Aeronautics and Space Report of the President

Fiscal Year 2024 Activities

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The National Aeronautics and Space Act of 1958 directed the annual Aeronautics and Space Report to include a "comprehensive description of the programmed activities and the accomplishments of all agencies of the United States in the field of aeronautics and space activities during the preceding calendar year." In recent years, the reports have been prepared on a fiscal-year basis, consistent with the budgetary period now used in programs of the Federal Government. This year's report covers activities that took place from October 1, 2023, through September 30, 2024. Please note that these activities reflect the Federal policies of that time and do not include subsequent events or changes in policy.

On the title page, clockwise from the top left: **1.** An ALTIUS unmanned aircraft system sails through the skies at Yuma Proving Ground, Arizona. Credit: U.S. Army Combat Capabilities Development Command–Aviation and Missile Center/Jose Mejia-Betancourth. **2.** This long-exposure photograph taken September 2, 2024, by NASA astronaut Matthew Dominick shows star trails and streaks of city lights as the International Space Station orbited 258 miles above Earth. Credit: NASA/Matthew Dominick. **3.** The James Webb Space Telescope captured this detailed view of supernova remnant Cassiopeia A in near-infrared light. Credit: NASA, European Space Agency (ESA), Canadian Space Agency (CSA), Space Telescope Science Institute (STScI), Danny Milisavljevic (Purdue University), Ilse De Looze (UGhent), and Tea Temim (Princeton University). **4.** On October 13, 2023, NASA's Psyche spacecraft launched on its mission to a metal-rich asteroid by the same name on a SpaceX Falcon Heavy Rocket. Credit: NASA/Aubrey Gemignani. **5.** U.S. Air Force F-16 Fighting Falcons participate in an exercise over the Pacific Ocean on August 9, 2024. Credit: U.S. Air Force/Staff Sgt. Monica Roybal. **6.** NASA's Earth Polychromatic Imaging Camera (EPIC) imager on the Deep Space Climate Observatory (DSCOVR) satellite captured this view of Earth on April 8, 2024, as millions of Americans witnessed a total solar eclipse. Credit: NASA Epic Team.

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The National Space Council

Revived by executive order on June 30, 2017, and renewed on December 1, 2021, the National Space Council advises and assists the President on national space policy and strategy, including advising on international space activities and fostering closer coordination and cooperation among the domestic civil, national security, and commercial space sectors. The National Space Council membership, which includes the heads of the agencies, departments, and offices responsible for the United States space enterprise, supported the Council's Chair, Vice President Kamala Harris, in fiscal year (FY) 2024.

The Council meets to publicly discuss the status of administration priorities and propose recommendations to the president regarding national space policy and strategy. In addition to an audience composed of stakeholders from industry, government, academia, and nongovernmental organizations, the White House and the National Aeronautics and Space Administration (NASA) livestream Council meetings on the internet to encourage public engagement and transparency.

The Council is supported by a Users' Advisory Group (UAG) composed of non-federal representatives of industries and other persons involved in aeronautical and space activities. The UAG members are organized into six subcommittees: Exploration and Discovery; National Security Space; Economic Development and the Industrial Base; Science, Technology, Engineering and Mathematics (STEM) Education, Diversity, and Inclusion; Climate and Societal Benefits; and Data and Emerging Technology.

Fostering New and Expanded Space Partnerships

Throughout FY 2024, the National Space Council reinforced its commitment to strengthening the United States' leadership in space, with a distinct focus on expanding international

partnerships and ensuring the country's long-term presence in space. One of the key moments came during the December 2023 National Space Council meeting, where Vice President Harris outlined the continued evolution of international collaboration in space, particularly in response to emerging challenges and opportunities in areas like lunar exploration and space sustainability.

Establishing Rules for Novel Space Activities

The Biden-Harris administration's release of an approach for the authorization and supervision of novel space activities was another important announcement at the December 2023 meeting. Composed of both executive action and a legislative proposal, the proposal represents significant steps forward to shape the future of the commercial space industry by establishing rules that are strong enough to promote safety, sustainability, and predictability but flexible enough to ensure innovation.

Cybersecurity Leadership for Space Systems and Supporting Infrastructure

Recognizing the pivotal role of space systems to global critical infrastructure and resilience, and to further protect space systems and supporting infrastructure vital to our national and economic security, the National Space Council played a central role in directing updates to cybersecurity standards for U.S. civil and national security space systems. In FY 2024, the Council collaborated with federal agencies to develop an executive order designed to increase space system resilience against cyber threats. This effort is a key area of focus to protect U.S. civil and national security space assets from malicious attacks and to promote cybersecurity norms.

Expanding Global Partnerships for Space Exploration

The Artemis Accords, central to the Biden-Harris administration's diplomatic efforts in space, expanded significantly in FY 2024. By the end of the fiscal year, the number of signatories had increased from 29 to 43. The administration forged new commitments from nations, including Japan, which included President Joe Biden and Prime Minister Kishida Fumio announcing a joint mission to send a Japanese astronaut to the surface of the Moon alongside U.S. astronauts. The United States also strengthened bilateral cooperation with international partners through space dialogues chaired or co-chaired by Council staff in calendar year 2024 with France, Germany, Japan, and Italy.

The Council also worked closely with several agencies to better understand and help expand space partnerships in the global south, particularly in Africa and South America,

focusing on leveraging space for developmental and environmental use and capacity building in space science education.

Pioneering Space Sustainability Initiatives

Sustainability in space continued to be a critical focus for the National Space Council in FY 2024. Under the Council's leadership, federal agencies made significant progress in updating the U.S. Orbital Debris Mitigation Standard Practices, promoting safe and responsible space activities. The Council also worked with international partners to strengthen space sustainability policies, particularly for cislunar space and deep space activities, ensuring that exploration efforts remain safe and sustainable for future generations.

The Council also supported interagency collaboration to develop a space sustainability strategy that would provide a framework for international space agencies and private-sector actors to ensure responsible operations in Earth orbit and beyond.

Sustaining U.S. Leadership in Low Earth Orbit

A major priority of the National Space Council in FY 2024 was ensuring sustained U.S. leadership in low Earth orbit (LEO) as the International Space Station (ISS) approaches decommissioning. To this end, the Council worked closely with NASA and other federal agencies to develop strategies for transitioning to Commercial Low Earth Orbit Destinations (CLDs) and further expanding the economic sphere of the United States into LEO. This transition is critical for continuing international partnerships, advancing space science, and fostering a thriving commercial space ecosystem.

Empowering Future Generations Through STEM Education and Workforce Development

The National Space Council continued to lead federal efforts to enrich space-related STEM education and workforce development. In FY 2024, the Space Council expanded its efforts to promote space careers, launching a national awareness campaign that highlighted the diverse opportunities available in the space industry and expanding the Space Workforce Coalition to now include states from each region of our Nation.

The Space Council also initiated new programs to inspire and prepare the next generation of space professionals, including Find Your Place in Space Week.

Additional FY 2024 Key Announcements:

(1) **Broader Space Diplomacy Efforts:** The National Space Council engaged bilaterally and multilaterally to strengthen the United States' diplomatic position and promote responsible behavior in space for new space actors. This includes the facilitation of the first U.S.-Africa Space Forum and ongoing discussions with the newly established African Space Council.

(2) **Space Commercialization Initiatives:** The Council worked closely with the Department of Commerce and the Department of Transportation to develop new frameworks for supporting the U.S. space industry. This included the creation of a knowledge repository for private-sector space operators and drafting a charter for the Private Sector Interagency Steering Group.

(3) **Export Control Modernization:** To ensure U.S. leadership in the global space economy, the National Space Council directed the Department of State and Department of Commerce to modernize export controls for space technologies. Two Notices of Proposed Rulemaking (NPRMs) were prepared for public comment, while additional updates to export controls were finalized and implemented without the need for public comment.

National Aeronautics and Space Administration

NASA

Exploration Systems Development Mission Directorate

The Exploration Systems Development Mission Directorate (ESDMD) manages the development of NASA's Moon to Mars architecture and planning for an integrated deep space human exploration approach, including systems for Artemis missions to the Moon.

Strategy and Architecture Office

The Exploration Systems Development Mission Directorate Strategy and Architecture Office translates NASA's Moon to Mars Objectives into an integrated portfolio that leverages diverse government, academic, industry, and international stakeholders. Architecting from the right as outlined in the Moon to Mars Strategy and Objectives Development document, the office begins with the broadest, long-term goals—farthest in the future on the timeline—and works backward to ensure that each objective is traced to relevant systems and their execution. From there, the office develops potential concept solutions, conducts analyses, and empowers pre-formulation activities to identify the human exploration campaign elements needed in the architecture to fulfill the needs of Moon to Mars exploration.

In FY 2024, the Strategy and Architecture Office accomplished the following:

- Hosted the Architecture Concept Review in November 2023. At this meeting, agency leadership assessed the results of the 2023 strategic analysis cycle, which informs architecture decisions by decomposing the Moon to Mars Objectives into the use cases and functions necessary to achieve them. As part of this decomposition, the team also identified architecture gaps that will require new architecture elements, assets, or technologies. The 2023 Architecture Concept Review was the second under NASA's architecture process, and the first in the now-standard annual cycle.

- Released Revision A of NASA's Architecture Definition Document, which captures the current state of the Moon to Mars Architecture. It establishes the process, framework, and decomposition of the Moon to Mars Objectives, empowering the success of executing systems, programs, and projects toward achieving our goals. The new revision included the following:
    - Four new sub-architectures (disciplines that NASA must master to achieve the Moon to Mars Objectives): Data Systems and Management, Infrastructure Support, In Situ-Resource Utilization Systems, and Autonomous Systems and Robotics.
    - Six additional exploration elements, which include several international partnerships: Gateway Extravehicular Robotic System (Canadian Space Agency), Gateway Lunar View refueling module (European Space Agency), Gateway Airlock Module, Human-class Delivery Lander, Pressurized Rover, and Lunar Terrain Vehicle.
    - After publication of the Architecture Definition Document, NASA formalized two new international partnerships for the provision of two of the new elements. The Japan Aerospace Exploration Agency will provide the Pressurized Rover, and the Mohammed Bin Rashid Space Centre will provide the Gateway Airlock Module. These partnerships will be included in Revision B of the document, which the agency anticipates releasing in December 2024.
- Published 13 white papers in January 2024. The white papers elaborate on specific technical topics and capture NASA's latest thinking on select architecture topics. Highlights include technical considerations for lunar operations, key drivers for Mars mission planning, and lessons learned from past human spaceflight that inform the Moon to Mars Architecture.
- Published two mid-cycle white papers as part of the 2024 Architecture Concept Review. Released in June, these papers signal key areas of NASA strategic focus to industry, academia, and the international community.
    - "Lunar Surface Cargo" analyzes projected needs and capability gaps for the transportation of cargo to the lunar surface.
    - "Lunar Mobility Drivers and Needs" discusses the need to move cargo and assets around the lunar surface and the factors that will significantly impact mobility systems.
- Released a Broad Agency Announcement for lunar logistics and mobility studies as an appendix to the Next Space Technologies for Exploration Partnerships-2

(NextSTEP-2). This effort seeks proposals for industry-led concept definition and maturation studies that address lunar surface logistics and uncrewed surface mobility capabilities.

- Developed and documented a new pre-formulation process, which clarifies the reviews and milestones that new exploration projects pass before they begin the formal development process established in NASA policy documents. Pre-formulation activities during FY 2024 included element initiations and preparation for mission concept reviews for the initial surface habitat element, which could provide a home for astronauts on the Moon, and the small cargo lander element, which could deliver equipment and supplies. These new elements will be included in Revision B of the Architecture Definition Document.
- Hosted the 2024 Architecture Workshops at the National Academy of Sciences in Washington, DC. Welcomed 140 attendees from 110 organizations to the workshop for industry and academia and 50 attendees from 18 countries to the workshop for international partners. These workshops offer attendees a venue to provide feedback on the architecture and discuss potential collaboration opportunities.
- Established and hosted cross-cutting forums and avenues for communication between NASA mission directorates and communities of expertise. Key milestones for new collaboration forums include the following:
    - Approval of the charter for the Utilization Coordination and Integration Group, which brings together stakeholders to document Artemis astronaut utilization priorities in a document called the Strategic Utilization Planning Agreement.
    - Initiation of the Technology Coordination and Integration Group, which brings together diverse technology development expertise and stakeholders across the agency to discuss capability gaps, ongoing research, and needed innovations.
- Sponsored and participated in the Revolutionary Aerospace Concepts Academic Linkage (RASC-AL) leveraging the competition to garner innovation in lunar architecture development. These contests fuel innovation in systems concepts, analogs, and technology prototyping by engaging university students with the challenges of space exploration.
- Conducted various human-in-the-loop tests in service to lunar architecture development and Artemis risk reduction. This work includes the Space Environment Analog for Training, Engineering, Science, and Technology 7 (SEATEST 7)—an underwater analog test contributing to NASA's understanding of lunar logistics considerations and lunar navigation simulations.

- Coordinated numerous technical interchange meetings with international space agencies, fostering collaboration on future exploration systems and integrating their expertise into the architecture development effort. The agencies included the European Space Agency (ESA), Canadian Space Agency (CSA), Japan Aerospace Exploration Agency (JAXA), Italian Space Agency (ASI), United Arab Emirates' Mohammed Bin Rashid Space Center (MBRSC), German Space Agency (DLR), Saudi Space Agency (SSA), the French Centre National d'Études Spatiales (CNES), the Korean AeroSpace Administration (KASA), and the Israel Space Agency (ISA). NASA is pursuing study agreements with additional space agencies that will allow technical discussions on future collaboration.
- Represented NASA through participation in and presentations at many science- and exploration-focused forums, including at conferences like the International Astronautical Congress and for groups like the Mars Exploration Program Analysis Group and the Lunar Exploration Analysis Group.
- Made significant progress on 2024 strategic analysis cycle tasks, resulting in substantial evolution of NASA's Moon to Mars Architecture. NASA will document many of these updates in revision B of its Architecture Definition Document.
    - Refined the architecture roadmapping and decision shepherding processes, making significant progress on the initial seven driving Mars architecture decisions identified as part of the 2023 Architecture Concept Review. NASA anticipates completing one of those decisions as part of the 2024 Architecture Concept Review and will document associated processes and additional decisions in a new appendix to the Architecture Definition Document.
    - Identified and prioritized a list of architecture-driven technology gaps to help inform investments that NASA and industry make to develop and mature technologies for human exploration. The full list will be published in an appendix of the Architecture Definition Document. As part of this effort, the Strategy and Architecture Office also contributed these gaps to the Space Technology Mission Directorate's list of civil space shortfalls (which includes a list of shortfalls prioritized for human exploration).

For more details on the Strategy and Architecture Office's work and to access architecture white papers and definition documents, visit www.nasa.gov/architecture.

Moon to Mars Program Office

Artemis missions are opening a new era of scientific discovery and economic opportunity at the Moon while validating operations and systems to prepare for human missions to Mars. NASA

established the Moon to Mars Program Office within ESDMD to focus on hardware development, mission integration, and risk management functions for programs critical to the agency's deep space human exploration. The Moon to Mars Program Office includes the Exploration Ground Systems (EGS), Space Launch System (SLS), Orion, Human Landing System (HLS), Extravehicular Activity and Human Surface Mobility (EHP), and Gateway programs. The office also leads planning and analysis for long-lead developments to support Mars missions. Since the successful test flight of Artemis I, the agency and its partners have made steady progress toward incorporating lessons learned and preparing for the first crewed Artemis flight. Additional milestones and accomplishments in FY 2024 are laying the groundwork for future exploration at the Moon.

Exploration Ground Systems

The EGS program, based at NASA's Kennedy Space Center in Florida, develops and operates the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport, launch, and recovery. Most importantly, EGS integrates, verifies, and validates all hardware prior to launch, ensuring that capabilities developed across the agency work as a functioning system. In FY 2024, EGS successfully completed the following tasks:

- EGS completed a series of tests with mobile launcher 1, which will be used to launch the first crewed Artemis mission, at Launch Pad 39B. These preparations ranged from a launch day demonstration for the crew, closeout crew, and the pad rescue team, to testing the emergency egress system, water flow system, and the new liquid-hydrogen sphere at the launch pad.
- The Artemis launch team continued to perform launch countdown simulations to prepare for launch, as well as practicing with the other new ground systems additions—like the emergency egress system—now that there will be crew aboard.
- Out at sea, the Artemis II crew, the recovery team from EGS, and members of the Department of Defense tested the procedures and tools that will be used to help the crew to safety when they splash down in the ocean at the end of their 10-day, 685,000-mile journey around the Moon.
- EGS completed the processing of the SLS solid rocket booster segments inside the Rotation, Processing and Surge Facility ahead of stacking for Artemis II.
- EGS received the Artemis II core stage, the powerhouse that will produce more than 2 million pounds of thrust during launch. In addition to the core stage, the Artemis II launch vehicle stage adapter, the Artemis III core stage boat tail, and the Artemis IV core stage engine section all arrived at Kennedy for processing.

- Mobile Launcher 2 (ML2), the primary interface between the ground, SLS rocket, and Orion spacecraft, completed its critical design review, which demonstrated that the ML2 design is completely integrated—both interdependencies between the 40+ subsystems as well as the external interfaces with flight hardware and other ground systems. Construction was completed on the first four of seven tower module assemblies. Umbilical testing to support the new upper stage at the spaceport's Launch Equipment Test Facility is underway.

Space Launch System

NASA's SLS is a super heavy-lift rocket that provides the foundation for human exploration beyond Earth orbit. With its unprecedented capabilities, SLS is currently the only rocket that can send crew to the Moon. On November 16, 2022, SLS took to the sky from Launch Complex 39B at Kennedy, making history as the most powerful rocket NASA has ever launched. The successful Artemis I mission ushered in a new era of exploration, as NASA prepares to send astronauts to the Moon as a prelude to human exploration of Mars. Post-flight data reviews determined that SLS met or exceeded performance expectations and that the rocket is ready to support a crewed flight on Artemis II and future crewed missions. NASA's SLS and industry team have hardware in work for Artemis II, III, IV, and V and long-lead items through Artemis IX. In FY 2024, the SLS team achieved the following milestones toward those missions:

- Shipped Artemis II core stage and launch vehicle stage adapter shipped to Kennedy to be stacked and integrated with other SLS elements and the Orion spacecraft for the first crewed launch of SLS.
- Completed final testing and checkout for the Artemis II Interim Cryogenic Propulsion Stage at United Launch Alliance's facilities at Cape Canaveral Space Force Station.
- Loaded Artemis II flight software onto the core stage flight computers.
- Completed all major structures for the Artemis III core stage and shipped the Artemis III core stage boat tail and Artemis IV engine section primary structure to Kennedy.
- Completed processing and stored Artemis III and IV RS-25 engines, as well as Artemis IV RL10 Exploration Upper Stage engines for Green Run testing.
- Successfully completed RS-25 engine hot fire certification testing, marking the end of a five-year program to develop a new variant redesigned, simplified, and improved, with production 30 percent more affordable, for first flight on Artemis V.

Orion

Orion is the exploration spacecraft that will carry Artemis crews to space, provide emergency abort capability, sustain astronauts during their missions, and provide safe reentry from deep space return velocities. In FY 2024, NASA continued to build off the accomplishments of the

successful Artemis I mission, the record-setting 25.5-day mission around the Moon in which an uncrewed Orion traveled a total of 1.4 million miles and tested the systems of the spacecraft in the extreme environment of deep space before flying astronauts on Artemis II. With a successful Artemis I mission complete, NASA and Lockheed Martin continue to process the Orion spacecraft for Artemis II and build Orion for Artemis III, IV, and V. In FY 2024, the Orion team achieved milestones for the following Artemis missions:

- After its successful mission around the Moon, the Artemis I crew module—now known as the Environmental Test Article—arrived at the Neil A. Armstrong Test Facility at NASA's Glenn Research Center in Ohio, where teams are performing abort-level acoustic vibration and other environmental testing to ensure Orion is ready for crew to fly on Artemis II.
- At Kennedy, teams are working on the Artemis II spacecraft that will carry astronauts around the Moon. Orion's crew and service modules were mated and powered on, and the spacecraft underwent two rounds of testing inside an altitude chamber that simulates vacuum conditions of deep space. The team checked out Orion for electromagnetic interference and compatibility, then followed up with a series of qualification testing. The spacecraft returned to the altitude chamber in October to complete test requirements not fully executed during earlier testing.
- The Artemis III and IV crew modules are in work at Kennedy. The Artemis III European Service Module arrived at Kennedy from Airbus facilities in Bremen, Germany, and was joined with the crew module adapter. The service modules for the Artemis IV, V, and VI missions are also in production in Germany, and the crew module pressure vessel for Artemis V is being welded together at NASA's Michoud Assembly Facility in New Orleans.

Human Landing System

The HLS program is responsible for the landers that will safely carry astronauts from lunar orbit to the Moon's surface and back during NASA's Artemis campaign. During the initial Artemis missions, the astronauts will live inside the pressurized crew cabin portion of the lander for up to a week, conducting scientific work and moonwalks. In FY 2024, the HLS program continued working with industry on the development of the commercially owned landers for Artemis III, IV, and V. Additionally, the HLS program accomplished the following:

- Awarded SpaceX and Blue Origin an option under existing HLS contracts to develop cargo variants of their human lunar landers. These cargo variants are expected to carry approximately 26,000–33,000 pounds (12 to 15 metric tons) of payload to the lunar surface. This initial award allows the companies to proceed with development

for their cargo landers through Preliminary Design Review, the step that establishes the basis for proceeding with detailed design.

- Worked collaboratively with SpaceX to continue development of their Starship HLS and supporting spacecraft for Artemis III and IV and incorporate them into Artemis mission planning. SpaceX conducted three more flight tests of the integrated Starship/Super Heavy launch vehicle system, as well as several development milestones related to thrusters, flight systems, launch architecture, and relative navigation in support of an upcoming orbital cryogenic propellant transfer demonstration. SpaceX also completed other milestones related to engine development, hardware (docking adapter and payload interfaces), crew elevator, and the first test of astronauts in pressurized spacesuits working in a full-scale mockup of the Starship HLS airlock.
- Worked collaboratively with Blue Origin to continue development of its Blue Moon MK2 lander for Artemis V and incorporate it into Artemis mission planning. Blue Origin completed several development milestones, including Certification Baseline Review, Preliminary Design Review, and Design Analysis Cycles, to continue to mature the mission architecture. Blue Origin also completed two milestones in support of initial development of its large cargo lander.
- Completed Key Decision Point-C for Artemis III Starship HLS, a milestone in the agency's project management life cycle, at which point NASA establishes a cost and schedule baseline that is reported to Congress and used to track performance. NASA has established the baseline estimate of $2.34 billion for the remaining costs to develop the Starship HLS to perform an uncrewed demonstration and complete a checkout in lunar orbit prior to receiving the Artemis III crew launched from Earth in NASA's Orion spacecraft atop the SLS rocket.

Extravehicular Activity and Human Surface Mobility

The EHP serves as NASA's program to develop next-generation spacesuits, human-rated rovers, and tools, along with all required spacewalking support systems that will enable astronauts to survive and work outside the confines of a spacecraft to explore on and around the Moon. The program represents a cornerstone of NASA's Artemis campaign to return humans to the Moon and explore deep space, as well as continuing a critical role supporting the space station and the commercialization of low Earth orbit. In FY 2024, the program achieved the following milestones:

- Under the Exploration Extravehicular Activity Services contract, Axiom Space completed the preliminary design review of its lunar spacesuit and is working toward entering its critical design review in 2025. Additionally, Axiom Space is also working

to prepare its lunar spacesuit for demonstration in a microgravity environment on the International Space Station to reduce risk for Artemis missions.

- NASA selected Intuitive Machines, Lunar Outpost, and Venturi Astrolab under the Lunar Terrain Vehicle Services contract to advance capabilities for a lunar terrain vehicle. The three companies are currently in a one-year-long feasibility study with NASA planning to issue a final demonstration task order in 2025, where it will downselect and award one company the chance to demonstrate their vehicle on the Moon.
- NASA and JAXA signed an implementing arrangement under which Japan will design, develop, and operate a pressurized rover for crewed and uncrewed exploration on the Moon. NASA currently plans to use the pressurized rover on Artemis VII and subsequent missions over an approximate 10-year lifespan.
- The current Extravehicular Activity Space Operations contract was extended through September 2030, allowing the agency to maintain critical spacewalking capability on the International Space Station. This entails sustaining engineering and processing of the legacy Extravehicular Mobility Unit spacesuit and spacewalking tools and crew aids, hardware integration, mission planning, extravehicular activity hardware development (as required), and real-time operations support for the space station through its end of life.

Gateway

The Gateway program is an international collaboration building humanity's first space station to orbit the Moon. As a central component of NASA's Artemis campaign, Gateway will host capabilities for sustained exploration and research in deep space, including docking ports for a variety of visiting spacecraft; space for international teams of astronauts to live, work, and prepare for lunar surface missions; and on-board science investigations. In FY 2024, the Gateway program achieved the following milestones:

- Gateway is in the full development phase for its first elements, the Habitation and Logistics Outpost (HALO), provided by Northrop Grumman, and the Power and Propulsion Element module, provided by Maxar Space Systems. Both pieces are progressing through fabrication and assembly. HALO will arrive in the United States for final outfitting in 2025, and the Power and Propulsion Element is proceeding through testing and installation of hardware.
- NASA and the MBRSC entered into an agreement for the MBRSC to provide the Gateway Airlock Module, now referred to as the Crew and Science Airlock module. To fulfill a commitment in the agreement, NASA will fly a United Arab Emirates astronaut to Gateway on a future Artemis mission.

- Maturation continues on the three radiation-focused science payloads selected as the first scientific investigations to fly aboard Gateway. The science payloads will help investigators better understand unpredictable space weather from the Sun and galactic cosmic rays from deep space that astronauts and their equipment will encounter.
- The European Space Agency began initial fabrication of the Lunar I-Hab module that will be delivered to and integrated with Gateway on Artemis IV.
- The Canadian Space Agency is in the fabrication phase for Candarm3 advanced robotics.
- SpaceX and Gateway's Deep Space Logistics are working toward a systems requirements review after receiving authority to proceed in December 2023.

Mars Campaign Office

The Mars Campaign Office (MCO) oversees a portfolio of technology development projects that enable sustained human lunar surface exploration and are extensible to the human exploration of Mars. Early investment in these exploration-critical areas reduces mission risk while leveraging partner capabilities and lowering life-cycle costs for future sustained lunar and Mars missions. In FY 2024, these projects continued to advance human exploration technologies through a combination of ground and low Earth orbit testing.

- **MCO Carbon Dioxide Removal System:** In January, the Thermal Amine Swingbed (TAS) controller upgrade was completed, enabling 100 percent of the International Space Station carbon dioxide removal for nominal seven-crew operations to be performed by the combined TAS and Four-bed Carbon Dioxide (4BCO2) removal system. The TAS is a thermally regenerated solid amine, like those used on the Space Shuttle and demonstrated on Orion, that is smaller than the legacy systems and less prone to creating dust that fouled the legacy Carbon Dioxide Removal Assembly (CDRA) on the space station. The 4BCO2 system is an evolution of the CDRA that contains upgraded beds with material less susceptible to dusting, more robust air valves, improved heater design, and new blower that is sized to improve performance and is optimized for four-crew removal.
- **Autonomous Satellite Technology for Resilient Application (ASTRA):** The ASTRA hardware and software payload was launched with host Sidus Space's Lizzie Sat-1 (LS-1) satellite on March 6. After completion of LS-1's primary objectives, the ASTRA flight software autonomously operated targeted mission objectives and continues to monitor the health of the satellite's power and guidance, navigation, and control systems via a vehicle system manager. ASTRA will continue to provide system health data to the LS-1 satellite flight team for the remainder of the vehicle life.

- **Miniaturized Intravenous Fluid Generation (IVGen Mini):** The team completed manufacturing and assembly of the first engineering prototype for the IVGen Mini and began initial ground testing. IV fluids are used to treat 37 of 120 targeted spaceflight conditions, but IV fluids expire approximately 16 months from manufacture date. The IVGen Mini is a small space-rated device that will generate medical-grade IV fluids on a "just-in-time" basis using potable water already on board the spacecraft, which will ensure the availability of treatments during long-duration missions to Mars and reduce the mass and volume of the integrated medical system.
- **Trash Compaction and Processing System (TCPS):** The TCPS reduces trash volume by 70 percent, safens the trash, has over 95 percent water recovery, and produces tiles for easy storage (radiation shielding) or jettison. In FY 2024, the team completed the manufacturing and assembly of the engineering development unit and began benchtop characterization and integrated testing.
- **Crop Production and Monitoring:** Assembly was completed on the Ohalo engineering development unit. Ohalo is a test rig for the evaluation of crop production systems and technologies in microgravity that will initially serve as a platform for the evaluation of water delivery and volume optimization concepts that operate independently from gravity. Due to its modular design, Ohalo can also serve as a test platform for new plant growth technologies for items such as hyperspectral imagers, advanced plant sensors, robotic aids, and automation controls. Initial interface testing of Ohalo, with two plant nutrition delivery system prototypes developed by Utah State University and Sierra Space under the Ohalo grants activity, occurred in spring 2024.

