NASA
Office of Inspector General

Review of NASA's Space Technology Mission Directorate Portfolio

December 19, 2022

IG-23-005

Office of Inspector General

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RESULTS IN BRIEF

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WHY WE PERFORMED THIS AUDIT

With a fiscal year (FY) 2022 budget of $1.1 billion and approximately 2,500 projects under its management, NASA's Space Technology Mission Directorate (STMD) oversees a portfolio of space technology investments that support the Agency as it seeks to sustain and extend human activities in space, explore the solar system, search for evidence of past and present life, expand the commercial space economy, and ensure American global leadership in space technology. STMD works with academia, industry, other government agencies, and international partners through traditional acquisition methods, industry partnerships, prize competitions, space technology research grants, and Space Act Agreements. The Directorate uses a strategic framework to guide its technology investment decisions, and since 2020 STMD has increasingly focused on supporting NASA's Artemis and Moon to Mars plans, with almost a third of its budget—$337 million—allocated by Congress for projects related to these efforts.

In this audit, we examined the extent to which NASA's management of its STMD portfolio aligns to space technology needs and whether performance measures and outcomes reflect the Directorate's goals. To complete this work, we interviewed STMD officials to understand the processes that guide technology investment decisions and how the Directorate develops and reports on its performance goals. We also reviewed NASA's strategic and performance plans and reports as well as STMD's portfolio plan, strategic framework, and data from the STMD Portfolio Analysis Resource (SPAR) database.

WHAT WE FOUND

In 2020, STMD began the Strategic Technology Architecture Roundtable (STAR) initiative to prioritize technology gaps within the Directorate's portfolio. This process uses information from stakeholders to identify priority technology gaps that should be addressed in the near term. The first iteration of the STAR process took 2 years and culminated with the 2022 issuance of reports describing how STMD's portfolio contributes to achieving 17 desired outcomes to close technology gaps related to commercial competitiveness as well as Moon, Mars, and future science missions. We found the stakeholders we interviewed were generally satisfied with the STAR process because it sufficiently integrated their feedback on priority technology needs.

While the STAR process establishes the framework to integrate stakeholder needs and prioritize investment decisions, STMD does not have a reliable way to measure the cost of its efforts to close the gaps. STMD's SPAR system is designed to offer insights into the Directorate's portfolio; however, it does not include accurate and complete project costs due to infrequent updates, use of cost estimates, and exclusion of costs deemed sensitive procurement information. Furthermore, we found STMD is still working to map its investments to the 17 desired outcomes established through the STAR process, with only 20 percent of projects active in FY 2021 mapped to 1 or more desired outcomes. Incomplete cost information and mapping of projects limits the visibility STMD officials have over an already complex portfolio. Annually, STMD selects hundreds of new projects from thousands of proposals, and in FY 2022 STMD canceled several projects to fund higher priority needs. Without a complete picture of how STMD's projects contribute to desired outcomes, NASA and other stakeholders do not have the information necessary to inform these strategic investment and divestment decisions.

As part of its performance management process, NASA develops strategic objectives and performance goals that allow the Agency to measure and track progress towards achieving its goals. We found that in FYs 2020 and 2021, STMD achieved satisfactory performance against its strategic objective—to innovate and advance transformational space technologies—and for some goals it significantly exceeded its targets. While STMD's performance goals historically focused on a variety of quantifiable outputs that demonstrate effective management of project cost, schedule, and performance, these measures did not fully capture the extent to which STMD-funded technologies help achieve the Directorate's strategic objective. Acknowledging this shortfall, in FY 2022 STMD altered several performance goals to focus on outcome-based measures. For example, STMD removed the output-based measure of investing in a target number of projects and replaced it with new outcome-based measures such as achievement of knowledge transitions and external partner investments. However, outcome-based performance measures can be difficult to quantify, especially for early-stage projects with future potential but little immediate application. Consequently, STMD will need to continue its efforts to develop outcome-based measures where appropriate and communicate to stakeholders the importance of programs best measured by these difficult-to-quantify measures.

What We Recommended

To ensure that STMD has visibility into how its portfolio aligns to priority outcomes to inform future investment and divestment decisions, we recommended the Associate Administrator for STMD: (1) reexamine its SPAR data system to ensure it provides as accurate and complete a picture of project costs as is practicable and (2) update its STARPort data system with complete information on project alignment to STAR desired outcomes for all projects active in FY 2021 and beyond. Additionally, to better illustrate whether STMD-funded technologies help achieve the Directorate's strategic goals, we recommended the Associate Administrator for STMD: (3) complete efforts to develop additional outcome-based performance measures based on the transition, advancement, and infusion of technologies.

We provided a draft of this report to NASA management who concurred with our recommendations and described planned actions to address them. We consider the proposed actions responsive and will close the recommendations upon completion and verification.

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Acronyms

ESDMD	Exploration Systems Development Mission Directorate
FY	fiscal year
MUREP	Minority University Research and Education Project
OIG	Office of Inspector General
OSAM	On-orbit Servicing, Assembly, and Manufacturing
SBIR	Small Business Innovation Research
SMD	Science Mission Directorate
SOMD	Space Operations Mission Directorate
SPAR	STMD Portfolio Analysis Resource
STAR	Strategic Technology Architecture Roundtable
STMD	Space Technology Mission Directorate
STTR	Small Business Technology Transfer
TRL	technology readiness level

INTRODUCTION

NASA's Space Technology Mission Directorate (STMD) manages approximately 2,500 projects a year in pursuit of new technologies to ensure American global leadership in space technology and enable exploration missions to the Moon and Mars and science missions focused on Earth, the solar system, and beyond.[1] With a fiscal year (FY) 2022 budget of $1.1 billion, STMD works with academia, industry, other government agencies, and international partners on a wide range of activities and since 2020 has increasingly focused on technologies to support future Artemis missions that will return humans to the Moon after more than 50 years.

Given STMD's role in supporting key Agency and Administration objectives—including sending humans to the Moon and eventually to Mars—it is crucial that the Directorate focus on priority needs and continuously monitor its performance to ensure it is achieving its intended goals. In this audit, we examined the extent to which NASA's management of its STMD portfolio aligns to space technology needs and whether performance measures and outcomes reflect the Directorate's goals. See Appendix A for details of the audit's scope and methodology.

At NASA, "space technology" refers to applied research and development that furthers knowledge in a particular field or produces materials, devices, systems, or methods applicable to space flight missions. STMD leads the Agency's efforts to develop a portfolio of technologies that support the Agency as it seeks to sustain and extend human activities in space; explore the structure, origin, and evolution of the solar system; search for evidence of past and present life; and expand the commercial space economy.

Background

Established in 2013, STMD oversees an overall portfolio of space technology investments characterized by three portfolio themes—Early Stage Innovations and Partnerships, Technology Maturation, and Technology Demonstrations. Twelve STMD programs support technology development efforts at varying levels of maturity, some of which have matured all the way to flying on active missions and being adopted by the commercial space sector.[2] See Figure 1 for a description of STMD's portfolio and programs. In awarding projects, STMD uses traditional acquisition methods as well as industry

[1] NASA Procedural Requirements 7120.8A, *NASA Research and Technology Program and Project Management Requirements* (September 14, 2018) define a project as a specific investment identified in a Program Plan having defined requirements, a life-cycle cost, a beginning, and an end. For the purposes of this report, we refer to STMD's technology development efforts as projects, regardless of whether they meet these criteria.

[2] STMD became a Mission Directorate in 2013 after originating as the Space Technology Program in 2010 under the Office of the Chief Technologist.

partnerships, prize competitions and challenges, space technology research grants, and Space Act Agreements.[3]

Figure 1: STMD Portfolios and Programs (as of Fiscal Year 2022)

Early Stage Innovations and Partnerships Portfolio

Small Business Innovation Research
Engages small business and entrepreneurs in research and development of technologies that meet NASA needs and have the potential for commercialization.

Small Business Technology Transfer
Supports collaboration between small businesses and research institutions in research and development of technologies that meet NASA needs and have the potential for commercialization.

Early Career Initiative
Encourages innovation from future NASA leaders to address the technology needs of NASA and the nation.

Prizes, Challenges, and Crowdsourcing
Creates opportunities for public participation in NASA research and technology solutions to support NASA missions and inspire new aerospace capabilities.

Space Technology Research Grants
Challenges academic researchers to examine the theoretical feasibility of ideas that are critical to making science, space travel, and exploration more effective, affordable, and sustainable.

NASA Innovative Advanced Concepts
Nurtures visionary ideas that could transform future NASA missions with the creation of breakthroughs, engaging America's innovators and entrepreneurs as partners in the journey.

Center Innovation Fund
Supports NASA Centers in addressing the technology needs of NASA and the nation.

Technology Transfer[a]
Ensures that NASA innovations are broadly available to the public.

Technology Maturation Portfolio

Game Changing Development
Delivers transition-ready solutions that enable new capabilities or radically alter current approaches.

Technology Demonstrations Portfolio

Technology Demonstrations
Conducts ground-based testing and space flight demonstrations to demonstrate prototypes and transition capabilities to NASA missions.

Small Spacecraft Techologies
Enables unique missions through rapid development and demonstration of capabilities for small spacecraft.

Flight Opportunities
Rapidly demonstrates promising space exploration technologies through suborbital testing using flight providers.

