: NASA OIG presentation of Agency Information.

¹⁷ NASA's Artemis campaign seeks to return humans to the Moon's surface in 2025 before sending crewed missions to Mars in the 2030s.

¹⁸ An HEC ecosystem includes servers, storage, software, and technical support.

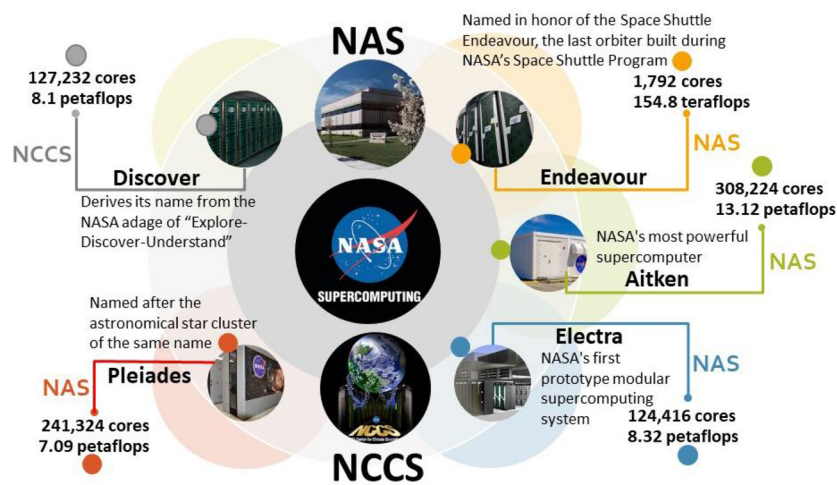
¹⁹ A computer cluster is a set of connected computers (nodes) that work together as if they are a single (much more powerful) machine.

²⁰ TCP/IP stands for Transmission Control Protocol/Internet Protocol—a suite of communication protocols used to interconnect network devices on the internet or intranet.

NASA's HEC Facilities

Leveraging on-premises HEC at two locations—the NASA Advanced Supercomputing (NAS) facility at Ames in California and the NASA Center for Climate Simulation (NCCS) at Goddard in Maryland—provide a range of assistance from designing safer aircraft and space vehicles to solving challenging weather and climate prediction problems.²¹ At both the Ames and Goddard facilities, computing time is available to NASA-sponsored scientists or engineers for high-performance processing and analysis using the HEC assets. The Ames facility has four HEC assets while the Goddard facility houses one. Figure 3 provides additional information on NASA's HEC assets.

Figure 3: NASA HEC Assets (as of June 2023)



Source: OIG presentation of NASA information.

Note: A core is essentially a small central processing unit (CPU) built into a big CPU. It can independently perform or process all computational tasks. A teraflop is a rate of computing speed that achieves one trillion FLOPS. One petaflops equals one quadrillion operations per second and represents an extremely fast computing speed for a single machine.

In the early 1980s, Congress established the NAS facility at Ames with a charter to provide HEC capabilities for numerical simulations of proposed commercial and military aircraft designs. NASA's premier HEC facility began operation in 1987, and today NAS continues advancing key technologies in aeronautics and space explorations, such as rotorcraft (helicopter) stall dynamics and asteroid impact simulations for planetary defense.

²¹ On-premises, also known as "on-prem," simply means that the IT infrastructure is hosted on-site.

As of June 2023, the four HEC systems at the NAS facility—Aitken, Electra, Pleiades, and Endeavour—are used by 1,885 researchers from NASA Centers, universities, and industry to support the Agency's mission to explore space and to understand our planet.²²

Likewise, Goddard's HEC facility—with 1,410 current users—has provided resources to NASA scientists and engineers for more than 30 years. With an emphasis on climate simulation, the NCCS analyzes and models data on winds, clouds, precipitation, and atmospheric pollutants to enable scientific discoveries that will benefit humankind. As the centerpiece of Goddard's NCCS, the Discover HEC is capable of calculations at nearly 8.1 petaflops.²³ Discover is particularly suited for large, complex, communications-intensive problems employing large matrices and science applications.

As of November 2023, the on-premises HEC systems at Ames were ranked among the world's top 500 systems—Aiken #85, Pleiades #132, and Electra #143, respectively. NAS's Endeavour and Goddard's Discover on-premises HEC are not ranked in the *TOP500*.²⁴ See Appendix D for additional details.

Additionally, to augment NASA's on-premises HEC resources, both the NAS and NCCS offer commercial HEC cloud services provided by Amazon Web Services (AWS) on a pay-for-use basis.²⁵ Pricing depends on computing processor time, space used, the frequency of request, and the amount of data transferred out of AWS. The NAS HEC commercial cloud, launched in August 2019, allows NASA scientists, engineers, and collaborators to perform workloads that require additional resources to complement on-premises resources. Likewise, through the NCCS, the Science Managed Cloud Environment (SMCE) provides access to the commercial HEC cloud for NASA researchers and their collaborators. Managed by personnel at Goddard, SMCE utilizes commercial AWS by enabling access to HEC cloud resources for rapid prototyping and collaboration. The SMCE is specifically designed for data in a Federal Information Security Modernization Act low-security environment providing a "ready to go" cloud science analytics platform with access to high-performance computing.²⁶

NASA's HEC Organizational Structure and Users

With a fiscal year 2023 budget of about \$74 million, along with additional funding received from each of the Mission Directorates, the HEC capability is governed by the Mission Support Council and managed by the Agency's Science Mission Directorate (SMD).²⁷ The use of directorate funds enables HEC assets to operate as an Agency-wide resource. While SMD oversees and coordinates resource requirements (time and capacity) for all of NASA, each of the Mission Directorates has the autonomy to manage their allocated time, capacity, data, and user access based on project requirements.

²² NAS deployed a fifth HEC system, Cabeus, after the completion of our review. Cabeus is not subject to our review.

²³ To match what a 1-petaflops computer system can do in just one second, you would have to perform one calculation every second for 31,688,765 years.

²⁴ Begun in 1993 and updated every 6 months, the *TOP500* provides a ranked list of the most powerful general purpose computer systems in common use for high-end applications.