International Space Station

The International Space Station (ISS) has evolved into an advanced microgravity laboratory for human space operations and science over the last two decades. The ISS offers researchers worldwide the opportunity to utilize the unique environmental conditions of low Earth orbit (LEO), supporting hundreds of experiments across every major scientific field at any given time. With over 23 years of research and nearly 4,000 experiments hosted aboard the ISS, now more than ever discoveries and developments are taking shape. The ISS's ability to foster research has aided in the growing commercial space economy, allowing new players to enter the space marketplace and launching flourishing businesses back on Earth.

In FY 2024, Commercial Resupply Services (CRS) flights from Northrop Grumman and SpaceX supported five cargo flights to the ISS, delivering over 37,000 pounds of science investigations, hardware, and critical supplies. Also in FY 2024, Northrop Grumman's Cygnus spacecraft continued to provide station reboosts. This function provides added capability and redundancy, working in concert with Russian propulsion systems that provide attitude control during a reboost.

Additional cargo missions were completed by NASA's partners. Roscosmos provided four Progress cargo missions of nearly 12 tons of food, fuel, and supplies. Significant experiments and equipment were returned to Earth by the SpaceX Dragon capsule, while the Northrop Grumman Cygnus and Progress spacecraft provided significant assistance as trash removal mechanisms by performing a destructive reentry. These resupply missions enabled ISS crewmembers to support research, maintenance, and other operational tasks.

Expedition 70 began near the beginning of FY 2024 with NASA astronauts Loral O'Hara and Jasmin Moghbeli, European Space Agency (ESA) astronaut Andreas Mogensen; Japan Aerospace Exploration Agency (JAXA) astronaut Satoshi Furukawa; and Roscosmos cosmonauts Oleg Kononenko, Nikolai Chub, and Konstantin Borisov; they transitioned to Expedition 71 in April 2024 with the undocking of the Soyuz 70S spacecraft. The Soyuz 70S vehicle returned NASA astronaut Loral O'Hara, Roscosmos cosmonaut Oleg Novitskiy, and spaceflight participant Marina Vasilevskaya of Belarus. O'Hara completed approximately 3,264 orbits of Earth and a journey of more than 86.5 million miles. She worked on scientific activities aboard the space station, including investigating heart health, cancer treatments, and space manufacturing techniques during her stay aboard the orbiting laboratory.

The Expedition 71 crew included NASA astronauts Michael Barratt, Matthew Dominick, Tracy Dyson, and Jeannette Epps, as well as Roscosmos cosmonauts Nikolai Chub and Oleg Kononenko. Dominick, Barratt, Epps, and Alexander Grebenkin arrived at the station on the SpaceX Dragon Endeavour spacecraft as part of the Crew-8 mission. Expedition 70

crewmembers (Moghbeli, Mogensen, Satoshi, and Borisov) returned to Earth on SpaceX Dragon Endurance, ending the Crew-7 team's mission.

Joining Expedition 71 were NASA astronauts Butch Wilmore and Suni Williams. They arrived on Boeing's Starliner spacecraft and successfully docked to the ISS on June 6. Starliner launched on a United Launch Alliance Atlas V rocket from Space Launch Complex-41 at Cape Canaveral Space Force Station in Florida. However, NASA and Boeing identified helium leaks and experienced issues with the spacecraft reaction control thrusters as Starliner approached the space station. For several months after docking, engineering teams collected data, conducted flight and ground testing, hosted independent reviews with agency propulsion experts, and developed various return contingency plans. The uncertainty and lack of expert concurrence did not meet the Agency's safety and performance requirements for human spaceflight, thus prompting NASA leadership to move the astronauts to return on the Crew-9 mission. The Starliner spacecraft departed from the station on September 6, 2024, and landed several hours later at White Sands Space Harbor in New Mexico.

Expedition 71 completed in September 2024 upon the departure of Soyuz 71S. Spanning 184 days in space, NASA astronaut Tracy C. Dyson's mission included covering 2,944 orbits of Earth and a journey of 78 million miles. Roscosmos cosmonauts Nikolai Chub and Oleg Kononenko, who launched with Laurel O'Hara to the station in 2023, returned after 374 days in space and a trip of 158.6 million miles, spanning 5,984 orbits.

In FY 2024, there were a total of four spacewalks supported by the onboard crew and ground teams, two of which were U.S. extravehicular activities (EVAs). On the first U.S. EVA in November, Moghbeli and O'Hara were able to complete one of the spacewalk's two major objectives, replacing one of the 12 trundle bearing assemblies on the port solar alpha rotary joint, which allows the arrays to track the Sun and generate electricity to power the station. Mission Control told the station crew that the solar array was functioning well after the bearing replacement. Spacewalkers also removed a handling bar fixture to prepare for future installation of a roll-out solar array and properly configured a cable that was previously interfering with an external camera. The next U.S. spacewalk was scheduled to occur on June 13, 2024, but was postponed before egress due to crewmember suit discomfort.

The second U.S. EVA was scheduled to occur on June 24, 2024, with NASA astronauts Tracy C. Dyson and Mike Barratt, with the primary intention to complete the removal of a faulty electronics box, called a radio frequency group, from a communications antenna on the starboard truss of the space station. However, the activity ended early due to a water leak in the service and cooling umbilical unit on Dyson's spacesuit. The spacewalk lasted a total of 31 minutes.

The two spacewalks on the ISS's Russian Segment tackled a variety of objectives, including inspection and photography of an external backup radiator on the Nauka multipurpose

laboratory module, as well as isolating the radiator from Nauka's cooling system. Additional work included completing the deployment of one panel on a synthetic radar communications system on the Russian segment of the complex and installing equipment and experiments to analyze the level of corrosion on station surfaces and modules.

The ISS National Laboratory continued to fly science experiments, technology demonstrations, and education programs for the benefit of humanity. In FY 2024, the Center for the Advancement of Science in Space (CASIS), managers of the ISS National Lab, in partnership with NASA's Biological and Physical Sciences Division, announced the winners of the Igniting Innovations solicitation. Five projects were selected, all addressing the goals of the Cancer Moonshot initiative and accelerating the translation of stem cell and organoid-based disease models. Dr. Catriona Jamieson from the University of California, San Diego, will develop an experiment aiming to use patient-derived tumor organoids to study accelerated cancer development in microgravity and identify new cancer therapeutic targets; results could lead to new treatments that target evasive cancer stem cells to prevent cancer recurrence. Dr. Arum Sharma of Cedar-Sinai Medical Center will grow cardiac spheroids with blood vessels in space for cardiovascular disease modeling and to test how cancer drugs affect the heart. Mari Anne Snow from Eascra Biotech and Yupeng Chen from the University of Connecticut seek to produce cancer therapeutics in space using Janus base nanomaterials (JBNs) designed to target drug delivery to solid tumors, improving cancer treatment and reducing side effects. This would allow JBNs to carry larger amounts of drugs for more effective treatment. Dr. Shay Soker from Wake Forest University Health Science plans to use organoids created from cells recovered from colorectal cancer patients to see if chemotherapy works better in space, offering insight into improved chemotherapies. Results from this project could also lead to personalized cancer treatment. And finally, Dr. Cassian Yee from the University of Texas MD Anderson Cancer Center will use microgravity to better understand how T cells work in order to develop new immunotherapy treatments for patients with cancer and autoimmune diseases.

In FY 2024, the investigation Flawless Space Fiber by Flawless Photonics manufactured more than seven miles of optical fiber over a one-month period. The investigation produced more than 2,200 feet in one day, surpassing the previous record of 82 feet. This demonstrates that commercial lengths of fiber can be produced in space. These fibers, made of ZBLAN, could translate into significant energy savings by reducing the need to boost signals on long-distance transmissions. In FY 2024, the ISS National Laboratory continued to host one of the most successful ISS Research and Development Conferences in Boston, Massachusetts, with 936 registrants.

Commercial Space Division

Commercial LEO Development Program

NASA's Commercial LEO Development Program was established with the goal to facilitate the development of commercially owned and operated LEO destinations in which NASA is one of many customers. NASA has been executing on this goal since 2020 with a two-phase strategy. Currently, Phase 1 agreements include several commercial LEO destination (CLD) providers for early design and development of CLDs. The two partners under a funded Space Act Agreement (SAA) and the one partner under a firm-fixed-price contract have successfully achieved their respective milestones for FY 2024. CLDP has also provided technical expertise, lessons learned, and data to several unfunded SAAs. Through all of these industry partnerships, NASA continued to advance the development of CLDs.

Commercial Crew Program

NASA's Commercial Crew Program (CCP) enables NASA to maximize the use of the ISS, where astronauts have lived and worked continuously since the year 2000. The CCP and our International Partners provide a critical function of transporting crews, cargo, and supplies to and from the ISS for a typical mission duration of approximately six months. The first goal of NASA's CCP is to facilitate U.S. private industry development of safe, reliable, and cost-effective human space transportation to and from LEO and the ISS for use by the U.S. Government and other customers. The second goal of the CCP is to enable the purchase by NASA of commercial services to meet the agency's ISS crew transportation needs once the capability is matured and certified.

During FY 2024, NASA's CCP and partners continued flying ISS crew rotation missions and conducted a crewed demonstration flight to and from the ISS.

As described in the previous section, in FY 2024, NASA's CCP partner SpaceX flew two operational crew rotation flights to and from the ISS.

The eighth operational mission of SpaceX (Crew-8) in the CCP launched on March 4, 2024, and will return to Earth early in October 2024.

Following Crew-8's successful docking to the ISS, SpaceX's Crew-7 mission concluded with a successful landing on March 12, 2024.

The SpaceX Crew-9 mission launched on September 28, 2024, transporting one NASA astronaut and one Russian cosmonaut. The remaining two empty seats will be used by the Boeing Crew Flight Test (CFT) members as their return flight to Earth at the end of the Crew-9 mission.

NASA CCP's partner, Boeing, successfully launched their CFT on June 5, 2024. CFT was the first crewed flight of Boeing's Starliner Commercial Transportation System. The Starliner

remained docked at the orbiting laboratory until September 6, 2024, before returning to Earth. Due to various technical problems experienced during the test flight, NASA determined that the original crew would not return to Earth on Starliner but would remain aboard the ISS and will return on the Crew-9 mission.

Launch Services Office

In FY 2024, NASA's Launch Services Office (LSO) successfully launched two NASA science missions and a weather satellite for the National Oceanic and Atmospheric Administration (NOAA). The Psyche spacecraft launched aboard a Falcon Heavy from Kennedy Space Center (KSC) in October 2023. The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite launched aboard a Falcon 9 from Cape Canaveral Space Force Station (CCSFS) in February 2024. In June 2024, NOAA's fourth and final satellite in the Geostationary Operational Environmental Satellites (GOES)–R Series (GOES-U) launched aboard a Falcon Heavy from KSC. In addition to launching NASA's science and weather satellites, LSO acquired one new launch service for NASA's Science Mission Directorate (SMD) and one new launch service for NOAA. The launch service for the Compton Spectrometer and Imager (COSI) mission will launch aboard a Falcon 9 rocket from CCSFS in Florida in August 2027. The launch service for NOAA's Joint Polar Satellite System (JPSS) 4 mission will launch aboard a Falcon 9 rocket from Vandenberg Space Force Base (VSFB) in California. Both services were awarded in July 2024 and are competitively awarded Launch Services Task Orders under the NASA Launch Services II contract.

Along with full end-to-end launch service management, the program also offers advisory support, expertise, and knowledge to NASA programs and projects utilizing launch services not procured and managed by LSO. In FY 2024, the program provided these advisory services to several programs and missions, including the ISS Cargo Resupply Services missions, the Commercial Crew Program (CCP), Artemis, and Gateway Programs, and SMD's NASA–Indian Space Research Organisation (ISRO) Synthetic Aperture Radar (NISAR) mission.

In addition, under the Venture-Class Acquisition of Dedicated and Rideshare (VADR) launch service contract, LSO provides a broad range of commercial launch services capable of delivering NASA's high-risk-tolerant payloads ranging from Class D payloads to higher-risk-tolerant payloads, including CubeSats, to a variety of orbits. These Class D and small satellite payloads, carried on Federal Aviation Administration (FAA)–licensed launches, tolerate relatively high risk and serve as an ideal platform for technical and architecture innovation, contributing to NASA's science research and technology development in addition to fostering a growing U.S. commercial launch market. In FY 2024, the Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE) Mission 1 successfully launched atop Rocket Lab's Electron rocket in May 2024, followed by PREFIRE Mission 2 in June 2024. Both spacecraft launched

from Rocket Lab's Launch Complex 1 in Māhia, New Zealand. In July 2024, a collection of eight CubeSats launched under the Venture Class Demonstration (Demo) 2 contract as part of NASA's Educational Launch of Nanosatellites (ELaNa) 43 mission. The CubeSats were lifted off aboard Firefly's Alpha rocket from VSFB in July 2024. This was the final mission under the VCLS Demo-2 contract. LSO also acquired one new NOAA VADR Class D launch service through a competitively awarded VADR launch service task order. In September 2024, NASA selected Firefly Aerospace, Inc., to provide a VADR launch service for the QuickSounder mission. QuickSounder will launch aboard Firefly's Alpha rocket from VSFB in February 2026. In August 2024, LSO added three new companies to the VADR contract: Arrow Science and Technology LLC of Webster, Texas; Impulse Space, Inc., of Redondo Beach, California; and Momentus Space LLC of San Jose, California. There are currently 14 companies providing launch services for VADR missions.

NASA and LSO continue to partner with academic institutions, nonprofits, and NASA centers to launch small research satellites through the CubeSat Launch Initiative (CSLI). As of the end of FY 2024, 165 CubeSats from 38 states, the District of Columbia, and Puerto Rico have been launched successfully, with 50 CSLI-sponsored CubeSats preparing for upcoming launches on NASA, other U.S. agency, and commercial missions. In FY 2024, 17 CSLI-sponsored CubeSats were launched.

In May 2024, Firefly's Alpha launch vehicle completed Category 1 certification. Launch Vehicle certification activities are currently ongoing with United Launch Alliance's Vulcan category 2/3 certification and Blue Origin's New Glenn category 1 certification ahead of the Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) launch.

Human Spaceflight Capabilities

Human Research Program

NASA's Human Research Program (HRP) conducts ground- and space-based research to ensure that astronauts are adequately protected from the hazards of spaceflight. Over the last year, HRP has achieved high-impact results to address the human health and performance risks identified by the Moon to Mars Program and those identified by the Office of the Chief Health and Medical Officer. In addition to conducting studies on the physiological and psychological risks of spaceflight and testing countermeasures to protect crewmembers from those risks, HRP developed collaborations with universities, the commercial space industry, the U.S. Government, and International Partners to leverage its research funding and accelerate risk mitigation development to enable space exploration.

In FY 2024, HRP continued operations of the most complex human research study ever performed on the ISS—the Complement of Integrated Protocols for Human Exploration

Research (CIPHER) study. Through CIPHER, astronauts participate in an integrated set of 14 studies sponsored by NASA and International Partner agencies. CIPHER investigators then integrate data across all the studies, and those data will be evaluated to identify patterns and gain a deeper understanding of how the human body reacts to long durations in space. Astronauts flying both six-month missions and yearlong missions can sign up to participate, and these different durations will provide longitudinal physiological and psychological response curves to inform future Mars Crew Health and Performance systems. So far, six astronauts have consented to CIPHER since the study began.

Three 45-day simulated missions within the Human Exploration Research Analog (HERA) occurred during FY 2024. These missions simulated a journey to Mars and back, as well as the isolation, confinement, and remote conditions that future crews may experience on long journeys to the Moon or Mars. The HERA missions included 18 human health and performance studies that aimed to assess team conduct, dynamics, and behavioral health, as well as how crew members perform with limited privacy, among other research questions. They also explored the effects of crew autonomy on performance and behavior and tested how well tools and technologies supported crews' independence from mission control on Earth. Ten studies are new to HERA, including seven led by scientists outside the United States. These international studies are collaborations with the United Arab Emirates' Mohammed Bin Rashid Space Centre and ESA. The HERA mission that egressed on June 24 notably included one crewmember from the United Arab Emirates, a first for this analog. Furthermore, each crewmember on that mission hailed from a different cultural background, thus allowing for the understanding of multicultural team dynamics.

HRP collaborated with the Naval Medical Research Unit Dayton (NAMRU-D) to use the Navy's Disorientation Research Device, better known as the "Kraken," for a study on space motion sickness. The collaboration also has significant Johnson Space Center (JSC) Flight Operations Directorate involvement since the Kraken is being considered for use as an astronaut motion-based landing trainer. Study participants were spun at 2.5 G for about an hour. Kraken, which is housed at Wright-Patterson Air Force Base in Ohio, can perform as a centrifuge and a multi-degree-of-freedom motion base simulator. Investigators strategically recruited candidates to achieve equal participation by men and women for the study. The goal of this experiment is to assess whether specific head motions performed after disorientation can alleviate symptoms of dizziness, nausea, and/or vertigo.

HRP also continued an international collaboration with the Deutsches Zentrum für Luft-und Raumfahrt (DLR; German Aerospace Center) through the :envihab (Environment and Habitat) Facility in Cologne, Germany. A new set of studies, which began at the end of FY 2024, is conducting a series of 60-day strict head-down tilt bed rest campaigns to investigate potential interventions to address sensorimotor disorientation due to altered gravity.

Research continued this year at the National Science Foundation's Antarctic base at Palmer Station to evaluate a suite of immune countermeasures to mitigate the negative effects of isolation and confinement on human immune system functionality. The Antarctic location is ideal for this work because an earlier validation study demonstrated similar immune dysfunction between long-duration astronauts and Antarctic winter-over participants. Two HRP studies were also carried out at Amundsen-Scott South Pole Station: one focused on whether virtual reality eases the stress of isolation and confinement, and the other examined team problem-solving dynamics in operational settings.

HRP's 2024 Investigators' Workshop (IWS)—the primary venue for reporting progress and results on research aimed at ensuring safe, productive, and efficient human spaceflight—has grown significantly year over year. As compared to the 2023 IWS, the latest workshop offered more presentations, attracted the participation of more countries, and accrued a greater number of registrants overall. At the 2024 IWS, HRP also initiated new award/guest lecture series and collaborated with the Minority University Research and Education Project (MUREP) to award four undergraduate students with travel grants. Science highlights of the workshop spanned a variety of topics, including assessments of blood clot risk during parabolic flight, the development of a portable sensorimotor disorientation ground analog, the use of AI to identify Spaceflight Acute Neuro-Ocular Syndrome, research indicating that ionizing radiation on Mars missions likely will not adversely affect drug degradation, and new insights into whether lunar dust can be considered an allergen.

HRP awarded funds for 11 new NASA studies to better understand how to best support the health and performance of crewmembers during long-duration spaceflight missions. Together, the studies will help measure physiological and psychological responses to physical and mental challenges that astronauts may encounter during spaceflight. The projects will address numerous spaceflight risks related to team performance, communication, living environment, decision making, blood flow, and brain health. With this information, NASA will better mitigate risks and protect astronaut health and performance during future long-duration missions to the Moon, to Mars, and beyond. The 11 finalists were selected from 123 proposals in response to the 2024 Human Exploration Research Opportunities available through the NASA Solicitation and Proposal Integrated Review and Evaluation System. Selected proposals originate from ten institutions, and the cumulative award totals about $14.6 million. The durations of the projects range from one to five years.

Between February and July, 25 participants from 10 countries participated in the Space Health Impacts for the NASA Experience (SHINE) program. SHINE is a joint effort between Johnson Space Center and Ames Research Center to train early career scientists, senior researchers, and principal investigators in HRP's science aspects and NASA's risk management strategies focused on human health in space. In FY 2024, SHINE offered a weekly didactic

curriculum focused on space radiation and navigating HRP's funding structures. An in-person practicum at NASA's Space Radiation Laboratory is scheduled for early FY 2025.

HRP also coordinated with commercial partners to fly science experiments on Polaris Dawn—a private crewed spaceflight operated by SpaceX on behalf of Shift4 CEO Jared Isaacman that launched and returned in late FY 2024. In one experiment, Polaris Dawn crew test-drove a commercial device that collects and integrates measurements of health, including blood pressure, heart rate, respiration rate, and temperature. The technology also provides ultrasound imaging, including an experimental telemedicine feature that could help diagnose future crewmembers in near-real time. Another experiment focused on understanding and preventing the motion sickness symptoms that many astronauts experience in space. Participating crewmembers described their motion sickness symptoms, what interventions they tried to alleviate their symptoms, and whether any approaches helped. Crewmembers also participated in a variety of other health studies on behalf of the NASA-funded Translational Research Institute for Space Health (TRISH), a consortium with various academic institutions. As part of that work, the Polaris Dawn mission helped set a new baseline for collecting standard health data on commercial spaceflights, creating a complement to the datasets routinely collected from NASA astronauts and missions.

Rocket Propulsion Test

The Rocket Propulsion Test (RPT) Capability Portfolio Program is responsible for strategic management and sustainment of NASA's expertise and facilities for testing rocket engines.

In 2024, RPT test facilities continued to provide reliable and timely support to NASA, commercial, defense, and NASA International Space Partner requirements for purposes of component, engine, and rocket-stage testing. RPT delivered test capabilities to support technology advancement, capability demonstration, risk retirement, hardware qualification, and launch readiness for more than 400 tests (over 14,000 seconds). RPT placed priority on testing rocket engines and components for NASA and its collaborative commercial partners for the Artemis Program in 2024.

At Stennis Space Center (SSC) in Mississippi, the final round of 12 hot fire certification tests on the newly redesigned SLS RS-25 engine were completed in the A-1 Test Stand. Roughly 70 percent of the components on this engine were upgraded, and the successful completion of this testing enabled production of new engines for use on Artemis V and subsequent missions. The SSC B-2 Stand continues to be readied to support green-run stage testing and checkout of the Exploration Upper Stage (EUS) prior to its debut on the Artemis IV mission. Test activity in the E-Complex at SSC, a versatile multi-user complex for development testing, continues to be very active in support a variety of commercial engine, turbo-pump, thruster, and component test requirements.

At Marshall Space Flight Center (MSFC) in Alabama, testing supported both NASA internal, commercial reimbursable, and NASA collaborative projects with industry. MSFC supported testing of new innovative designs and new additive manufacturing techniques for engines and components, including rocket nozzles that both are easier to manufacture and provide better performance. In 2024, MSFC conducted testing in evaluation of liquid rocket engines for landers, on-orbit stages, and spacecraft.

At White Sands Test Facility (WSTF) in New Mexico, testing supported NASA, commercial, and defense customers with hot firings, acceptance testing, and qualification of thrusters and thruster system components. One notable unplanned activity deserving of recognition is the critical testing that supported on-orbit flight anomaly resolution of Reaction Control System issues experienced on the Crewed Flight Test (CFT) of the Boeing CST-100 Starliner Service Module. Beyond a busy schedule of other hot fire testing in ambient and simulated altitudes, other work included risk evaluation for NASA's Gateway program regarding in-space freezing of vented propellant (or propellant simulant) and the demilitarization (rendering safe) of old/inert Minuteman III propulsion systems. To relieve schedule conflicts and support customer demand, work to reactivate Test Stand 405 was conducted.

At Glenn Research Center's Armstrong Test Facility in Ohio, the Sierra Space Dream Chaser Cargo System (DCCS) completed thermal vacuum qualification testing in the In-Space Propulsion Facility (ISPF) prior to shipment to KSC as part of NASA's efforts to expand commercial resupply in low Earth orbit.

Space Communications and Navigation

NASA's Space Communications and Navigation (SCaN) Program is the backbone of NASA's space communications infrastructure, providing essential services to over 100 missions, both within and beyond our solar system. SCaN oversees two critical networks: the Deep Space Network (DSN) and the Near Space Network (NSN). Together, they enable groundbreaking missions such as relaying commands to spacecraft, transmitting spectacular images from the James Webb Space Telescope (JWST), receiving data from the Voyager spacecraft currently in interstellar space, and supporting communications for astronauts aboard the ISS.

Beyond operations, SCaN is NASA's leading authority on spectrum management, ensuring secure and efficient communication across national and international platforms. The program actively supports future missions by planning and integrating new capabilities, fostering commercial partnerships, and developing the next generation of communication and navigation technologies.

In FY 2024, SCaN continued to deliver reliable, resilient communications, surpassing network proficiency requirements (95 percent), with both the DSN and NSN achieving

99 percent performance. Key efforts included demonstrating optical communications to dramatically boost data speeds for both robotic and crewed missions, including those for Artemis.

SCaN expanded its capability by completing the lunar upgrade of Deep Space Station 34 (DSS-34), a 34-meter antenna, adding uplink and downlink capabilities across multiple frequency bands. The program also strengthened its international partnerships by making significant progress on the Lunar Exploration Ground Sites (LEGS) infrastructure, which is dedicated to supporting the high demands of future lunar missions, by selecting a site location in Australia and signing an international agreement with the government of South Africa.

In its commitment to commercial collaboration, SCaN awarded contracts to Intuitive Machines and Aalyria Technologies to explore innovative lunar communication solutions. This included a dual-purpose navigation and communication lunar surface terminal and advancements in Network Orchestration and Management Systems to integrate services across multiple commercial and governmental networks. NASA also awarded Intuitive Machines a contract to provide lunar relay services as part of the NSN. This firm-fixed-price contract will play an essential role in NASA's Artemis campaign by providing communication and navigation services for lunar exploration, including missions to the Moon's South Pole. These relays will enhance landing opportunities and ensure vital communication coverage, reducing reliance on the DSN and expanding the NSN's capabilities for future lunar missions.

The Communications Services Project (CSP) achieved significant progress toward demonstrating commercial space-relay communications services through its Funded Space Act Agreements with six industry partners. Key highlights include demonstrations of optical laser communications during the SpaceX Polaris Dawn mission and between two Amazon Project Kuiper prototype satellites. The CSP continues to define service requirements that will lead to a future service acquisition and validation campaign resulting in the delivery of operational services to the NASA NSN in 2031.

SCaN supported significant scientific and exploration milestones, partnering with NASA's Space Technology Mission Directorate (STMD) and the Jet Propulsion Laboratory (JPL) for the launch of the Deep Space Optical Communications (DSOC) payload aboard the Psyche mission in October 2023. DSOC achieved historic milestones, including the transmission of a laser signal from 290 million miles away, the farthest laser communication ever recorded, and a sustained data rate of 6.25 megabits per second while 240 million miles from Earth.

The program also launched the Integrated Laser Communication Relay Demonstration (LCRD) Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) payload on November 9, 2023, enhancing optical communications for the ISS by establishing a relay link with NASA's LCRD, pushing the boundaries of data transmission in low Earth orbit.

SCaN played an influential role in shaping the future of space communications policy in FY 2024. The program engaged in national and international forums, including spectrum

policy negotiations and participation in the World Radiocommunication Conference (WRC-23). SCaN also spearheaded the complex negotiation process with the Kingdom of Spain to renew the government-to-government treaty for the continued operation of the DSN site in Madrid, a critical component of NASA's deep space communications infrastructure. In this effort, SCaN collaborated closely with NASA's Office of the General Counsel and the Office of International and Interagency Relations to ensure the successful renewal of the treaty, securing future support for NASA's deep space missions.

As part of its global leadership, SCaN organized the Interoperability Plenary (IOP), a gathering of 15 international space agencies to address key topics such as space communication commercialization and lunar communication. The NASA delegation to the 16th meeting of United Nations (UN) International Committee on Global Navigation Satellite Systems (GNSS) (ICG) was led by SCaN.

In summary, NASA's SCaN program is a critical enabler for every NASA mission, from human exploration to robotic scientific discovery. Its commitment to innovation, international collaboration, and the advancement of communication technologies ensures NASA's continued leadership in space exploration. SCaN's vision of one team, one mission, one network remains a guiding principle, positioning NASA to meet the challenges of tomorrow's space missions.

Science Mission Directorate

In FY 2024, NASA's Science Mission Directorate (SMD) managed over 125 missions across its five divisions: Astrophysics, Biological and Physical Sciences, Earth Science, Heliophysics, and Planetary Science. Astrophysics missions further our understanding of the universe and our place in it, including searching for other Earth-like planets capable of supporting life. Space biology research helps scientists understand the effects of microgravity, radiation, and other spaceflight stressors on living systems, while physical science research enables scientists to understand the novel behaviors of physical phenomena in space, such as quantum physics, fluids, materials and combustion. Earth Science missions study Earth as a system to advance scientific understanding of our home planet, support stronger economies, and study environmental changes. Heliophysics missions study the Sun and how its activity affects Earth and interplanetary space, while Planetary Science missions advance our knowledge of the origins and history of our solar system, identify the potential for life beyond our own planet, increase the body of knowledge necessary for humans to explore beyond low Earth orbit, and assess threats to our planet from the impact of near-Earth objects. In addition to these divisions, SMD is home to the Exploration Science Strategy and Integration Office (ESSIO), the Joint Agency Satellite Division (JASD), and the Mars Sample Return (MSR) Program Office.