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

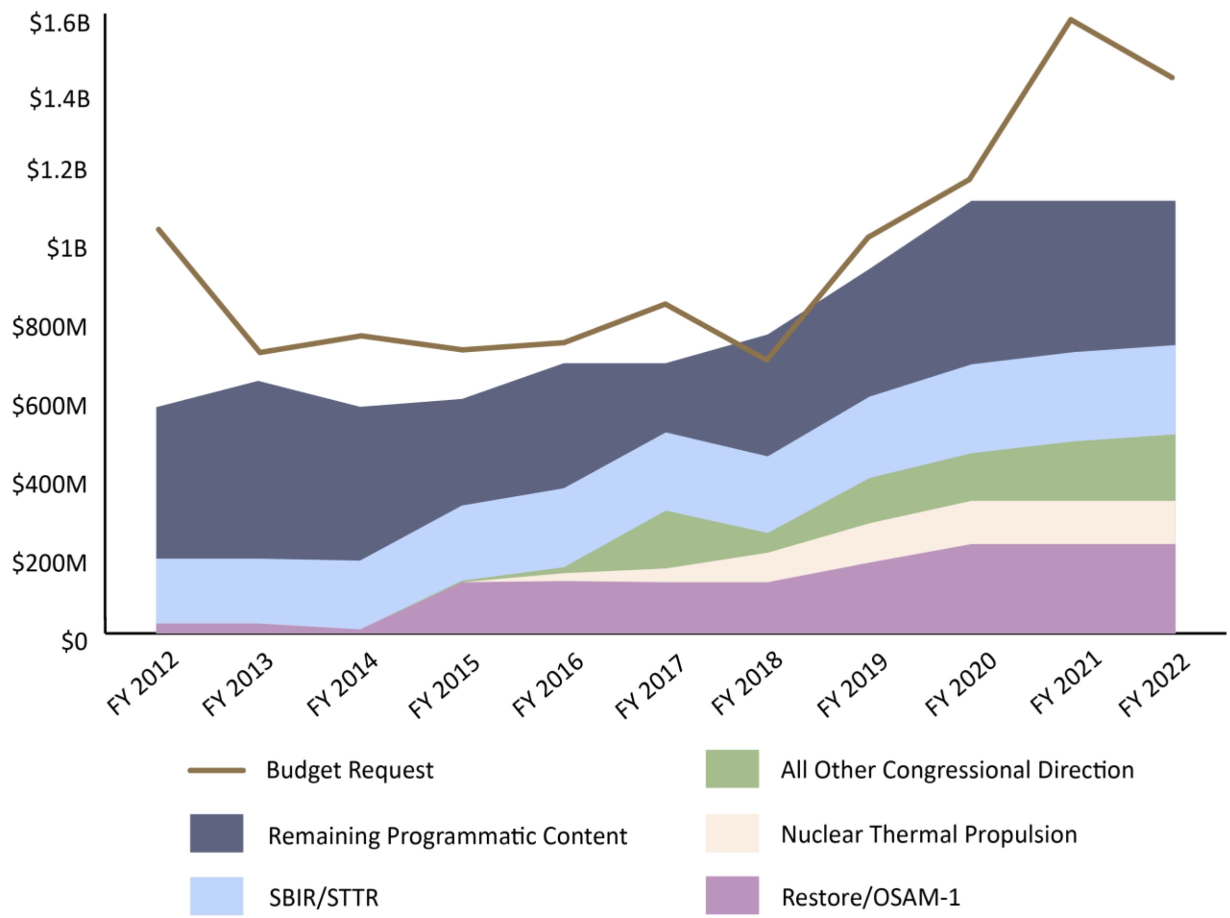
[a] Unlike STMD's other programs, Technology Transfer does not fund any projects.

Despite significant growth in STMD's budget—from $575 million in FY 2012 to $1.1 billion in FY 2020—the Directorate's budget has remained flat the past 2 fiscal years with more than 60 percent of its spending directed by Congress, requiring STMD to invest in specific technologies and programs at

[3] Traditional acquisition methods include contracts subject to Federal Acquisition Regulations. Space Act Agreements are between NASA and another party requiring a commitment of Agency resources including personnel, funding, services, equipment, expertise, information, or facilities to advance science and technology and stimulate industry to start new endeavors. Industry partnerships, prize competitions and challenges, and space technology research grants are discussed further in Figure 1.

specified dollar amounts (see Figure 2). As a result, the Directorate has about the same amount of discretionary funds as it did at the time of its inception. For example, Congress has mandated that STMD fund technologies that support NASA's Moon to Mars goals, including FY 2022 mandates to spend $227 million for a project to demonstrate the capability to autonomously refuel and extend the life of on-orbit satellites and $110 million to develop a nuclear thermal propulsion system for future exploration missions.[4] In addition, NASA is statutorily required to spend 3.65 percent of its total extramural research and development budget on Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs.[5] While STMD is required to invest a specific percentage in SBIR and STTR programs, the Directorate exercises discretion in choosing what projects to fund under these programs.

Figure 2: STMD Appropriation History (Fiscal Years 2012 to 2022)



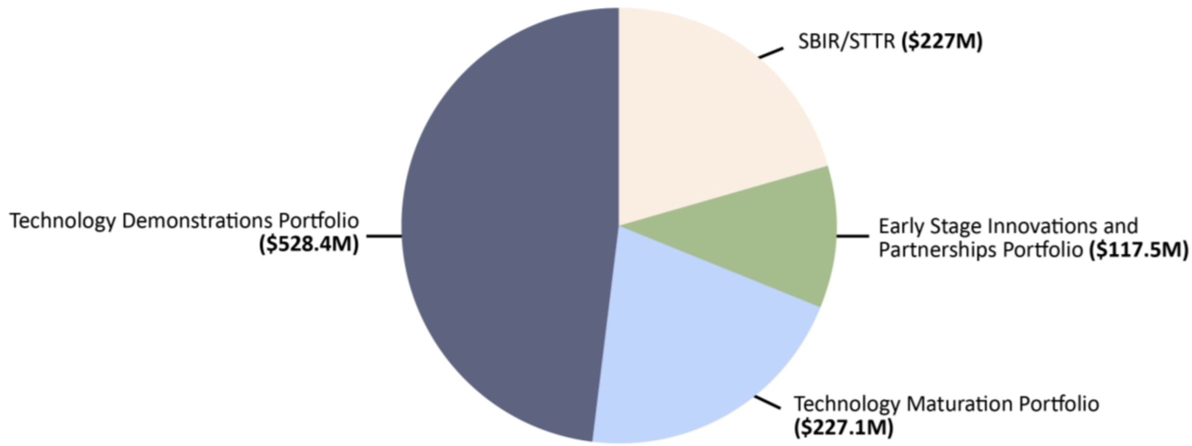
Source: NASA OIG presentation of Agency information.

4 NASA's efforts to develop On-orbit Servicing, Assembly, and Manufacturing (OSAM) capabilities span multiple projects, most notably OSAM-1 and OSAM-2. NASA has funded development of nuclear thermal propulsion to varying degrees for more than 60 years with a variety of activities across industry, academia, and partnerships with the U.S. Department of Energy.

5 NASA's extramural research and development budget funds activities performed by entities outside of NASA. SBIR and STTR are separate programs; however, for the purposes of this report we frequently refer to the programs jointly because both are managed under a single STMD office.

Within STMD's overall budget, its three portfolios—Early Stage Innovations and Partnerships, Technology Maturation, and Technology Demonstrations—have their own budgets. While managed by the Early Stage Innovations and Partnerships Portfolio, SBIR and STTR programs have a standalone budget. Figure 3 represents STMD's FY 2021 funding by portfolio and SBIR/STTR.

Figure 3: Fiscal Year 2021 STMD Budget Summary



Source: NASA OIG presentation of Agency financial information.

At $528.4 million, the Technology Demonstrations Portfolio represented STMD's largest FY 2021 investment. Projects under this portfolio perform at the highest maturity levels and encompass all activities related to technology advancement from payload development to vehicle capability enhancements and flight tests. Further, they have the potential to make significant advances in an established technology resulting in reduced mission risk or greater capability. For example, NASA's Laser Communications Relay Demonstration project is designed to increase bandwith 10 to 100 times more than previous capabilities for communications from space to the ground and back as well as between spacecraft. Initially started in 2011, the project cost over $300 million before successfully launching in December 2021. According to STMD officials, in May 2022 NASA determined that this technology was performing at full functionality—demonstrating new high-bandwidth communications technology.

The Technology Maturation Portfolio was the Directorate's second highest investment, accounting for $227.1 million in FY 2021. Technology Maturation projects perform at mid-maturity levels, generally taking technologies from initial laboratory concepts to a complete engineering development prototype, such as the Regolith and Ice Drill for Exploring New Terrain—a drill that NASA plans to use to extract soil from up to 3 feet below the lunar surface to search for water at the Moon's poles.

Performing at the earliest stages of maturity with the intent to accelerate the development of groundbreaking, high-risk/high-payoff space technologies, the Early Stage Innovations and Partnerships Portfolio accounted for $117.5 million of STMD's FY 2021 budget. Funded separately from other Early

Stage Innovations and Partnerships activities, the SBIR and STTR programs accounted for $227 million in FY 2021. SBIR/STTR projects, by nature, are relatively low dollar value—initial awards are generally up to $150,000—but according to STMD officials have produced significant value for NASA missions. For example, the Mars Perseverance Rover's robotic arm contains a small ultraviolet laser used to search for signs of potential life. The laser was developed by an 11-person company using a series of NASA SBIR awards beginning in 1997.

"The NASA SBIR program has enabled a very complicated technology to be developed that if it were left to private enterprise, never would have been built. We believe we are at the forefront of a large number of commercial and government applications…but it has taken 17 years. No venture capitalist would have waited that long."—NASA interview with CEO of Photon Systems Inc.