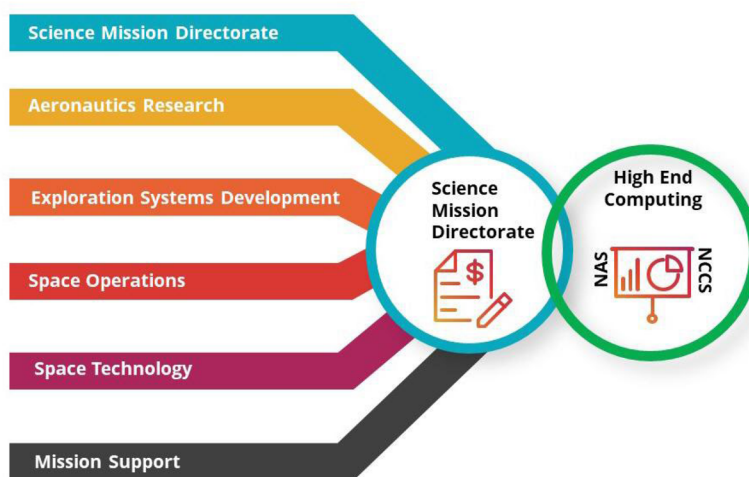
²⁵ Cloud computing services is the practice of using a network of remote servers hosted on the internet for centralized data access and storage to computer services or resources such as Microsoft Office 365 or Google Apps.

²⁶ According to the Federal Information Security Modernization Act of 2014, Pub. L. No. 113-283, (2014), if the loss of confidentiality, integrity, or availability is projected to have a limited harm on the organization's activities, assets, or persons, the potential impact is considered low.

²⁷ The Mission Support Council serves as the Agency's senior decision-making body regarding the integrated mission support portfolios such as IT, capability portfolios, and associated investments.

More than a decade ago, the Agency identified HEC as one of five capability portfolios (CP)—a collection of functionally similar, site-specific capability components—in accordance with NASA policy.²⁸ NASA Procedural Requirements (NPR) 8600.1 provides guidance on how to strategically and centrally manage CPs that are determined to be of importance to the Agency and calls for HEC to be managed in an integrated manner and within budget constraints to meet current and future requirements and strategic needs. Below, Figure 4 displays the HEC organizational structure.

Figure 4: NASA's HEC Organizational Structure (as of December 2023)



Source: NASA OIG presentation of the HEC organizational structure.

During fiscal year 2023, NASA's HEC resources were utilized by more than 3,000 users—of which more than half were attributed to external parties consisting of authorized foreign nationals and educational partnerships. Users typically participate in NASA-affiliated research, research in partnership with NASA or research that utilizes NASA data. Scientists and researchers who are considered foreign nationals—anyone who is neither a U.S. citizen, a U.S. lawful permanent resident, nor a U.S. protected individual—must adhere with U.S. export control policies and regulations. Generally, Agency HEC use by approved foreign nationals is permitted regardless of whether access to HEC resources is from within the U.S. or abroad, and according to Agency officials, NASA follows federal mandates and restrictions on foreign nationals.

²⁸ NPR 8600.1, *NASA Capability Portfolio Management Requirements* (April 22, 2019). NASA's CPs are Aerosciences Evaluation and Test Capabilities; High-End Computing Capability; Rocket Propulsion Test Program; Space Environments Testing Management Office; and Aircraft Management Advisory Board.

SUSTAINED LEADERSHIP ATTENTION AND RENEWED COMMITMENT ARE NEEDED TO REINVIGORATE NASA'S HEC

HEC permeates NASA activities by providing computing services to engineers, scientists, and researchers alike, however, we found NASA's HEC stewardship and competitiveness is waning. For example, the Agency's HEC organizational structure contributes to ineffective and undisciplined management, resource oversubscription negatively impacts mission work, and the cloud approach and cybersecurity practices lack a comprehensive strategy. In our view, without elevating HEC leadership to an executive level position, better engaging relevant stakeholders, and employing an integrated Agency-wide HEC strategy, NASA's science and research objectives will continue to be constrained, likely impacting future mission priorities and goals.

Organizational Structure Hinders NASA's HEC Efforts

Although NASA's mission is unique, the challenges the Agency faces in managing a decentralized HEC environment are not. We examined HEC organizational placement and executive leadership at two agencies—the National Oceanic and Atmospheric Administration (NOAA) and the Department of Energy (DOE)—that, like NASA, are geographically diverse, independently managed, and support numerous users.²⁹ Unlike at NASA, NOAA and DOE HEC capabilities are managed at an executive level, which provides the capability with greater organization visibility. At NASA, the Associate Administrator for SMD is responsible for directing and overseeing five broad scientific pursuits: Earth science, planetary science, biological and physical sciences, heliophysics, and astrophysics; HEC is buried in Earth science under the Earth Science Research Program despite being used across much of the Agency. Within SMD, a scientist wearing dual hats—Earth science programmatic compute activities and HEC capability manager—manages HEC at both the NAS facility and NCCS.

NASA. HEC is not managed as a program or centralized Agency strategic service, and organizational placement resides several layers deep within SMD—hindering the Agency's ability to efficiently allocate resources, adapt to varying mission needs, and quickly respond to technology advancements. Furthermore, while the Office of the Chief Information Officer (OCIO) has some oversight of HEC, similar to its involvement with large procurements and governance through control boards, it is not directly engaged in HEC activities or governance.

According to Agency policy, CPs provide NASA with the ability to manage components strategically and centrally in a way that balances the needs and demands of programs and projects and external

²⁹ Executive leadership guides decision-making by influencing activities such as fulfilling organizational goals, strategic planning, funding, and integrating new technologies into agency processes. For the purpose of this report, we further define executive leadership as leadership at NASA's Associate Administrator level.

partners.³⁰ Although NASA identified HEC as a CP, we found that key guiding documents and frameworks are absent, such as a management plan—an agreement between the sponsoring Mission Directorate and the CP manager detailing how the portfolio will be managed—and a commitment agreement designed to engage all relevant stakeholders and identify HEC as a strategic activity. While the sponsoring Mission Directorate and CP manager are responsible for periodically evaluating the efficiency, effectiveness, and performance of the portfolio and its capability components, during the course of our audit, HEC internal stakeholders expressed frustration at the lack of a management plan detailing how HEC resources are allocated. In short, without a management plan and commitment agreement, important aspects of the administration of HEC resources remain obscured to stakeholders.

Additionally, while NASA has engaged in HEC activities for more than 30 years, the Agency is not keeping up with today's rapid technological developments and specialized scientific and advanced research computing requirements due to funding and organizational constraints. NASA's current HEC infrastructure is built almost exclusively on cores of central processing units (CPUs), which lack the computational capabilities of the more modern graphics processing units (GPUs)—currently in use within the field worldwide.³¹ The NAS facility, for instance, has more than 18,000 CPUs and only 48 GPUs, with an even larger disparity observed at the NCCS. HEC officials raised multiple concerns regarding this observation, stating that the inability to modernize NASA's systems can be attributed to various factors such as supply chain concerns, modern computing language (coding) requirements, and the scarcity of qualified personnel needed to implement the new technologies. Ultimately, this inability to modernize its current HEC infrastructure will directly impact the Agency's ability to meet its exploration, scientific, and research goals. One such example is the Agency's use and development of AI, which we examined in a May 2023 report.³² HEC officials explained that, based on increasing stakeholder demand, they are "starting to tackle AI workloads that require new and different hardware." While HEC can support some small AI projects, the Agency's current HEC ecosystem cannot support projects that require a massive data stream.