SMD includes programs and opportunities for engagement and involvement with our science mission. The Science Activation program leverages unique science infrastructure, content, and experts to engage learners of all ages with NASA science. In FY 2024, 66 million learning interactions were reported for the April total solar eclipse alone! Working with community-based institutions such as libraries, museums, science centers, and planetariums, the Science Activation program continued its work in FY 2024 through 37 competitively selected cooperative agreements, adding more than 60 new partners and 200 partner subject matter experts (SMEs) for a total of over 590 partners and 963 partner SMEs in all 50 states, territories, and the District of Columbia. Additionally, SMD's Citizen Science Initiative has 30 active projects that harness the energies of the public and use the rigors of science to create new discoveries. In FY 2024, NASA citizen scientists were coauthors on more than 30 peer-reviewed scientific publications—for a total of 519 citizen science coauthors since the beginning of the initiative.

Astrophysics

The Astrophysics Division is dedicated to exploring the universe. It seeks to address how the universe works through the studies that probe the nature of black holes, dark energy, dark matter, and gravity; explore the origin and evolution of the galaxies, stars, and planets that make up our universe; and discover and study planets around other stars and investigate whether they could harbor life. Below are significant highlights from FY 2024.

Roman Space Telescope Ready for Integration

The Nancy Grace Roman Space Telescope (Roman) is on track to be launched in FY 2027. The mission aims to help astronomers better understand the nature of dark energy and dark matter, as well as the diversity of exoplanets. In FY 2024, most major hardware elements were completed and delivered to Goddard Space Flight Center (GSFC). In May, NASA's Jet Propulsion Laboratory (JPL) successfully delivered the Coronagraph Imager instrument, after completing all functional and environmental testing, to demonstrate that its performance meets or exceeds requirements. BAE Systems successfully delivered the Wide Field Instrument in August after completing all testing, demonstrating excellent optical performance and validating all requirements. Engineers at L3Harris performed the first optical tests of the telescope at ambient temperature and pressure, achieving first light. The team was performing thermal vacuum testing at the end of FY 2024. The team at GSFC completed the spacecraft bus in September. The project made significant progress on science preparations for Roman during the year as well. At the beginning of the year, the newly selected science teams formally began their work in preparing for the testing of the full data processing and analysis pipelines with the Science Operations Center and Science Support Center. To support the observations, the Roman project has formed a set of Core Community Survey definition committees to engage with the community to maximize overall science return; their preliminary survey designs are due in November. Following an advisory committee recommendation, NASA has chosen a Galactic Plane Survey as Roman's first General Astrophysics Survey, in addition to the three major surveys determined by the National Academies of Sciences, Engineering, and Medicine's Decadal Survey in 2010. In July 2024, NASA's Office of Inspector General reported positively on the progress of Roman. At the end of September, Roman passed its Systems Integration Review and is now ready to proceed to the integration phase before launch.

Hubble Space Telescope Continues to Produce New Discoveries

Hubble continues to deliver scientific return and demand, as indicated by 930 proposals from 3,560 unique investigators from 51 countries and 44 states submitted in 2024. Hubble and the Transiting Exoplanet Survey Satellite (TESS), working together, detected the nearest Earth-sized exoplanet that passes across the face of a neighboring star. This alignment, called a transit, opens the door to follow-on studies to see what kind of atmosphere, if any, the rocky world might have. With only 1.07 times Earth's diameter, the planet is a rocky world, with approximately the same surface gravity as Earth; but with a surface temperature of roughly 500 degrees Fahrenheit, it is too hot for life as we know it. Astronomers using the Hubble Space Telescope have found more black holes than expected in the early universe. Astronomers searched multiple images in the survey field of the landmark Hubble Ultra Deep Field, making use of Hubble's incredible archive and timeline. By comparing Hubble Wide Field Camera 3

near-infrared exposures taken in 2009, 2012, and 2023, astronomers found evidence for flickering supermassive black holes in the hearts of early galaxies. The new observational results suggest that some black holes likely formed by the collapse of massive, pristine stars during the first billion years of cosmic time.

James Webb Space Telescope's 1,000th day in space

The James Webb Space Telescope (Webb) celebrated its 1,000th day in space in FY 2024 and has continued its groundbreaking observations. In the most recent Space Telescope Science Institute proposal cycle, Webb set a record by receiving over 1,900 unique proposals from investigators across the world. This is evidence of the immense impact Webb has had, and will continue to have, on the science community across various disciplines. For instance, in a new study of the Serpens Nebula, Webb has resolved what previously appeared as blurry blobs into crisp protostellar outflows. And much to researchers' surprise, those outflows are seen to be aligned, suggesting that we caught this region at a unique moment in its history and providing information into the fundamentals of how stars are born. Webb was designed to seek out the first stars and galaxies in the universe. After just two years of observations, astronomers have used Webb to find the most distant galaxy ever observed. This galaxy formed a mere 290 million years after the Big Bang. Additionally, Webb data reveal that the early universe has many more supermassive black holes than previously expected. Their presence is testing theories about how they formed and how the seeds needed to create them came into existence. Since Webb has found so many galaxies that formed 500 million years after the Big Bang, astronomers can trace the buildup of elements across cosmic time as these galaxies reionized the intergalactic medium.

SPHEREx Completes Critical Testing Milestones

The Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer (SPHEREx) mission, planned for launch in 2025 from the Vandenberg Space Force Base (VSFB), was built to address three central questions in astrophysics: how did the universe begin, how did galaxies begin, and what are the conditions for life outside the solar system? In FY 2024, the SPHEREx payload flight hardware, including the telescope and detectors, was assembled and tested, with results that met or exceeded the science requirements for the SPHEREx mission. Subsequently, the SPHEREx payload and spacecraft bus were mated together into the flight observatory and successfully completed space environmental testing during the spring and summer of 2024, thus readying the mission for final preparations in the upcoming launch year.

Biological and Physical Sciences

The Biological and Physical Sciences Division (BPS) has a twofold mission: 1) to enable deep-space human exploration missions by better understanding how living and physical systems respond to the harsh conditions of space, and 2) to pioneer scientific discovery in ways that cannot be done on Earth. BPS is seeking to enable and utilize the commercial space industry and has advanced these efforts through the Commercially Enabled Rapid Space Science (CERISS) program. By conducting revolutionary research in extraordinary places, BPS advances fundamental science across a range of disciplines. Below are significant highlights from FY 2024.

First NASA-Funded Researcher to Fly on Suborbital Rocket

In August 2024, BPS-funded researcher Rob Ferl, plant biologist with the University of Florida, flew on Blue Origin's New Shepherd 26 mission. This is the first instance of a NASA-funded researcher flying with their experiment on a commercial suborbital vehicle. The experiment was co-funded with NASA's Flight Opportunities Program. Ferl froze plant samples at various stages of the flight while his co-principal investigator, Anna-Lisa Paul, conducted identical ground experiments simultaneously. This research seeks to understand how changes in gravity during spaceflight affect plant biology and could contribute to insights for future space crops.

NASA Demonstrated "Ultra-Cool" Quantum Sensor for the First Time in Space

Members of the Cold Atom Lab science team measured subtle vibrations of the ISS—the first time ultra-cold atoms have been employed to detect changes in the surrounding environment in space. The team made their measurements with a quantum tool called an atom interferometer, which can precisely measure gravity, magnetic fields, and other forces. Scientists and engineers on Earth use this tool to study the fundamental nature of gravity and advance technologies that aid aircraft and ship navigation. The study was featured in an August 2024 *Nature* publication.

Initial Response to 2023–32 Decadal Survey Recommendations

BPS presented its initial response to the National Academies of Sciences, Engineering, and Medicine's "Thriving in Space" Decadal Survey in March 2024 and briefed the Academies on the division's progress in October 2024. The division began developing strategic roadmaps around five key goals that align with the Decadal Survey's Key Science Questions and priority recommendations: Precision Health, Space Crops, Quantum Leaps, Foundations, and Space Labs.

Experiment Data Utilized by Commercial Companies for Exploration Engineering

Data from Zero Boil-off Tank (ZBOT-1) experiments informed improvements to commercial software to better predict fluid behavior for cryogenic propulsion systems. This NASA-sponsored fundamental research is now helping commercial partners who are designing future landing systems for human explorers. Blue Origin and Lockheed Martin, participants in NASA's Human Landing Systems program, are using data from the ZBOT experiments to inform future spacecraft designs.

"Igniting Innovation" Awards and New Solicitation for Using Space to Cure Disease on Earth

In partnership with the ISS National Laboratory, BPS announced the selection of five projects through the inaugural Igniting Innovation solicitation for cancer and other disease-related research and technology development on the space station. The projects, which were announced at the annual ISS Research and Development Conference in Boston in July 2024, will harness the unique microgravity environment to advance cancer research to benefit patients on Earth and support the national Cancer Moonshot initiative. A second round of Igniting Innovation solicitations, which opened in August 2024, is focused on leveraging the space environment to advance ways to prevent, diagnose, and treat diseases such as cancer, cardiovascular disease, and neurodegenerative disease.

Earth Science

Earth is a rapidly changing, interconnected, living planet. The Earth Science Division (ESD) and its partners use unique global observations from space, air, sea, and land, and integrative research activities, to understand natural and human-caused changes to Earth systems. A key goal of the Earth Science Division is to help provide scientific information to benefit life on Earth in areas such as agriculture, water and food security, urban planning, disaster preparedness and response, transportation, air quality, resource management, and many others. ESD delivers the technology, expertise, global observations, and applications that help us map the myriad connections between our planet's vital processes and the ongoing natural and human-caused changes. Below are significant highlights from FY 2024.

Earth System Observatory Missions Pass Key Decision Points

Following guidance from the most recent National Academies of Sciences, Engineering, and Medicine's Decadal Survey, NASA is designing the next generation of integrated Earth missions called the Earth System Observatory (ESO). Each mission delivers critical measurements on its own, but taken together as a single observatory, the ESO delivers unprecedented understanding of our Earth, providing key data to inform decisions on how we address Earth

system change, prepare for and respond to natural hazards, fight and mitigate forest fires, and improve agricultural processes. The first of these missions is a partnership with the Indian Space Research Organisation (ISRO). The NASA-ISRO Synthetic Aperture Radar (NISAR) mission assists planners and decision makers with managing hazards and natural resources. In FY 2024, the Gravity Recovery and Climate Experiment–Continuity (GRACE-C) mission passed Key Decision Point (KDP)-C and is now in implementation, and the Surface Biology and Geology–Thermal Infrared mission passed KDP-B to move forward in formulation. These missions deliver critical measurements such as drought assessment, ice sheet loss, and water-use planning for agriculture, volcanic plumes, surface temperature, and evapotranspiration.

Earth Information Center Opens at the Smithsonian

The Earth Information Center, a physical and virtual space to show people Earth as NASA sees it, continued its physical location at NASA Headquarters and opened its second physical location at the National Museum of Natural History. This center showcases large, breathtaking visualizations, as well as interactive media, stories, and narratives to inspire action. The intent is to stimulate communities to explore solutions and provide opportunities for connecting science to action.

PREFIRE Mission Launches to Understand Earth's Heat Transfer

NASA's Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE) CubeSats launched on May 25, 2024, and June 4, 2024. PREFIRE is helping scientists understand the balance between incoming heat energy from the Sun and the outgoing heat given off at Earth's poles. Specifically, PREFIRE is giving researchers information on where and when far-infrared energy radiates from the Arctic and Antarctic environments into space. The two satellites pass over the same part of Earth at different times of day, giving researchers information on changing conditions and how relatively short-lived phenomena like cloud formation, moisture changes, and ice sheet melt affect far-infrared emissions over time.

PACE Mission Delivers Unprecedented Ocean and Atmospheric Data

NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite, launched February 8, 2024, and its science-quality data became publicly available in April 2024. PACE data are allowing researchers to study microscopic life in the ocean and particles in the air, advancing understanding of issues including ocean/atmosphere interactions, fisheries' health, harmful algal blooms, air pollution, and wildfire smoke.[1] Using PACE's Ocean Color Instrument, scientists can identify specific communities of phytoplankton that play different roles in marine

1 See https://science.nasa.gov/earth/oceans/early-adopters-of-nasas-pace-data-to-study-air-quality-ocean-health/.

ecosystems.[2] Most are benign, but some are harmful to human health—so distinguishing phytoplankton communities is a key mission of the satellite. PACE's two multi-angle instruments allow scientists to measure cloud properties, which are important for understanding climate, and monitor, analyze, and identify atmospheric aerosols to better inform the public about air quality.

Earth Venture Suborbital Airborne Missions Selected

In April 2024, NASA selected six new airborne missions as part of the Earth Venture Suborbital program. These six missions include domestic and international studies of fire-induced clouds, Arctic coastal change, air quality, landslide hazards, shrinking glaciers, and emissions from agricultural lands. The missions are planned for 2026 to 2029. Three lead investigators were chosen for each mission, with at least one required to be an early-career scientist. Full staffing of the science teams and selection of complementary instruments are also being competed. NASA's suite of airborne missions center on the use of instruments mounted on aircraft to make measurements in finer detail—both in spatial resolution and in shorter timescales—than can be made by many satellites. Competitively selected, these missions provide opportunities to supplement satellite observations and make innovative measurements.

Four New Earth System Explorer Investigations Announced

In May 2024, NASA selected four proposals for concept studies of missions to help better understand key Earth science focus areas. These proposed studies include Earth's protective ozone layer, ocean surface currents, greenhouse gases, and changes in ice and glaciers around the world. The four investigations are part of NASA's Earth System Explorers Program, which conducts principal investigator–led space science missions as recommended by the National Academies of Sciences, Engineering, and Medicine's most recent Decadal Survey for Earth Science and Applications from Space. The program is designed to enable high-quality Earth system science investigations to focus on previously identified key targets. As the first step of a two-step selection process, each of these proposals will receive $5 million to conduct a one-year mission concept study. After the study period, NASA will choose up to two proposals to go forward to development and launch, with readiness dates expected in 2030 and 2032.

Commercial SmallSat Data Acquisition Program Expands Awardees

The NASA Commercial SmallSat Data Acquisition (CSDA) program selected eight companies for a new award to acquire Earth observation data and provide related services for the agency. Under the contract, the recipients will be responsible for acquiring observation data

2 See https://www.nasa.gov/centers-and-facilities/goddard/nasa-wants-to-identify-phytoplankton-species-from-space-heres-why/.

from commercial sources that support NASA's Earth science research and application activities. The goal of these awards is to give NASA a cost-effective way to augment or complement the Earth observations acquired by the agency and other U.S. Government and international agencies. This brings the total number of commercial vendors on the CSDA contract to 15. These vendors offer data from synthetic aperture radar, precipitation radar, multispectral and hyperspectral imagers, radio occultation, methane emissions, and digital elevation models.

Earth Science Data Contributes to Disaster Response

NASA's Disasters Response Coordination System is a new effort designed to deliver timely, actionable science to support disaster response organizations throughout the United States and worldwide. Established in June 2024, the system unifies NASA's work with partner agencies. NASA provides expertise with mapping, datasets, and analyses that help decision making and protect lives and livelihoods during and after disasters. For example, in 2024, when back-to-back hurricanes Helene and Milton brought devastating flooding, landslides, wind damage, and power outages to Florida and the southern United States, the system supported FEMA, USGS, the American Red Cross, and state emergency management agencies in their response efforts. The Disasters team shared multiple datasets to enhance partners' situational awareness, including nighttime lights maps to provide awareness of power outages, maps of flooding and flood damage, and maps to provide awareness of existing and potential landslides. These efforts directly contributed to local search-and-rescue efforts and to positioning supplies (such as generators) where they could be most impactful.

NASA Teams Up with Farmers for Food Security

NASA continues to expand access to and use of Earth science data by farmers in the United States and worldwide. In the United States, NASA scientists are teaming with land-grant universities and agriculture organizations to develop farmer-to-scientist projects in states including Iowa, Kansas, Hawaii, New York, and Illinois. These projects include sustainable agriculture, crop models for farm management, nitrogen management, irrigation management, and artificial intelligence in agriculture. Worldwide, NASA scientists continue to develop global food supply reports to the G20 Agriculture Ministers in coordination with USDA, continue to provide satellite data and processing for USDA Foreign Agricultural Service, and are scaling these efforts to countries at risk (e.g., Sudan, Kenya, Togo). NASA agriculture efforts leverage ESD-wide capabilities through our flagship consortia, NASA Acres and NASA Harvest, as well as from the NASA Capacity Building program and NASA center research and modeling efforts.

FireSense Supports Interagency Wildfire Assessments

NASA FireSense works with wildland fire management agencies in the United States, including the Forest Service, Environmental Protection Agency, and Department of Interior agencies, among others, to co-develop technological solutions for wildland fire management, mitigation, and recovery. FireSense leads airborne technology demonstrations on active fire- and smoke-impacted areas. These activities included a flight campaign with crewed aircraft spanning nine locations across four states in the western United States to measure pre-, active, and post-fire environments. They also included a small Uncrewed Aircraft Systems (UAS) campaign—with partners from the National Weather Service and the Forest Service—that successfully demonstrated fire weather data collection capabilities to improve fire behavior modelling on active fire incidents.

Heliophysics

Our Sun—the only star we can study up close—makes life on Earth possible while also producing radiation and energy that can have detrimental impacts on life and the technologies on which humans have grown to rely. NASA's Heliophysics Division studies the Sun and its influences on Earth, its extended atmosphere, interplanetary space, and, in turn, the atmospheres of planets and technology that exist across the solar system. Solar activity can interfere with satellite electronics, communications, and GPS signals, and it can also impact the radiation that spacecraft and astronauts experience in transit to the Moon, Mars, and other planets.

Two Launches for Heliophysics

In FY 2024, the Heliophysics Division launched two missions, the Atmospheric Waves Experiment (AWE), and the CubeSat Radio Interferometry Experiment (CURIE). AWE launched to the ISS on November 9, 2023, to study colorful bands of light in Earth's atmosphere, called airglow, to determine what combination of forces drives space weather in the upper atmosphere. CURIE rode to space in July on the inaugural launch of ESA's Ariane 6 rocket from the Guiana Space Center in Kourou, French Guiana. After deployment, the CURIE separated into two CubeSats to study radio burst emissions from solar eruptive events, such as flares and coronal mass ejections, to determine the location and size of radio burst source regions and then track their movement outward from the Sun.

Heliophysics' Big Year

NASA's Heliophysics Big Year took place primarily in 2024, marking a global celebration of solar science and the Sun's influence on Earth and the entire solar system. Beginning with the annular solar eclipse in October 2023 and continuing through Parker Solar Probe's closest approach to the Sun in December 2024, all those interested in sharing the science, art,

and beauty of heliophysics have had the opportunity to engage in solar science events, such as watching solar eclipses, experiencing auroras, participating in citizen science projects, and other fun Sun-related activities.

2024 Total Solar Eclipse

A total solar eclipse happens when the Moon passes between the Sun and Earth, completely blocking the face of the Sun. On Monday, April 8, 2024, a total solar eclipse began over the South Pacific Ocean and made its way northwest across North America, passing over Mexico, the United States, and Canada. NASA's engagement efforts for this eclipse reached tens of millions of people, helping them understand their place in space and how NASA studies this complex system. More than 400 NASA employees engaged with the public at 14 locations in the path of totality, and NASA distributed over two million pairs of eclipse safety glasses across the United States in advance of the eclipse. NASA's English broadcast had more than 12 million live viewers, and the agency's Spanish broadcast had more than 4 million live viewers. Social media engagements with Barbie, Cookie Monster, Elmo, Snoopy, and Lego accounts helped NASA spread the message of science and safety with younger audiences.

NASA-funded science teams gathered novel data on the Sun's atmosphere and the Sun-Earth connection in ways that are possible only during a total solar eclipse. NASA deployed two eclipse-chasing WB-57 jet planes to study the Sun's corona and Earth's upper atmosphere, known as the ionosphere. The jets were able to fly higher and faster than commercial aircraft, extending their time in the Moon's shadow to conduct experiments and take measurements while in an eclipse. NASA also launched sounding rockets and weather balloons to monitor disturbances in the ionosphere during the April 2024 total solar eclipse and the October 2023 annular solar eclipse. More than 36,000 citizen scientists participated in the October 2023 annular solar eclipse and the April 2024 total solar eclipse, producing an incredible amount of data that are under analysis and will support eclipse research for decades to come. The next total solar eclipse that can be seen from the contiguous United States will be on August 23, 2044.

Parker Solar Probe Breaks Records and New Ground

Parker Solar Probe is a first-of-its-kind mission to "touch" the Sun to understand how energy and heat move through the solar atmosphere and the corona, as well as what accelerates solar wind and energetic particles like coronal mass ejections. Since its launch in 2018, the Parker Solar Probe has set records for the first spacecraft to fly through the corona, the fastest human-made object at 430,000 miles per hour, and closest approach to the Sun, coming to within 4.51 million miles on September 30, 2024. By the end of FY 2024, Parker had completed 21 orbits around the Sun and 6 of 7 planned flybys of Venus. Solar Cycle 25 began in December 2019,

and Parker continues to witness an increasing number of solar events as the Sun's activity nears solar maximum, which scientists believe has begun. Parker Solar Probe was named in honor of Eugene Parker (June 10, 1927–March 15, 2022), a pioneering American solar plasma physicist who first proposed the concept of solar wind.

Voyager Persists After 47 Years

Launched in August and September 1977, the deep space Voyager probes remain a beacon of inspiration and persistence 47 years later as they return data from multiple billions of miles away. The Voyager team continues to innovatively maintain spacecraft operations, conducting a complicated thruster swap on Voyager 1 in August and turning off a science instrument to preserve power on Voyager 2 in September. Voyager is the longest-traveled human invention considering the latest estimates of their distance from the Sun and Earth and their speed of travel in the interstellar medium.

Space Weather Features Prominently for Millions Across the Globe

The NASA Space Weather Program continued its mission to provide an improved framework to increase our understanding of how the Sun impacts our everyday lives on Earth. In the current Solar Cycle 25, heliophysicists believe we entered solar maximum late in FY 2024, the most volatile part of the Sun's 11-year cycle. Evidence of solar maximum became apparent to unusually large populations as they witnessed auroras at shockingly low latitudes in May 2024. These events followed the massive geomagnetic storm that sent highly energized particles into Earth's atmosphere, creating a tantalizing visual treat in the nighttime skies. The storm was the most powerful recorded since 2003, and the auroras it sparked were possibly some of the strongest displays recorded in 500 years. This is the first solar maximum in which the general public had access to smartphones and high-quality cameras at their fingertips. The level of citizen science engagement was unprecedented, with people across the globe reporting their sightings to the NASA-sponsored aurorasaurus.org, the first and only citizen science initiative that tracks auroras around the world via reports on its website and social media.

A Healthy Sounding Rocket Program

The Heliophysics Division manages the agency's sounding rocket program, providing robust, versatile, and cost-effective flight opportunities for researchers and students. Sounding rockets carry scientific instruments into space along a parabolic trajectory for brief scientific experiments that can sometimes be developed in just a few months. In FY 2024, the Heliophysics Division launched 17 sounding rockets, including six during the eclipses and two as part of NASA's RockOn and RockSat-X workshops that introduced students to rocketry through a weeklong course at Wallops Flight Facility.

Data from the NASA-led Endurance sounding rocket made the first successful detection of Earth's ambipolar electric field: a weak, planet-wide electric field as fundamental as Earth's gravity and magnetic fields. First hypothesized more than 60 years ago, the ambipolar electric field is a key driver of the "polar wind," a steady outflow of charged particles into space that occurs above Earth's poles. This electric field lifts charged particles in our upper atmosphere to greater heights than they would otherwise reach and may have shaped our planet's evolution in ways yet to be explored.

JEDI Instrument Selection

NASA selected a new instrument to study the Sun and how it creates massive solar eruptions. The agency's Joint EUV coronal Diagnostic Investigation (JEDI) captures images of the Sun in extreme ultraviolet (EUV) light, a type of light invisible to our eyes that reveals many of the underlying mechanisms of the Sun's activity. Once integrated aboard ESA's Vigil space weather mission, JEDI's two telescopes focus on the middle layer of the solar corona, a region of the Sun's atmosphere that plays a key role in creating the solar wind and the solar eruptions that cause space weather. The Vigil space mission, planned to launch in 2031, is expected to provide around-the-clock space weather data from a unique position at Sun-Earth Lagrange point 5—a gravitationally stable point about 60 degrees behind Earth in its orbit.

Planetary Science

NASA's Planetary Science Division advances scientific knowledge of our solar system through exploration and research. Pushing the limits of spacecraft and robotic engineering, the division's portfolio of missions explores every major body in the solar system and many smaller ones. The data from these missions support research into questions that include the history and continued evolution of planets, moons, and small bodies (e.g., asteroids, comets); the origin of life and the potential for life elsewhere; and the hazards and resources present as humans explore space. In addition, the division's Planetary Defense Coordination Office identifies threats to Earth posed by impacts of near-Earth objects. Below are significant highlights from FY 2024.

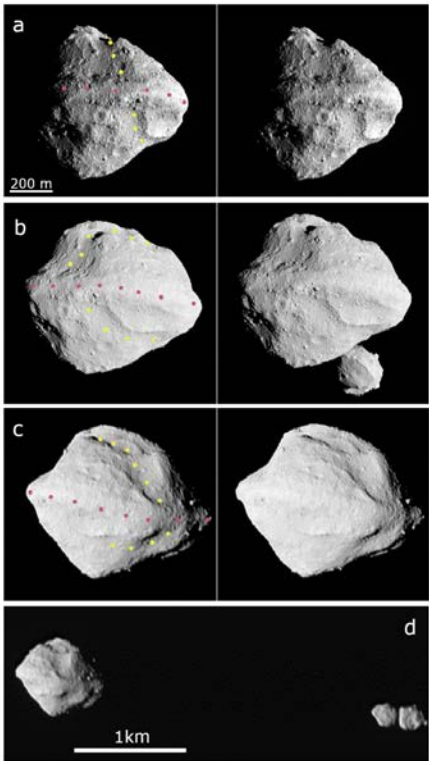
Europa Clipper

NASA's Europa Clipper mission to explore Jupiter's icy moon Europa passed a mission planning milestone in September 2024 and launched in October 2024. Beyond Earth, Europa is considered one of the solar system's most promising potentially habitable environments; scientists believe that there is an ocean beneath Europa's surface that contains twice as much liquid water as Earth's oceans. Europa Clipper is the largest spacecraft NASA has ever developed for a planetary mission. After an approximately 1.8-billion-mile journey, Europa Clipper is to

enter orbit around Jupiter in April 2030, where the spacecraft will conduct a detailed survey of Europa to determine whether the icy world could have conditions suitable for life. Coming as close as 16 miles to the surface, the spacecraft is equipped with nine science instruments and a gravity experiment, including an ice-penetrating radar, cameras, and a thermal instrument to look for areas of warmer ice and any recent eruptions of water.

NASA Lucy Images Reveal Asteroid Dinkinesh to Be Surprisingly Complex

NASA launched the Lucy mission in October 2021 to explore a record-breaking number of asteroids, flying by three asteroids in the solar system's main asteroid belt and by eight Trojan asteroids that share an orbit around the Sun with Jupiter. The Lucy spacecraft has accomplished its first close-up look at an asteroid. Images from the November 2023 flyby of asteroid Dinkinesh by NASA's Lucy spacecraft showed a trough on Dinkinesh where a large piece—about a quarter of the asteroid—suddenly shifted, a ridge, and a separate contact binary satellite (now known as Selam). Scientists say this complicated structure shows that Dinkinesh and Selam have significant internal strength and a complex, dynamic history. Dinkinesh and its satellite are the first two of 11 asteroids that Lucy's team plans to explore over its 12-year journey.



Panels a, b, and c each show stereographic image pairs of the asteroid Dinkinesh taken by the NASA Lucy Spacecraft's Lucy–Long Range Reconnaissance Imager in the minutes around closest approach on November 1, 2023. The yellow and rose dots indicate the trough and ridge features, respectively. These images have been sharpened and processed to enhance contrast. Panel d shows a side view of Dinkinesh and its satellite Selam taken a few minutes after closest approach. (Credit: NASA/GSFC/SwRI/JHUAPL/NOIRLab)

Psyche Mission Launch and Deep Space Optical Communications Milestone

Psyche is a NASA mission to study a metal-rich asteroid with the same name, located in the main asteroid belt between Mars and Jupiter. The spacecraft launched from Kennedy Space Center atop a SpaceX Falcon Heavy on October 13, 2023, thus beginning NASA's first mission to study an asteroid that has more metal than rock or ice. After leaving our atmosphere, Psyche made the most of its rocket boost and coasted beyond the orbit of Mars. In July 2024, NASA's Deep Space Optical Communications technology demonstration broke

yet another record for laser communications by sending a laser signal from Earth to the Psyche spacecraft when it was about 290 million miles (460 million kilometers) away; the same distance between Earth and Mars when the two planets are farthest apart. In May 2026, a Mars gravity assist is to put the spacecraft on its direct trajectory to the asteroid. By August 2029, the Psyche spacecraft is to begin exploring the asteroid that scientists think—because of its high metal content—may be the partial core of a planetesimal, a building block of an early planet.