Space Technology Mission Directorate Portfolio

In a 10-year period from 2012 to 2021, STMD managed more than 9,000 space technology projects in its overall portfolio. Over the course of each year, active projects are closed out or canceled and new projects begin.[6] For example, in FY 2021 STMD managed almost 2,500 active projects, including approximately 750 new projects selected from a pool of 3,200 proposals from universities, small businesses, industry, individual innovators, research and development centers, and other government agencies.

STMD uses a strategic framework to guide its technology investment decisions. The framework identifies priorities based on technologies needed to ensure American global leadership in space technology and meet the Agency's mission goals (see Figure 4). The Strategic Technology Architecture Roundtable (STAR) is the process STMD uses in collaboration with relevant stakeholders to identify and prioritize technology gaps within its portfolio. Stakeholders include industry as well as NASA's Exploration Systems Development Mission Directorate (ESDMD), Space Operations Mission Directorate (SOMD), Science Mission Directorate (SMD), Principal Technologists, Systems Capability Leadership Teams, and Center Chief Technologists.[7] Once technology gaps are identified and translated into outcomes defined in STMD's strategic framework, STMD utilizes its STARPort data system to capture its goals and desired outcomes, illustrate how the Directorate's various capabilities align, and link investments in space technology to desired outcomes. In addition to investing in the most pressing near-term needs identified in the STAR strategic framework, STMD's Early Stage Innovations and Partnerships Portfolio invests in technologies designed to push the boundaries of what is possible.

[6] STMD's portfolio management system categorizes inactive projects as closed out or canceled. Closed out means the project concluded as planned, while canceled means the project was terminated before completion.

[7] ESDMD, SOMD, and SMD all have their own, smaller-scoped technology development programs and also work with STMD to jointly develop technologies. Principal Technologists reside across multiple NASA Mission Directorates and serve as technical experts and advocates for defining portfolio investment strategies to achieve their respective exploration and science mission goals. Systems Capability Leadership Teams are groups of subject-matter experts within STMD and from other parts of NASA who collaborate on technology areas to identify ongoing efforts and gaps. Center Chief Technologists provide input to STMD on Center technology priorities and consider STMD guidance when selecting projects for their Center to pursue but have a high level of autonomy when funding Center-level technology projects.

Figure 4: STMD Strategic Framework

Lead	Thrusts	Outcomes	Primary Responsibilities
Ensuring American Global Leadership in Space Technology	**GO** Rapid, Safe, and Efficient Space Transportation	• Develop nuclear technologies enabling fast in-space transits. • Develop cryogenic storage, transport, and fluid managment technologies for surface and in-space applications. • Develop advanced propulsion technologies that enable future science/exploration missions.	• Nuclear Systems • Cryogenic Fluid Management • Advanced Propulsion
Advance U.S. space technology innovation and competiveness in a global context	**LAND** Expanded Access to Diverse Surface Destinations	• Enable lunar/Mars global access with approximately 20-ton payloads to support human missions. • Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies. • Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.	• Entry, Descent, Landing, and Precision Landing
Encourage technology-driven economic growth with an emphasis on the expanding space economy	**LIVE** Sustainable Living and Working Farther from Earth	• Develop exploration technologies and enable a vibrant space economy with supporting utilities and commodities: ◦ Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations. ◦ Scalable ISRU production/utilization capabilities including sustainable commodities on the lunar and Mars surface. ◦ Technologies that enable surviving the extreme lunar and Mars environments. ◦ Autonomous excavation, construction, and outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in-situ resources. • Enable long duration human exploration missions with Advanced Habitation System technologies (Low TRL STMD, Mid-High TRL SOMD/ESDMD).	• Advanced Power • In-Situ Resource Utilization • Advanced Thermal • Advanced Materials, Structures, and Construction • Advanced Habitation Systems
Inspire and develop a diverse and powerful U.S. aerospace technology community	**EXPLORE** Transformative Missions and Discoveries	• Develop next-generation high performance computing, communications, and navigation. • Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions. • Develop technologies supporting emerging space industries including Satellite Serving and Assembly, In Space/Surface Manufacturing, and Small Spacecraft technologies. • Develop vehicle platform technologies supporting new discoveries. • Develop technologies for science instrumentation supporting new discoveries (Low TRL STMD/Mid-High TRL STMD. SMD funds mission specific instrumentation TRLs 1 to 9). • Develop transformative technologies that enable future NASA or commercial missions and discoveries.	• Advanced Avionics Systems • Advanced Communications and Navigation • Advanced Robotics • Autonomous Systems • Satellite Servicing and Assembly • Advanced Manufacturing • Small Spacecraft • Rendezvous, Proximity Operations, and Capture • Sensor and Instrumentation

Source: NASA OIG presentation of Agency information.

Note: in-situ resource utilization (ISRU) and technology readiness level (TRL).

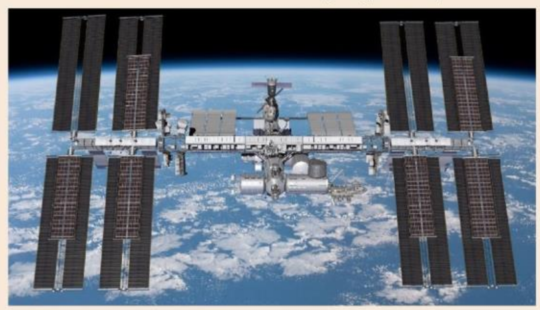
Pathways to Technology Maturation

STMD investments span a range of technology readiness levels (TRL) measured from 1 to 9 as technologies mature from basic research to actual use. However, technology development, which does not always follow a straight-line path of advancement, often results in a stall point—colloquially referred to as the "valley of death"—where projects have difficulty transitioning to the next stage of development. This stall point generally occurs at the mid-TRL levels (TRLs 3 through 5). In an effort to help overcome stall points, STMD programs support technology development at various stages of maturity, with a particular focus on technologies at the mid-TRL level.

Technology readiness levels (TRL) are a measurement system used to assess the maturity level of a particular technology. There are nine technology readiness levels. TRL 1 is the lowest where scientific research begins, and TRL 9 is the highest where a technology has been "flight proven" during a successful mission.

Technology Maturation is STMD's portfolio specifically designed for mid-TRL projects. The Game Changing Development program, which falls under the Technology Maturation umbrella, aims to advance exploratory concepts that may lead to entirely new capabilities or radically alter current approaches, enabling the Agency's future space missions and advancing commercial technologies and markets. Through the Game Changing Development program, STMD provides the funding and resources to advance technologies over the mid-TRL "valley of death" and to prepare for technology demonstration or use on actual missions. For example, Roll-Out Solar Arrays advanced from concept to development of a functional prototype and eventual use on the International Space Station in June 2021. Roll-Out Solar Arrays provide power to space infrastructure using a compact, affordable design with autonomous capabilities.

Roll-Out Solar Arrays (ROSA)



Source: NASA.

ROSA technology was developed as an alternative to existing solar array technology. These arrays are a compact design, more affordable, and offer autonomous capabilities that can enhance a wide spectrum of scientific and commercial missions from low Earth orbit to interplanetary travel. Installed in June 2021 onboard the International Space Station, ROSAs provide additional power supporting more cutting-edge scientific research. ROSAs are also powering deep space exploration and scientific missions such as the Double Asteroid Redirection Test and Gateway's Power and Propulsion Element. Additionally, ROSA's design has been integrated into commerical satellites. ROSA secured nearly 20 NASA Small Business Innovation Research awards and completed crucial technology demonstrations through STMD's Game Changing Development, Technology Demonstrations, and Flight Opportunities programs.

Estimated cost: $17.8 million

Expected TRL range at project completion:

1	2	3	4	5	6	7	8	**9**

In addition to supporting mid-TRL projects with its Technology Maturation Portfolio, STMD plans to enhance its Early Stage Innovations and Partnerships Portfolio investment strategies by placing particular emphasis on advancing mid-TRL technologies to levels sufficiently mature for development. Specifically, NASA has recognized that SBIR/STTR Phase I and II awards—which fall under the Early Stage Innovations and Partnerships umbrella—may not be sufficient in either dollars or time for an organization to complete the research and development and the commercialization activities required for the project to be selected by a more advanced STMD program or to make the project ready for infusion into a NASA mission or the commercial marketplace.[8] As a result, NASA has several initiatives to support small businesses beyond Phase I and Phase II awards.[9] Furthermore, in FY 2022 STMD began to conduct analyses of programs and existing policies and evaluations of proposed process improvements, as well as implement related performance measurement improvements to identify the root cause and help early-stage innovations overcome the "valley of death."

Moon to Mars and Other Technology Destinations

Since 2020, STMD has increasingly focused on supporting NASA's Moon to Mars goals. These goals will require technologies that enable humans to live and work in deep space, navigate and travel to distant locations, manufacture products in space or on planetary surfaces, land on and depart from planetary surfaces, and communicate with Earth over significant distances. To this end, in FY 2022 Congress mandated that STMD spend $337 million–almost a third of the Directorate's $1.1 billion budget—on projects designed to accomplish these goals.

Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE)

Source: NASA.

CAPSTONE is a microwave oven-sized CubeSat that will test an elongated, halo-shaped lunar orbit for potential use on long-duration lunar missions such as Gateway. Launched in June 2022, it will complete a 4-month journey to the Moon where it will stay in orbit for several months gathering crucial data and demonstrating spacecraft-to-spacecraft navigation services, enabling future lunar operations. CAPSTONE is developed and supported through STMD's Small Spacecraft Technology Program, and a key software was developed through the Small Business Innovation Research Program.