The lack of organizational structure and strategic focus also affects the evolution of AI technologies—meaningfully impacting NASA's mission success. As a primary user of HEC capabilities, NASA's AI users create processes, refine data, and develop capabilities to help solve HEC limitations and improve data-driven enhancements. NASA's AI community is expanding its own organizational structure and implementing the use of "tiger teams" to help assist with the alignment of AI leadership across the Agency. AI officials discussed their intent for their tiger teams to engage with HEC leadership in efforts to advocate for areas that HEC could assist with AI advancement. However, in our judgement, such efforts are likely to prove less fruitful given the limitations of the Agency's HEC organizational structure and capability deficiencies.

NOAA and DOE. At both NOAA and DOE, HEC is managed at an executive level. At NOAA, HEC is the cornerstone of weather forecasting, climate and weather research, and understanding coastal issues. HEC investments are managed as an integrated enterprise by the NOAA Office of the Chief Information Officer's High-Performance Computing and Communications Program. Additionally, NOAA's High

³⁰ NPR 8600.1.

³¹ The term "processor" is often used to refer to a CPU. A GPU is an electronic circuit that can perform mathematical calculations at high speed. A GPU's design allows it to perform the same operation on multiple data values in parallel, increasing its processing efficiency for compute-intensive tasks.

³² NASA OIG, *NASA's Management of Its Artificial Intelligence Capabilities* (IG-23-012, May 3, 2023).

Performance Computing Board provides strategic guidance and oversight for the execution of the enterprise and the allocation of HEC resources.

At DOE, the Office of Science—a program office—oversees world-class HEC to advance energy and scientific technology. The Office of Science is led by a presidentially nominated, Senate-confirmed director and two senior-career federal deputy directors. DOE’s Frontier supercomputer and its scientists are leading the world in science and technology innovation.³³ The Frontier supercomputer, which can model and simulate complex problems associated with the nation’s energy sector, helps maintain U.S. leadership in AI and HEC systems.

HEC Oversubscription Impacts Missions

NASA’s HEC is currently oversubscribed and overburdened by demand and competing priorities. HEC officials use an Agency website for capacity planning and management—balancing user requirements against resource availability. Quarterly updates to the 5-year Capacity Plan—in conjunction with a Data Management Plan—provide a catalyst encouraging scientists to “think up front,” identify their needs, and understand HEC resource limitations. Generally, HEC capacity allocations are determined and prioritized at the Mission Directorate level. Each organization prioritizes requests against criteria such as mission priority, anticipated science workload, available capacity, and utilization time. Importantly, operational mission work is given HEC resource priority over research and development activities.

According to HEC officials, resources are currently operating at capacity and are oversubscribed—meaning more time is requested by missions than capacity can provide—with demand sometimes exceeding supply by as much as threefold. To make the most of the schedule ebb and flow, resources are typically allocated at 140 percent of HEC resource capacity to eliminate potential idle time. While this oversubscription permits smaller jobs—which typically take less time—to take advantage of availability gaps, larger, more intensive compute jobs are often delayed. HEC officials explained they are concerned that vital resources needed for mission innovation are strained, receiving three times more requests than capacity allows. Given that wait times vary in length, depending on resource availability, trickle-down schedule delays can cause impacts to a launch or critical manufacturing. For example, the Mars Ascent Vehicle, an element in the Mars Sample Return Program, has experienced schedule delays waiting on NAS facility resources. Specifically, a 3-week delay was encountered for critical Computational Fluid Dynamics (CFD) simulations needed for key milestone reviews.³⁴

Similarly, Aeronautics Research Mission Directorate (ARMD) stakeholders identified NAS resource oversubscription as a formal risk due to allocated HEC compute resources falling short of the organization’s needs. According to the stakeholders, ARMD programs are unable to meet their performance objectives due, in part, to capacity limitations driven by NAS demand exceeding availability. For example, the oversubscription risk and shortage of HEC resources affected NASA’s

³³ Frontier, the most powerful supercomputer in the world, is located at the DOE’s Oak Ridge National Laboratory in Tennessee.

³⁴ CFD is a powerful tool that creates a digital simulation visualizing the flow of fluids and the way they are affected by objects. It shows how temperature, pressure, and velocity are going to behave in a design.

Sustainable Flight Demonstrator—a partnership between NASA and The Boeing Company—causing ARMD to consider purchasing their own HEC resources at a projected cost of \$3.1 million.³⁵

During discussions with about a dozen HEC stakeholders, we identified additional examples of oversubscription and competing priorities. Officials within the Office of the Chief Engineer explained that job delays in resource availability and the subsequent impacts across the Agency have not been studied. Accordingly, NASA officials do not know whether paying more to run a job sooner, on an HEC commercial cloud resource for example, outweighs the cost of idle scientists and mission impacts while waiting for on-premises NASA HEC system availability.

Table 1 below depicts some HEC issues impacting NASA missions.

Category	Issue and Impact
Hardware/System	Bad nodes (slow, crash, or reboot) cause jobs to fail; users have to work with HEC support to take those nodes offline. ³⁶
	Network issues degrade inter-node communication and cause jobs to fail.
	File system stability causes very slow response times (several minutes); file systems won't mount on compute nodes causing job to fail.
Resource Availability	High system usage has led to long queue times (several days to weeks for typical size jobs of ~2000 cores).
	Forced to get a reservation to meet project schedules after getting little throughput in the normal queues; impacted systems: Commercial Crew Program, Human Landing System, Space Launch System Exploration Upper Stage, and Mars Ascent Vehicle.
Large Resource Requests	Several high node count/long duration reservations have dominated system resources and impacted Exploration Systems Development Mission Directorate and Space Operations Mission Directorate.
	Directorates make allocation requests to HEC management; stakeholders are not engaged to justify resource allocation and prioritize mission share; it is not clear how the determination of mission priority is made.
Program Schedule	Human Landing System has experienced multiple delays in analyzing critical components and CFD simulations due to lack of available resources.

Source: NASA.