Surprising Phosphate Finding in NASA's OSIRIS-REx Asteroid Sample

Scientists have eagerly awaited the opportunity to dig into the 4.3-ounce (121.6-gram) primitive asteroid Bennu sample collected by NASA's Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) mission since it was delivered to Earth in late FY 2023. The aim is to find out whether the material would hold secrets of the solar system's past and the prebiotic chemistry that might have influenced the origin of life on Earth. An early analysis of the Bennu sample, published in June 2024 in *Meteoritics & Planetary Science,* demonstrates that this excitement was warranted. The OSIRIS-REx Sample Analysis Team found that Bennu contains the original ingredients that formed our solar system. The asteroid's dust is rich in carbon and nitrogen, as well as organic compounds, all of which are essential components for life as we know it. The sample also contains magnesium-sodium phosphate, which was a surprise to the research team, as it was not seen in the remote sensing data collected by the spacecraft at Bennu. Its presence in the sample hints that the asteroid could have splintered off from a long-gone, tiny, wetter world.

Mars Sample Return

The Mars Sample Return mission aims to bring scientifically chosen samples from Mars back to Earth. In FY 2024, the Agency conducted additional analysis and paused development on some components of the mission following an independent review board's assessment that the mission had a near-zero probability of meeting existing launch readiness dates and would cost $8–10 billion, significantly more than original agency estimates. To further explore more affordable and faster methods of bringing samples from Mars's surface back to Earth, NASA awarded contracts to conduct 90-day studies to eight industry proposers. Additionally, NASA centers, NASA's JPL, and the Johns Hopkins Applied Physics Laboratory produced studies. Once the studies are completed, NASA will assess study findings to consider alterations or enhancements for a potential MSR path forward. NASA has established an independent team to review study results and provide its evaluation to the administrator.

Exploration Science Strategy and Integration Office

The Exploration Science Strategy and Integration Office (ESSIO) was created within SMD to develop and implement a science strategy to enable robotic and human exploration of the Moon and beyond.

CLPS Sends NASA Back to the Moon

NASA's CLPS initiative leverages commercial capabilities and technology to deliver scientific instruments and technology demonstration payloads to the Moon, with the goal of building a sustainable lunar economy that will produce rapid, frequent, and affordable access to the lunar surface and cislunar space. In FY 2024, two CLPS vendors launched their respective landers to the Moon. The first was Astrobotic's Peregrine Mission 1 (PM-1), which flew on the first demonstration flight of United Launch Alliance's (ULA's) Vulcan-Centaur rocket. After a successful launch and separation, PM-1 experienced a leak in its propulsion system that prohibited a landing attempt on the lunar surface. After testing as many systems and gathering as much science instrument data as possible, PM-1 reentered Earth's atmosphere and burned up over the Pacific Ocean. Astrobotic convened a Failure Review Board with NASA as an observer and released a final report outlining the leak and future mitigation strategies.

Image from IM-1 lander upon approach to landing on the lunar surface near 80.1S, 1.4E. (Credit: Intuitive Machines)

The second lander, Intuitive Machines' Nova-C (IM-1), launched and successfully soft-landed on the lunar surface. During landing, one of its landing legs collapsed and the lander tilted over at 30 degrees, providing some hurdles to communications and operations of all of NASA's instruments. However, NASA's instruments were turned on, operated as expected, and returned as much data as possible given the lander orientation. Both PM-1 and IM-1 produced lessons-learned documents, and both companies are applying to their next CLPS missions (Intuitive Machine's IM-2 and Astrobotic's Griffin Mission 1, both in 2025 to the lunar South Polar region). Additionally, all instruments have been delivered and integrated onto the Firefly Blue Ghost Mission 1, which will deliver ten NASA instruments to the Mare Crisium region of the Moon in 2025.

Joint Agency Satellite Division

The Joint Agency Satellite Division (JASD), together with NOAA, manages the development and launching of reimbursable satellite programs, projects, and instruments. More information about these satellite programs can be found in the Department of Commerce chapter of this report.

Aeronautics Research Mission Directorate

During FY 2024, NASA's Aeronautics Research Mission Directorate (ARMD) made great strides in furthering its innovative vision of cleaner, safer, and more advanced air travel and atmospheric flight at every speed and altitude.[3]

Collaborating with partners and aviation experts in government, industry, and academia, NASA's aeronautical innovators continued implementing new ideas and capabilities in ARMD's wide-ranging portfolio, guided by a comprehensive Strategic Implementation Plan to transform aviation for the 21st century.[4]

During FY 2024, ARMD demonstrated real progress and value with its scientific and engineering efforts affecting key drivers of the global aeronautics industry in four transformational areas—ultra-efficient airliners, high-speed commercial flight, advanced air mobility, and future airspace and safety—fueled by an innovation ecosystem.

NASA Aeronautics is composed of four programs, each making contributions to these transformational areas and innovation ecosystem: the Advanced Air Vehicles Program, Airspace Operations and Safety Program, Integrated Aviation Systems Program, and Transformative Aeronautics Concepts Program. ARMD also manages NASA's wind tunnels and several other test facilities through the Aerosciences Evaluation and Test Capabilities portfolio.

Ultra-Efficient Airliners

NASA Aeronautics made progress toward the goal of enabling cleaner aviation with reduced environmental impact under the Sustainable Flight National Partnership—a collaboration with partners in government, industry, and academia to accelerate U.S. progress toward achieving net-zero greenhouse gas emissions in aviation by 2050.[5] NASA worked to make aviation more sustainable and contributed viable solutions in multiple areas, including electrified aircraft propulsion, small-core gas turbines, advanced high-efficiency airframes, and high-rate manufacturing of composite materials.

Under a Funded Space Act Agreement, NASA and Boeing have been developing the X-66 Sustainable Flight Demonstrator—a single-aisle demonstrator aircraft that will validate new fuel-efficient designs aimed at lowering emissions from commercial aviation. The X-66 represents a key step in helping the United States achieve net-zero greenhouse gas emissions from aviation by 2050—one of the environmental goals articulated in the White House's U.S. Aviation Climate Action Plan.[6]

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3 https://www.nasa.gov/feature/aeronautics-transformations/

4 https://www.nasa.gov/directorates/armd/armd-strategic-implementation-plan/

5 https://www.nasa.gov/directorates/armd/sfnp/

6 https://www.nasa.gov/image-article/new-look-at-nasa-boeing-sustainable-experimental-airliner/

During FY 2024, engineers began work to modify an MD-90 aircraft to become the X-66, the design of which features more fuel-efficient transonic truss-braced wings. Concurrently, NASA aeronautical innovators continued studying the aircraft's design and preparing for the aircraft through several activities, including the development of a full-size cockpit simulator, a model of the aircraft's wings for wind tunnel testing, and wind tunnel tests for phases of flight such as deep stall.[7]

Through the Electrified Propulsion Flight Demonstration project, NASA achieved significant progress in developing two hybrid-electric powered demonstrator aircraft as demonstration vehicles in collaboration with industry partners GE Aerospace and magniX.

During FY 2024, magniX unveiled the livery of their aircraft, a heavily modified de Havilland Dash 7 that will demonstrate more sustainable electrified aviation technology in flight.[8] The company also successfully conducted tests in NASA's Electric Aircraft Testbed facility to demonstrate the capabilities of a battery-powered engine at high altitudes.[9]

NASA Aeronautics also moved forward with its Hybrid Thermally Efficient Core project, which is developing a more fuel-efficient hybrid-electric small-core jet engine in collaboration with GE Aerospace.[10] This year, the project moved into its second phase of research, which will see NASA and GE begin to design and build the unique jet engine and eventually demonstrate its technology.[11]

The High-Rate Composite Aircraft Manufacturing project also advanced with the achievement of new partnerships in its Advanced Composites Consortium.[12] As part of the consortium, government, industry, and academia continued to explore and develop ways to manufacture lighter-weight composite aircraft materials four to six times faster than current methods.

Also during FY 2024, NASA and government and industry partners collaborated to study contrail formation, including when sustainable aviation fuels are in use. The flight campaign involved NASA's now-retired DC-8 research aircraft flying in formation with Boeing's ecoDemonstrator Explorer, a 737-10 passenger jet, to gather data on the contrails.[13]

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7 https://www.nasa.gov/image-article/boneyard-airplane-sees-new-life-as-a-nasa-x-66-simulator/ and https://www.nasa.gov/centers-and-facilities/armstrong/nasa-armstrong-builds-model-wing-to-help-advance-unique-design/

8 https://www.nasa.gov/aeronautics/hybrid-electric-aircrafts-new-colors/

9 https://www.nasa.gov/aeronautics/nasa-magnix-test-hybrid-electric-planes/

10 https://www.nasa.gov/aeronautics/nasa-ge-hybrid-electric-research-092024/

11 https://www.nasa.gov/aeronautics/more-sustainable-jet-engine-prepared/

12 https://www.nasa.gov/aeronautics/hicam-composite-new-partners-082424/

13 https://www.nasa.gov/image-article/nasa-and-partners-study-contrail-formation/

High-Speed Commercial Flight

NASA Aeronautics continued its mission to quiet the sound of sonic booms to enable a new market in high-speed commercial air travel.[14] Through the Quesst mission, NASA made progress toward demonstrating that loud sonic booms can be reduced to quieter sonic "thumps" using the uniquely shaped X-59 aircraft. The survey data gathered by the aircraft—once flown over select communities in the United States—will be shared with international and federal regulators to determine the adoption of new rules to lift the current ban on supersonic air travel over land.

During FY 2024, the X-59 aircraft had its official rollout ceremony at contractor Lockheed Martin's Skunk Works facility in Palmdale, California.[15] The rollout ceremony, a key tradition in aeronautics research, signified the achievement of the aeronautical innovators who tirelessly advanced the aircraft toward completion.[16]

Subsequent to the rollout ceremony, the X-59 underwent ground testing and validation prior to its first flight—expected during 2025. NASA and Lockheed Martin initiated a rigorous process to test the aircraft to ensure that its systems perform as expected and to verify airworthiness.[17]

As part of the overall Quesst mission, NASA researchers also conducted tests on ground equipment essential to recording the X-59's quieter sonic "thump." Using NASA's F-15 and F-18 research aircraft, researchers flew above the ground testing equipment to prepare for their use in the Quesst mission.[18]

Advanced Air Mobility

NASA made valuable progress on its Advanced Air Mobility (AAM) mission.[19] As use cases for drones and other new uncrewed aircraft begin to transform aviation, NASA has led the vision community-wide for making this new type of flight sustainable, reliable, quiet, and, above all, safe.

NASA Aeronautics made key contributions to safely developing an air transportation system that moves people and cargo between places previously not served or underserved by aviation using revolutionary new aircraft. These contributions enable such aircraft to conduct missions including emergency response, civic resource management, and sustainably transporting packages and passengers.

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14 https://www.nasa.gov/aeronautics/supersonic-flight/

15 https://www.nasa.gov/news-release/nasa-lockheed-martin-reveal-x-59-quiet-supersonic-aircraft/

16 https://www.nasa.gov/aeronautics/x-59-rollout-preview/

17 https://www.nasa.gov/aeronautics/x-59-closer-to-safe-first-flight/

18 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-instruments-will-listen-for-supersonic-x-59s-quiet-thump/

19 https://www.nasa.gov/aeronautics/drones-and-you/

During FY 2024, NASA conducted studies aimed at gathering data on increasing passenger comfort for vehicles such as air taxis. The information from these tests will help enable the burgeoning AAM field.[20] AAM companies continue to use NASA-developed software to help them design these new vehicles, which can operate at a volume acceptable to the public.[21]

This past year, NASA began conducting Beyond Visual Line of Sight (BVLOS) operations for drones within a special flight range located adjacent to NASA's Langley Research Center in Virginia and at a flight range near Houston. As part of NASA's work to safely integrate new kinds of air vehicles into the National Airspace System (NAS) for AAM uses, NASA has safely and successfully flown multiple drones beyond the visual light of sight with no physical observers present.[22] This research involves NASA directly engaging with federal, state, and local governments about how drones can operate safely beyond sight on public safety missions—and do so in airspace shared with drones on commercial missions.[23]

One such public safety mission of focus during FY 2024 has been NASA's Wildland Fire Management Initiative. In collaboration with the wildland fire management community at the state, local, federal, and industry levels, NASA has worked to identify areas in which it can help lessen the impact of devastating wildfires that result in part from human-caused climate change. NASA is providing its expertise in areas such as aeronautics, space technology, and climate science to advance the state of the art in wildland fire management.[24]

NASA continued to mature technology essential to the AAM mission, such as autonomy. NASA, Sikorsky, and the Defense Advanced Research Projects Agency collaborated this fiscal year to test autonomous flight technologies using helicopters above the Long Island sound. Monitored by safety pilots, the helicopters used NASA software to fly autonomously along multiple planned routes safely. NASA technology also enabled the safety pilots to monitor flight path options that the software selected whenever course corrections needed to occur.[25]

Also this year, NASA developed a new tool to gather key data on flight autonomy for AAM. A special camera pod attached to NASA helicopters in flight gathered real-time flight data to increase the pool of knowledge autonomous vehicles have to draw from while operating solo.[26]

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20 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-prepares-for-air-taxi-passenger-comfort-studies/

21 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-noise-prediction-tool-supports-users-in-air-taxi-industry/

22 https://www.nasa.gov/aeronautics/nasa-flies-autonomous-drones/

23 https://www.nasa.gov/image-article/nasa-seeks-safety-input-for-drones/

24 https://www.nasa.gov/image-article/developing-new-wildland-fire-technology/

25 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-autonomous-flight-software-successfully-used-in-air-taxi-stand-ins/

26 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-develops-pod-to-help-autonomous-aircraft-operators/

Future Airspace and Safety

NASA continued to engage with the diverse community of operators and stakeholders to establish a vision for the NAS of the future and identify and overcome technical barriers to its achievement.[27] NASA achieved further steps to transform the NAS through several air traffic management research activities. Alongside partners and stakeholders in government, industry, and academia, NASA advanced new technology to improve airspace and airport operations by reducing emissions, saving fuel, preventing passenger delays, and easing airport operations.

Work to improve the efficiency of airline operations continued through technology demonstrations at major airports such as Dallas Fort Worth International Airport, Texas; Charlotte Douglas International Airport, North Carolina; and elsewhere in collaboration with major U.S. airlines. Using NASA-developed software, airlines, the Federal Aviation Administration (FAA), and other stakeholders have been successfully implementing new routing technologies that save fuel and reduce delays.[28]

Related to this work, NASA released a new web portal to stakeholders to provide access to a database that greatly helps them improve airline operations. As part of the Digital Information Platform project, NASA has expanded access to its digital cloud-based technology to streamline airport and airspace operations for airlines.[29]

NASA also worked to expand these tools and technologies to other applications and altitudes, such as Upper Class E airspace—where need is anticipated in the near future for more robust air traffic management and separation.[30]

NASA further explored, discovered, and recognized the impact on safety from these technical advancements in aviation and any associated emerging operations—and developed solutions to the most pressing technical challenges. Working alongside government and aviation industry organizations, NASA made progress developing the concept and requirements for an assured In-Time Aviation Safety Management System, an integrated set of services, functions, and capabilities to address operational risks and hazards of a transformed NAS. These efforts will keep air travel the safest form of transportation.[31]

Innovation Ecosystem

NASA continued to explore previously unrecognized opportunities for transforming aviation through its innovation ecosystem, through which NASA explores early-stage, next-generation

27 https://nari.arc.nasa.gov/skyforall/

28 https://www.nasa.gov/aeronautics/air-traffic-solutions/

29 https://www.nasa.gov/aeronautics/digital-information-platform-could-help-improve-air-traffic/

30 https://www.nasa.gov/aeronautics/new-class-e-air-traffic-management-demoed/

31 https://www.nasa.gov/directorates/armd/aosp/sws/

experimental research ideas to streamline and establish new methods and technologies for 21st-century aviation.

NASA Aeronautics continued collaborating closely with universities in the United States to pioneer sustainable aviation technologies for the near- and far-term visions of a zero-emissions aviation future. Through its well-received University Leadership Initiative (ULI) and other activities, NASA pushed the frontiers of the possible with the help of our next-generation workforce. ULI provides an opportunity for the U.S. university community to receive NASA funding and take the lead in building their own teams and setting their own research agenda with goals that support and complement NASA aeronautics research goals. The seventh round of ULI awards was issued during FY 2024.[32]

NASA also announced the winner of the 2024 Gateways to Blue Skies Competition, as well as the topic for next year's competition: Advancing Aviation for Natural Disasters.[33] Each year, NASA challenges diverse, multi-disciplinary teams of college students to conceptualize unique solutions for aviation-themed problems at the system level. The winners receive stipends to present their research at an annual forum and the opportunity to be an intern at one of NASA's centers.[34]

Also during FY 2024, NASA released to the public Aviary—a new open-source software tool for aircraft modeling that helps users discover optimal solutions for traditional, hybrid-electric, and all-electric aircraft designs. Released in December 2023 on GitHub, the Aviary tool is free and accessible to all and continues to grow as contributions are made by the public.[35]

NASA also made progress in its research of fundamental technologies that eventually may find themselves in aviation applications, such as solid-state batteries. The Solid-state Architecture Batteries for Enhanced Rechargeables and Safety activity has achieved breakthroughs in cell-level energy density, temperature performance, and improvements in cycling in a solid-state architecture. These improvements contribute to an increase in battery effectiveness, safety assurance, and capability for uncrewed and crewed electric aircraft concepts.[36]

In addition, a new NASA-developed alloy, GRX-810, was licensed during FY 2024 to several companies to produce and market to airplane and rocket equipment manufacturers, as well as the entire supply chain. The 3D-printable alloy is a breakthrough for the extreme temperatures and harsh conditions of air and spaceflight.[37]

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32 https://www.nasa.gov/aeronautics/university-teams-to-explore-aero-research/

33 https://www.nasa.gov/aeronautics/collegiate-teams-to-focus-on-natural-disasters-in-2024-gateways-to-blue-skies-competition/

34 https://www.nasa.gov/centers-and-facilities/langley/university-teams-selected-as-finalists-to-envision-new-aviation-responses-to-natural-disasters/

35 https://www.nasa.gov/aeronautics/aviary-software-overview/

36 https://www.youtube.com/watch?v=_RbepOFRvx0

37 https://www.nasa.gov/centers-and-facilities/glenn/nasa-licenses-3d-printable-superalloy-to-benefit-us-economy/

Space Technology Mission Directorate

NASA's Space Technology Mission Directorate (STMD) leads the development and infusion of breakthrough technologies that shape the future of space exploration. With innovation at our core, STMD is laying the groundwork for America's journey into space as we return to the Moon, look beyond to Mars, and return benefit to humanity here on Earth. These cutting-edge advancements not only propel NASA's missions but empower our Nation's commercial industry, academic, and government partners, ushering in a new era of discovery for all.

Civil Space Shortfall Ranking Process and STMD Restructuring

In FY 2024, STMD kicked off a new collaborative process to better integrate the community's most pervasive technical challenges to further guide NASA's space technology development and investments.[38] STMD published a document overviewing 187 shortfalls—technology areas requiring further development to meet future exploration, science, and other mission needs—and asked the aerospace community to rate their importance.

In July 2024, STMD released the 2024 Civil Space Shortfall Ranking document, integrating the input received from NASA mission directorates and centers, small and large industry organizations, other government agencies, academia, and other interested individuals.[39] STMD will use the integrated ranked list and annual updates as one of several investment decision-making factors moving forward.

At the same time, STMD initiated a formal process for its proposed restructuring and received approval from Congress and the Office of Management and Budget (OMB) to move forward. The goal of the mission directorate restructuring is to become more agile and effective by reorganizing from a Technology Readiness Level (TRL)–based structure to a capability-focused management approach. The shift requires a thoughtful but action-oriented approach to planning and implementing the transition, and, as such, Acting Associate Administrator Clayton Turner established the STMD Restructuring Team (SRT) to help. The SRT began working with NASA Human Resources, unions, and other Agency organizations to obtain internal approval. FY 2025 will be a transition year to fully formulate the new STMD structure.

Technology Demonstrations

The **Technology Demonstration Missions (TDMs)** program provides the capability to demonstrate cross-cutting system-level technology solutions that benefit multiple space missions by

38 https://www.nasa.gov/directorates/stmd/nasa-refines-national-space-technology-development-priorities/

39 https://www.nasa.gov/general/nasa-releases-first-integrated-ranking-of-civil-space-challenges/ and https://www.nasa.gov/wp-content/uploads/2024/07/civil-space-shortfall-ranking-july-2024.pdf?emrc=671bd325d155b

proving out those technologies in real or simulated environments.[40]

NASA's Deep Space Optical Communications (DSOC) experiment is the agency's first demonstration of optical communications beyond the Earth-Moon system.[41] The technology demonstration made headlines when it beamed the first ultra-high-definition video from space, featuring a cat named Taters, from the Psyche spacecraft to Earth on December 11, 2023, from 19 million miles away.[42] DSOC concluded the first phase of its operations since launching aboard Psyche on October 13, 2023, by breaking the record for laser communications this summer by sending a laser signal from Earth to NASA's Psyche spacecraft about 290 million miles away.[43]

Members of the DSOC team react to the first ultra-high-definition streaming video to be sent via laser from deep space on December 11 at NASA's Jet Propulsion Laboratory. Sent by the DSOC transceiver aboard the Psyche spacecraft, nearly 19 million miles from Earth, the video features a cat named Taters. (Credit: NASA/JPL-Caltech)

Following completion of the Phase 1 Fission Surface Power (FSP) System Design contracts—which focused on developing concept designs for a small, electricity-generating nuclear fission reactor that could be used during a future demonstration on the Moon and to inform future designs for Mars—NASA provided funding to extend the three Phase 1 contracts.[44] This extension helps to gather more information to improve the concept designs and better inform the Phase 2 solicitation, when industry will be invited to design, develop, and test the FSP system for demonstration on the Moon.

The Cryogenic Fluid Management (CFM) project performed two demonstrations this year.[45] The first demo was the Radio Frequency Mass Gauge (RFMG) on the Commercial Lunar Payload Services (CLPS) Intuitive Machines IM-1 launch on February 15, 2024.[46] The RFMG hardware performed nominally throughout the mission, and the project met

40 https://www.nasa.gov/space-technology-mission-directorate/tdm/

41 https://www.nasa.gov/mission/deep-space-optical-communications-dsoc/

42 https://www.jpl.nasa.gov/news/nasas-tech-demo-streams-first-video-from-deep-space-via-laser/

43 https://www.jpl.nasa.gov/news/nasas-psyche-spacecraft-optical-comms-demo-en-route-to-asteroid/ and https://www.jpl.nasa.gov/missions/psyche/

44 https://www.nasa.gov/centers-and-facilities/glenn/nasas-fission-surface-power-project-energizes-lunar-exploration/ and https://www.nasa.gov/tdm/fission-surface-power/

45 https://www.nasa.gov/space-technology-mission-directorate/tdm/cryogenic-fluid-management-cfm/

46 https://www.nasa.gov/centers-and-facilities/glenn/nasa-tests-new-spacecraft-propellant-gauge-on-lunar-lander/

its minimal data-received requirements. The second demo occurred when SpaceX launched Starship 3 on March 14, 2024, and performed a settled in-space tank-to-tank transfer of cryogenic propellent (liquid oxygen).[47] The CFM objective of the launch and technology demonstration was to transfer a minimum of three metric tons of liquid oxygen (LOX) from the Starship header LOX tank to the main LOX tank. After a review of data, the CFM project concluded that the on-orbit CFM demonstration milestone requirements were achieved.

After a year of working to complete various deliverables and integration activities, it was determined to shut down the On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) project.[48] NASA assessed the remaining implementation risk, lack of a transition partner and an uncertain infusion path, and the need to prioritize other NASA technology development efforts in making this decision. NASA has developed numerous innovative satellite-servicing technologies, many of which have been transferred or licensed to commercial companies for their use.

NASA's Solar Electric Propulsion (SEP) project is developing critical technologies to extend the distance and duration of ambitious new exploration and science missions carried out by NASA and its partners.[49] The Advanced Electric Propulsion System (AEPS), built by Aerojet Rocketdyne, an L3Harris Technologies company, provides 12 kilowatts of propulsive power—over two times more powerful than current state-of-the-art in-space electric propulsion systems.[50] Three AEPS thrusters will be used on the Power and Propulsion Element (PPE) to maneuver Gateway during its planned minimum 15-year mission. In FY 2024, the AEPS thruster continued environmental qualification testing to certify the thrusters for flight.

The COnsortium for Space Mobility and ISAM Capabilities (COSMIC) commenced operations in November 2023 with a kickoff event at the University of Maryland, which was attended by approximately 500 people in person and virtually.[51] Since kickoff, 206 organizations have joined COSMIC as consortium members, with 916 individual participants associated with those organizations. Of those participants, 11 percent are from academia, 38 percent from government, and 51 percent from industry.

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47 https://www.nasa.gov/directorates/esdmd/artemis-campaign-development-division/human-landing-system-program/nasa-artemis-mission-progresses-with-spacex-starship-test-flight/

48 https://www.nasa.gov/mission/on-orbit-servicing-assembly-and-manufacturing-1/

49 https://www.nasa.gov/space-technology-mission-directorate/tdm/solar-electric-propulsion/

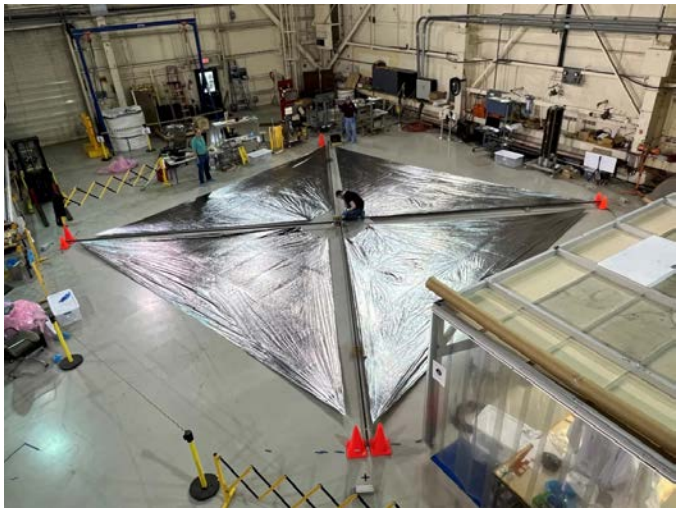
50 https://www.nasa.gov/centers-and-facilities/glenn/nasa-aerojet-rocketdyne-put-gateway-thruster-system-to-the-test/ and https://www.nasa.gov/humans-in-space/the-propulsion-were-supplying-its-electrifying/

51 https://www.nasa.gov/news-release/nasa-creates-in-space-servicing-assembly-manufacturing-consortium/

Technology Maturation

The **Game Changing Development (GCD)** program has oversight of more than 100 projects led by NASA centers, industry, research laboratories, and academia.[52] These projects span Technology Readiness Levels (TRLs) 3 to 7 and are executed through analytical modeling, concept studies, ground-based testing, and spaceflight demonstrations.

- The Advanced Composite Solar Sail System (ACS3) launched on April 23, 2024, atop a Rocket Lab Electron rocket in Māhia, New Zealand.[53] The ACS3 demonstration uses a 12-unit (12U) CubeSat built by NanoAvionics to deploy a new type of boom developed by GCD.[54] These deployable composite booms are made from flexible polymer and carbon fiber materials that are stiffer and 75 percent lighter than previous boom designs. Mission operators confirmed deployment success on August 29, 2024.[55] Through the end of the fiscal year, the team analyzed images and data from the spacecraft to better understand how the boom technology demonstration performed.