Estimated cost: $23.8 million

Expected TRL range at project completion:

1 2 3 4 5 6 7 8 9

STMD's efforts to support the first three Artemis missions include integrating a thermal protection system on the heat shield of the Orion Multi-Purpose Crew Vehicle, developing equipment to extract surface samples and scout the lunar surface, and implementing systems for surface communication and dust mitigation. Looking forward, STMD has several projects under development required to support a long-duration, sustained presence on the Moon that will also be critical for crewed missions to Mars. For example, in June 2022 STMD launched a CubeSat—a miniaturized satellite—designed to test an elongated, halo-shaped lunar orbit that NASA intends to use for the Gateway, a small space station that will be placed in an orbit around the Moon. STMD is also working on resource mapping, oxygen extraction, and water mining to harness resources on the lunar surface as well as nuclear power generation

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8 According to 15 U.S.C. § 638 and guidance from the NASA SBIR/STTR Program Management Office, SBIR/STTR Phase I is considered an idea generation stage, and NASA awards up to $150,000 with the goal of determining the scientific and technical merit and feasibility of ideas that appear to have commercial potential. NASA SBIR Phase I awards are up to 6 months, while STTR Phase I awards are up to 13 months. NASA SBIR/STTR Phase II allows for awards up to $850,000 to further develop technologies which meet particular program needs and can include prototype development. SBIR/STTR Phase II awards are up to 24 months.

9 SBIR/STTR post-Phase II awards include Phase II Sequential, Phase II Extended, Civilian Commercialization Readiness Pilot Program, and Phase III. Phase II Sequential awards are in the pilot stage by invitation only; they are designed to be a one-time opportunity to continue the work of an initial Phase II award. Phase II Extended awards require investors to match funding. Civilian Commercialization Readiness Pilot Program awards focus on projects with near-term infusion or commercialization and require investors to match funding. Phase III is the commercialization of innovative technologies, products, and services resulting from either a Phase I or Phase II contract; Phase III awards must be funded from non-SBIR funding sources.

on the lunar surface to operate rovers and conduct experiments. These and other efforts to develop capabilities for lunar surface exploration are supported by STMD's Lunar Surface Innovation Initiative and the Lunar Surface Innovation Consortium.[10]

In addition to technologies supporting Moon and Mars destinations, the Directorate supports the development of technologies that benefit life on Earth, such as production of clean energy, sustainable manufacturing, and advanced insulative materials.[11] To advance exploration on other celestial bodies inside our solar system, STMD funds technologies such as autonomous decision-making that would allow multiple spacecraft to share data and make quick decisions together while traveling vast distances from Earth. Also, to answer the question of whether we are alone in the universe, STMD supports the development of technologies such as a mission concept that utilizes solar gravitational lensing to view a potentially habitable exoplanet in detail.[12]

Furthermore, STMD invests in technologies designed to enhance foundational knowledge essential to advancing early technologies to the next level of development. For example, improving understanding of 3D printing materials properties could result in more reliable and longer-lasting components exposed to the extreme environments of space; developing new battery technologies could increase performance and safety for astronauts conducting space walks; and enhancing methods to detect dark energy in our solar system could lead to a fundamental shift in our understanding of physics and the universe.

Partnerships Promote Diversity in Space Technology Entities

STMD competitively awards projects that establish partnerships with universities, small businesses, industry, individual innovators, research and development centers, and other government agencies.[13] The majority (64 percent) of STMD's extramural partnerships in projects active in FY 2021 were with industry, including small businesses (see Figure 5).

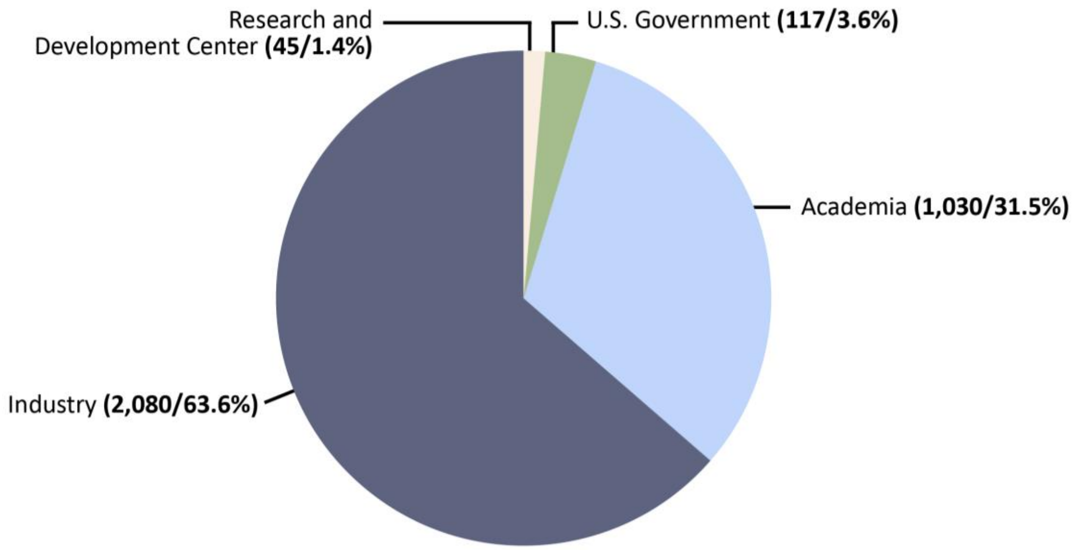
[10] Facilitated by the Johns Hopkins University Applied Physics Laboratory, the Lunar Surface Innovation Consortium is a nationwide alliance of universities, industry, nonprofits, NASA, and other government agencies with a vested interest in establishing a sustained presence on the Moon.

[11] Clean energy comes from renewable, zero-emission sources that do not pollute the atmosphere. Sustainable manufacturing is the creation of manufactured products through economically sound processes that minimize negative environmental impacts while conserving energy and natural resources. Advanced insulative materials are thinner and have higher thermal resistance than traditional insulation.

[12] Solar gravitational lensing is a conceptual imaging technique that would take advantage of gravity's warping effect on space-time to view details of a planet outside our solar system. In order to capture an exoplanet image through the solar gravitational lens, a telescope would have to be placed at least 14 times farther away from the Sun than Pluto, past the edge of our solar system, and further than humans have ever sent a spacecraft.

[13] For the purposes of this report, partnerships refer to entities that contribute to projects in STMD's portfolio, including STMD-funded contributions.

Figure 5: STMD Fiscal Year 2021 Extramural Partnerships by Type

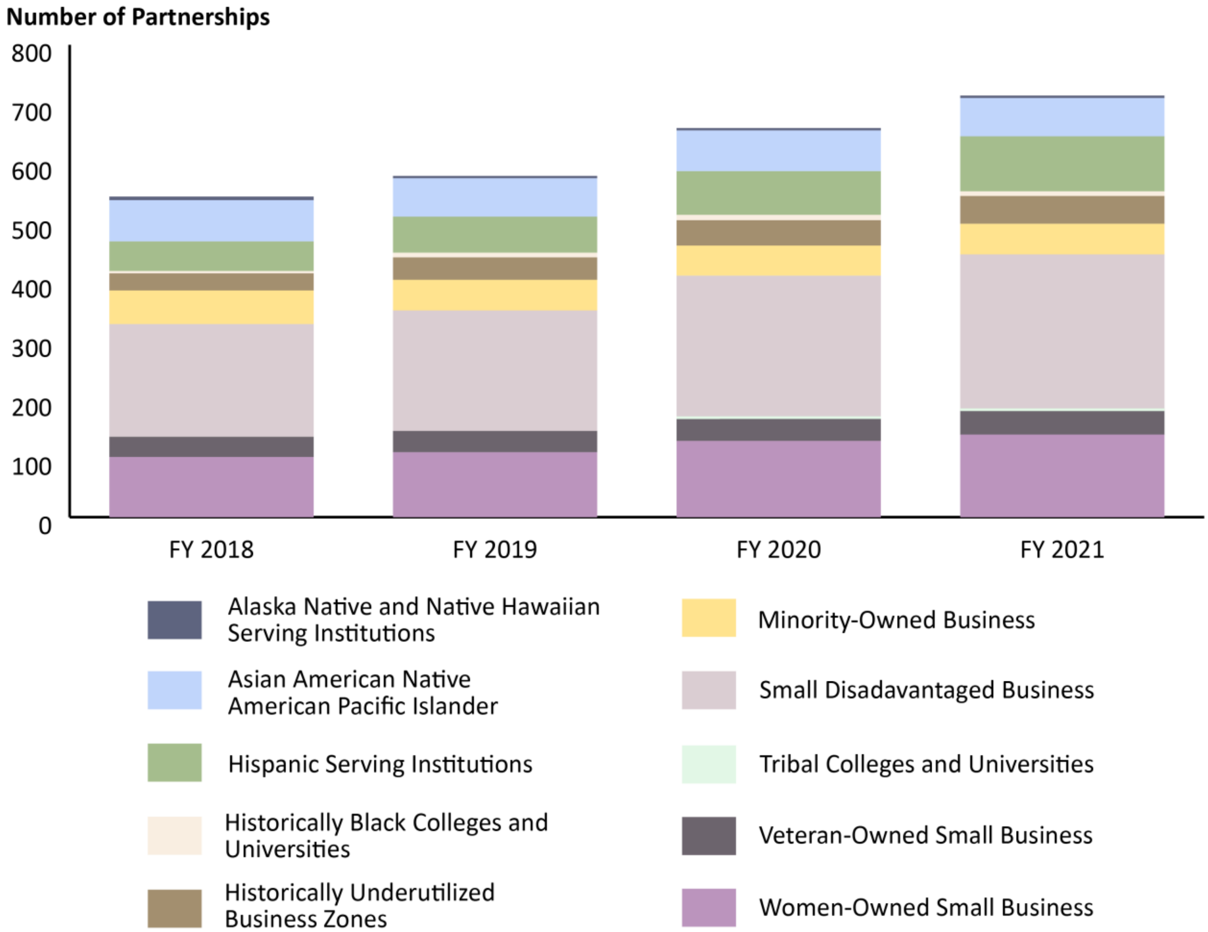


Source: NASA OIG presentation of Agency STMD Portfolio Analysis Resource (SPAR) data.