To satisfy unmet HEC needs, individual NASA organizations have circumvented the queue by purchasing additional HEC assets directly from vendors. While essential to overcoming the technological challenges inherent to many NASA projects, this scenario also leads to using alternative means to “get the job done” outside of the current HEC structure and capability. For example, the Space Launch System (SLS) Program purchases and operates their own HEC clusters due to lack of availability and reliability of NAS

³⁵ The purpose of the Sustainable Flight Demonstrator project is to engage with industry, academia, and other government organizations to identify, select, and mature key airframe technologies, such as new wing designs, that have a high probability of transition to the next generation single-aisle seat class airliner.

³⁶ A node is any computer or other device connected to a network that sends, receives, or redistributes data. For example, computers, file servers, network-connected printers, and routers are all nodes.

systems.³⁷ SLS officials explained that they invest about \$250,000 annually to purchase and locally manage HEC clusters to ensure availability—necessitated, in part, to combat issues such as a 2-year delay in NAS resource availability required for aerosciences database analysis. Simply put, due to HEC resource oversubscription, the SLS Program does not reliably trust they can run jobs in time to meet their schedule needs.

On much smaller scales, HEC clusters at Johnson Space Center and Marshall Space Flight Center operate for the sole purposes of supporting site-specific engineering projects within their purview, including those for the Artemis campaign such as Orion (crew capsule), Gateway (orbiting lunar outpost), and SLS. Center officials explained that individual HEC assets are acquired for numerous reasons, such as the lack of access to existing HEC assets, lack of allocation availability, or lack of required software/technology for a specific project or function.

Frequently, these assets are unidentified and not managed as part of existing enterprise-wide HEC capabilities. Multiple NASA officials across organizational boundaries said that if an HEC asset was purchased directly by a mission or project, the OCIO does not know or manage the asset, and that project teams are doing what they want—essentially operating undisciplined, in a “free-for-all” HEC environment. We found that multiple independent HEC assets exist outside the HEC capability portfolio and are located at various NASA Centers. For example, Langley Research Center’s (Langley) Computational Research Facility pays for and maintains K-Cluster as a mid-range HEC designed to be a proxy for the Pleiades asset at Ames.³⁸ As a local on-demand resource, K-Cluster offers Langley developers a way to supplement unavailable NAS resources. According to NASA officials, Center-owned HEC assets are a “third rail”—meaning a controversial and unresolved issue. Unanswered organizational questions persist, such as should Centers have their own HEC resources; does it make sense to incorporate and manage those clusters at the Agency level; and should Center assets be a shared or exclusive resource.

In fact, Agency officials told us that, except for Goddard and Stennis Space Center, there are independent HEC assets installed at almost every NASA Center. In the case of Center-managed HEC, the purchasing costs of the HEC assets are frequently paid for by program-specific funds while power consumption for these Center-specific assets is funded by the Centers. Moreover, the complex cooling mechanisms required to maintain proper HEC operating temperatures adds not only real estate required to house the HEC systems in the local data centers, but also additional water and power infrastructure and consumption. The cost of maintaining Center HEC assets represents a hidden cost that is not accounted for in Agency HEC budgets or reporting. As a result, competing priorities and an unpredictable HEC oversubscription strategy have created schedule delays, encouraged the development of shadow assets—information technology on the Agency’s network that the Chief Information Officer did not purchase or authorize for use. Figure 5 displays the HEC infrastructure, including cooling pipes, at Langley.

³⁷ The SLS is a two-stage, heavy-lift rocket that launches the Orion Multi-Purpose Crew Vehicle into space.

³⁸ A mid-range supercomputer has, at most, one order of magnitude lower performance level than a high-end supercomputer.

Figure 5: Langley's High-End Compute Infrastructure (as of August 2023)



Source: OIG HEC photographs taken at Langley on August 24, 2023.

NASA's HEC Lacks a Comprehensive Commercial Cloud Strategy

NASA's HEC and, by extension, the Agency's HEC user base, does not have an overarching strategy on commercial cloud versus on-premises use. SMD, as the manager and largest user of NASA's on-premises HEC facilities, lacks a single, cohesive cloud approach needed to match evolving scientific and technological mission goals. Although NASA acquired commercial HEC cloud computing beginning in 2019 to complement and expand the Agency's current HEC on-premises capabilities, we found that cloud adoption among HEC users has been lackluster because of misconceptions among the various stakeholders about cloud computing related to cost, scheduling, and capacity. For instance, stakeholders explained that although they were aware of NASA's HEC cloud computing capabilities, they were hesitant to use the cloud due to unknown scheduling practices or assumed greater costs. However, OCIO officials stated that cloud pricing has improved dramatically from what was determined in previous cost studies and that a mechanism for capacity planning and scheduling was already in use by the HEC community. HEC and OCIO officials told us they were hopeful that with a more a strategic and integrated approach, cloud misconceptions can be resolved. Given that SMD currently operates five cloud computing environments with redundant capabilities, a centrally managed HEC cloud environment would benefit NASA's scientific goals by enabling a more optimized approach to managing HEC resources.

To address HEC needs, SMD officials explained they are focusing on combining the commercial cloud and on-premises resources to maximize the benefits of both—the former is more expensive and unrestricted, the latter is more affordable and constrained. Depending on user requirements, resource availability, and cost, the overall goal is to “marry” the best architecture required to support HEC applications. For example, a small weather simulation forecast can be quickly operational in the cloud,

whereas it could take days to run a similar model with NASA HEC on-premises resources due to time and availability constraints.

Currently, NASA's ability to process large amounts of data from projects, such as heliophysics, is limited due to HEC resource capacity constraints.³⁹ According to SMD officials, resource challenges need to be met not only with investments in hardware, but also expertise in software and code modernization. Because about half of HEC resources are used for modeling, SMD management initiated a study to further evaluate augmenting HEC resources with cloud computing.⁴⁰ Chartered in 2022, the Data and Computing Architecture Study addressed the question of whether a coordinated cloud and on-premises computing infrastructure can meet SMD's data and computing needs, enable efficiencies, and support SMD's transition to open-source science. The study results were released in November 2023. The SMD Management Advisory Council agreed with the study recommendations to improve coordination and alignment of HEC, but a timeline for implementation has not yet been established.

Both NOAA and DOE use various commercial cloud service providers, such as AWS and Google Cloud, to supplement their on-premises HEC resources as a way to meet specific resource-intensive peak computing demands. Commercial cloud environments can provide additional computational resources to meet dynamic HEC user demands, including immediate access to new and novel technologies such as new chip architectures, graphics processing units, and other parallel file systems.⁴¹ However, NASA's lack of charging policy contributes to cloud misconceptions and uncertainty about when it is appropriate—in terms of cost, time, and schedule—to use HEC cloud versus on-premises resources for the task at hand.