Engineers at NASA's Langley Research Center test deployment of the Advanced Composite Solar Sail System using deployable composite booms. The GCD-developed booms have answered the need for lightweight, foldable, and rollable structural material to enable large deployable systems on small satellites. (Credit: NASA)

52 https://www.nasa.gov/stmd-game-changing-development/

53 https://www.nasa.gov/mission/acs3/ and https://blogs.nasa.gov/smallsatellites/2024/04/23/nasas-solar-sail-we-have-liftoff/

54 https://www.nasa.gov/centers-and-facilities/langley/deployable-composite-booms-dcb/

55 https://blogs.nasa.gov/smallsatellites/2024/08/29/nasa-composite-booms-deploy-mission-sets-sail-in-space/

- GCD provided mission support and/or delivered flight hardware for 16 flight demonstrations (one on board the International Space Station, eight to CLPS demonstrations, and seven Lunar-G Flight Opportunities payloads). Some highlights include the following:
    - From February to April 2024, a number of GCD technologies took the microgravity test in a series of parabolic flights that aim to advance innovations supporting the agency's space exploration goals.[56] The flights took place aboard Zero Gravity Corporation's G-FORCE ONE aircraft and helped to advance several promising space technologies.
    - On January 8, 2024, Astrobotic's Peregrine lander launched on United Launch Alliance's Vulcan rocket from the Cape Canaveral Space Force Station in Florida.[57] A version of GCD-developed Navigation Doppler Lidar (NDL) was a mission-critical system aboard the Peregrine lander—a lidar (Light Detection and Ranging)–based descent and landing sensor. NDL provided guidance, navigation and control capabilities and accuracy with reduced size, weight, and power. Additionally, Peregrine's engine technology was matured through a 2018 Tipping Point Award with Frontier Aerospace. STMD created the opportunity for Frontier and Astrobotic to partner together to advance and demonstrate the thruster under the Thruster for the Advancement of Low-Temperature Operations in Space (TALOS) project. Axial thrusters developed through that arrangement were integrated into the Astrobotic Peregrine-1 lander.
    - On February 15, 2024, Intuitive Machines' Nova-C lander launched on a SpaceX Falcon 9 rocket from NASA's Kennedy Space Center in Florida.[58] The Radio Frequency Mass Gauge technology demonstration sought to measure the amount of propellant in spacecraft tanks in a low-gravity space environment.[59] Using sensor technology, the gauge measured the amount of cryogenic propellant in Nova-C's fuel and oxidizer tanks, providing data that could help predict fuel usage on future missions. The Navigation Doppler Lidar (NDL), which provides precise velocity and range data, served as a backup sensor to Nova-C's primary navigation systems. NDL performed flawlessly throughout the mission and provided measurements from 10 km to the Moon's surface, far exceeding the 6-km

56 https://www.nasa.gov/directorates/stmd/game-changing-development-program/next-generation-nasa-technologies-tested-in-flight/

57 https://www.nasa.gov/missions/artemis/clps/nasa-sending-five-payloads-to-moon-on-astrobotics-peregrine-lander/

58 https://www.nasa.gov/news-release/nasa-artemis-science-first-intuitive-machines-flight-head-to-moon/

59 https://www.nasa.gov/centers-and-facilities/glenn/nasa-tests-new-spacecraft-propellant-gauge-on-lunar-lander/

expectation.[60] The Stereo Cameras for Lunar Plume-Surface Studies payload consisted of a suite of four tiny cameras to capture imagery showing how the Moon's surface changes from interactions with the spacecraft's engine plume during and after descent.[61]

- GCD led the successful management and implementation of 16 new public-private partnership Tipping Points that were awarded with a Funded Space Act Agreement (FSAA) procurement mechanism.[62]
- In February 2024, members of the assembly, test, launch, and operations team for the Cooperative Autonomous Distributed Robotic Exploration (CADRE) project marked completion of the three lunar rovers that will fly on Intuitive Machines-3 in 2025.[63] The flight hardware is ready for integration with the CLPS IM-3 Nova-C lander.
- The High Performance Spacecraft Computing (HPSC) project achieved numerous technical accomplishments in FY 2024, including software development, higher-fidelity simulations, and radiation tolerance validation.[64] In FY 2025, prototypes will be shipped to NASA's Jet Propulsion Laboratory, where independent benchmarking and performance assessments will be made.
- In September 2024, the in situ resource utilization (ISRU) Pilot Excavator (IPEx) team successfully completed a demonstration in a simulated lunar autonomy testbed with operators monitoring from a remote control room at Swamp Works at NASA's Kennedy Space Center.[65] The primary goal of IPEx is to dig up lunar soil, known as regolith, and transport it across the Moon's surface. This process is designed to enable the extraction of vital resources, such as hydrogen, oxygen, and water, which are essential for life-support systems.

The Technology Maturation portfolio also includes the **Lunar Surface Innovation Initiative (LSII)**, which was established in 2019 to ensure a cohesive strategy for the development of needed lunar infrastructure capabilities. In addition to providing unique subject matter expertise and consultation, Johns Hopkins University Applied Physics Laboratory (JHUAPL) also facilitates the Lunar Surface Innovation Consortium (LSIC). LSII has supported the investment of over $400 million through STMD programs to establish collaborations across industry and academia.

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60 https://www.nasa.gov/centers-and-facilities/langley/nasas-laser-navigation-tech-enables-commercial-lunar-exploration/

61 https://www.nasa.gov/missions/artemis/clps/tiny-nasa-cameras-to-picture-interaction-between-lander-moons-surface/

62 https://www.nasa.gov/space-tech-industry-partnerships/

63 https://www.nasa.gov/cooperative-autonomous-distributed-robotic-exploration-cadre/

64 https://www.nasa.gov/game-changing-development-projects/high-performance-spaceflight-computing-hpsc/

65 https://www.nasa.gov/isru-pilot-excavator/

- Through LSII, NASA issued a Request for Information (RFI) on November 6, 2023, to support ISRU technology maturation with the release of the Lunar Infrastructure Foundational Technologies demonstration. LSII facilitated an Industry Forum to answer questions from government, industry, and academic communities, resulting in 79 responses from 73 unique organizations representing 21 states and 8 foreign countries.[66]
- LSIC continues to increase collaboration between NASA, other government agencies, industry, academia, and nonprofit organizations with a shared interest in advancing lunar surface technology. On behalf of LSII, LSIC hosted two biannual meetings during FY 2024.
- LSIC has added new participants, growing the consortium to an active community of over 3,200 participants from nearly 1,000 organizations across 50 states, the District of Columbia, Guam, Puerto Rico, and 78 countries. LSIC opened full membership to international participants in August 2024, which was highlighted at the International Astronautical Congress in Milan, Italy, by LSII speakers from JHUAPL in attendance.

Flight Opportunities and Small Spacecraft Technology Portfolio

The **Flight Opportunities** and **Small Spacecraft Technology** portfolio supports disruptive technology advancement and unique missions to change the pace of space exploration, discovery, and space commerce.[67] The portfolio's speed, flexibility, and access to a wide array of commercial suborbital/orbital capabilities provide opportunities to rapidly address technology gaps and emerging needs.

In FY 2024, the Small Spacecraft Technology program and its partners launched six technology demonstration missions and operated 15 spacecraft on orbit.

Technology demonstration missions launched and operational in FY 2024 include the following:

- PY4 is a low-cost, rapid-turnaround, four-satellite technology demonstration based on the open-source PyCubed avionics framework.[68] This swarm of four 1.5-unit CubeSats successfully achieved its baseline mission requirements, including mesh networking communications, inter-satellite ranging, and magnetorquer-only (no reaction wheels) Sun pointing.
- The Advanced Composite Solar Sail System (ACS3) is the first use of composite booms, sail packing, and deployment systems developed by NASA's Langley Research

66 https://www.nasa.gov/general/stmd-lift-1-industry-day/

67 https://www.nasa.gov/stmd-flight-opportunities/ and https://www.nasa.gov/smallspacecraft/

68 https://www.nasa.gov/directorates/stmd/small-spacecraft-technology-program/nasa-to-demonstrate-miniature-cubesat-swarm-technology/

Center.[69] ACS3 completed its primary objective of deploying seven-meter booms, consequently unfurling a solar sail measuring approximately nine meters per side.

- Pathfinder Technology Demonstrator 4 (PTD-4) will demonstrate the NASA Marshall Space Flight Center–built Lightweight Integrated Solar Array and anTenna (LISA-T), a deployable solar array with an integrated antenna to improve power and communication.[70]
- The Pathfinder Technology Demonstrator R (PTD-R) payload is demonstrating a new type of ultraviolet and shortwave infrared telescope. The in-space telescope, called Deep Purple, was built by Lawrence Livermore National Laboratory.

Technology demonstration missions continuing operations in FY 2024 include the following:

- Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) continues to mature its Cislunar Autonomous Positioning System (CAPS) navigation technology as well as provide operational data for the Artemis Program's Gateway.[71] Having operated for over 600 days in lunar orbit, CAPSTONE is extended to December 2025.
- Starling, which launched in July 2023, is the first demonstration of the capabilities for a fully autonomous distributed space mission.[72] Starling completed its primary mission objectives in 2024. Numerous "firsts" were achieved, including autonomous distribution of information and data between spacecraft, relative navigation using star trackers, and foundation of an ad hoc mesh network.

Demonstration missions awarded or under development in FY 2024 that made substantial advancements include the following:

- A Phase III Small Business Innovation Research contract was awarded to Starfish Space of Seattle, Washington, to develop and complete the Small Spacecraft Propulsion and Inspection Capability (SSPICY) mission. SSPICY will demonstrate electric propulsion capabilities for rendezvous and proximity operations.[73]
- The DiskSat technology demonstration team advanced through major milestones, including the verification of the spacecraft's design and readiness for continued development. DiskSat is a high-power and high-aperture alternative to CubeSats.[74]

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69 https://www.nasa.gov/mission/acs3/

70 https://www.nasa.gov/smallspacecraft/pathfinder-technology-demonstrator/

71 https://www.nasa.gov/mission/capstone/

72 https://www.nasa.gov/mission/starling/

73 https://www.nasa.gov/centers-and-facilities/ames/getting-sspicy-nasa-funds-orbital-debris-inspection-mission/

74 https://www.nasa.gov/mission/disksat/

In FY 2024, the Flight Opportunities program supported 84 tests of technology payloads via 38 flights with six U.S. commercial flight providers: Aerostar, Astrobotic, Blue Origin, Virgin Galactic, World View, and Zero Gravity Corporation. These flight tests took technologies into challenging gravity, pressure, thermal, and vibration conditions, increasing technology readiness and validating feasibility while reducing the costs and technical risks of future missions. Among the program's many accomplishments in FY 2024, the following are particularly noteworthy:

- Increasing Researcher Access to Flight Testing: Through its recent indefinite-delivery/indefinite-quantity solicitation, Flight Opportunities selected 15 companies to receive contracts, more than doubling its cadre of commercial flight providers. In addition, the contracts now provide access to hosted orbital vehicles, which offers researchers easier access to orbital testing of payloads.
- Hands-On Research During Suborbital Flight Test: The program supported Robert Ferl's flight aboard a Blue Origin suborbital rocket—the first for a NASA-funded researcher—leveraging the University of Florida researcher's familiarity with the payload and biological experiment objectives.[75]
- Innovations for Landing in the Dark: Nighttime flights tested three technologies to help spacecraft land safely at areas of significant scientific interest in the Moon's permanently shadowed regions.[76] The Astrobotic lander vehicle flew the payloads over the company's newly built simulated moonscape.
- A "Cell Tower in the Sky" for Wildland Firefighters: NASA, the U.S. Forest Service, and Aerostar conducted an 11-day high-altitude balloon flight over several U.S. fires, successfully testing a technology that provided persistent long-term evolution (LTE) coverage and infrared thermal imagery to incident teams.[77]
- Advancing a New Era in Space Optics: Parabolic flights with Zero Gravity Corp. enabled testing of a revolutionary "fluidic telescope" concept to determine if giant mirrors can be created from liquids in space.[78] These optics would significantly reduce cost, construction time, and failure risk and would allow astronomers to see farther and deeper into space with greater detail.

75 https://www.nasa.gov/directorates/stmd/first-nasa-supported-researcher-to-fly-on-suborbital-rocket/

76 https://www.nasa.gov/stmd-flight-opportunities/access-flight-tests/nasa-techleap-prize-information/nighttime-precision-landing/

77 https://www.nasa.gov/stmd-flight-opportunities/flight-summaries/improving-firefighter-safety-with-strato/

78 https://www.nasa.gov/directorates/stmd/niac/niac-studies/fluidic-telescope-flute-enabling-the-next-generation-of-large-space-observatories-2/

University of Florida researcher Rob Ferl (seated) and co-principal investigator Anna-Lisa Paul practice the experiment to study the effect of gravity transitions on the plants' gene expression. (Credit: University of Florida)

Early-Stage Innovations and Partnerships

The **Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR)** program invested more than $200 million in small businesses and research institutions in FY 2024 through its various Phase I, Phase II, and Post Phase II opportunities.[79]

- Phase I and II—NASA invested almost $45 million in 297 SBIR and STTR Phase I proposals from small businesses across the country to develop new technologies to address agency priorities, such as carbon neutrality and energy storage for various applications in space and on Earth. Approximately 34 percent of the companies selected were first-time NASA SBIR/STTR recipients. In addition, the program made 107 SBIR and 21 STTR Phase II awards—totaling over $111 million—to successful Phase I awardees to expand upon their prior work and create a prototype of their technology.
- Post Phase II—NASA invested over $34 million in American small businesses via its Post Phase II opportunities to continue technology development toward a NASA mission and/or commercialization. This work includes the Civilian Commercialization Readiness Pilot Program (CCRPP), Phase II–Extended, and Sequential Phase II, through which NASA invested in two U.S. small businesses for their work on 1) xWalker–Enhanced Inspection and Manipulation for Lunar Assembly and 2) Mars Oxygen and Methane System.

79 https://www.nasa.gov/sbir_sttr/

- SBIR Ignite—In FY 2024, NASA continued its SBIR Ignite pilot initiative, which has a greater emphasis on commercialization compared to the mainline SBIR solicitations. In December 2023, NASA announced its second round of SBIR Ignite Phase I awards, selecting 10 small businesses to receive up to $150,000 each; all 10 small businesses then were selected for up to $850,000 each in Phase II awards in August 2024. The third year of SBIR Ignite also got underway, with the Phase I solicitation releasing in June 2024 and selections announced in October 2024.

Since its inception in FY 2011, the **Space Technology Research Grants (STRG)** program has funded exciting space technology research via 1,090 grants at 133 universities across 48 states and the territory of Puerto Rico.[80] There are currently nearly 300 active awards. In FY 2024, NASA made 82 such awards across three solicitations:

- Eight new Early Stage Innovation awards are conducting research to develop radiation-tolerant sensing technologies, study the dynamics of rocket plume surface interactions during landings on the Moon and Mars, and advance novel new refrigeration systems for the cooling of spacecraft.[81]
- Eight new Early Career Faculty awards are leveraging the capabilities of university faculty early in their careers to develop solutions to the problem of orbital debris, improve the modeling of the heating of spacecraft during atmospheric entry, and develop novel new refrigerants for spacecraft thermal control.[82]
- Sixty-six new NASA Space Technology Graduate Research Opportunity grants are engaging university graduate students to work on research topics of high relevance to NASA while simultaneously training the next generation of the space technology workforce.[83]

The **NASA Innovative Advanced Concepts (NIAC)** program's early-stage investments funded transformative space technology concepts to bolster technology development, economic growth, and the expansion of national aerospace capabilities.[84] Visionary ideas from innovators across America were chosen for their potential to revolutionize future NASA missions through the development of bold, technically credible, early-stage breakthrough technologies. In FY 2024, NIAC awarded 13 Phase I awards, six Phase II awards, and one Phase III award totaling $7.9 million across industry, academia, and NASA Centers. NIAC also completed 14 2023 Phase I studies and six 2022 Phase II studies.

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80 https://www.nasa.gov/space-technology-mission-directorate/space-technology-research-grants/

81 https://www.nasa.gov/early-stage-innovations-esi/

82 https://www.nasa.gov/early-career-faculty-ecf/

83 https://www.nasa.gov/nasa-space-technology-graduate-research-opportunities-nstgro/

84 https://www.nasa.gov/stmd-the-nasa-innovative-advanced-concepts-niac/

Prizes, Challenges, and Crowdsourcing (PCC) conducts and promotes the use of prize competitions, challenges, and crowdsourcing projects as tools to advance NASA research and development and serve other mission needs.[85] The program had a prolific year in FY 2024, launching 65 NASA projects, receiving more than 10,000 solutions from more than 29,000 participants, and awarding more than $9 million using procurement and prize authorities. The program calculates that 96 percent of projects significantly or incrementally advanced the technology of NASA projects, and projects that used the PCC toolkit to solve a problem or meet a need reported a collective savings to NASA of more than $8.8 million when compared to using traditional methods.

- The program continues to mobilize and sustain NASA's internal crowd. In total, PCC hosted 28 internal challenges via the NASA Spark platform, with more than 1,200 solutions received across the agency.
- PCC concluded and named the winners of three long-duration **Centennial Challenges** in the summer of 2024:[86]
    - The Break the Ice Lunar Challenge awarded $1.5 million to two top-placing U.S. teams for developing and demonstrating rover technologies that could support excavation and transportation of icy regolith on the Moon's South Pole, a targeted site for crewed Artemis missions.[87]
    - In coordination with the Canadian Space Agency, NASA awarded $1.25 million to three U.S. teams in the Deep Space Food Challenge.[88] This challenge sought novel food production technologies or systems to provide low-waste, safe, nutritious, and tasty food for long-duration human exploration missions.
    - The Watts on the Moon Challenge awarded $1.5 million to two U.S. teams for their novel power transmission solutions addressing energy distribution, management, and storage.[89] The innovations from this challenge aim to support NASA's Artemis missions, which will establish a long-term human presence on the Moon.
- In September 2024, the program launched the LunaRecycle Challenge, a new $3 million Centennial Challenge that seeks the design and development of energy-efficient,

85 https://www.nasa.gov/prizes-challenges-and-crowdsourcing/

86 https://www.nasa.gov/prizes-challenges-and-crowdsourcing/centennial-challenges/

87 https://www.nasa.gov/general/california-teams-win-1-5-million-in-nasas-break-the-ice-lunar-challenge/

88 https://www.nasa.gov/news-release/nasa-awards-1-25-million-to-three-teams-at-deep-space-food-finale/

89 https://www.nasa.gov/news-release/nasa-awards-1-5-million-at-watts-on-the-moon-challenge-finale/

The husband-and-wife duo of Terra Engineering, Valerie and Todd Mendenhall, won the final phase of NASA's Break the Ice Lunar Challenge at Alabama A&M's Agribition Center in Huntsville, Alabama. Terra Engineering's "Fracture" rover, shown here, received the top prize after a series of trials, using terrestrial resources like gravity-offloading cranes, concrete slabs, and a rocky track with tricky obstacles to mimic the environment on the Moon. (Credit: NASA)

low-mass, and low-impact recycling solutions that address physical waste streams and improve the sustainability of lunar missions.[90]

The **Center Innovation Fund (CIF)** provides annual seed funding to each NASA center and NASA's Jet Propulsion Laboratory, stimulating workforce creativity and innovation by developing transformative technologies that may enhance or enable future NASA missions and advance national aerospace capabilities.[91] Since its inception in 2011, CIF has funded over 1,200 innovative center projects, generating approximately 380 NASA New Technology Reports, 450 publications, 100 patents and patent-pending applications, over a dozen commercial licenses, and two spinoff companies.

The **Early Career Initiative (ECI)** provides the opportunity for NASA early-career civil servants to propose and work on two-year technology projects with industry and academic partners, engage in hands-on technology development, and employ innovative approaches to project management.[92] Initiated as a pilot effort in 2014, ECI has funded 34 highly innovative projects through FY 2024 and has recently selected five new projects to start in FY 2025. To date, ECI projects have published at least 100 papers and 40 NASA New Technology Reports, resulting in three U.S. patents with an additional five patent applications pending.

90 https://www.nasa.gov/news-release/nasa-seeks-innovators-for-lunar-waste-competition/

91 https://www.nasa.gov/center-innovation-fund/

92 https://www.nasa.gov/center-innovation-fund/#Prior-ECI-Selections-Include

In FY 2024, the NASA **Technology Transfer (T2)** program saw a successful year of transferring technologies and software to industry and entrepreneurs:[93]

- T2 executed 180 licensing agreements, a 29 percent increase from the previous fiscal year. The program is currently finalizing a new strategic framework to enhance the program, as well as establishing a new Level 2 office at Glenn Research Center.
- T2 released 5,722 software usage agreements (SUAs), breaking the record for number of SUAs released in a fiscal year. This success can be attributed to streamlining the software release process, as well as a well-executed cross-agency release strategy including social media from multiple accounts.
- In January, NASA's *Spinoff* publication released the latest edition, which features success stories of more than 40 companies using NASA technology, expertise, and research to create new products and services for consumers across the world.

STEM Engagement

Sponsored and managed by STMD's Flight Opportunities program, NASA's TechRise Student Challenge invites teams of 6th- through 12th-grade students to design, build, and launch science and technology experiments for space exploration and Earth observation on suborbital flights.[94] In January 2024, NASA announced the third cohort of TechRise teams, representing nearly 500 students from 46 U.S. states and territories, including two tribally controlled schools.[95] In summer 2024, these 60 teams flew their completed payloads aboard either a high-altitude balloon (World View) or a rocket-powered lander (Astrobotic).

In November 2023, seven university teams—awarded about $1.1 million in March 2023—showcased their concepts supporting metal production on the Moon at the Breakthrough, Innovative, and Game-Changing (BIG) Idea Challenge Forum.[96] Among the teams acknowledged, the University of Utah received top honors, researching how to extract and refine iron from reduced lunar regolith. The BIG Idea Challenge is sponsored by NASA through a collaboration between STMD's Game Changing Development program and the Office of STEM Engagement's National Space Grant College and Fellowship Project.

In July 2024, NASA announced that 23 minority-serving institutions would receive up to $50,000, $1.2 million in total, to grow their research and technology capabilities and collaborate on research projects through NASA's Minority University Research and Education Project

93 https://technology.nasa.gov/

94 https://www.nasa.gov/stmd-flight-opportunities/access-flight-tests/techrise/

95 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-selects-winners-of-third-techrise-student-challenge/ and https://www.bie.edu/news-article/bie-students-kansas-south-dakota-participate-nasa-techrise-student-challenge

96 https://www.nasa.gov/centers-and-facilities/langley/university-teams-take-off-the-training-wheels-to-develop-alternative-rovers/ and https://www.nasa.gov/directorates/stmd/university-of-utah-takes-top-honors-in-big-idea-lunar-forge-challenge/

(MUREP) Partnership Learning Annual Notification (MPLAN) award. MPLAN originated as a collaboration between STMD and MUREP and now receives support from NASA's Aeronautics Research Mission Directorate and Space Operations Mission Directorate.

Pictured here from left to right, Zephyr Proffitt and Tayah Day of Red Mountain High School in Mesa, Arizona, work on building their experiment during the 2023–2024 TechRise Student Challenge. (Credit: Red Mountain High School)

Throughout FY 2024, STMD continued to promote both issues of its interactive graphic novel series, *First Woman: NASA's Promise for Humanity*. The series aims to inspire the next generation of explorers as NASA works toward landing the first woman and first person of color on the Moon under the Artemis program. The second issue, released digitally in English and Spanish in early FY 2024, introduced new characters to broaden its outreach, including to Native American and Indigenous communities and international partners. The accompanying immersive app was also updated, adding six new technologies and one new extended reality environment, which allows users to engage with the telescope mission featured in the story. *First Woman* connects with diverse audiences, promotes STEM literacy, and highlights the technology innovations critical to NASA's missions.

Mission Support Directorate

The Mission Support Directorate (MSD) enables NASA's missions by providing foundational support capabilities responsive to evolving space and flight mission needs. These services and capabilities ensure that NASA has the right people, technical skills, physical assets, and financial resources it needs to explore the unknown, innovate for the future, and inspire the world.

MSD manages the funding, governance, and strategic alignment of the following NASA budgetary programs: Mission Services and Capabilities; Engineering, Safety, and Operations; Construction of Facilities; and Environmental Compliance and Restoration.

Mission Services and Capabilities

The Mission Services and Capabilities program provides enterprise support service solutions including workforce, information technology, mission-enabling services, and infrastructure and technical capabilities. Each program ensures that critical agency operations are effective, efficient, and safe and meet statutory, regulatory, and fiduciary responsibilities. These mission-enabling services and capabilities provide efficient and effective administration across all NASA centers and NASA Headquarters. Some FY 2024 accomplishments within Mission Services and Capabilities include the following:

- Exceeded the 90 percent implementation goals outlined in Executive Order 14028 titled "Improving the Nation's Cybersecurity" for critical cybersecurity measures on all information systems, including data encryption and multi-factor authentication, solidifying NASA's IT security posture against data loss and mitigating the risk of malicious attacks on mission-critical systems.
- Processed millions of still images from on board the International Space Station, hundreds of thousands of Earth observation time-lapses, and archived over 8,000 hours of mission video. The NASA Mission Imagery Photo Archive team performed myriad activities in support of NASA's imagery needs, including digitization of physical imagery, processing downlinks, managing metadata to ensure searchability, and archiving as appropriate. Among other purposes, the processing, cataloging, and archiving of downlinked imagery support Mission Control playbacks to assist critical real-time decisions.
- Finalized and initiated a 20-year vision for guiding future development and resource allocation across NASA with the implementation of the Agency Master Plan. The Plan addresses current and future challenges, mission stakeholders' engagement, and agency budget alignment, and it identifies desired outcomes for all real property through data-driven planning. By prioritizing mission requirements in a cost-effective manner, the Plan also drives affordability, particularly in the context of a significantly underfunded maintenance and construction budget.

- Supported 33,969 hours of space environments testing and simulation and completed a large chamber study in conjunction with the Agency Master Plan to assess productivity and value of all chambers in alignment with current mission requirements. The strategic valuation of these assets in conjunction with total life-cycle cost information for this set of capabilities is critical to NASA's mission.
- Introduced the *ASPIRE* program, an internal leadership development cohort focusing on a diverse, agency-wide group of senior-level employees selected for their high potential for assuming executive-level roles and responsibilities in support of NASA's evolving missions. The program provides extensive professional development to prepare the next generation of NASA leaders.
- Implemented an agency-wide mentoring engagement pilot called *AMPED* to make mentoring and development open to NASA civil servants from across the agency, including those in a hybrid work environment. Mentoring dramatically reduces turnover and gives employees the type of personal engagement they want and need.
- Executed over 130 new agreements or agreement extensions with foreign partners across NASA's entire portfolio of activities, which can contribute significantly to the national goals of each partner. Facilitated 14 new Artemis Accords signatories, bringing the total to 43 at the end of FY 2024. The Artemis Accords facilitate a sustainable future in space exploration for the international community by providing a common set of governing principles.
- Provided emergency management, uniformed protective services, and fire support to NASA and its partners during launches. This entails securing the flight caution area, providing crew and family protection, managing guest access to the center, vetting foreign nationals, conducting pad rescue, and coordinating counter-unmanned aircraft support.

Engineering, Safety, and Operations

Engineering, Safety, and Operations provides for the management and operations of NASA Headquarters, nine centers, and component facilities under the Agency Technical Authority and Center Engineering, Safety, and Operations programs. Both programs support scientific and engineering activities. They contribute to the reduction of program risks by ensuring that technical skills and assets are ready and available to meet program and project milestones, mission and research endeavors are technically and scientifically sound, and center practices are safe and reliable. Some FY 2024 accomplishments within Engineering, Safety, and Operations include the following:

- Led efforts to ensure independent technical insight and assessment of programs at key programmatic milestones. Identified and recommended opportunities for major

improvements through reinvention or reengineering and through the review of engineering requirements and standards. These activities contributed to the successful launches and missions of Psyche, Crew-8, and Crew-9, as well as the safe launch and return of the Boeing Crew Flight Test.

- Published guidance to support multiple human spaceflight programs, including Orion, Space Launch System, Gateway, Human Landing System, extravehicular activity, and Lunar Surface Mobility. The recently published guidance explains to NASA partners how to show that the design of an avionic system meets safety requirements for crewed missions.
- Supported the development and execution of more than 24 research protocols in behavior and performance, group dynamics, individual adaptation to isolation and confinement, viral reactivation, and nutrition in extreme environments.
- Supported 16 of NASA's highest-profile programs and projects by assuring that safety- and mission-critical systems and software will operate reliably, safely, and securely. Identified 1,242 significant software-related issues, including 43 issues with the potential to cause loss of mission or degradation of an essential mission capability.
- Obtained successful system requirements review and preliminary design review for a technology demonstration mission of the Multi-layer Acoustics and Conductive-grid Sensor (MACS) flight unit. MACS will detect millimeter-sized orbital debris at 600 to 1,000 kilometers altitude, a capability that will fill a crucial gap in future mission planning and assessment of space environments.

Construction of Facilities

Construction of Facilities repairs the NASA facilities so they can support mission needs. Construction of Facilities focuses on the agency's highest-priority construction projects and continues to replace obsolete and deteriorating facilities that directly support NASA's mission. Some FY 2024 accomplishments include the following:

- Divested of 39 facilities, resulting in an annual maintenance cost avoidance of $1 million.
- Removed a total of $5.5 million in deferred maintenance projects through divestment.
- Reduced 530,000 square feet in NASA's infrastructure portfolio through divestment.
- Participated in 55 active Enhanced Use Leases across the agency.

Environmental Compliance and Restoration

Environmental Compliance and Restoration supports agency-wide environmental compliance and risk management initiatives. At every center, Environmental Compliance and Restoration

is investigating contaminated sites; remediating contaminated soil, water, and other media; and monitoring for continued compliance with agency objectives and obligations. Some FY 2024 accomplishments include the following:

- Engaged with the Environmental Protection Agency and sought expert interpretation of the Toxic Substance Control Act to reveal potential programmatic risks and near-term solutions to avoid those risks. Toxic Substance Control Act regulations are designed to improve personnel safety through the elimination of possible exposures to toxic substances. NASA's activities in these areas ensure compliance with regulations and protect the NASA workforce.
- Removed 2,600 pounds of trichloroethylene from the Santa Susana Field Laboratory groundwater using two pilot treatment techniques.
- Treated more than 1.8 billion gallons of contaminated groundwater at all centers to ensure compliance with regulations and protect human health and the environment.