Note: Projects may have more than one partnership. This chart represents the total number of extramural partnerships for projects active in FY 2021. We did not include partnerships with international organizations because they only comprise 0.1 percent of partnerships during the time period. Numbers in the chart are rounded and may not add to 100 percent.

Throughout its overall portfolio, STMD also aims to promote diversity, equity, inclusion, and accessibility through its partnerships with underserved communities. From FY 2018 to FY 2021, the number of underrepresented organization partnerships with STMD increased by 31 percent from 543 to 714 (see Figure 6). STMD participates in the NASA Science, Technology, Engineering, and Mathematics Engagement Minority University Research and Education Project (MUREP) to support Minority Serving Institutions, including Historically Black Colleges and Universities. Through MUREP, NASA reaches scientists, engineers, and students from underserved and underrepresented communities. For example, in 2021, NASA awarded grants, up to $50,000 each, to 11 Minority Serving Institutions to foster partnerships between those institutions and U.S. small businesses while also potentially lowering the barriers of entry to participation in NASA's STTR program. Moving forward, STMD's Early Stage Innovations and Partnerships, Technology Maturation, and Technology Demonstrations portfolios seek to explore new approaches to increase participation by underserved communities. These efforts support NASA's 2021 Mission Equity effort to assess its programs, procurements, grants, and policies, and examine what potential barriers and challenges may exist for communities that are historically underrepresented and underserved.

Figure 6: STMD Number of Underrepresented Organization Partnerships (Fiscal Years 2018 to 2021)



Source: NASA OIG presentation of Agency SPAR data.

Note: This chart indicates the number of partnerships per fiscal year with Minority Serving Institutions and industry with socioeconomic set-aside statuses. If a project partners with a Minority Serving Institution or small business, each of those partnerships are counted for each year the project was active even if the partner's status changed during or after project completion.

DIRECTORATE'S PROCESS PROVIDES THE FRAMEWORK FOR INTEGRATING STAKEHOLDER NEEDS BUT INCOMPLETE DATA LIMITS VISIBILITY INTO STMD'S PORTFOLIO

STAR Process Establishes Framework for Integrating Stakeholder Needs into STMD's Portfolio Plan

In 2020, STMD began the Strategic Technology Architecture Roundtable (STAR) initiative to identify and prioritize technology gaps within the Directorate's portfolio. Led by the STMD Chief Architect, the STAR process asks stakeholders to provide information on technology needs and then prioritizes those needs to create an integrated list of top priority technology gaps that should be addressed in the near term. The STAR process is intended to capture technology gaps and establish timeframes to ensure American global leadership in space technology and support three primary mission focus areas: (1) Artemis Moon missions, (2) human Mars missions, and (3) future science missions.

STMD's first iteration of the STAR process took 2 years to complete and culminated with the 2022 issuance of reports describing how the Directorate's project portfolio contributes to achieving 17 desired outcomes to close technology gaps related to commercial competitiveness as well as Moon, Mars, and future science missions.[14] See Table 1 for a list of the 17 desired outcomes.

[14] The reports, known as Envisioned Future Priorities, describe the envisioned future for the desired outcome and the plan to achieve the envisioned future, including tactical next steps.

Table 1: Strategic Framework Desired Outcomes

Develop nuclear technologies enabling fast in-space transits.
Develop cryogenic storage, transport, and fluid management technologies for surface and in-space applications.[a]
Develop advanced propulsion technologies that enable future science/exploration missions.
Enable lunar/Mars global access with approximately 20-ton payloads to support human missions.
Enable science missions entering/transiting planetary atmospheres and landing on planetary bodies.
Develop technologies to land payloads within 50 meters accuracy and avoid landing hazards.
Sustainable power sources and other surface utilities to enable continuous lunar and Mars surface operations.
Scalable in-situ resource production/utilization capabilities including sustainable commodities on the lunar and Mars surfaces.[b]
Technologies that enable surviving the extreme lunar and Mars environments.
Autonomous excavation, construction, and outfitting capabilities targeting landing pads/structures/habitable buildings utilizing in-situ resources.
Enable long duration human exploration missions with Advanced Habitation System technologies.
Develop next-generation high performance computing, communications, and navigation.
Develop advanced robotics and spacecraft autonomy technologies to enable and augment science/exploration missions.
Develop technologies supporting emerging space industries including satellite servicing and assembly, in space/surface manufacturing, and small spacecraft technologies.
Develop vehicle platform technologies supporting new discoveries.
Develop technologies for science instrumentation supporting new discoveries.
Develop transformative technologies that enable future NASA or commercial missions and discoveries.

Source: NASA OIG presentation of Agency information.

[a] Cryogenic propellants are fluids chilled to extremely cold temperatures.
[b] In-situ resource utilization means generating products with locally available materials such as those found on the Moon and Mars.

The STAR process began in 2020 with STMD and NASA stakeholders responsible for the three mission focus areas working together to identify technology gaps. Then, STAR engaged with additional NASA, industry, and academic stakeholders to review the gaps and closure plans to inform STMD's overall portfolio. Moving forward, now that STMD has completed its first iteration of the STAR process, the Directorate plans to target its project solicitations to allow industry and academia to compete in developing the best approaches to close the gaps. To ensure that its portfolio remains aligned with evolving industry and NASA needs, STMD will continue the STAR process by continuously updating plans and publishing reports annually.

We found that NASA stakeholders we interviewed were generally satisfied with the STAR process. Specifically, in contrast to findings in our December 2015 audit that the Directorate's strategic planning process lacked a formalized authority to coordinate space technology needs across the Agency's Mission Directorates, stakeholders responsible for the three mission focus areas stated that STMD provided ample opportunities to integrate their feedback when developing the priority gap lists and that their needs were taken into consideration when formulating the 17 desired outcomes.[15] Furthermore, the

[15] NASA OIG, *NASA's Efforts to Manage Its Space Technology Portfolio* (IG-16-008, December 15, 2015).

STAR process allowed stakeholders to comment on the top priority technologies they believe would be most helpful to address industry and NASA needs. For example, the highest priority identified by both the STMD Chief Architect and other stakeholders was High Performance Spaceflight Computing technology that offers expanded computational performance and more efficient use of energy.[16] Other top priorities include quantum sensing, an advanced sensor technology capable of high-precision measurements for space position, navigation, and timing; demonstration of an aerocapture flight maneuver that inserts a spacecraft into its proper orbit using less fuel to allow for larger payloads; and nuclear electric propulsion that is more efficient than chemical rockets.

Incomplete Data Limits Visibility into STMD's Portfolio That Could Aid in Decision-Making

Portfolio Database Does Not Include Accurate and Complete Project Costs

While STMD has established a framework to identify and prioritize technology gaps within the Directorate's portfolio, it does not have a reliable way to evaluate how its expenditures align to those gaps. Developed in 2020, the STMD Portfolio Analysis Resource (SPAR) system provides an integration platform for STMD project data. SPAR provides STMD analysts data to support the development of reports, assessments, and inquiry responses to NASA leadership, the Office of Management and Budget, and Congress. These reports are designed to offer insights about the Directorate's overall portfolio across fiscal years including technology investments by program, partnership type, desired outcome, target destination, and TRL. However, we found that STMD is limited in its ability to provide costs associated with its various portfolio characteristics because SPAR only captures project budgets twice each year rather than on a continuous basis.[17] Furthermore, for some projects under STMD's Early Stage Innovations and Partnerships Portfolio, such as those for Space Technology Research Grants and NASA Innovative Advanced Concepts, SPAR only includes cost estimates. At the same time, SPAR excludes costs for some projects in the Technology Demonstrations Portfolio such as Flight Opportunities when the costs include sensitive procurement information like launch service costs. The limited cost insights provided by SPAR make it difficult for the Agency and other stakeholders to ensure STMD's portfolio spending aligns to its strategic goals.

Alignment of Projects to Desired Outcomes Is Incomplete

Data collected in SPAR feeds other STMD-managed data systems such as STARPort, which is intended to capture data linking projects to desired outcomes based on stakeholder needs. While STMD has established a framework to integrate stakeholder needs, we found that the Directorate is still working to map its investments to desired outcomes. In spring 2022, STMD began retroactively linking projects to

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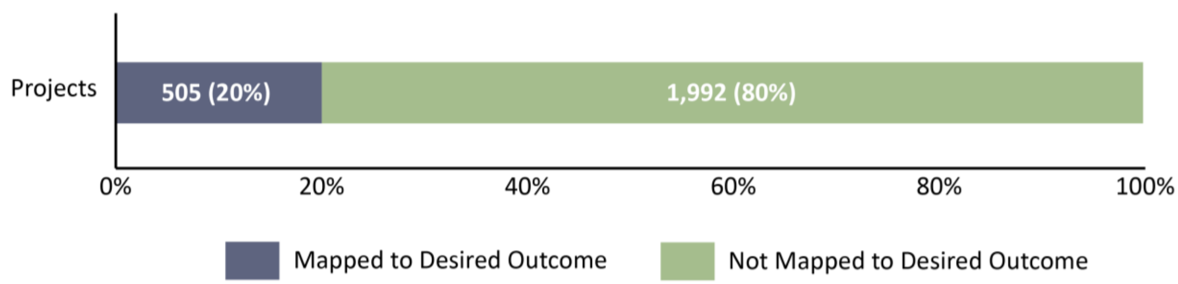
16 In August 2022, STMD awarded a $50 million firm-fixed-price contract to develop a High Performance Spaceflight Computing processor designed to provide up to 100 times the computational capacity of current space flight computers. As part of NASA's ongoing commercial partnership efforts, the contractor will also contribute significant research and development costs to complete the project.