Diluted Cybersecurity Practices Expose HEC Risks

Cybersecurity controls in any HEC environment are atypical of those applied in a standard IT enterprise environment and are difficult to implement. NASA further compounds these issues through a myriad of shortcomings stemming from the decentralized deployment and management of its HEC assets. The difficulty of balancing performance demands for HEC projects against cybersecurity controls and applications is not unique to NASA. Compared to a typical IT environment, HEC systems are by definition designed and optimized to run at a high-performance level and operate exotic software to solve complex scientific problems by processing large amounts of data and performing calculations at high speeds. For example, HEC systems run complex AI software to model climate research, interpret geospatial data from satellite images, and use CFD to simulate environments impacting space vehicles.⁴² Given that peak performance is the metric most HEC users are concerned with, OCIO officials explained that security controls are historically treated as an afterthought and implemented such that they do not interfere with usability or performance.

³⁹ Heliophysics studies the nature and dynamic interactions of the Sun, the heliosphere, the plasma environments of the planets, and interstellar space.

⁴⁰ Modeling allows high-fidelity simulations of systems in environments that are difficult or impossible to create on Earth, allows removal of humans from experiments in dangerous situations, and provides visualizations of datasets that are extremely large and complicated.

⁴¹ A chip architecture is the overall design of a microchip encompassing both the hardware and software components—defining how they work together. A parallel file system is a type of storage system designed to store data across multiple networked servers and to facilitate high-performance access through simultaneous, coordinated input/output operations between clients and storage nodes.

⁴² Geospatial data directly or indirectly references a specific geographical area or location related to the Earth.

Most federal agencies and enterprises standardize their cybersecurity practices by implementing the controls published by NIST.⁴³ While these controls can be generalized to a degree, they are descriptive in their design and purpose—asking the system owner to implement the most stringent measures available such as strict access controls, user monitoring, multi-factor authentication, and constant or frequent asset scanning. For complex reasons, overly stringent controls do not work effectively in an HEC environment. Specifically, monitoring software can slow processing speed, and scanning tools can negatively impact the delicate system environment utilized by HEC servers and nodes. However, instead of seeking to find a balance for compensatory controls that could meet some, if not most, cybersecurity requirements, the mission-oriented HEC user base’s approach typically involves repeated waiver requests—known as risk-based decisions—to bypass the intended control, or built-in generic controls. Consequently, neither overly stringent security measures, nor waivers, offer practical solutions to protect the Agency’s HEC environments from cyber threats.

During our review, HEC officials explained that HEC system administrators conduct manual audit log analysis on a sporadic basis—mainly to identify performance bottlenecks instead of detecting potential cybersecurity threats or vulnerabilities. We found this practice counterintuitive from a cybersecurity perspective for multiple reasons. For example, best practices, such as separation of duties, require independent analysis to prevent log manipulation by a potential insider threat. Also, manual log reviews are impractical, slow, and prone to human error such as not identifying anomalous patterns or indicators of questionable or malicious activity.

HEC officials said that an automated monitoring solution, such as Splunk, is under consideration to convert data into operational intelligence using reports, charts, and alerts.⁴⁴ We found that NAS facility personnel are in the process of procuring a standalone instance of Splunk at an annual cost of \$34,000. While an automated monitoring and analysis solution is ideal, we question the need to purchase a separate Splunk license when the OCIO holds an enterprise-wide license. NASA OIG previously reviewed the Agency’s software asset management practices and found that duplicative spending and mismanagement of licenses is a problem throughout NASA.⁴⁵ In our view, this is a missed opportunity to consolidate analysis between the OCIO and Mission Directorates for improved cyber-situational awareness and software license cost avoidance.

NASA further exacerbates these cybersecurity issues as the result of poor management practices and limited oversight. In addition to the propensity for projects to build their own HEC clusters as previously discussed, we observed OCIO-mandated cybersecurity controls being ignored or bypassed by the Mission Directorates because they perceive the controls as overly stringent. Since these projects did not engage with OCIO in meaningful discussions about how best to implement various, essential tools—such as BigFix—needed for IT asset discovery and inventory are absent, resulting in the inability to identify and/or classify HEC systems.⁴⁶ Additionally, the high level of use of NASA HEC assets by external or

⁴³ NIST Special Publication 800-53, Revision 5, *Security and Privacy Controls for Information Systems and Organizations* (September 2020, includes updates as of December 10, 2020).

⁴⁴ Splunk is a software platform to search, analyze, and visualize machine-generated data gathered from the websites, applications, sensors, and devices that make up the IT infrastructure.

⁴⁵ NASA OIG, *NASA’s Software Asset Management* (IG-23-008, January 12, 2023).

⁴⁶ BigFix provides computer management services, including asset inventory/discovery, security vulnerability detection and remediation, security policy enforcement, software distribution, IT compliance reporting, patch management, and software license management. This is NASA’s primary system management tool.

foreign users further compounds cyber risk. Collectively, these issues raise serious questions about the overall security posture of NASA's HEC environment.

As previously discussed, while NASA's main HEC capabilities are found within the NAS and NCCS computing facilities, several other organizations operate individual HEC clusters for their own specific purposes. These individual HEC assets are owned and managed independent of NASA's primary systems, and each owner employs their own methodologies for system management, including the common tenets of cybersecurity such as monitoring and vulnerability mitigation/patching. These individual HEC clusters are not always placed on NASA's or public-facing networks, which limits the effectiveness of BigFix to discover, inventory, and monitor these assets for any known vulnerabilities that may need to be patched or mitigated. Also, the owners do not always annotate that these systems are high-performance or HEC in nature within the Agency's current asset system of record, known as Risk Information Security Compliance System (RISCS), and there is no automatic or unique classification mechanism within the system to do so.⁴⁷ This further complicates the Agency's ability to inventory and monitor its systems as there is no way to manually search RISCS for systems that are undetectable by BigFix. Similarly, these issues are not limited to the outlying, independent, Center HEC clusters. We found that NASA's HEC infrastructure likely poses additional risks due to insufficient asset monitoring and poor inventory, regardless of location or owner.