Department of Defense

DOD

Aeronautics

Rotorcraft

Army

In FY 2024, Army Aviation remained committed to modernization and readiness advancements to increase the capabilities and lethality of Aviation forces in multi-domain and large-scale combat operations. Nested within the Army's Regionally Aligned Readiness and Modernization Model, the Aviation enterprise strove to strike a balance between the demands associated with modernization and the need for a highly trained ready force that continues to see high demand. Army Aviation remained deployed in support of U.S. Central Command, U.S. European Command , and U.S. Indo-Pacific Command). Home station aviation formations conducted training in support of their assigned Divisions focused on large-scale combat operations, humanitarian assistance support, disaster relief efforts, and training for contingencies.

In FY 2024, the Army continued its modernization efforts across the entire aviation fleet. Rotary-wing aircraft fielding of the AH-64E Apache, HH/UH-60M Black Hawk, CH-47F Chinook, UH-60V Black Hawk, and UH-72A/B Lakota ensured that Army aircraft will provide capability for decades to come. As the Army modernizes its current fleet of rotary-wing aircraft and Unmanned Aircraft Systems (UAS), it looks to the future with Future Vertical Lift (FVL) initiatives. The FVL Cross-Functional Team (CFT) worked closely with industry and is already integrating new technologies into the current force.

The AH64D/E is the Army's attack and reconnaissance helicopter. During FY 2024, the Army continued fielding the newest AH64E version 6 to active and National Guard units. AH-64E Version 6 delivers quality and capability improvements to include the latest communications, navigation, sensor, and weapon systems. The E-model has multiple upgrades from

its predecessors, such as the improved Modernized Target Acquisition Designation Sight/Pilot Night Vision System, which includes a new integrated infrared laser that allows for easier target designation and enhanced infrared imagery capabilities. The AH-64E Version 6 also provides Manned/Un-Manned Teaming Extended, which allows video from 62 offboard sensors to be seen by the flight crew and allows for control of the MQ-1C Gray Eagle.

The UH/HH-60 Black Hawk is the Army's combat utility helicopter. This flexible system provides air assault, aeromedical evacuation, command and control, and general support to full-spectrum operations across the multi-domain environment. The Program Executive Office for Aviation's Utility Helicopters Project Office continued to modernize the Black Hawk fleet with the UH-60V in FY 2024. The UH-60V updates legacy analog systems to a digital and open architecture. This architecture provides commonality with the UH-60M using a similar Pilot-Vehicle Interface.

The CH-47F Chinook is the Army's only heavy-lift cargo helicopter supporting combat and other critical operations. In FY 2024, the Army continued fielding CH-47F Block I aircraft and accepted delivery of two CH-47 Block II aircraft. Block II is a performance update to Block I aircraft, consolidating multiple separate engineering change proposals to maintain airworthiness and sustainment of the Chinook fleet while addressing obsolescence concerns on the current fleet. The CH-47F Block II program provides additional benefits to increase commonality and interoperability across the H-47 fleet; improve design life; lower maintenance cost; and enhance reliability, safety, airworthiness, and cybersecurity.

Future Vertical Lift

The FVL CFT is an Army-led, multi-service initiative, focused on enhancing vertical lift dominance through affordable next-generation assets that provide increased reach (speed, range, and endurance), protection, lethality, agility, and mission flexibility. The CFT addresses aviation capability gaps against peer and near-peer competitors through four signature modernization efforts: 1) Future Long Range Assault Aircraft (FLRAA), 2) Future Unmanned Aerial Systems (FUAS), 3) Launched Effects (LE), and 4) Modular Open System Approach (MOSA).

FLRAA is a tiltrotor aircraft designed to replace a portion of the UH-60 fleet. FY 2024 efforts continued to feed FLRAA requirements through Special User Evaluations providing critical soldier-led feedback. Soldiers provided vital input while evaluating cabin configurations and rapid ingress and egress options during air assault operations. As part of FUAS, the Future Tactical Unmanned Aerial Systems (FTUAS) competitive flight demonstrations were performed by two vendors seeking to inform future requirements.

In FY 2024, the CFT continued its campaign of learning through ongoing demonstration and experimentation. Significant FY 2024 events included Project Convergence Capstone 4 (PCC4) and Experimentation Demonstration Gateway Event (EDGE24). PCC4 was an Army

Futures Command–led modernization event that incorporated and informed FVL signature efforts while also allowing FVL efforts to nest with larger Army employment concepts. The PCC4 experimentation event focused on integrating LE into deep sensing operations to learn how autonomous behaviors can provide critical priority intelligence to commanders at all levels. EDGE24 was an FVL CFT-led event that featured 15 industry and government partners focused on experimentation with collaborative autonomous behaviors that informed LE. In support of those efforts, EDGE24 involved robust data collection/analysis from the Army's Test and Evaluation Command for feedback and lessons learned.

Navy

The CH-53K King Stallion provides the Marine Corps with a platform with increased lift, range, survivability, and maintainability compared to the legacy CH-53E. CH-53K delivered six aircraft in FY 2024 and continues to make progress toward its first operational deployment in FY 2027.

The VH-92A Patriot Presidential Helicopter completed a major milestone by conducting its first Presidential Lift mission in August 2024. Also during FY 2024, VH-92A became the first rotary-wing aircraft in the world to fly with the SpaceX Starlink/Starshield Proliferated Low Earth Orbit Satellite Communication capability. Additionally in FY 2024, the final VH-92A aircraft was delivered to the government, closing out the production run of 23 aircraft.

The V-22 Osprey tiltrotor capability remains in high demand from Combatant Commanders for the essential transportation of personnel and equipment in support of worldwide operations. In FY 2024, the program continued progress toward improvements in safety and reliability through enhancements to the design and monitoring of critical components. The U.S. Navy V-22 variant, the CMV-22, delivered six aircraft in FY 2024, and the U.S. Marine Corps MV-22 variant delivered six aircraft in FY 2024. The program continued progress toward the redesign of the Input Quill Assembly and made progress toward the Tailored Nacelle Improvement, a cost-effective initiative to increase fleet reliability and maintainability.

The AH-1Z and UH-1Y program is focused on maintaining combat capability to meet and defeat near-peer threats as part of the Marine Littoral Regiment. In FY 2024, two Developmental Test Aircraft were modified with a Digital Interoperability upgrade providing Link-16 connectivity, and the aircraft have begun Structural Improvement and Electrical Power Upgrade modifications, thus optimizing the aircraft to improve mission capabilities, aircrew safety, and interoperability by increasing the electrical power capacity on the aircraft.

In FY 2024, the Navy approved the Analysis of Alternatives for a Future Vertical Lift Maritime Strike (FVL[MS]) platform and commenced the creation of the Capability Development Document. FVL(MS) will fill critical capability gaps left when the aging MH-60 and MQ-8 fleets reach their end of service life.

Fixed Wing

Navy

In FY 2024, the F-35 Lightning II Joint Strike Fighter (JSF) Program delivered its 265th aircraft to the Department of the Navy and its 1,000th aircraft across all partners and Foreign Military Sales (FMS) cases. The F-35 Program also received Under Secretary of Defense for Acquisition and Sustainment Milestone C approval on March 12, 2024, to proceed into the Production and Deployment Phase and continue into the Operations and Support Phase. The JSF Program secured its 10th and 11th FMS cases and onboarded the Czech Republic and the Hellenic Republic of Greece, via signed Letters of Offer and Acceptance, for the procurement of 24 F-35As valued at $4.5 billion and 20 F-35As valued at $3.5 billion, respectively.

The Navy continues to phase out its E-2C aircraft as it transitions its squadrons to the E-2D Advanced Hawkeye. To date, the program has delivered 62 aircraft, which have been deployed as part of the carrier strike group and are providing early warning and battle management command and control for the fleet. The Navy has fielded multiple Delta System/Software Configurations and will continue to update them to remain on pace with future threats and maintain platform performance.

In FY 2024, the Navy continued its Service Life Extension Program of the E-6B Mercury National Command and Control Aircraft and delivered its ninth Block II configured aircraft to the fleet. The E-6B Recapitalization program continued progress toward entry into the Engineering Manufacturing Development phase in FY 2024 and plans for contract award in early FY 2025. This program will utilize the C-130J stretched Super Hercules with a combination of existing and modernized nuclear command, control, and communications mission systems.

The P-8A Poseidon is DOD's only long-range, full-spectrum, Anti-Submarine Warfare, cue-to-kill platform, with substantial armed Anti-Surface Warfare and networked intelligence, surveillance, and reconnaissance capabilities. The P-8A continued Increment 3 Block 2 development and testing with two test aircraft in FY 2024, the largest P-8A post-production modification to date. Additionally, the first three U.S. Navy Fleet aircraft were inducted into modification at the Boeing Cecil facility in FY 2024.

The Navy offers the Department of Defense a specialized airborne electronic attack platform, the EA-18G Growler, deployed from both aircraft carriers and expeditionary airfields. The EA-18G is integral to sustaining combat power by denying adversaries control of the electromagnetic spectrum. With over 15 years of combat experience, the fleet is now being modified to bring Growler Block II online, a critical component of the Joint Warfare Concept 3.0. In FY 2024, the fleet integrated the Next Generation Jammer Mid-Band (NGJ-MB), which represents a substantial improvement in capability over legacy jammers. By integrating NGJ-MB, advanced sensors, mission computers, crew-vehicle interface, and state-of-the-art

networking with the Growler's venerable legacy capabilities, Growler Block II represents a critical step in maintaining dominance in the electromagnetic warfare domain. Further, the Navy awarded a contract in FY 2024 for the engineering and manufacturing development of the Next Generation Jammer Low-Band. This latest increment will counter a larger capacity of adversary systems in the low-frequency electromagnetic spectrum.

The Navy's fourth- and fifth-generation strike fighter programs, including the F/A-18 Super Hornet, are essential for advancing air combat capabilities with enhanced stealth, sensor integration, and strike power. The Super Hornet, which entered service in the late 1990s, remains highly versatile and the backbone of the Carrier Air Wing. The aircraft has been modernized through numerous upgrades, including the introduction of Block III, which adds advanced network-centric capabilities, improves survivability, and reduces radar signature. In FY 2024, the Navy continued to extend the life of these aircraft to 10,000 flight hours and upgraded the F/A-18E/F aircraft to the Block III configuration capability.

Air Force

The B-21 Raider conducted a successful first flight on November 10, 2023.

Unmanned Aircraft System

Army

In FY 2024, the Army issued an Aviation Rebalance Execution Order (EXORD) identifying Shadow systems for divestiture by September 30, 2024. While the Shadow Block III was originally identified as the replacement for the RQ-7Bv2 Shadows in the Brigade Combat Teams (BCT) and Special Operation Forces, the EXORD reprioritized the FTUAS to replace all Shadows in the field. FTUAS provides vertical takeoff and landing requirements and a runway-independent capability to supply the BCT commander with a Multi-Domain Operations–capable Reconnaissance, Surveillance, and Target Acquisition (RSTA). FTUAS is currently executing a Middle Tier Acquisition–Rapid Prototyping (MTA-RP) effort. In FY 2024, FTUAS down selected the number of vendors in competition to two to execute the MOSA conformance and developmental testing phases.

The LE Family of Systems consists of short-range (SR), medium-range (MR), and long-range (LR) variants. Each variant consists of an air vehicle, effector payload, missions system applications, and associated support equipment designed to autonomously or semi-autonomously deliver effects as a single LE or as a member of a team. In FY 2024, LE-MR continued to execute an MTA-RP.

In FY 2024, the Army identified the requirement for a Maneuver Battalion and lower-level UAS to ensure the ability to conduct RSTA with multiple payloads. These initiatives include Short Range Reconnaissance (SRR) and Medium Range Reconnaissance (MRR). SRR

operates at the Platoon Level and is composed of two planned tranches of capability. Tranche 1 completed fielding in FY 2024. The MRR enables Maneuver Companies to conduct reconnaissance, communications extension relay, Lethality Anti-Personnel/Anti-Materiel, Electronic Warfare-sensing/Signals Intelligence missions, etc.

Navy

The MQ-4C Triton provides a UAS to meet the requirements for persistent global maritime Intelligence, Surveillance, and Reconnaissance (ISR) services. Along with the P-8A Poseidon, the MQ-4C Triton UAS is an integral part of the Maritime Patrol and Reconnaissance Force. In 2024, MQ-4 successfully stood up two additional orbits in support of the 6th and 5th Fleet while sustaining 7th Fleet operations. The program also continued the development of the next increment of advanced payload capabilities. Additionally, the program delivered the first UAS to Australia in support of the Co-Operative program.

The MQ-25 program is rapidly developing an unmanned capability to embark on CVNs (aircraft carriers) to increase the strike range, capability, and lethality of the Carrier Air Wing through organic mission and recovery tanking. In FY 2024, the MQ-25 program completed multiple lab integration test events, and the static test article was delivered for testing. The Unmanned Carrier Aviation Mission Control System is the system of systems required to control the MQ-25A air vehicle; the first installation of a CVN Unmanned Air Warfare Center completed onboard the USS George H.W. Bush (CVN 77) in FY 2024.

The MQ-9A Marine Corps Block V (Extended Range) Marine Air Ground Task Force UAS Expeditionary Medium Altitude Long Endurance program addresses shortfalls in high-endurance, long-range unmanned systems with ISR, Electronic Warfare, and lethal strike capabilities. In FY 2024, the program deployed two operational detachments to the 7th Fleet and continued the development of the next increment of advanced payload capabilities.

Weapons

Navy

Tactical Tomahawk (TACTOM) is the Nation's premier, all-weather, long-range, deep-strike offensive weapon against fixed and mobile targets. It is launched from surface, subsurface, and ground platforms. In FY 2024, the TACTOM program pursued multiple phases to increase production capacity as overall demand increased across DOD and foreign FMS customers. In addition, the program made significant progress in the development and testing of the Block V Maritime Strike Tomahawk and Joint Multiple Effects Warhead System variants in FY 2024, which achieved additional requirements while utilizing existing infrastructure.

The Long-Range Anti-Ship Missile (LRASM) is a semi-autonomous, long-range anti-ship missile that reduces dependence on external targeting platforms and Global Positioning System

navigation with capability to penetrate sophisticated enemy air defense systems. In FY 2024, LRASM continued incremental upgrades to capabilities to deter adversaries and enable lethality in contested environments. Additional improvements in performance, range, survivability, and the addition of a land attack capability are underway. Expanded aircraft platform integration efforts and execution of the LRASM FMS case ensure versatility in employment.

The Hypersonic Air-Launched Offensive Anti-Surface Warfare (OASuW) (HALO) weapon system represents a longer-term capability that encompasses both increased performance and the capacity to target and neutralize near-peer fleets, protecting U.S. maritime interests. In FY 2024, the HALO program continued competitive technical maturation and design development culminating in Technical Review events.

Aviation Survivability Equipment

Army

Aviation Survivability Equipment (ASE) is essential to providing protection for aircraft against current and emerging advanced threats. The focus of Army ASE is to ensure that the current fleet of aircraft remain protected against threats while developing to integrate ASE on FVL aircraft. Current fielded ASE systems include the Common Missile Warning System, Limited Interim Missile Warning System, Advanced Threat Infrared Countermeasures, Common Infrared Countermeasure, APR-39C(V)1/4 and APR-39D(V)2 Radar Warning Receivers, and AVR-2B Laser Detection System (LDS).

AVR-2B LDS alerts aircrew to laser energy from enemy weapon systems and is factory-modified on the AH-64 and UH-60. It began fielding on CH-47 aircraft in FY 2024.

Propulsion

Army

The Improved Turbine Engine (ITE) T901 is the replacement engine for the UH60 and AH64 Fleets. The T901 is designed to address current performance capability gaps, increasing aircraft range, endurance, and payload. The ITE Program continued making significant accomplishments throughout FY 2024. Most notably, two T901 engines were delivered in June 2024 for integration in the UH-60M platform. The delivery of the two engines to the UH-60M marked the first two T901 engines that will be flown in the enduring fleet.

Advanced Manufacturing for Aeronautics and Space Technology

Advanced manufacturing and innovation are essential to America's leadership in aeronautics and space technology. The Department of Defense Manufacturing Technology Program (DOD ManTech) aids that mission through helping to build a responsive world-class manufacturing capability to meet warfighter needs affordably and rapidly throughout the defense

system life cycle. While DOD ManTech supports technologies across the Services many of the program's activities promote joint applications that advance American aeronautics and space technology. The following DOD ManTech activities occurred in FY 2024:

- Navy ManTech's Composites Manufacturing Technology Center (CMTC) developed an alternative method to fabricate non-flight-critical parts that will support the F-35 Program's full rate production. Navy ManTech leveraged previous data to validate HexPEKK® 3D-printed material and demonstrated performance against F-35 specifications for non-flight-critical parts. Candidate parts developed and tested could be implemented on aircraft as early as FY 2025. Savings of over $16 million for the F-35 Program are estimated.
- Navy ManTech's CMTC developed and demonstrated an automated in-process inspection system for automated composite lamination. The inspection system provides a significantly more robust and repeatable process and removes a considerable degree of the variability introduced by manual layup. An automated in-process inspection system has significant potential to mitigate or eliminate costly rework and excessive material consumption and increase production rates. Navy ManTech's technology targets automated fiber placement machines used to produce nacelles for the F-35 Program.
- Air Force ManTech engineers established a memorandum of understanding with the NASA In-Space Manufacturing (ISM) Program at Marshall Space Flight Center to develop joint roadmaps related to in-space welding; in-space electronics manufacturing; and space access, mobility, and logistics. These roadmaps will aid in fostering future collaborations and gap identification, ensuring that both civil and military needs are being met from future ISM efforts. This partnership represents a major step forward in advancing in-space manufacturing capabilities and will have a significant impact on future space missions.
- The DOD Joint Additive Manufacturing Working Group launched Workbench for Additive Materials (WAM). WAM securely shares additive manufacturing (AM) materials performance data, materials allowables, and design curves within U.S. Government (USG) agencies. WAM hosts both internal USG-developed materials data and data licensed to the USG. An advisory team evaluates the pedigree of the data to ensure quality. The initial deployment of WAM contains four sets of metal AM data for key aerospace alloys.
- The OSD ManTech Joint Acceleration of Hypersonic Vehicle Aerostructure Alternatives (JAHVAA) program kicked off a milestone-based three-round competition to look at alternative high-temperature materials to Carbon-Carbon (C/C)

through extended processing development and testing. The manufacturability improvements of Thermal Protection System materials for Hypersonic Glide Vehicles may ease the burden on the C/C supply chain and create manufacturing parallel paths, potentially benefiting the aeronautical systems materials supply chain.

- OSD ManTech Manufacturing of Carbon-Carbon Composites for Hypersonics Applications (MOC3HA) Task 5 is taking the manufacturing technologies from earlier tasks of automation, acceleration, and variability reduction of 2D/3D Carbon-Carbon composites and transitioning the technology into a relevant production environment to be demonstrated on hypersonics program relevant parts. These investments strengthen the Carbon-Carbon supply base, which is a material commonly used in aeronautical and space systems.

One unique program launched and supported by DOD ManTech is the set of nine DOD Manufacturing Innovation Institutes. Each institute is a public-private partnership designed to overcome the challenges faced by American manufacturing innovators in a variety of technology areas. In FY 2024, many of the institutes collaborated with their industry, academia, and small business members to accomplish several successes in advanced manufacturing for aeronautics and space technology. Examples of those successes are provided below:

- America Makes has been working with Ursa Major Technologies, Inc. (Ursa Major) since 2021 to successfully advance the productionization of AM for advanced copper alloy (GRCop-42) components. GRCop-42 is a NASA-developed alloy used in high-heat applications such as liquid rocket engine combustion devices due to its high thermal conductivity and strength. Most recently, Ursa Major demonstrated a robust and efficient process for developing high-performance rocket engine components using AM, specifically the thrust chamber assembly for the Hadley engine, where GRCop-42 AM enabled enhanced engine performance. Ursa Major's rocket engines are more than 80 percent 3D-printed by mass, allowing for accelerated development and production timelines and the application of real-time improvements from testing, ultimately reducing costs. America Makes kicked off Phase 3 of the High-Temperature Application Program, where discussions focused on opportunities to test and evaluate Ursa Major's Storable Liquid Rocket Engine, known as Draper, on a Stratolaunch hypersonic test vehicle.
- Manufacturing x Digital (MxD), the DOD Digital Manufacturing and Cyber Security Institute, conducted a Digital Education, Resilience, and Innovation for Supply Chain (DERISC) for one of the world's preeminent manufacturers of highly efficient integrated power and propulsion solutions. The DERISC provides U.S. manufacturers with a unified and systematic approach to renewing and securing their supply chains by providing the tools, protocols, skills, and information they need to

undertake a secure digital transformation. DERISC is a comprehensive methodology to develop a one-of-a-kind platform that will inform, empower, and train U.S. manufacturers and their workforce to lead in the opportunities and challenges they face today in cybersecurity. The company used the project to secure several hundred of its suppliers.

- MxD piloted and validated a Technical Data as a Service project for a leading global aerospace company headquartered in the United States. The purpose of the project was to develop a Data-as-a-Service Platform for collection, storage, management, and access of Technical Data Packages (TDPs) to facilitate the acquisition of technical data. The platform captures the as-designed TDP and the as-built TDP as the product moves through the various life-cycle activities. This promotes the accurate exchange of technical data between the manufacturer and suppliers.
- MxD conducted a Sensor Augmented Factory Environment (SAFE) project for a leading global aerospace company headquartered in the United States. The SAFE project was structured to develop, test, and demonstrate an Internet of Things (IoT) architectural framework for integrating end-point devices as sensor technologies that assess common worker safety risks in a manufacturing environment. The project focused on wearable technologies for workplace safety and associated IoT integration protocols for privacy and security.
- AIM Photonics, the integrated photonics DOD manufacturing innovation institute, received $73,000 from NASA's Langley Research Center (LaRC) for "Government Access." NASA civilian researchers at LaRC submitted a photonic integrated circuit design to AIM Photonics for fabrication on March 4, 2024, under AIM Photonics' 24-01 Active multi-project wafer run. Under this work, NASA is seeking to explore applications, including photonic lanterns. Other groups across NASA also submitted designs to AIM Photonics in FY 2024 for fabrication under beta-run offerings to explore quantum-photonic devices, including researchers at Goddard Space Flight Center and the Jet Propulsion Laboratory. This activity identifies how AIM Photonics is enabling NASA researchers to perform critical work to support future space missions by leveraging the manufacturing capabilities developed under and accessible through AIM Photonics.
- NextFlex, the flexible hybrid electronics DOD Manufacturing Innovation Institute, collaborated with General Dynamics Mission Systems (GDMS) and the University of Massachusetts Lowell to develop direct-write techniques for the integration of lightweight circuits directly onto composite structures used in space vehicles. The developed technology allows for significant mass savings in electronics by removing the need for a traditional printed circuit board. Through a project with NextFlex,

engineers at GDMS and the University of Massachusetts Lowell demonstrated manufacturing techniques for integrating conformal electronic circuits with active and passive components into doubly curved, non-planar composite structures. Leveraging previous Institute project results, the team developed processes to print metallic patterns onto the composite parts and attach electronic components. GDMS plans to transition this manufacturing technology to integrate circuits, sensors, and antennas into multilayer composite structures.

- The ARM Institute (ARM-I), the Advanced Robotics for Manufacturing DOD Manufacturing Innovation Institute, has led a team including members from Lockheed Martin, the University of Southern California, Carnegie Mellon University (CMU), and CapSen Robotics to develop a proof-of-value prototype for a fixtureless robotic assembly system (FRAME). This reconfigurable autonomy software enhances high-mix/low-volume manufacturing by autonomously identifying, inspecting, and assembling parts while optimizing human-robot collaboration. The FRAME prototype demonstrated mock-up satellite assembly capabilities to significantly reduce production costs by minimizing setup and labor times, addressing the complexities of traditional manufacturing methods that rely on custom fixtures and pre-programmed motions. It tackles key challenges such as task planning, high-fidelity sensing, dexterous grasp planning, real-time adaptive processes, and a contingency planner to ensure efficient assembly without compromising quality. Ultimately, FRAME serves as an open standard architecture that enables the ARM-I community to enhance their capabilities by integrating various robots and sensors into their operations.
- The ARM-I has led a team primed by RTX and partnered with the Robotics Institute at CMU and Wason Technology to develop robotic capabilities for continuous ultrasonic welding (CUW) of lightweight carbon-fiber-reinforced thermoplastic composites (CF-TPCs), achieving a potential 3 to 5 times increase in welding speed. Key accomplishments included the establishment of two robotic welding cells, the design and integration of a CUW end effector, and the development of a multi-modal sensor package for enhanced control. A Neural Network-based in situ control method and sensor-based adaptive planning were successfully demonstrated, showcasing the technology's capability to handle both large and small composite parts. The project's successful demonstrations and assessments confirmed that all key performance parameters were met, significantly advancing the readiness level of the CUW process. This achievement is expected to facilitate the adoption of CF-TPCs in the aerospace industry, enhancing manufacturing efficiency and recyclability.
- The ARM-I led a team from GridRaster Inc. and Lockheed Martin to develop a highly accurate, modular mixed-reality (MR) technology stack for Department of

Air Force depots. This MR solution demonstrated accurate part localization in space to assist robotics with tasks like part identification and optimized path planning for robotic painting operations while eliminating the need for costly camera infrastructure and improving throughput.

- The ARM-I, with the support of Air Force ManTech, led the Depot-Factory Artificial Intelligence for Repair (DFAIR) program with prime investigator Titan Robotics, Inc. DFAIR demonstrated an enhanced mobile manufacturing robotic systems at Warner Robins Air Logistics Complex by integrating advanced artificial intelligence (AI) and machine learning technologies. The project addressed technology gaps by developing modular hardware and software that enabled efficient fastener identification and classification without prior knowledge of the part, optimized defastening operations, and facilitated semi-autonomous operation. Titan Robotics, Inc., successfully demonstrated the technology on an F-15 wing, showcasing significant improvements in process efficiency and accuracy. Titan Robotics, Inc., highlighted the scalable AI methodology that could enhance defastening operations across Air Force depots.
- The ARM-I has partnered with the Air Force Research Laboratory (AFRL) and the Boeing Company on a project titled "Connected Learning: Secure Computing for Cloud Robotics." This initiative, involving Boeing Research and robotics integrator Electro Impact, successfully established the machine learning operations pipeline to acquire data and demonstrated the trained micro-service in a cloud environment leveraging its manufacturing facility in St. Louis, Missouri. This micro-service will be used to train an Electro Impact robotic system at Tinker Air Force Base, Oklahoma, in the future. The project highlights the importance of advanced robotics and digital manufacturing in the efforts of scaling robotic solutions across the Air Force Organic Industrial Base.
- The ARM-I has partnered with AFRL and Titan Robotics, Inc., to leverage Autonomous Mobile Manipulators (AMMs) to support the workforce. The Agile Autonomous Mobile Manipulator (A2M2) Project has developed a common AMM architecture that prioritizes modularity, scalability, and robustness, enabling efficient implementation across various United States Air Force (USAF) facilities. This standardized approach reduces costs and development time, thus addressing challenges related to custom-designed AMMs. The flexibility and adaptive autonomy of AMMs facilitate high-precision tasks in diverse environments, aligning with the USAF's sustainment goals. Ultimately, the A2M2 architecture promotes industry standardization, paving the way for broader cost-effective deployment of flexible AMMs within DOD.

Space

The United States Space Force

For information about the United States Space Force (USSF) and the Assistant Secretary of the Air Force for Space Acquisition and Integration, please visit their websites at https://www.spaceforce.com/ and https://www.safsq.hq.af.mil/.

Space Control

Space Innovation, Integration, and Rapid Technology Development (SIIRTD) delivers Standard Space Trainers and Distributed Mission Operations–Space capabilities to the warfighter and provides cutting-edge analysis with critical modeling and simulation tools, providing analytic rigor that supports the command's warfighter strategies. SIIRTD had a very successful FY 2024 with several major accomplishments:

- Delivered simulators for Orbital Warfare
- Developed simulators for Space Domain Awareness (SDA), adding to Electronic Warfare and Missile Warning
- Matured tech to integrate mission simulations, AI threat models, and visualization tools in synthetic space environment
- Deployed tool for Commander, Space Forces; integrated into major theater exercise and operations to provide Commander, Space Operations Command (SpOC) and Combatant Commands (CCMDs), with status of space forces in near-real time
- Deployed orbital anomaly algorithm operationally at National Space Defense Center; increased capability, saving countless man-hours

Under Defense Cyber Operations, in FY 2024, prototype Defensive Cyber monitoring and protection capabilities continued deployment at multiple locations to protect space operations centers. A total of 16 network enclaves are protected to date. These systems enable cyber operators in Delta 6 Mission Defense Teams to monitor networks to detect, isolate, and recover from attacks. Additionally, the Defense Cyber Operations–Space program continued in the planning phase of the Software Acquisition Pathway to advance from prototyping to a formal acquisition program by early in the 2025 calendar year.