17 The official financial system of record for NASA is Systems Analysis Program Development. While this system maintains updated budget information, it does not include detailed project information such as partnership type, desired outcome, target destination, and TRL.

1 or more of its 17 newly established desired outcomes in its STARPort data system. The Directorate first focused on mapping mid- to high-TRL projects because these projects receive the majority of STMD funding. We found that as of September 30, 2022, STMD had only mapped 20 percent of its portfolio of projects to 1 or more desired outcomes for 2,497 projects active in FY 2021 (see Figure 7).[18] While the majority of the FY 2021 unmapped projects fall under programs that focus on low- to mid-TRL projects, we were not able to determine the cost of mapped and unmapped projects because SPAR does not include accurate and complete cost information.

Figure 7: Fiscal Year 2021 STMD Projects Mapped to Desired Outcomes (as of September 2022)



Source: NASA OIG presentation of Agency SPAR data.

Most (95 percent) of the FY 2021 unmapped projects fall under programs that focus on low- to mid-TRL projects (see Table 2). Specifically, STMD had tied 505 projects to desired outcomes and had yet to map an additional 1,992 active projects. Only 106 (5 percent) of the unmapped projects fall under the high-TRL programs of Technology Demonstrations, Small Spacecraft Technologies, and Flight Opportunities. SBIR/STTR projects—which make up 62 percent of STMD's overall portfolio and fall into the low- to mid-TRL—accounted for 17 percent of projects tied to desired outcomes. STMD officials acknowledged that these are initial mapping assignments and there are still investments that have not yet been mapped.

[18] Data used in the analysis of STMD projects came from a September 30, 2022, download of the SPAR system. As of September 28, 2022, desired outcome data from STARPort is also available in SPAR. We focused on FY 2021 projects to allow for maximum data accuracy and completeness.

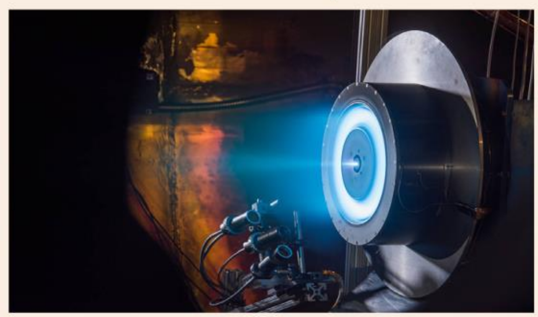
Table 2: Fiscal Year 2021 STMD Projects Mapped to Desired Outcomes (as of September 2022)

TRL	Program	Number of Projects		Tied to Desired Outcome(s)		Not Tied to Desired Outcome(s)	
5-7	Technology Demonstrations	27	(1.1%)	18	(3.6%)	9	(0.5%)
4-6	Flight Opportunities	148	(5.9%)	80	(15.8%)	68	(3.4%)
3-7	Small Spacecraft Technologies	37	(1.5%)	8	(1.6%)	29	(1.5%)
3-6	Game Changing Development	122	(4.9%)	86	(17.0%)	36	(1.8%)
2-6	SBIR/STTR	1,546	(61.9%)	86	(17.0%)	1,460	(73.3%)
2-4	Early Career Initiative	12	(0.5%)	3	(0.6%)	9	(0.5%)
1-6	Prizes, Challenges, and Crowdsourcing	17	(0.7%)	1	(0.2%)	16	(0.8%)
1-4	Space Technology Research Grants	408	(16.3%)	219	(43.4%)	189	(9.5%)
1-4	NASA Innovative Advanced Concepts	53	(2.1%)	3	(0.6%)	50	(2.5%)
1-3	Center Innovation Fund	127	(5.1%)	1	(0.2%)	126	(6.3%)
	Totals	**2,497**	**(100.0%)**	**505**	**(100.0%)**	**1,992**	**(100.0%)**

Source: NASA OIG presentation of Agency SPAR data.

As an example of what it means to tie a project to one or more desired outcomes, STMD has mapped its Solar Electric Propulsion project to two desired outcomes in its STARPort database: (1) develop nuclear technologies enabling fast in-space transits and (2) develop advanced propulsion technologies that enable future science/exploration missions. The Solar Electric Propulsion project is designed to demonstrate key technologies necessary for robotic- and human exploration-class solar electric transportation systems for commercial space operations and science missions. This project started in October 2014 and is projected to conclude in October 2028 at a high-TRL of 8 with a total life-cycle cost of $382 million. In contrast, STMD has not tied its Deep Space Atomic Clock project to one or more desired outcomes in the STARPort database. The Deep Space Atomic Clock is designed to provide timekeeping stability needed for the next generation of deep space navigation and radio science. The project started in October 2011 and concluded 10 years later at a high-TRL of 7 with a total life-cycle cost of almost $85 million.

Solar Electric Propulsion



Source: NASA.

The Solar Electric Propulsion project will develop and qualify an advanced 12 kilowatt, magnetically shielded electric propulsion Hall thruster applicable to human and robotic exploration missions. The lunar Gateway plans to use this thruster to maintain the spaceship's position around the Moon and move it to different locations. In addition, this technology will enable the use of high-power electric propulsion systems for long-term missions such as cargo transporation to Mars. Solar Electric Propulsion is developed and supported through STMD's Technology Demonstrations program and previously through the Game Changing Development program.

Estimated cost: $382.4 million

Expected TRL range at project completion:

1 2 3 4 5 6 7 8 9

While STMD officials concede that they have not completed the mapping of projects, they explained that some investments are intended to meet broader Agency goals rather than the specific set of desired outcomes identified through the STAR process. Specifically, STMD programs such as SBIR/STTR and Prizes, Challenges, and Crowdsourcing are Agency-wide efforts that support all NASA mission areas, including advanced aeronautics research that is not designed to align to STAR priorities. Furthermore, STMD officials noted that technologies within STMD's Early Stage Innovations and Partnerships Portfolio can take 20 or more years to advance to higher maturity levels and should not tie to the STAR strategic framework because they are designed to push the boundaries of what is possible beyond the most pressing, near-term needs. Nonetheless, these investments generally represent a small portion of unmapped projects. For example, 15 percent of unmapped SBIR/STTR projects active in FY 2021 were aeronautics research projects that are not designed to align to STAR priorities.

Incomplete mapping of Directorate projects limits the visibility STMD officials have over their vast portfolio, thereby hindering informed decision-making. Annually, STMD evaluates more than 3,000 proposals and selects more than 700 projects for funding. Furthermore, considering STMD's FY 2022 budget, the Directorate had to cancel several projects, and the STMD Chief Architect said that STMD should consider making further reductions in certain current projects to more fully fund higher priority needs. Without a complete picture of how STMD's projects are contributing to desired outcomes, it is difficult for the Directorate, Congress, and other stakeholders to have the information necessary to inform strategic investment and divestment decisions supporting NASA and Administration space technology goals.

STMD Generally Met Its Annual Performance Goals but Needs to Develop More Outcome-Based Measures

STMD Generally Met Annual Performance Goals

As part of its performance management process, NASA develops strategic objectives and performance goals and targets that allow the Agency to measure and track progress towards achieving these objectives. Since FY 2014, STMD has been responsible for NASA's strategic objective to innovate and advance transformational space technologies. As of FY 2022, STMD is also responsible for an Agency priority goal of ensuring American global leadership in space technology innovations. STMD aims to accomplish its strategic objective and Agency priority goal by identifying and funding critical technology gaps and growing NASA's space technology pipeline with emerging innovative technologies designed to drive the future of space exploration, science, and commercialization. To this end, NASA's FY 2022 Agency Performance Plan includes five performance goals designed to measure STMD's progress towards meeting these objectives.