More concerning, we identified extensive use of NASA's HEC assets by external and foreign national parties. As of May 2023, a total of more than 700 foreign national users (including legal permanent residents living in the United States on a green card) were reported as currently having access to the NAS facility or NCCS assets for their respective projects and studies, which is likely only a snapshot of the overall picture. We found that individual Center HEC asset users are not steadily tracked, and interconnection security agreement evaluations are not conducted to verify rights and accesses granted to international partners.⁴⁸ Furthermore, multiple security personnel associated with the HEC capability discussed the lack of user activity monitoring and their lack of involvement in the approval or review process for external parties to gain access to HEC systems or NASA datasets. As a result, limited cybersecurity practices expose the Agency's HEC resources at a higher risk than necessary. Without a refocused effort to implement better cybersecurity safeguards, NASA's HEC resources will continue to be high-value targets to adversaries—potentially posing risks to not just a singular asset, but to NASA's network and IT inventory as a whole.

⁴⁷ RISCS is a data repository that contains an inventory of the Agency's hardware and software, including system security and contingency plans for each information system.

⁴⁸ Interconnection security agreements regulate security-relevant aspects of an intended connection between an agency and an external system.

CONCLUSION

Preparing for future space exploration is not just about developing large rockets, exploring Mars, and making scientific discoveries. It is also about novel concepts, innovation, and trailblazing—using HEC to solve the most pressing problems with data-driven solutions. Since NASA’s inception in 1958 to present day, the Agency’s history is written with each unique scientific and technological achievement. NASA has landed people on the Moon, visited every planet in the solar system, touched the Sun, and solved some of the mysteries of our home planet. Although NASA’s HEC ecosystem is vital to sustaining mission priorities and advancing science, we found that executive leadership and stakeholder engagement is absent, lacking a cohesive approach to managing HEC across organizational boundaries. NASA’s HEC is currently oversubscribed and overburdened by demand and competing priorities, which impact the wait time for missions to use the assets. The Agency also lacks a strategy on commercial cloud use, contributing to stakeholder misconceptions about cost, scheduling, and capacity. Finally, due to the unique nature of the HEC environment, security controls are often bypassed or not implemented, increasing the risk of cyberattacks. Without an integrated HEC strategy, a more focused management approach, and advocacy, the Agency’s trailblazing science and technology research is severely limited while cyber risk is elevated.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To establish executive leadership and to strategically position NASA's HEC capability to better meet the needs of specialized scientific and advanced research computing requirements, we recommended NASA's Associate Administrator:

1. Appoint executive leadership to determine appropriate definition/scope, ownership, organizational placement, and structure (e.g., portfolio, program, enterprise service) of HEC within NASA.

In addition, we recommended that the NASA Associate Administrator establish a tiger team to collaborate and strategize on wide-ranging HEC issues to:

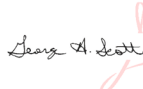
2. Develop enterprise-wide HEC stakeholder requirements to validate commitment agreements as required in NPR 8600.1.
3. Identify technology gaps, such as GPU transition and code modernization, essential for meeting current and future needs and strategic technological and scientific requirements.
4. Develop a strategy to improve HEC asset allocations and prioritization for usage, including the appropriate use of on-premises versus cloud resources.
5. Evaluate cyber risks associated with HEC assets to determine oversight and monitoring requirements, establish risk appetite, and address control deficiencies. Consider using NASA's Splunk enterprise platform as a shared resource.
6. Implement an HEC classification/category designation within RISCs for identifying HEC assets.
7. Develop an inventory of enterprise-wide HEC assets and formalize procedures for hardware and software life-cycle management.
8. Document data risk impact levels, classification, and export control categorization for all HEC jobs.
9. Identify and mitigate gaps in the foreign national accreditation access process.

We provided a draft of this report to NASA management who concurred with Recommendation 1 and partially concurred with Recommendations 2 through 9. NASA described planned actions to address Recommendation 1 and stated that a tiger team will be established to collaborate and strategize on HEC issues; subsequently, the tiger team will determine the implementation of Recommendations 2 through 9. While we consider management's comments responsive, OIG requests regular updates to understand the planned actions and timeline for implementation and to monitor progress towards implementation of Recommendations 2 through 9. The recommendations are resolved and will be closed upon completion and verification of the proposed corrective actions.

Management's comments are reproduced in Appendix E. Technical comments provided by management and revisions to address them have been incorporated as appropriate.

Major contributors to this report include Tekla Colón, Mission Support Audits Director; Scott Rigggenbach, Assistant Director; Joseph Cook; Linda Hargrove; Christopher Reeves; Vincent Whitfield, and Jaidan Williams. Courtney Daniels provided editorial support.

If you have questions about this report or wish to comment on the quality or usefulness of this report, contact Laurence Hawkins, Audit Operations and Quality Assurance Director, at (202) 358-1543 or laurence.b.hawkins@nasa.gov.

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George A. Scott
Acting Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from March 2023 through February 2024 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.

Our audit scope encompassed NASA's HEC capabilities. Specifically, we focused on relevant processes and controls related to policy framework, capacity planning, stakeholder engagement, and cybersecurity. During our audit we identified and reviewed applicable policy framework and criteria; interviewed responsible officials, key personnel, and stakeholders; evaluated the adequacy of the Agency's capacity planning tools and success metrics; and reviewed the capabilities and techniques employed to identify and mitigate HEC cybersecurity risks.

Methodology

We divided the audit into four subject areas: (1) policy framework, (2) capacity planning, (3) stakeholder engagement, and (4) cybersecurity. Key work completed for each subject area is summarized below.

To gain a holistic view of NASA's HEC capabilities, we focused on relevant processes and cybersecurity controls related to the HEC ecosystem. For each subject area, we collected and reviewed numerous federal and Agency policies, regulations, guidance, and industry best practices. We researched the *TOP500* rankings of HEC. We interviewed responsible NASA officials and stakeholders from the OCIO, Cybersecurity and Privacy Division, Kennedy Space Center's Chief Technology Officer, Mission Directorates, and officials responsible for overseeing HEC activities. We met with officials from Ames, Goddard, Johnson Space Center, Langley, and the Jet Propulsion Laboratory regarding the facilities unique to their Centers. We met with the Networking and Information Technology Research and Development Program's NASA representative for an overview of the Agency's participation in the program. We benchmarked best practices with DOE's Oak Ridge National Laboratory and NOAA. We participated in NIST's high-performance computing security working group biweekly meetings to increase our comprehension of the HEC technical architecture and functional cybersecurity overlays. Additionally, we conducted site visits at the Ames, Goddard, and Langley HEC facilities. Collectively, this informed our understanding and helped us assess the overall management of NASA's HEC capabilities.

Assessment of Data Reliability

We used limited computer-processed data extracted from NASA's IT systems during the course of this audit. Although we did not independently verify the reliability for all of the information provided, we compared it with other available supporting documents to determine data consistency and reasonableness. From these efforts, we believe the information we obtained is sufficiently reliable for this report.