Environmental Monitoring

The Electro-Optical/Infrared Weather System (EWS) is DOD's multi-phase proliferated materiel solution to satisfy capability gaps in cloud characterization and theater weather imagery.

The EWS technology demonstration CubeSat was launched in March 2024, and the operational demonstration is scheduled for launch in September 2025.

Weather System Follow-On–Microwave (WSF-M) is DOD's materiel solution to satisfy capability gaps in ocean surface vector winds, tropical cyclone intensity, and low Earth orbit energetic charged particles. The WSF-M Space Vehicle 1 was launched in April 2024, with full operational capability expected in FY 2025.

A residual National Oceanic and Atmospheric Administration (NOAA) geosynchronous Earth orbit (GEO) satellite (EWS-G2) was transferred to the USSF in 2024 and provides persistent Indian Ocean coverage supporting joint needs.

Missile Warning/Attack Assessment

The space segment of the Overhead Persistent Infrared (OPIR) program will replenish the Space Based Infrared System (SBIRS) constellation by delivering four resilient and survivable missile warning (MW) satellites (two GEO and two northern-latitude [polar] orbit), with the first GEO satellite to be delivered by 2025. In FY 2024, Next-Gen OPIR GEO completed Mission Payload (MPL-1) thermal vacuum testing through the combined government and contractor team. This enabled the successful testing and integration of the payload assembly onto the space vehicle and initiated further vehicle baseline testing that includes space-to-ground systems tests. Next-Gen OPIR Polar completed several Critical Design Audits for MPLs and the space vehicle bus. These activities enabled the completion of Critical Design Reviews and Critical Integration Reviews for the ground and space vehicle, which resulted in the award of a Phase 2 modification to initiate the polar satellite assembly, integration, and testing.

The USSF is pivoting to a proliferated and resilient Missile Warning/Missile Tracking (MW/MT) architecture to address new and emerging adversarial threats, including hypersonic missiles. The new architecture proliferates OPIR satellites in LEO and medium Earth orbit (MEO). The MW/MT LEO and MEO programs leverage spiral development models, Middle Tier of Acquisition, and Other Transaction Authorities to accelerate acquisition and capability delivery on two-year timelines to rapidly respond to emerging threats.

In 2024, the Space Development Agency launched four Tranche 0 Tracking Layer satellites and the Missile Defense Agency launched two Hypersonic and Ballistic Tracking Space Sensor satellites, placing these six MW/MT satellites into orbit for early tracking demonstrations.

Resilient-MW/MT MEO delivers a resilient, multi-plane architecture into counter threats. In FY 2024, USSF Space Systems Command continued to acquire MEO satellites in spiral development phases called Epochs, with launches scheduled to occur in 2027 and 2028.

The Ground Segment, Future Operationally Resilient Ground Evolution (FORGE), is developing a cyber-secure open OPIR mission framework capable of hosting applications and providing services to process mission data for missile warning, missile defense, battlespace

awareness, technical intelligence, and civil/environmental uses. FORGE enables threat-adaptive missile warning operations, which include command and control and processing of increased data collected by legacy SBIRS, Next-Gen OPIR, Resilient MW/MT MEO and LEO, and future constellations. In April 2024, FORGE delivered the first operational capability through the fielding of the FORGE data-processing framework to the OPIR Battlespace Awareness Center at Buckley Space Force Base, Colorado. This delivery provides increased cyber resilience and enhanced mission applications that bolster the OPIR battlespace awareness and technical intelligence missions with significant cyber-security improvements and enhanced missile detection and tracking.

Positioning, Navigation, and Timing

In FY 2024, the Global Positioning System (GPS) III Follow-on (GPS IIIF) continued with the Production and Deployment phase, with a planned production of 22 satellites adding increased anti-jam performance and hosting a search-and-rescue payload developed through international partnership. The first two GPS IIIF satellites are expected to be delivered to the government and available for launch in FY 2027.

The Military GPS User Equipment Program Executive Officer certification on the Navy lead platform was completed in FY 2024, while the Aviation lead platform is scheduled for completion in FY 2025.

Satellite Communications

Satellite Communications (SATCOM) provide protected strategic, protected tactical, wideband, narrowband, and commercial SATCOM capabilities to the department through several acquisition programs. The USSF is acquiring the Evolved Strategic SATCOM (ESS) system to meet protected strategic SATCOM requirements. ESS will provide survivable, secure, and jam-resistant communication for strategic users and provide nuclear command, control, and communications (NC3); it will also increase protected satellite communications resiliency and cybersecurity. The ESS request for proposal was released to industry on May 3, 2024, keeping the ESS program on track to deliver global protected, secure, jam-resistant strategic SATCOM to NC3 warfighters by the projected 2032 initial operational capability date.

The Protected Tactical SATCOM (PTS) program will provide a disaggregated protected tactical communications constellation of resilient (PTS-R) and global (PTS-G) satellites as a follow-on to the Advanced Extremely High Frequency program. Utilizing the Ka frequency band, PTS-R will provide beyond-line-of-sight (BLOS), improved anti-jam, low-probability-of-intercept satellite communications, through onboard signal processing and advanced beamforming, to expeditionary and tactical warfighters, enabling them to operate in close proximity to adversarial jammers. The PTS-R request for proposal was released to industry on June 7, 2024.

The Protected Tactical Enterprise Service (PTES) is the ground control system and central hub for Protected SATCOM systems and capabilities. PTES manages the USSF-developed Protected Tactical Waveform (PTW) and operationalizes the PTW over military and commercial satellites. PTES provides encrypted, anti-jam, frequency-hopping SATCOM via military and commercial satellites in MEO, GEO, and highly inclined orbit for joint and allied partners. PTES is frequency agnostic and is flexible for ground and space processing. It enables tactical warfighters to receive and transmit command and control and intelligence data in contested environments. In FY 2024, PTES continued development efforts to operationalize the PTW over Wideband Global SATCOM (WGS) (PTWoW) in MEO and GEO and integrate commercial capabilities into the architecture. After PTWoW is operational, the program will focus on extending PTW over commercial satellites.

The Enhanced Polar System (EPS) is a Polar Military Satellite Communications system that provides protected communications (anti-jam and low probability of intercept and detection) for users in the North Polar Region. The USSF procured two replenishment EPS payloads in the Enhanced Polar System–Recapitalization (EPS-R) program. These EPS-R payloads were hosted on two Space Norway satellites that were launched in August 2024 and are projected to reach initial operating capability in March 2025. This initiative promotes U.S. policy to strengthen international partnerships and saves an estimated $900 million in costs for the U.S. Government.

The USSF Commercial SATCOM Office (CSCO) procures Commercial SATCOM (COMSATCOM) for DOD by managing over 90 active customer contracts; leveraging 40 COMSATCOM providers; and administering DOD's Iridium gateway and associated SATCOM airtime contract for DOD, federal agencies, state and local governments, and foreign partners. In 2024, CSCO awarded a Multiple Award suite of not-to-exceed Indefinite Delivery, Indefinite Quantity contracts for Proliferated LEO Satellite-Based Services with a total cumulative contract ceiling value of $900 million shared across all the awards. This $900 million ceiling was quickly reached and subsequently increased to $13 billion. CSCO continues to advance the USSF's vision for an enterprise approach to the procurement, delivery, and management of SATCOM capabilities as the best means to create a responsive environment to CCMDs and other users across the spectrum of conflict.

COMSATCOM Enterprise Integration of Fighting SATCOM delivers Enterprise Management and Control (EM&C) and International MEO SATCOM. EM&C develops integration tools enabling military and commercial SATCOM systems to operate and be managed as a single enterprise. EM&C accelerates the delivery of real-time situational awareness and optimization of planning tools to improve visibility and delivery of SATCOM services across the joint force. During FY 2024, EM&C continued to develop software capabilities that enable responsive and resilient SATCOM for various space warfighting entities.

In the International MEO SATCOM program, the USSF will partner, explore, prototype, and integrate an international commercial SATCOM service into the DOD SATCOM enterprise. Luxembourg (LUX) MEO establishes the baseline satellite capability in partnership with the LUX Ministry of Defense, leveraging SES's mPOWER satellite constellation in MEO. In FY 2024, the USSF obligated funding to obtain mPOWER satellite capacity.

The Mobile User Objective System (MUOS) provides ultra-high-frequency (UHF) satellite communications for the joint warfighter, enabling beyond-line-of-sight communications and communications-on-the-move. MUOS has two payloads, a UHF Legacy payload that augments the UHF Follow-On constellation, and a Wideband Code Division Multiple Access payload that enables 3G-like voice and data services. The MUOS Service Life Extension Phase 1 contract was awarded in February 2024 to perform early design and risk reduction for follow-on production awards for MUOS satellites 6 and 7. The results of the Narrowband Analysis of Alternatives were presented to DOD leadership in February 2024, and a Narrowband way-ahead is currently being considered.

The WGS system provides high-capacity and -bandwidth SATCOM capability to support Unified CCMD's, military services', other DOD agencies', and international partners' global operations. The space segment operates in the military X-band and Ka-band with flexible connectivity between bands and coverage areas to support classified and unclassified data distribution and backhaul communications for users worldwide. The WGS-12 satellite production contract was awarded in March 2024. In FY 2024, WGS-11 and -12 satellites continued in construction and will each deliver twice the operational capability of legacy WGS satellites and provide critical high-capacity, wideband SATCOM to joint warfighters and International Partners.

DOD's Military Network constellation of satellites is designed to provide SATCOM and data transport capabilities from LEO. In FY 2024, 81 satellites were launched. When fully fielded, this constellation, critical to achieving Space Data Network resilience and capability objectives, will help provide warfighters needed SATCOM capabilities globally.

Space Access

National Security Space Launch

The National Security Space Launch (NSSL) program continues to successfully place satellites into orbit. As of September 30, 2024, there were five launches during FY 2024:

- December 29, 2023 Falcon Heavy USSF-52
- February 14, 2024 Falcon 9 USSF-124
- April 9, 2024 Delta IV Heavy NROL-70
- April 11, 2024 Falcon 9 USSF-62
- July 30, 2024 Atlas V 551 USSF-51

In FY 2024, the NSSL program completed the Phase 3 acquisition strategy and released the request for proposal to industry on October 14, 2023. NSSL Phase 3 is a dual-lane strategy with separate contract types. Lane 1 will utilize an Indefinite Delivery/Indefinite Quantity contract to award multiple Firm-Fixed-Price (FFP) contracts open to all qualified bidders. Lane 2 will consist of three competitively awarded FFP Indefinite Delivery Requirement contracts to the best-value, next-best-value, and third-best-value launch service providers who meet all NSSL orbits and unique mission capabilities. On June 14, 2024, the Space Systems Command awarded Lane 1 to United Launch Alliance (ULA), SpaceX, and Blue Origin launch service providers. Lane 2 award is targeted for second quarter of FY 2025. The NSSL Phase 3 will be the follow-on to the NSSL Phase 2's ordering period that ended in FY 2024.

In FY 2024, Space Systems Command, in partnership with the National Reconnaissance Office's (NRO) Office of Space Launch, conducted the Order Year 5 (OY5) Mission Assignment Board (MAB) for Phase 2 NSSL missions. On September 29, 2024, the OY5 MAB assigned 21 missions with Initial Launch Capability schedules ranging from FY 2025 to FY 2027. ULA was assigned GPS III-9, STP-5, SilentBarker-2, USSF-25, USSF-57, USSF-95, NROL-56, NROL-73, NROL-100(C), NROL-109, and SDA T2TL-C. SpaceX was assigned GPS III-10, GPS IIIF-1, USSF-70, USSF-75, NROL-77, SDA T1TL-F, SDA T1TR-A, SDA T1TR-E, SDA T2TL-A, and SDA T2TL-C.

Rocket Systems Launch Program

In FY 2024, the Space Force's Rocket Systems Launch Program (RSLP) continued to provide a low barrier for new entry launch vehicles, enabling a diverse vendor pool consisting of both large and small businesses with a mixture of mature and emerging launch providers. In FY 2024, RSLP added two new launch providers to its stable of Orbital Support Program–4 contractors: Stoke Space Technologies and Blue Origin. RSLP also awarded a launch service contract to Rocket Lab to launch the Space Test Program–S30 mission.

Launch Ranges

In FY 2024, range modernization efforts continued to implement the Chief of Space Operation's Spaceport of the Future (SOTF) vision for the Eastern and Western Ranges. This vision ensures that range instrumentation will not be a limiting factor in launch range capacity and launch cadence. In 2024, the Range Services Hosting Platform earned operational acceptance for the final of four phases. This upgrade provides a common platform for all range customers and operators. It also provides automated routing versus manual range reconfiguration, allowing centralized network management across the Internet Protocol network, additional capacity, plug-and-play for range users, and modernized information assurance. These efforts, along with the complete network upgrades on both the Eastern and Western Ranges,

enhanced compatibility with commercial systems, and increased launch throughput on both ranges, continue progress to meet the SOTF vision. The program entered the execution phase of the Software Acquisition Pathway in 2024. The program will continue the SOTF vision by virtualizing capabilities and employing open systems standards to achieve flexible and resilient ranges that stay ahead of the launch demand signal. Finally, the long-term fit-out of the new Range Communications Facility reached Full Operational Capability in 2024.

Space Command and Control

In FY 2024, the Space Command and Control (C2) program continued test and evaluation and delivery activities for the Advanced Tracking and Launch Analysis System, a significant operational C2 SDA capability that will allow the decommissioning of legacy systems. In April 2024, the program delivered its fifth annual report to Congress, and in FY 2024 the Unified Data Library program continued to onboard government and commercial data for use by C2 systems.

In FY 2024, the Satellite Control Network (SCN) continued the development of the Advanced Scheduling Tool system to automate the scheduling and connectivity of the network, with two of four development phases and installations complete. To augment the SCN, the Federal Augmentation service effort will use NOAA antennas. In FY 2024, installations were completed in Alaska and Virginia, and those facilities are entering testing and evaluation. In August 2024, the program executed an Other Transactional Authority award to build out the successful meshONE-Terrestrial meshed network prototype for the USSF. In May 2023, typhoon Mawar caused extensive damage—estimated to be at least $54 million—to the Guam Tracking Station. Two of the three antennas were back online in 60 days. USSF took the opportunity to replace the antenna needing a complete replacement with a new digital transportable to modernize and increase resiliency. This project started in FY 2024 and will complete in 2027. In FY 2024, work continued on the final Hybrid/Modular Transitional Remote Tracking Station upgrade at the LION-B antenna in Oakhanger, United Kingdom. This is a multi-phase project of refurbishment of one antenna and digital modernization for the entire site. Completion is expected to be accepted for operations in 2027.

Space Rapid Capabilities Office

The Space Rapid Capabilities Office (SpRCO), a USSF acquisition organization, delivers timely, combat-credible space and ground capabilities to protect space assets and defend joint forces from space-enabled threats. SpRCO works closely with the USSF Field Commands (i.e., Space Systems Command, SpOC, and Space Training and Readiness Command) to rapidly develop and field space capabilities that align with Combatant Command requirements and Service priorities. The organization is headquartered in Albuquerque, New Mexico, with

additional offices and staff in Washington, DC; Los Angeles, California; and Colorado Springs, Colorado. SpRCO is executing over a dozen programs, one of which is highlighted below.

Rapid Resilient Command and Control, a combined program with Space Systems Command, is developing a cloud-based satellite operations infrastructure that gives military operators more flexibility to command and reposition satellites in response to threats. The program will deliver critical, tactical ground segment software to operate dynamic USSF satellites with protect-and-defend missions and to provide many tactical satellite operations functions, such as Rendezvous and Proximity Operations planning, antenna brokering and telemetry, and tracking and command. In early January 2024, the program became the first USSF program to connect its commercial cloud environment to the real-time transfer service. By May 2024, it had deployed mission-unique software to the cloud and demonstrated end-to-end data flow for a classified USSF satellite program. In August 2024, the team reached another critical point by transmitting 11 commands from its commercial cloud to an on-orbit USSF satellite, with each command acknowledged by the satellite.

Commercial Space Strategy

On April 10, 2024, the USSF released its Commercial Space Strategy, which details how the Service is retooling processes and cultivating commercial partnerships to increase U.S. competitive advantage. This strategy aligns with the broader DOD Commercial Space Integration Strategy released on April 2, 2024. The Space Force will implement four lines of effort to achieve this Commercial Space Strategy: collaborative transparency, operational and technical integration, risk management, and securing the future.

During FY 2024, the USSF, through the USSF University Consortium, awarded about $100 million to U.S. universities to develop revolutionary technologies supporting three key areas: Beyond Geostationary Orbit and Space Domain Awareness, In-Space Operations, and Advanced Space Power and Propulsion. These three areas are anticipated to expand in the coming years, and the first experiment has already gone to the Space Experiment Review Board, requesting a flight in FY 2026. The current efforts comprise more than 40 individual technical development efforts spread across the three areas.

Space Domain Awareness

Space Domain Awareness (SDA) is the timely, relevant, and actionable understanding of the operational environment that allows military forces to plan, integrate, execute, and assess space operations. SDA is one of the United States Space Force's (USSF) five core competencies and is foundational to executing all space operations across the competition continuum. To address the rapidly expanding threats to the space enterprise, SDA is pivoting to protect and defend against threats by aligning materiel and non-materiel needs to deliver parallel operational

requirements simultaneously and equipping decision makers with access to integrated data from diverse ground-based and space-based sensors. In FY 2024, the USSF continued partnering with industry and allies to augment the Space Surveillance Network (SSN), exploit data, host payloads on nontraditional satellites, and place assets in new locations that would allow for persistent space control activities. Under the Maintenance of Space Situational Awareness Integrated Capabilities contract, sustainment, modifications, and development continued across the SSN in FY 2024. Furthermore, USSF continues to invest in government-owned, exquisite systems such as SilentBarker, the Geosynchronous Space Situational Awareness Program, and the Deep Space Advanced Radar Capability (DARC).

DARC will be a ground-based SDA radar system consisting of three geographically separated sites around the world that deliver deep space satellite tracking and custody capabilities. DARC will provide a critical, advanced, 24/7, all-weather radar system capability to counter existing and emerging threats in deep space. USSF Space Systems Command awarded the Site 2 contract in August 2024. Site 1 construction in Australia continued throughout FY 2024, and the capability is expected to begin operations in the first quarter of FY 2026. The location for Site 2 will be in Cawdor Barracks, Wales, United Kingdom, and Site 3 is planned for Lake Kickapoo, Texas.

Army

The U.S. Army Space and Missile Defense Command made progress in the area of Space Situational Awareness support for the tactical warfighter from the technology development effort called Lonestar. The Lonestar satellite has been on orbit since July 1, 2022. During FY 2023, bus checkouts were completed, and the bus is performing as designed, including in the areas of power, thermal, communications, and attitude control. The payload on-orbit checkouts were completed successfully, verifying that signal capture and processing are working as designed. The mission continues to operate the payload on a duty cycle attempting to maximize observation time within bus power limitations.

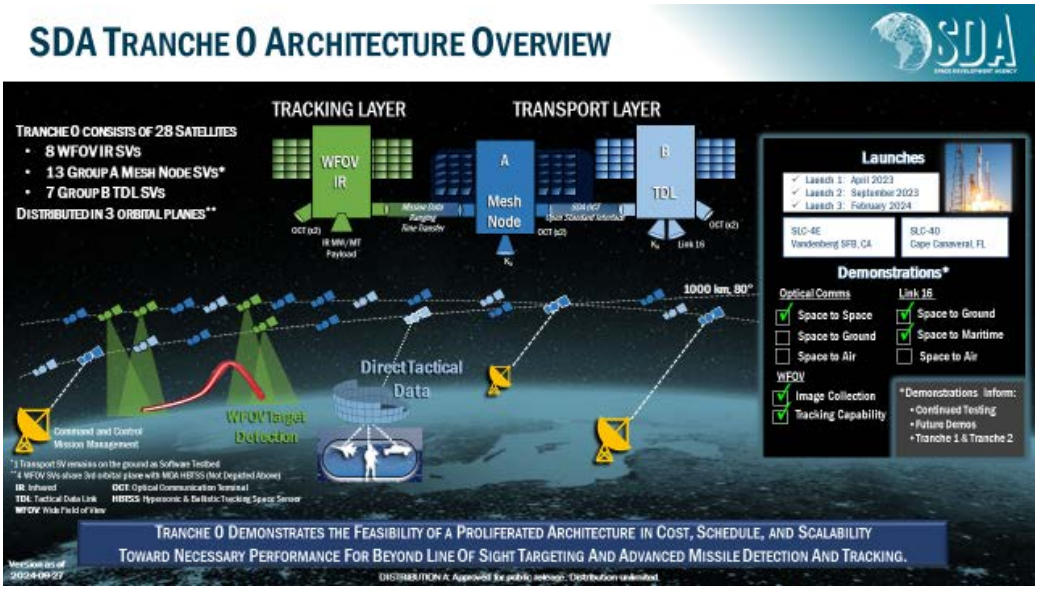
Classified data processing is performed over a longer duration of operations to do an assessment of end-product performance. During FY 2023, the Lonestar payload successfully collected on-orbit anomalies, and data analysis on the ground provided high confidence in the validity. Mission data analysis continued to be improved and accurately identified situational awareness events of interest in areas of conflict. The on-orbit demonstration supported a Technical Readiness Level 7 assessment because the Lonestar payload is a prototype that has been successfully demonstrated in an operational environment.

Space Development Agency

Recognized as DOD's constructive disruptor for space acquisition, the Space Development Agency (SDA) quickly delivers needed space-based capabilities to the joint warfighter to support terrestrial missions through development, fielding, and operation of the Proliferated Warfighter Space Architecture (PWSA). For more information, please visit https://www.sda.mil/.

PWSA Tranche 0—Warfighter Immersion

Tranche 0 (T0) is the warfighter immersion tranche and demonstrates the feasibility of a proliferated architecture in cost, schedule, and scalability toward necessary performance for BLOS targeting and advanced missile detection and tracking. T0 consists of 28 space vehicles (SVs), 27 of which were launched, and 20 are currently in LEO at an altitude of approximately 1,000 km conducting various demonstrations, while one remains on the ground as a testbed. For the first time in FY 2024, warfighters were exposed to future PWSA Transport Layer capability via "live" participation of Tranche 0 SVs in a range of operationally relevant exercises and wargame activities. An architectural overview of Tranche 0 is below.



Overview of PWSA Tranche 0.

T0 Transport Layer (T0TL). The T0TL demonstrates the ability to provide warfighters with periodic regional access to low-latency data connectivity via space-based extensions of existing tactical data links. York Space Systems and Lockheed Martin are on contract to each deliver ten SVs for a total of 20 SVs for T0TL. Seven of the T0TL SVs are configured with a Link 16

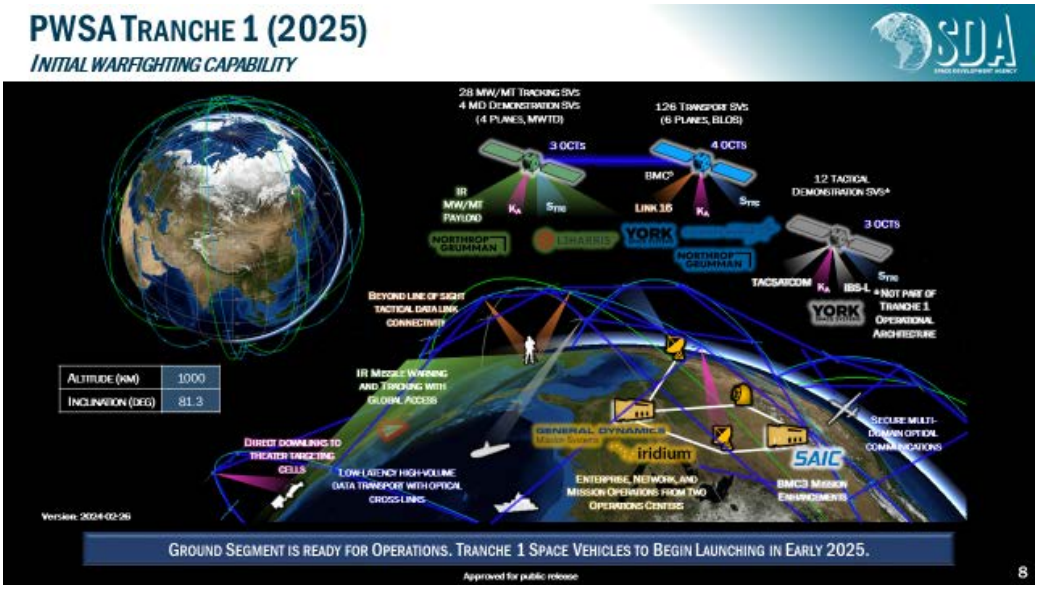
payload to demonstrate the warfighter-critical tactical data link from space. For the first time, this enables a true BLOS Link 16 tactical data link transmit/receive capability from space. Nineteen of 20 SVs are on orbit, while one remains on the ground as a software testbed. In FY 2024, the T0TL SVs continued to demonstrate firsts for Link 16 in space through successful space-to-ground, space-to-sea, and space-to-aircraft (atop a Naval aircraft carrier underway) demonstrations. For the first time, the T0TL York SVs successfully established in-space optical connectivity using SDA-compliant Optical Communication Terminal (OCT) payloads.

T0 Tracking Layer (T0TRK). T0TRK will demonstrate the ability to provide periodic regional access and to detect and track hypersonic vehicles. T0TRK SVs are configured with a wide-field-of-view (WFOV) infrared payload. SpaceX and L3Harris are each on contract to deliver four SVs for the T0TRK architecture. In FY 2024, the Space Development Agency successfully launched and delivered into orbit the final four T0TRK SVs in collaboration with the Missile Defense Agency (MDA) Hypersonic and Ballistic Tracking Space Sensor program. All T0TRK SVs have since successfully demonstrated first light and are progressing through early operations activities. The T0TRK SVs successfully demonstrated tracking capability by being able to detect different missile launches, rocket launches, the Starship reentry, and other activities. The SVs were then able to form two-dimensional tracks, using algorithms provided by MDA, and provide them to the ground for additional analysis. Finally, the T0TL SpaceX SVs successfully established in-space optical connectivity using Space Development Agency–compliant OCT payloads, exceeding connectivity threshold requirements.

T0 Launch and Ground. Tranche 0 ground support is provided by the U.S. Naval Research Laboratory and is based at Blossom Point Tracking Facility, Maryland. In FY 2024, T0 ground capabilities supported the launch of the final SVs and their integration into the T0 orbital architecture. Additionally, T0 Ground successfully supported all T0TL Link 16 activities and T0TRK tracking demonstration activities and participation in warfighter exercises and wargames.

PWSA Tranche 1—Initial Warfighting Capability

Tranche 1 (T1) forms the PWSA Initial Warfighting Capability and will provide regional persistence for Link 16, advanced missile detection, and beyond-line-of-sight targeting for the joint force. T1 consists of 161 space vehicles in LEO at an altitude of approximately 1,000 km across 11 orbital planes. SVs will begin launching in third quarter FY 2025. In FY 2024, all PWSA OCT suppliers successfully demonstrated inter-vendor interoperability using the Space Development Agency OCT interoperability ground testbed maintained by the Naval Research Laboratory. A Tranche 1 introductory graphic can be seen on the following page.



Overview of PWSA Tranche 1.

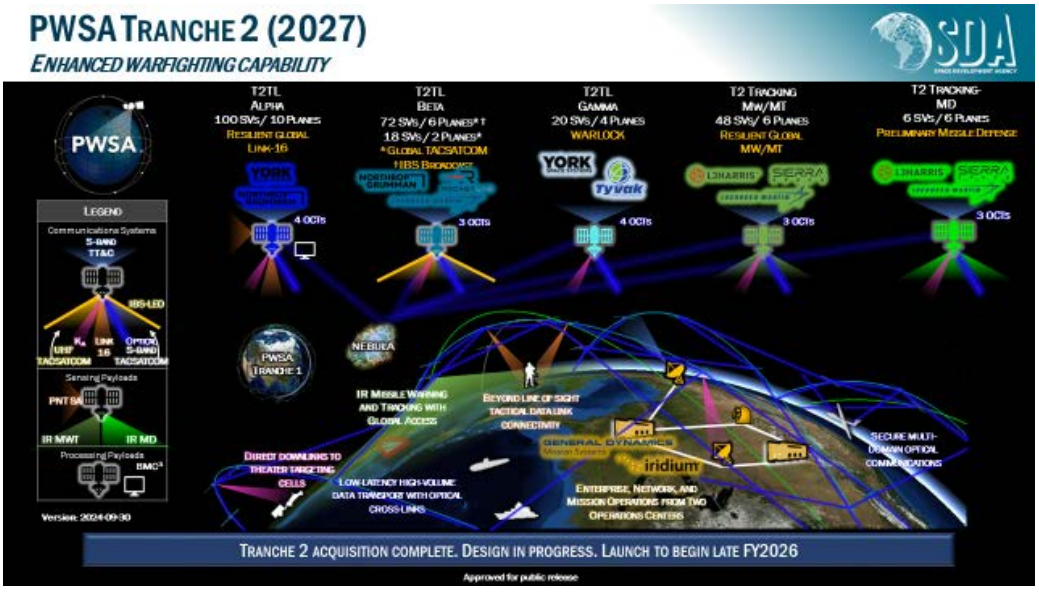
T1 Transport Layer (T1TL). The PWSA T1TL is providing global communications access and persistent regional encrypted connectivity in support of warfighter missions around the globe. T1 serves as the backbone for Joint All Domain Command and Control, built on low-latency data transport, as well as sensor-to-shooter and tactical systems connectivity. T1TL consists of 126 SVs across six near-polar orbital planes linked together to form a global space mesh network. The T1TL SVs are similar in capability to the T0TL SVs, with targeted technology enhancements, mission-focused payload configurations, increased integration, and greater production efficiencies. Each T1TL SV carries a Link 16 payload, enabling global access to the tactical data network for the warfighter. In addition, each SV also carries a second GPS receiver, which will allow the Space Development Agency to provide continuous GPS situational awareness data from a global perspective. In FY 2024, T1TL SVs continued executing Assembly, Integration, and Test (AI&T) activities.