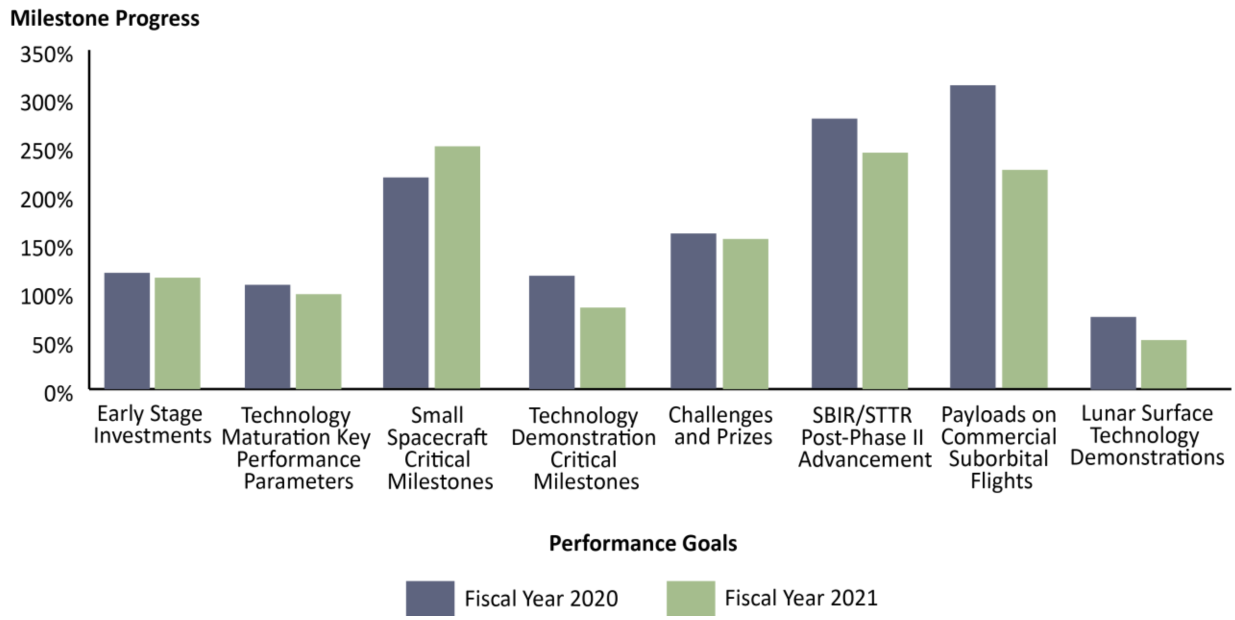
1. Foster a diverse U.S. engineering and technology talent base, expand commercial opportunities in the space industry, and advance innovative technology solutions.
2. Mature technology projects that offer significant improvement to existing solutions or enable new capabilities.
3. Rapidly develop and demonstrate technologies for exploration, discovery, and the expansion of space commerce through partnerships with U.S. industry and academia.
4. Demonstrate new technologies and cross-cutting capabilities that are of direct interest and use to NASA missions, as well as the commercial space sector.
5. Ensure American global leadership in space technology innovations through increased partnering with industry, broadening the base of innovation, and demonstrating key lunar surface and deep space technologies.

To demonstrate progress towards achieving its five goals, STMD established a targeted number of quantifiable outputs related to its portfolio of projects. For example, in FY 2022 STMD established a goal to offer 45 new opportunities under its Prizes, Challenges, and Crowdsourcing program and a goal to test 40 technologies orbitally or suborbitally under its Small Spacecraft Technologies and Flight Opportunities programs. STMD's FY 2022 goals also include measures that demonstrate effective management of its projects, such as completing seven major milestones specific to new technologies and cross-cutting capabilities that are of direct interest and use to NASA missions or the commercial space sector and achieving 60 percent of key performance parameters for Technology Maturation

Portfolio projects.[19] Finally, in FY 2022 STMD added new outcome-based goals related to its Early Stage Innovations and Partnerships Portfolio to achieve at least 1 knowledge transition from 75 percent of its research grants and achieve 3,600 technology licensing and software usage agreements.[20]

In FYs 2020 and 2021, STMD achieved satisfactory performance against its strategic objective, and for some goals STMD significantly exceeded its target (see Figure 8).[21] For example, in both years STMD advanced over 100 SBIR/STTR technologies past Phase II—more than 200 percent of its original target.

Figure 8: STMD Fiscal Years 2020 to 2021 Performance Goals



Source: NASA OIG presentation of NASA's Volume of Integrated Performance.

[19] Major milestones include key decision points, major reviews, and technology demonstrations. Key decision points are part of NASA's program and project life-cycle management requirements and provide checkpoints for decision-makers to determine whether a project meets the requirements to move forward (e.g., advancing from a concept to preliminary design). Major reviews can include any number of formal reviews that take place during the NASA project life cycle, including reviews of design, mission readiness, and flight readiness. Technology demonstrations take place either on the ground to mature technologies to the point of a prototype or in a space environment to prove success.

[20] A knowledge transition captures and transfers technologies, ideas, and expertise from STMD projects to other NASA employees, government agencies, and industry. Examples include published journal articles, patents, licensing, open-source software, and student hiring.

[21] NASA annually publishes progress towards achieving its performance goals and strategic objectives in its Volume of Integrated Performance, where it indicates whether a strategic objective demonstrates noteworthy progress, satisfactory performance, or is a focus area for improvement. We restricted our analysis of STMD's performance to FYs 2020 and 2021 because its FY 2022 performance will be reported in NASA's FY 2024 Volume of Integrated Performance, which will be published in FY 2023.

The Directorate's goals for those years are slightly different from the FY 2022 goals because, as required by NASA's performance planning process, STMD regularly evaluates and updates its performance goals and targets to ensure they accurately reflect NASA's budget, priorities, strategies, and programmatic plans. In FYs 2020 and 2021, STMD had four performance goals.

1. Encourage creative and innovative solutions to space technology challenges by investing in early-stage technologies and concepts from U.S. innovators. *[Established in FY 2011 and completed at the end of FY 2021.]*
2. Mature technology projects that offer significant improvement to existing solutions or enable new capabilities. *[Established in FY 2011 and continues in FY 2022.]*
3. Demonstrate new technology and capabilities to support NASA's missions and space industry growth. *[Established in FY 2014 and completed at the end of FY 2021.]*
4. Spur technology development through engagement with the commercial sector and general public. *[Established in FY 2017 and completed at the end of FY 2021.]*

STMD officials explained that performance goals and targets are updated annually after an internal strategic review. Factors that influence changes in performance targets include prior year performance, future funding level estimates, and feedback from the Office of Management and Budget. As a result of this process, the Directorate increased its targets for several goals between the time the goal was established and the time that it was completed. While this is in accordance with NASA's strategic planning process, it makes it difficult for the Agency and stakeholders to compare progress year to year as targets change and goals are added or removed.[22] For example, to measure progress towards a long-standing goal related to the Early Stage Innovations and Partnerships Portfolio, STMD sought to make 100 new investments in early-stage technologies when the goal was established in FY 2011 and continued to increase this target until it reached 210 new investments for both FYs 2020 and 2021.

Potential to Establish More Outcome-Based Goals

STMD's performance goals have historically focused on a variety of quantifiable outputs such as making investments and meeting milestones—measures that are essential for demonstrating effective management of project cost, schedule, and performance. However, these measures do not fully capture the extent to which STMD-funded technologies helped to achieve the Directorate's strategic objective to innovate and advance transformational space technologies. Without more fully demonstrating the achievements of its funded technologies, it will be difficult for decision-makers in NASA and Congress to prioritize technology development.

Acknowledging this shortfall, STMD modified several of its FY 2022 performance goals related to early-stage technologies to remove the output-based measure of investing in a target number of projects and replace it with more outcome-based measures. For example, new measures include achievement of knowledge transitions associated with research grants, external partner investments to further advance small business technologies, and technology licensing and software usage agreements. Also new in FY 2022 is an outcome-based goal to benchmark diversity, equity, inclusion, and accessibility

[22] STMD's changing performance measures limited our ability to assess progress over longer periods of time. For example, in FY 2019 NASA invested in 229 early-stage technologies, far exceeding its target of 185. As a result, this goal target was increased to 210 investments for subsequent years. Similarly, between FYs 2019 and 2020, STMD increased its target for prizes, challenges, and crowdsourcing activities from 4 to 42.

data and engage with underrepresented communities, which aligns with NASA's Mission Equity initiative to examine potential barriers for these communities relating to NASA procurements, grants, and policies.

In general, establishing and quantifying outcome-based performance measures for technology development projects is inherently difficult for several reasons. First, it is difficult to quantify outcomes such as knowledge transfer, technology integration, and economic impact. At the same time, technologies may have potential use far into the future but no immediate governmental or commercial demand. Specifically, technologies within STMD's Early Stage Innovations and Partnerships Portfolio can take 20 or more years to advance to higher maturity levels. Furthermore, there is no Agency or industry consensus on what constitutes technology development success.

Despite these challenges, in 2022 as part of the Directorate's portfolio management system development efforts, STMD improved its ability to track difficult-to-measure information such as project transition or infusion into use and advancement within a program (see Table 3). While STMD is still working to finalize the transition types and their definitions, this information could help NASA demonstrate the benefits of supporting various technology projects that often take many years to produce tangible value.

Table 3: Outcome-Based Project Performance Tracking

Outcome	Definition
Transitioned From Transitioned To	A technology is handed off for further development outside the original program. Transitions can be made to or from other NASA programs, other government agencies, commercial entities, academic institutions, or international partners. For example, an SBIR project transitions to another program if it proceeds past Phase II.
Advanced From Advanced To	A sub-category of transition, where a technology is handed off for further development to or from an entity within the same program. For example, a project can advance through several phases while remaining within the NASA Innovative Advanced Concepts program.
Infused	The technology is fully developed and was selected for use by a NASA mission, government agency, commercial entity, or international partner. For example, STMD-researched technologies have been infused into Artemis and International Space Station missions.

Source: NASA OIG presentation of Agency information.

Using these outcome-based performance measures, we found that STMD documented 77 of the 2,497 projects active during FY 2021 as transitioned, advanced, or infused. For example, a NASA challenge award related to vascular tissue research resulted in the technology transitioning to nonprofit organizations who are providing the top two award winners with flight opportunities to advance the technology onboard the International Space Station. Also, several technologies related to solar sails, radio telescopes, and robotic manipulation tasks have advanced through phases of the NASA Innovative Advanced Concepts program. Furthermore, a technology derived from the Laser Communications Relay Demonstration, which advanced the use of optical communications technology in space, was selected to be infused into NASA's Artemis mission in January 2022. During the Artemis II crewed flight, a laser communication system derived from the relay demonstration will attempt to stream live, 4K ultra high-definition video broadcasts from the Orion Multi-Purpose Crew Vehicle as well as provide enhanced science data transmission.

Laser Communications Relay Demonstration (LCRD)

Source: NASA.