Review of Internal Controls

We assessed internal controls and compliance with laws and regulations to determine NASA's overall HEC program management and cybersecurity preparedness. Control weaknesses and misaligned management practices are identified and discussed in this report. Our recommendations, if implemented, will improve NASA's overall HEC program and those identified weaknesses.

Prior Coverage

During the last 5 years, the NASA Office of Inspector General (OIG) has not issued any reports of relevance to the subject of this audit. Additionally, GAO has issued an ancillary report of interest to this topic. Unrestricted reports can be accessed at <https://oig.nasa.gov/> and <https://www.gao.gov/> respectively.

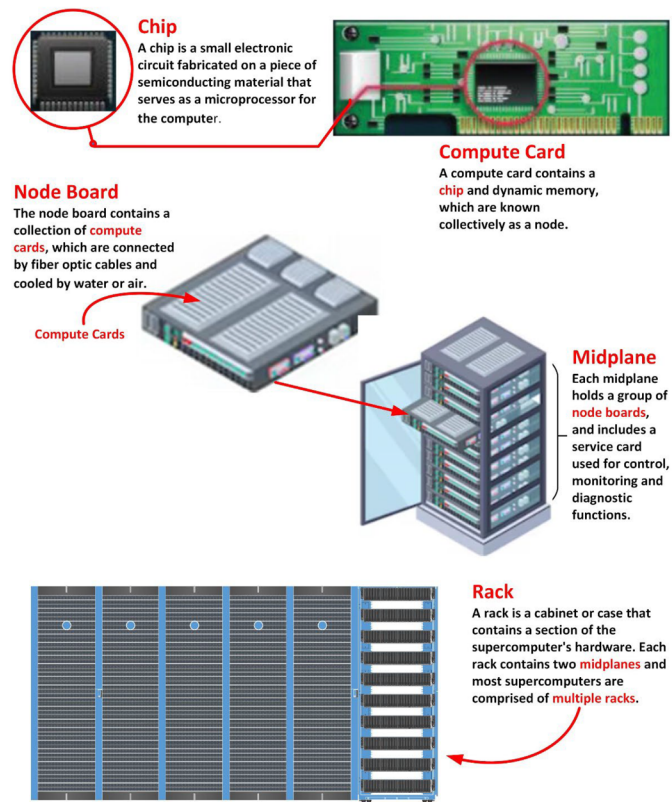
Government Accountability Office

High-Performance Computing: Advances Made Towards Implementing the National Strategy, But Better Reporting and A More Detailed Plan Are Needed ([GAO 21-104500](#), September 2021).

APPENDIX B: ANATOMY OF AN HEC

A high-end computer is a complicated machine. When scientists want to study something that is impossible to explore in a lab—like an exploding star or a fast-forming hurricane—the computer has to be super. As shown in Figure 6 below, various components enable HEC assets to produce massive amounts of computational power.

Figure 6: Anatomy of a High-End Computer



Source: OIG representation of DOE information.

APPENDIX C: EXAMPLES OF NASA'S HEC IN ACTION

Below is a representation of how HEC supports various NASA Mission Directorates in their work.

Science Mission Directorate (SMD)

Illustration of the Planetary System K2-138



K2-138 was discovered in 2017 using data from NASA's Kepler space telescope.

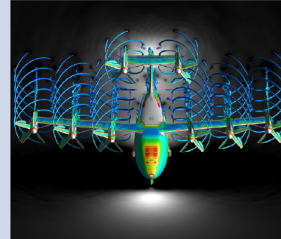
Source: NASA

SMD leveraged NASA's Pleiades supercomputer and ExoMiner AI network to analyze data provided by the Kepler space telescope in search of new planets. These combined technologies were able to comb through huge amounts of data to distinguish between real imagery and false positives—leading to the discovery of 301 exoplanets seemingly all at once.

Aeronautics Research Mission Directorate (ARMD)

Using NASA's supercomputing facilities, ARMD is simulating the aerodynamic performance of several promising air taxi vehicle configurations that will someday carry passengers and cargo in urban and suburban areas. The highly complex simulations will be used to help design and develop these future air taxis—also called Advanced Air Mobility vehicles—that will be safe, quiet, and efficient.

Air Flow Visualization for an Advanced Air Mobility Vehicle



Source: NASA

Space Launch System on the Launchpad



Source: NASA

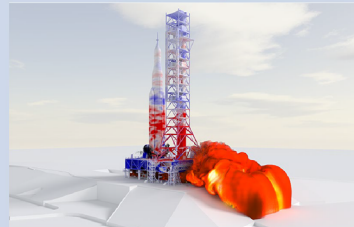
Exploration Systems Development Mission Directorate (ESDMD)

NASA's ESDMD has the responsibility of developing the SLS, which will send astronauts to the Moon in the next few years. They leverage NASA's HEC systems to conduct simulations generating terabytes of data that will be crucial for the final development and construction of the SLS to ensure crew safety and mission success.

Space Operations Mission Directorate

Working in tandem with the ESDMD, the Space Operations Mission Directorate is utilizing NASA's HEC systems to analyze wide ranges of data necessary to modernize Kennedy's Launch Pad 39B, bringing it up to date from the space shuttle era. Kennedy's launch pads will be used in NASA's future crewed Artemis missions to the Moon and Mars.

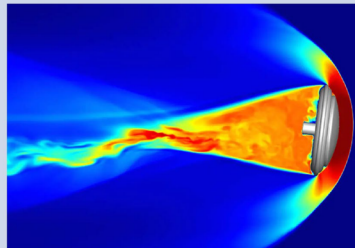
Simulation of SLS Launch Ignition



Simulation of a launch at Kennedy's Launch Pad 39B

Source: NASA

Entry Systems Modeling



Modeling used to design heatshields for spacecraft

Source: NASA

Space Technology Mission Directorate

The Space Technology Mission Directorate uses HEC resources to simulate a wide variety of conditions related to the development of space technologies—such as those used for guidance, navigation, and control of spacecraft. The Entry Systems Modeling project is one such simulation, using supercomputers to predict spacecraft performance during the extreme conditions of atmospheric entry.

APPENDIX D: WORLD TOP500 HEC RANKINGS

Begun in 1993 and updated every six months, the *TOP500* provides a ranked list (using the LINPACK benchmark) of HEC systems throughout the world.⁴⁹ Statistics on HEC are of major interest to manufacturers, users, and potential users. Such statistics facilitate the establishment of collaborations, the exchange of data and software, and a better understanding of high-performance computing.