The LCRD payload is hosted onboard a U.S. Department of Defense satellite where it plans to demonstrate optical communications capabilities advantageous for future space missions. Optical communications are designed to send data from space to the ground and back as well as from spacecraft to spacecraft with increased bandwidth and reduced size, weight, and power requirements. Launched in Decemeber 2021, LCRD will practice sending various test data, such as tracking and telemetry, over optical signals. LCRD is developed and supported through STMD's Technology Demonstations program and NASA's Space Communications and Navigation program.

Estimated cost: $317.6 million

Expected TRL range at project completion:

1	2	3	4	5	6	7	8	9

CONCLUSION

STMD's goal is to develop technological capabilities the Agency needs to achieve its missions and support American global leadership in space technology. STMD accomplishes this through partnerships with academia, industry, other government agencies, international partners, and by engaging the public.

In 2020, STMD began the STAR initiative to prioritize technology gaps within the Directorate's portfolio. Overall, NASA stakeholders we interviewed were generally satisfied with the STAR process because it sufficiently integrated their feedback on priority technology needs. While the STAR process establishes the framework to integrate stakeholder needs and prioritize investment decisions, STMD does not have a reliable way to measure the cost of its efforts to close the gaps. STMD's SPAR system is designed to offer insights into the Directorate's portfolio; however, it does not include accurate and complete project costs due to infrequent updates, use of cost estimates, and exclusion of costs deemed sensitive procurement information. In addition, we found that the Directorate is still working to map its investments to desired outcomes in STARPort. Incomplete cost information and mapping of projects limits the visibility STMD officials have over an already complex portfolio. Without a complete picture of how STMD's projects contribute to desired outcomes, it is difficult for the Directorate, Congress, and other stakeholders to have the information necessary to inform strategic investment decisions.

As part of its performance management process, NASA develops strategic objectives and annual performance goals that allow the Agency to measure and track progress towards achieving its goals. In FYs 2020 and 2021, STMD achieved satisfactory performance against each of its performance goals. However, the performance measures used are output-based and do not fully capture the extent to which STMD-funded technologies helped to achieve the Directorate's strategic objective to innovate and advance transformational space technologies. As part of the Directorate's portfolio management system development efforts, in 2022 STMD began supporting the ability to track some of this difficult-to-measure information such as projects that transitioned, advanced, or infused. While NASA has made progress in developing outcome-based performance measures, it is important that STMD more clearly demonstrate the achievements of its funded technologies to Congress and other stakeholders.

RECOMMENDATIONS, MANAGEMENT'S RESPONSE, AND OUR EVALUATION

To ensure STMD has visibility into how its portfolio aligns to priority outcomes to inform future investment and divestment decisions, we recommended the Associate Administrator for STMD:

1. Reexamine its SPAR data system to ensure it provides as accurate and complete a picture of project costs as is practicable.
2. Update its STARPort data system with complete information on project alignment to STAR desired outcomes for all projects active in FY 2021 and beyond.

To better illustrate whether STMD-funded technologies help achieve the Directorate's strategic goals, we recommended the Associate Administrator for STMD:

3. Complete efforts to develop additional outcome-based performance measures based on the transition, advancement, and infusion of technologies.

We provided a draft of this report to NASA management who concurred with our recommendations and described planned actions to address them. We consider the proposed actions responsive and will close the recommendations upon completion and verification.

Management's comments are reproduced in Appendix B. Technical comments provided by management and revisions to address them have been incorporated as appropriate.

Major contributors to this report include Ridge Bowman, Human Exploration Audits Director; Deanna Lee, Assistant Director; Amy Bannister; Dan Fenzau; Areeba Hasan; Antonia Islas; and Dimitra Tsamis. Additionally, Lauren Suls and Matt Ward provided editorial and graphics support; Cody Bryant provided data analytics support; and Shani Dennis provided legal 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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Paul K. Martin
Inspector General

APPENDIX A: SCOPE AND METHODOLOGY

We performed this audit from February 2022 through September 2022 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 objective was to examine the extent to which NASA's management of its STMD portfolio aligns to space technology needs and whether performance measures and outcomes reflect the Directorate's goals. To accomplish our objective, we performed the majority of our work with the STMD office at NASA Headquarters.

To determine the extent to which NASA's management of its STMD portfolio aligns to space technology needs, we conducted interviews with STMD officials to gain an overall understanding of the processes in place to guide technology investment decisions. We reviewed documentation, including NASA's strategic plan and STMD's portfolio plan, strategic framework, and internal status reports. We interviewed the STMD Chief Architect along with other NASA Mission Directorates to understand how STMD uses its STAR process to balance technology gaps, stakeholder needs, and technical or budgetary limitations when considering how to prioritize its portfolio of technology investments. We also reviewed the SPAR database to identify STMD projects mapped to 17 desired outcomes.

To determine if STMD's performance measures and outcomes reflect achievement of its intended goals, we reviewed NASA's strategic plan and STMD's portfolio plan. We reviewed federal guidance and interviewed STMD officials to understand how the Directorate develops and reports on its performance goals. We also reviewed NASA's annual performance plans and reports for FYs 2011 through 2022 and technology transfer data from STMD's portfolio management system.

Assessment of Data Reliability

Our audit used computer-processed data that we assessed as reliable. The SPAR system provides an integration platform for STMD project data. We used a September 30, 2022, download of SPAR to illustrate characteristics of STMD's portfolio of projects. We focused on projects active in FY 2021 to allow for maximum data accuracy and completeness. We corroborated information with other sources when possible and performed audit steps to validate the accuracy of the provided data. We determined that SPAR does not include accurate and complete cost information, so we did not include aggregate project costs in this report. We determined that the remaining SPAR data used was sufficiently reliable for the purposes of this report.

Review of Internal Controls

We reviewed internal controls associated with NASA's management of STMD relative to effectively integrating stakeholder needs into technology development investments and evaluating performance measures reflecting achievement of its intended goals. Control weaknesses are identified and discussed in this report. Our recommendations, if implemented, will improve those identified weaknesses.

Prior Coverage

During the last 7 years, the NASA Office of Inspector General and Government Accountability Office have issued four reports of significant relevance to the subject of this report; they can be accessed at https://oig.nasa.gov/audits/auditReports.html and https://www.gao.gov.

NASA Office of Inspector General

NASA's Efforts to Manage Its Space Technology Portfolio (IG-16-008, December 15, 2015)

Government Accountability Office

Leading Practices: Agency Acquisition Policies Could Better Implement Key Product Development Principles (GAO-22-104513, March 10, 2022)

Defense Science and Technology: Adopting Best Practices Can Improve Innovation Investments and Management (GA0-17-499, June 29, 2017)

Defense Advanced Research Projects Agency: Key Factors Drive Transition of Technologies, but Better Training and Data Dissemination Can Increase Success (GAO-16-5, November 18, 2015)

APPENDIX B: MANAGEMENT'S COMMENTS

National Aeronautics and Space Administration

Mary W. Jackson NASA Headquarters
Washington, DC 20546-0001

December 9, 2022

Reply to Attn of: Space Technology Mission Directorate

TO: Assistant Inspector General for Audits

FROM: Associate Administrator, Space Technology Mission Directorate

SUBJECT: Agency Response to OIG Draft Report, "Review of NASA's Space Technology Mission Directorate Portfolio (A-22-05-00-HED)

The National Aeronautics and Space Administration (NASA) appreciates the opportunity to review and comment on the Office of Inspector General (OIG) draft report entitled, "Review of NASA's Space Technology Mission Directorate Portfolio (A-22-05-00-HED), dated November 10, 2022. 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.

The Space Technology Mission Directorate (STMD) has been working for several years to strategically plan and invest in its portfolio using the Strategic Technology Architecture Roundtable (STAR) process and appreciated the positive feedback in this report on its implementation. We believe this audit process has been beneficial and has validated STMD's plans for improving the strategic management of our portfolio.

In the draft report, the OIG makes three recommendations addressed to the Associate Administrator for the STMD to ensure STMD has visibility into how its portfolio aligns with priority outcomes to inform future investment and divestment decisions and better illustrate whether STMD-funded technologies help achieve the directorate's strategic goals.

Specifically, the OIG recommends the following:

Recommendation 1: Reexamine its SPAR data system to ensure it provides as accurate and complete picture of project costs as is practicable.

Management's Response: NASA concurs. While the STMD Portfolio Analysis Resource (SPAR) will never be in full alignment with the system of record due to the timeliness of updates and the nature of some of the proprietary data, STMD will validate each of the budget values in the SPAR during each semiannual update.

Estimated Completion Date: December 31, 2023.

Recommendation 2: Update its STARPort data system with complete information on project alignment to STAR desired outcomes for all projects active in FY 2021 and beyond.

Management's Response: NASA concurs. NASA acknowledges the importance of linking projects to desired outcomes and as such has begun the process beginning with the highest dollar investments. STMD will evaluate each project and indicate its alignment towards STAR outcomes, although STMD recognizes that some investments may not align to STMD-desired outcomes, specifically in programs that are Agency-wide and support other Mission Directorates.

Estimated Completion Date: March 31, 2024.

Recommendation 3: Complete efforts to develop additional outcome-based performance measures based on the transition, infusion, and advancement of technologies.

Management's Response: NASA concurs. STMD has already developed select outcome-based performance measures and has plans to expand upon those measures. We recognize and agree with the importance of outcome-based measures, however, obtaining the data on transitions and infusions of thousands of projects remains a continuing challenge as we are reliant on private companies and individual researchers to provide such data, often years after the project has concluded.

Estimated Completion Date: December 30, 2024.

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 Ashley Edwards at (202) 358-1756.

James L. Reuter

cc: Office of the Chief Information Officer

Appendix C: Report Distribution

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