As of November 2023, the United States and China make up 53 percent of the machines on the *TOP500* supercomputer list—with a total of 161 and 104 HEC systems respectively. The world's top 10 HEC systems, as of November 2023, are listed below in Table 2. According to the November 2023 *TOP500* supercomputer world rankings, NASA HEC systems at Ames, Aiken, Pleiades, and Electra, are ranked numbers 85, 132, and 143, respectively. Ames' Endeavour and Goddard's Discover are not ranked in the *TOP500*.

Table 2: World Top HEC Rankings (as of November 2023)

Rank	Name	Owner	Location
1	Frontier 	Department of Energy	Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
2	Aurora 	Department of Energy	Argonne National Laboratory, Argonne, Illinois, USA
3	Eagle 	Microsoft Azure	Redmond, Washington, USA
4	Fugaku 	RIKEN Center for Computational Science	Kobe, Japan
5	LUMI 	EuroHPC	Kajaani, Finland
6	Leonardo 	EuroHPC	Cineca, Italy

⁴⁹ The LINPACK benchmark is a measure of a computer's floating-point rate of execution. It is determined by running a computer program that solves a dense system of linear equations.

7	Summit 	Department of Energy	Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA
8	MareNostrun 5 ACC 	EuroHPC	Barcelona, Spain
9	EOS NVIDIA DGX Super POD 	NVIDIA Corporation	Santa Clara, California, USA
10	Sierra 	Department of Energy	Livermore, California, USA

Source: OIG representation of *TOP500* rankings.

APPENDIX E: MANAGEMENT'S COMMENTS

National Aeronautics and Space Administration

Office of the Administrator
Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001



March 8, 2024

TO: Assistant Inspector General for Audits

FROM: Associate Administrator

SUBJECT: Agency Response to OIG Draft Report, "Audit of NASA's High-End Computing Program" (A-23-05-00-MSD)

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Audit of NASA's High-End Computing Program" (A-23-05-00-MSD), dated February 8, 2024.

In this draft report, the OIG found that executive leadership and stakeholder engagement is absent, lacking a cohesive approach to managing high-end computing (HEC) across organizational boundaries. The OIG opined that without an integrated HEC strategy, a more focused management approach, and advocacy, the Agency's trailblazing science and technology research is severely limited. The OIG makes nine recommendations addressed to NASA's Associate Administrator.

The OIG recommends the following to the NASA Associate Administrator to establish executive leadership and strategically position NASA's HEC to meet the Agency's specialized needs:

Recommendation 1: Appoint executive leadership to determine appropriate definition/scope, ownership, organizational placement, and structure (e.g., portfolio, program, enterprise service) of HEC within NASA.

Management's Response: NASA concurs. The NASA Associate Administrator will convene a working group to perform a strategic assessment of the HEC Capability Portfolio (CP) to determine the appropriate definition/scope, ownership, organizational placement, and structure within NASA. The working group will be led by the Science Mission Directorate as the organization where the HEC CP is currently managed. The composition of the working group will include officials drawn from such places as Chief Program Management Officer, Aeronautics Research Mission Directorate, Office of the Chief Information Officer, Office of Strategic Infrastructure, Ames Research Center, Goddard Space Flight Center, and Langley Research Center. The working group will provide findings to the NASA Associate Administrator.

Estimated Completion Date: March 29, 2024.

In addition, the OIG recommends "...that the NASA Associate Administrator establish a tiger team to collaborate and strategize on wide-ranging HEC issues..."

NASA concurs with the spirit and intent of the OIG recommendation and will establish a tiger team to collaborate and strategize on the issues identified by the OIG in recommendations 2 through 9 listed below.

Recommendation 2: Develop enterprise-wide HEC stakeholder requirements to validate commitment agreements as required in NASA Procedural Requirements 8600.1, NASA Capability Portfolio Management Requirements.

Recommendation 3: Identify technology gaps, such as graphics processing unit transition and code modernization, essential for meeting current and future needs and strategic technological and scientific requirements.

Recommendation 4: Develop a strategy to improve HEC asset allocations and prioritization for usage, including the appropriate use of on-premises versus cloud resources.

Recommendation 5: Evaluate cyber risks associated with HEC assets to determine oversight and monitoring requirements, establish risk appetite, and address control deficiencies. Consider using NASA's Splunk enterprise platform as a shared resource.

Recommendation 6: Implement an HEC classification/category designation within Risk Information Security Compliance System for identifying HEC assets.

Recommendation 7: Develop an inventory of enterprise-wide HEC assets and formalize procedures for hardware and software life-cycle management.

Recommendation 8: Document data risk impact levels, classification, and export control categorization for all HEC jobs.

Recommendation 9: Identify and mitigate gaps in the foreign national accreditation access process.

Management's Response to Recommendations 2-9: NASA partially concurs with each recommendation. NASA concurs with the spirit and intent of the OIG recommendations and will establish a tiger team noting however, that the implementation of each recommendation should be determined by the tiger team.

Estimated Completion Date: The tiger team will establish estimated completion dates for each recommendation numbered 2 through 9 as soon as practical and will communicate those dates to the OIG by December 31, 2024.

We have reviewed the draft report for information that should not be publicly released. As a result of this review, we have not identified any information that should not be publicly released.

Once 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 Kevin Gilligan at (202) 358-4544.



James M. Free

APPENDIX F: REPORT DISTRIBUTION

National Aeronautics and Space Administration

Administrator
 Deputy Administrator
 Associate Administrator
 Chief of Staff
 Associate Administrator for Science Mission Directorate
 Chief Information Officer
 Chief Engineer

Non-NASA Organizations and Individuals

Office of Management and Budget
 Deputy Associate Director, Climate, Energy, Environment and Science Division
 Government Accountability Office
 Director, Contracting and National Security Acquisitions
 Office of Science and Technology Policy
 Deputy Director, Science and Society

Congressional Committees and Subcommittees, Chairman and Ranking Member

Senate Committee on Appropriations
 Subcommittee on Commerce, Justice, Science, and Related Agencies
 Senate Committee on Commerce, Science, and Transportation
 Subcommittee on Space and Science
 Senate Committee on Homeland Security and Governmental Affairs
 House Committee on Appropriations
 Subcommittee on Commerce, Justice, Science, and Related Agencies
 House Committee on Oversight and Accountability
 Subcommittee on Government Operations and the Federal Workforce
 House Committee on Science, Space, and Technology
 Subcommittee on Investigations and Oversight
 Subcommittee on Space and Aeronautics

(Assignment No. A-23-05-00-MSD)