T1 Tracking Layer (T1TRK). The primary mission objective of the T1TRK program is to baseline an initial operational infrared missile warning and tracking capability designed to mature into a robust, resilient target tracking solution that closely integrates with T1TL to deliver low-latency sensor-to-shooter connectivity in support of military operations around the world. The T1TRK is planned to consist of four planes of seven SVs configured with an infrared payload, launched to 1,000 km. This set of SVs forms the initial element of the proliferated low Earth orbit (pLEO) portion of a USSF Space Warfighting Analysis Center force design representing an integrated approach to advanced missile detection, tracking, and defeat. In FY 2024, T1TRK SVs continued executing AI&T activities.

T1 Operations and Integration (O&I). T1 O&I will establish an integrated ground segment and provide operations and sustainment support for the complete T1 system. A team led by GDMS and Iridium are on contract to develop, procure, manage, and operate the SDA Operation Centers (OCs) and Ground Entry Points (GEPs), as well as build underlying software and networking; manage the integration of PWSA segments with external mission partners; and conduct integration, testing, and verification of mission operations. Operation of the T1 Enterprise and future capability layers and tranches is planned to be conducted from two functionally equivalent, geographically separated, government-owned and contractor-operated Space Development Agency OCs via globally dispersed radio frequency and optical GEPs: Redstone Arsenal, Alabama (SDA-South), and Grand Forks Air Force Base, North Dakota (SDA-North). In FY 2024, GDMS successfully completed the build-out of SDA-North and SDA-South and held the Ground Readiness Review.

PWSA Tranche 2—Enhanced Warfighter Capability

Tranche 2 (T2) is the PWSA Enhanced Warfighting Capability tranche and is planned to provide global persistence for all capability in Tranche 1 plus demonstration of advanced tactical data link(s) and future proliferated missions. T2 consists of 264 SVs across 28 planes. A T2 introductory graphic can be seen below.



Overview of PWSA Tranche 2.

T2 Transport Layer (T2TL): The T2TL completes the global pLEO mesh communications data transport capability required by the warfighter for worldwide operations and begins to

proliferate needed warfighting capability. T2TL will provide global persistence and is sized to support at least two adversarial campaigns and future proliferation of prototypes demonstrated in T1 and additional advanced tactical data links and/or waveforms. T2TL is planned to include 216 Transport SVs, which break out into three SV variants:

- **Tranche 2 Transport Alpha (T2TL-α):** The T2TL-α prototype constellation is made up of 100 SVs distributed between four low-inclination and six high-inclination planes. The T2TL-α SVs are similar in capability to the T1TL SVs, with targeted technological enhancements, increased integration, and greater production efficiencies. In FY 2024, the Space Development Agency completed two Other Transaction Authority (OTA) contract agreements to York Space Systems and Northrop Grumman for a total of $1.3 billion to build and operate the 100 T2TL-α SVs. Since then, Northrop Grumman has completed design through critical design review (CDR) and York Space Systems has completed design through preliminary design review.
- **Tranche 2 Transport Beta (T2TL-β):** The T2TL-β prototype constellation is made up of 90 SVs distributed between six high-inclination planes. The T2TL-β SVs are similar to the Tranche 1 Demonstration and Experimentation System (T1DES, see "PWSA Futures Programs" section below) SVs while integrating targeted technology enhancements, mission-focused payload configurations, increased integration, and greater production efficiencies. T2TL-β will incorporate the tactical satellite communications (TACSATCOM) technology demonstrated by T1DES. Two offerors, Lockheed Martin and Northrop Grumman, awarded agreements for a total of $1.5 billion to each build and operate 36 SVs. In FY 2024, Northrop and Lockheed Martin completed design through CDR. Also in FY 2024, an additional OTA agreement was completed with Rocket Lab to build and operate 18 T2TL-β SVs. Since then, Rocket Lab has completed design through System Design Review (SDR).
- **Tranche 2 Transport Gamma (T2TL-Gamma):** The T2TL-Gamma prototype constellation is made up of 20 SVs distributed between four planes. T2TL-Gamma will continue to expand the demonstration of advanced TACSATCOM capabilities through the Tranche 2 timeframe and beyond. In FY 2024, the Space Development Agency completed two OTA agreements with York Space Systems and Tyvak Nano-Satellite Systems for a total of $424 million to each build and operate 10 SVs.

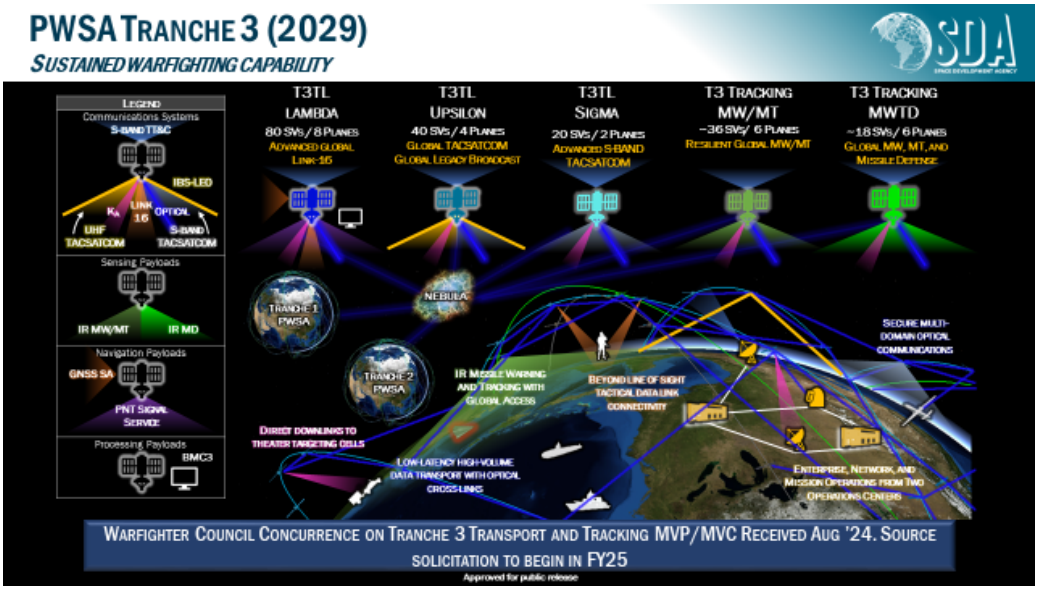
T2 Tracking Layer (T2TRK): The T2TRK proliferates MW/MT infrared sensors on 54 SVs for near-global continuous stereoscopic coverage providing MW/MT mission capabilities and incorporates missile defense (MD) infrared sensors on six SVs capable of generating MD-quality tracks to provide access to MD mission capabilities. The T2TRK SVs are

distributed across six high-inclination orbital planes. In FY 2024, the Space Development Agency completed three OTA agreements to L3Harris, Sierra Space, and Lockheed Martin for a total of $2.6 billion to each build and operate 16 T2TRK vehicles designed through SDR.

T2 Ground, Management, and Integration: The Ground, Management, and Integration (GMI) effort will expand, enhance, and evolve existing PWSA Ground Segment capabilities (established by T1 O&I). GMI will enable the onboarding of PWSA Tranche 2 SVs and mission capabilities via an extensible ground architecture while maintaining operational support to T1. In FY 2024, GDMS was awarded $492 million to perform design, analysis, engineering studies, and technical augmentation for the PWSA Ground segment.

PWSA Tranche 3 (T3)—Sustained Warfighting Capability

T3 is the PWSA Sustained Warfighting Capability (WFC) tranche and is planned to provide advanced improvements over T2 plus future warfighting applications. These include better sensitivity and accuracy for missile tracking; better targeting capabilities for BLOS; additional positioning, navigation, and timing (PNT) capabilities; advances in laser communications, tactical data links, and radio frequency (RF) communications; and advancements in autonomous operations. The T3 prototype constellation is composed of approximately 194 SVs across 26 planes at an altitude of 1,000 km. In FY 2024, the Space Development Agency WFC concurred with the presented minimum viable capabilities for the T3 Transport and Tracking layers, which is shown below.



Overview of PWSA Tranche 3.

PWSA Futures Programs

In FY 2023, the Space Development Agency established the PWSA Future Programs (PFP) Office to consolidate select demonstration activities across the agency.

National Defense Space Architecture Experimental Testbed (NExT)—Space Development Agency Experimental Testbed. The goal of NExT is to field and connect SVs with emerging mission partner-developed and provided payload capabilities in support of DOD end users. Ball Aerospace Technologies Corp (now BAE Corp) is on contract for the development, manufacture, deployment, and operations of three NExT SVs and mission-enabling ground systems. Agreements have been formed with mission partners to provide payloads for NExT. These payloads will demonstrate a range of capabilities to include tactical electronic support; alternative positioning, navigation, and timing; and telemetry monitoring for advanced systems testing over broad ocean areas. In FY 2024, BAE completed CDR and is now in AI&T.

Hybrid Acquisition for Proliferated LEO (HALO): The HALO Effort is an acquisition approach to solicit and award rapid, affordable mission-feasibility demonstrations. This solicitation provides an opportunity for industry to submit proposals for eligibility into an established vendor pool to compete for specific flight demonstration opportunities in the future. A key goal of HALO is to put in place a flexible and fast contracting mechanism to compete and award T2 Demonstration and Experimentation System and other Space Development Agency demonstration projects. In FY 2024, the Space Development Agency released the HALO solicitation to industry, completed source solicitation activities, and authorized 19 entrants in into the HALO vendor pool.

Battle Management Command, Control, and Communications (BMC3)

BMC3 Application Factory (AppFac): The BMC3 AppFac will enhance the capabilities of the PWSA to provide ubiquitous data communications and accelerated decision-making focused on enhancing the warfighter's ability to find-fix-finish from a targeting perspective. The Space Development Agency awarded a $64 million OTA to Science Applications International Corporation (SAIC) to establish the BMC3 software development and hosting environment for the PWSA. SAIC will be responsible for the implementation of an AppFac and secure interoperable-middleware layer to allow the PWSA BMC3 ecosystem to execute mission applications in support of warfighter needs. In FY 2024, SAIC achieved the BMC3 AppFac minimum viable capability. Additionally, BMC3 issued a Broad Agency Announcement for Battle Management Mission Application, which invited proposals for containerized software applications for the PWSA. The BAA includes five priorities for areas for early development of applications:

(1) BMC3 management
(2) Power and resource management
(3) Link 16 integration
(4) Automated network management
(5) Cybersecurity

Additional Noteworthy Progress

Small Business Innovative Research/Small Business Technology Transfer Research

The Space Development Agency (SDA) continued and expanded partnerships with small businesses via the Small Business Innovative Research (SBIR) and Small Business Technology Transfer Research (STTR) programs. In FY 2024, the Space Development Agency achieved a greater-than-50-percent transition rate for completed Phase 2 development efforts and awarded a total of 28 new SBIR/STTR efforts. Awards topics included the following:

- Integrate commercial sensing to Transport Layer
- Develop OCT technology and industrial base
- Transportable laser communications ground station
- Develop Link-16 technology
- Cyber
- Networking
- In-space processing
- Increase power for spacecraft bus
- Generic BMC3 hardware and middle solutions
- Seamless multi-level security
- Open interfaces and standards
- High performance, low size, mass, and power clocks for space

In each case, the Space Development Agency encouraged small business partners to focus on key technology developments suitable for deployment on orbit with the goal of increasing warfighter capability.

In FY 2024, the Space Development Agency continued leveraging the USAF and USSF AFWERX and SpaceWERX programs, submitted recommendations into Open and Specific Topic calls, interacted with small businesses via Collider events, and aligned SDA small business needs and interests with those of the greater USSF enterprise. Through small business partnerships, SDA remains committed to the development of optical, radio frequency, data, cybersecurity, space and ground operations, and battle management capabilities of warfighting value throughout the PWSA and greater USSF Programs of Record.

Federal Aviation Administration

FAA

The U.S. Department of Transportation's Federal Aviation Administration (FAA) provides the safest, most efficient aerospace system in the world. Through modernization, the U.S. National Airspace System (NAS) is transitioning from tactical and reactive air traffic control to more strategic and integrated air traffic management, driven by advanced automation and information sharing. As air traffic continues its post-pandemic rebound, the FAA is balancing the sustainment of current operations with continued investments in modernization and moving closer to regular use of Trajectory Based Operations (TBO).

NAS Modernization Efforts. Broadly, NAS modernization efforts in recent years, including FY 2024, have focused on maintenance of operations, not modernization. However, in FY 2024, the FAA, in collaboration with the European Union Single European Sky Air Traffic Management Research (SESAR) Joint Undertaking, completed the development and publication of the full set of Aeronautical Telecommunications Network–Internet Protocol Suite (ATN/IPS) Standards. This includes the International Civil Aviation Organization's (ICAO) IPS Standards and Recommended Practices, as well as associated Technical Manuals, the Radio Technical Commission for Aeronautics IPS Minimum Aviation System Performance Standards, and the Airlines Electronic Engineering Committee IPS Form Fit and Function Standards. IPS technology is a critical enabler of smart routing and secure hyperconnected operations for future aviation.

Global Information Management Harmonization. With FAA participation, the ICAO Information Management Panel developed a global interoperable approach for effective information management across the air navigation system. This development resulted in two major documents in 2024: the Procedures for Air Navigation Services–Information Management (Doc 10199) and the Manual on the System-Wide Information Management Implementation

(Doc 10203). These publications support global harmonization and provide the framework for future information management practices.

Trajectory Based Operations (TBO) Roadmap. The 14th Air Navigation Conference endorsed the continued development of TBO in the global ICAO context. The FAA, working closely with other ICAO Member States, particularly in coordination with the European Union, refined a recommendation for a TBO roadmap. This roadmap focuses on key enablers, including System-Wide Information Management, Flight and Flow Information for a Collaborative Environment (modern flight planning and management), and Aeronautical Information Management (AIM), which includes modernizing Notices to Airmen (NOTAMs).

The FAA's international efforts to advance TBO and other air traffic management technologies are complemented by innovative operational procedures at key airports across the United States, ensuring that these global advancements are reflected in domestic operations.

Innovative Operational Procedures. As of August 2024, the Terminal Flight Data Manager (TFDM) is operational at 10 major airports across the United States, including Los Angeles, Phoenix, Tampa, Charlotte, and Cleveland. The TFDM system addresses increasing airport surface congestion caused by growing commercial air traffic, improving traffic planning, and reducing delays.

The **Data Communications (Data Comm)** program also progressed in 2024, with 16 En Route Centers fully operational as of August. Over 38 percent of En Route air carrier traffic used Data Comm in June 2024, providing more efficient air-to-ground communications compared to traditional voice channels. The avionics installation rate reached 77 percent, with positive user feedback as implementation expanded.

The **Cloud National Test Bed (CNTB)** continued to serve as a high-security platform for developing and testing FAA mission-essential systems. This initiative is a core part of the FAA's Automation Evolution Strategy, incorporating industry best practices for software development, delivery, and management.

New Entrants. As NAS modernization continues, the FAA is developing the next iteration of airspace management, with a focus on enhancing information-sharing capabilities and supporting new aviation technologies and services.

The FAA successfully completed the initial deployment of the **Research and Development Operating Environment (RD-OE)** to support FAA research needs. RD-OE, one of four planned cloud environments (alongside Administrative, Mission-Essential, and Mission-Critical), enables agile development and helps mature prototypes into solutions for the NAS. Since its May 2024 launch, RD-OE has onboarded four tenants: Separation Assurance Systems Engineering, Flight Information Management Capability, Cloud En Route Automation Modernization-In-A-Box, and UAS Traffic Management (UTM) Flight Management System. Leveraging RD-OE, these programs were able to successfully conduct and demonstrate their research.

At the **Unmanned Aircraft Systems (UAS) Traffic Management (UTM) Key Site**, located in North Texas, the FAA, in collaboration with industry, validated the use of UTM to mitigate the risk of collision between drones, which are now being used more frequently in operations such as package delivery. The FAA accepted the use of a UTM service that allows highly automated coordination between different drone operators, a first for U.S. aviation. Additional drone operators have since begun the process of obtaining FAA acceptance for the use of UTM services to mitigate drone-to-drone collision risk for beyond-visual-line-of-sight (BVLOS) operations. These activities continue to inform future FAA efforts to authorize UTM services more broadly, including the development of UTM rules to normalize wide-scale BVLOS drone operations without special authorizations.

The urban air mobility **(UAM) Airspace Management Demonstration** successfully showcased seamless data exchanges and interactions between Air Traffic Services and cooperative environments, ensuring the smooth integration of UAM traffic across both domains. These exchanges included crucial elements such as constraints, flight plans, handoffs (both voice and digital), and aircraft position data. The demonstration proved that UAM aircraft can safely operate within the NAS, leveraging cooperative areas while sharing critical information with the FAA, third-party service providers, and operators.

Advanced Air Mobility (AAM) is an emerging aviation ecosystem that leverages new aircraft and an array of innovative technologies to provide the opportunity for more options for transportation. The FAA is taking an incremental approach to AAM integration. The FAA engaged with project stakeholders across the country, including in Los Angeles, Houston, Orlando, and South Florida, to support the initial integration of electric vertical takeoff and landing operations. Tabletop exercises and simulations were conducted to refine use cases with subject matter experts, including air traffic controllers, airport operators, and original equipment manufacturers (OEMs), to ensure that market-driven AAM operations are safely and efficiently integrated into the National Airspace. Concurrent with the site-specific use case refinement, the FAA continued to work with industry in areas necessary for AAM implementation, including aircraft certification, operational certification, infrastructure, environment, hazardous materials and safety, and community engagement. Additionally, the FAA has been working with its federal partners to develop a national strategy for AAM integration.

Aviation Workforce Development Grants

When commercial aviation passenger levels rebounded in 2023, workforce challenges manifested as widespread flight cancellations and delays. Well before COVID-19, Congress anticipated these challenges and, through Section 625 of the FAA Reauthorization Act of 2018, established two grant programs to expand the aviation workforce. The Aircraft Pilots

Workforce Development Grants program encourages students to become pilots, aerospace engineers, or unmanned aircraft systems operators. The Aviation Maintenance Technical Workers Workforce Development Grants program helps prepare tomorrow's aviation maintenance technicians. The FAA provides these grants to academia and the aviation community to help prepare a talent pool of pilots and aviation maintenance technicians.

In FY 2024, the FAA awarded a third round of grants totaling $13.5 million in Aviation Workforce Development Grants to 32 educational institutions across the country.

Veterans Pilot Training Pilot Program

In addition to the above grant programs, the FAA has established a new prototype program to assist military veterans who hope to become commercial aircraft pilots. Known as the Veterans Pilot Training Pilot Program, the program's main goals are to recruit and enroll veterans in a program that will support their successful completion of an airline transport pilot certification and provide metrics, data, and feedback on the feasibility and viability of a larger-scale program to inform and improve the program's future implementation.

In July 2022, the FAA awarded the University of North Dakota (UND) a four-year cooperative agreement to begin this program. Two years after the award, the program continues to cultivate collaboration and community engagement, which supports higher ratings for retention and performance among veterans enrolled. The program enhanced UND's engagement with aviation industry partners. Veterans not only have seen cost savings from exercising their Veterans Administration benefits but also received mentorship and entry-level employment in the aviation industry, such as serving as Certified Flight Instructors. Entry-level employment created pathways for veterans to earn additional flight hours not earned after graduating at UND but required to achieve a Restricted Airline Transport Pilot certification.

Aircraft Certification Reform

The FAA embraces the need to promote and sustain the primacy of safety through continuous and proactive safety risk management throughout its workforce, across industry, and with other aviation authorities. The FAA continues to improve its certification and safety oversight processes, including by comprehensively implementing the provisions of the Aircraft Certification, Safety, and Accountability Act (ACSAA).

In FY 2024, the FAA identified the following general themes in the ACSAA:

- Treat aircraft as complex systems, fully considering how all the elements in the operating system interact.

- Integrate human factors considerations more effectively throughout all aspects of the design and certification process.
- Improve the agency's oversight process by ensuring the coordinated and flexible flow of data and information.
- Focus on the workforce of the future and develop expertise to evaluate technological advances.

In FY 2024, the FAA:

- Issued for public comment a draft revision to FAA Order 8100.15, Organization Designation Authorization (ODA) Procedures, which introduces a risk-based oversight approach for ODA holders and institutionalizes other enhancements to the FAA's oversight that address requirements of ACSAA and were incorporated via other policy vehicles in response to ACSAA. These requirements include increased FAA involvement in ODA Unit Member selection and appointment, the assignment of FAA Safety Advisors to certain ODA Unit Members, and the need for ODA holders to monitor for and take action to eliminate interference with the performance of FAA functions.
- Received the final report from the Section 103 ODA Expert Panel and committed to addressing all recommendations aimed at the FAA. The FAA also set the expectation with Boeing that they would address all recommendations in the report that were aimed at Boeing. The Section 103 ODA Expert Panel was a joint industry and FAA panel made up of a diverse group of aviation safety experts. The panel evaluated the effectiveness of Boeing's Safety Management processes in instilling an appropriate safety culture, the effectiveness of measures instituted by Boeing to ensure a commitment to safety in their interactions with Boeing's ODA, and Boeing's capability to make reasonable and appropriate decisions regarding functions delegated to Boeing's ODA by the FAA.
- Chartered the Changed Product Rule (CPR) Aviation Rulemaking Committee (ARC) in April 2024, outlining specific tasks and recommendations to be provided to the FAA within 6 months of the kickoff meeting. The CPR ARC initiated its activities, and the FAA anticipates that the ARC will submit its final recommendations in December 2024. The CPR ARC is evaluating the need for new rulemaking, as well as FAA policy and guidance development, to ensure that an adequate certification basis is established for changed products. The ARC is considering requirements from Section 117 of the Aircraft Certification, Safety, and Accountability Act (Pub. L. 116-260, 134 Stat. 2309) and recommendations from the CPR International Authorities Working Group (IAWG). The recommendations of the CPR IAWG address improving the CPR process through clarifications to policy, guidance, and training.

- Published the Final Rule for System Safety Assessments (SSA) on August 27, 2024, in response to Section 115 of the Aircraft Certification, Safety, and Accountability Act. The FAA amended certain airworthiness regulations to standardize the criteria for conducting safety assessments for systems, including flight controls and powerplants, installed on transport-category airplanes. With this action, the FAA seeks to reduce the risk associated with airplane accidents and incidents that have occurred in service and reduce the risk associated with new technology in flight control systems. The intended effect of this action is to improve aviation safety by making SSA certification requirements more comprehensive and consistent. The FAA also issued three new Advisory Circulars (ACs) and revised two existing ACs to provide guidance material for the regulations in the final rule.
- Published the Final Rule for Safety Management Systems (SMS) on April 26, 2024, in response to Section 102 of the Aircraft Certification, Safety, and Accountability Act. This updated rule extends the requirement for an SMS to all certificate holders operating under the rules for commuter and on-demand operations, commercial air tour operators, production certificate holders who are holders or licensees of a type certificate (TC) for the same product, and holders of a TC who license out that TC for production. This updated rule is intended to improve aviation safety by requiring organizations to implement a proactive approach to managing safety.
- In response to Section 105 of ACSAA, the FAA published a Notice for Proposed Rulemaking (NPRM) on "Disclosure of Safety Critical Information" on January 25, 2024, which would implement certain ACSAA mandates by requiring applicants for, and holders of, new and amended transport-category airplane TCs to submit, and subsequently continue to disclose, certain safety-critical information to the FAA. The proposed rule amends Section 21.1, 21.3, 21.15, and 21.113 to require applicants to submit certification plans with specific content early in the certification process, and it also includes requirements applicable to holders of Part 25 TCs to submit certain safety-critical information, if known and not previously submitted. These TC holders would thereafter be required to continue to disclose such information upon discovery. Also associated with Section 105, the FAA issued the following policies on November 20, 2023: Policy Statement PS-AIR-21-2023-01, Classification of Type Design Changes That Would Materially Alter Safety Critical Information as Major Design Changes, and Notice 8110.118, Submittal and Disclosure of Safety Critical Information by Applicants for Transport Category Airplane Type Certificates.

As part of ACSAA, the FAA implemented the Voluntary Safety Reporting Program (VSRP) to enable confidential reporting of identified safety concerns by all FAA Aviation

Safety (AVS) employees. The AVS VSRP emphasizes risk-based, data-driven decisions and is structured to ensure alignment and integration with other activities across the FAA. Like other voluntary safety reporting programs, the AVS VSRP employs collaboration between management and unions throughout the process. The event review team, which is an independent body composed of AVS management and union representatives, collaborates to determine acceptance, risk assignment, investigation, and corrective actions for the submitted safety concerns by consensus. The program started in April 2021 and has received approximately 600 concerns, of which 84 percent were successfully closed.

Unmanned Aircraft Systems

Unmanned Aircraft Systems (UAS), also known as drones, continue to increase in number, size, and complexity. The FAA is committed to offering pathways for UAS operations to enable new and innovative applications for these technologies.

In 2014, the FAA issued the first Type Certificates for UAS to Insitu ScanEagle and Aerovironment Puma in the restricted category. The FAA utilized knowledge and experience gained from previous Special Airworthiness Certificates in the Experimental Category projects. Beginning in 2015, the FAA began to regulate small drones with the Registration and Marking Requirements for Small Unmanned Aircraft interim final rule. Shortly thereafter in 2016, the FAA published requirements for small UAS operations and the certification of remote pilots in the "Small UAS rule," now codified in Title 14 Code of Federal Regulations (14 CFR) Part 107. Subsequent rulemakings, including the Operation of Small Unmanned Aircraft Systems Over People final rule (amendment to 14 CFR Part 107) and the Remote Identification of Unmanned Aircraft final rule (established 14 CFR Part 89) provided safety and security requirements to further integrate small UAS into the NAS.

The Operation of Small Unmanned Aircraft Systems Over People final rule revised training prerequisites and established criteria allowing UAS operations over people under specific conditions. For the first time, the rule also allowed for UAS operations at night under certain conditions. The FAA utilized data from waivers to formulate standardized, data-driven operating requirements for safe operations over people and at night.

The Remote Identification (RID) of Unmanned Aircraft Final Rule added a security mitigation to the FAA's integration of UAS in the NAS. RID is a digital "license plate" for an unmanned aircraft enabling the FAA to identify owners or operators of a UAS that is broadcasting a RID, including upon request by law enforcement and national security partners. The RID broadcast also includes a unique serial number and UAS locational information to anyone within range using a RID broadcast receiver. These can be dedicated RID receiver systems or other existing technology, such as a smartphone. However, while all smartphones technically

have the hardware capable of receiving the RID broadcast, not all smartphones allow the implementation of software enabling viewing of the RID broadcast information. Effective utilization of RID by federal, state, local, territorial, and tribal enforcement agencies may require the use of or installation and availability of RID receiver technology.

To further enhance security measures, the FAA is in the final stages of collaboration with the Department of Homeland Security (DHS) on an Application Programming Interface (API) that will allow DHS authorized users to query the FAA drone registration and flight authorization databases themselves, streamlining the process of identifying owners or operators of UAS from the RID broadcast.

Parallel to rulemaking efforts, the FAA permits industry to conduct UAS operations outside the scope of Part 107 through waivers. Waivers allow the industry to push the limits of UAS while providing the FAA with data. The FAA then uses the data to amend Part 107 to include operating requirements for safe night operations. The data-driven approach allows the FAA to amend Part 107 training prerequisites and establish criteria allowing operations over people under specific conditions.

Safely enabling routine, scalable, and economically viable BVLOS operations marks the next significant step in drone integration. The FAA's strategic plan involves transitioning from case-by-case approvals via waivers and exemptions to the development of requirements for BVLOS operations like infrastructure inspection, public safety, package delivery, agriculture, and more.

In pursuit of this objective, the FAA is crafting an NPRM aimed at standardizing routine BVLOS drone operations. This effort draws from insights gathered from waivers and exemptions, the airworthiness certification process, and the recommendations outlined in the final report of the UAS BVLOS Aviation Rulemaking Committee presented to the FAA in March 2022.

In the meantime, the FAA is using existing 14 CFR Part 11 processes to permit more complex drone operations. The FAA issued four exemptions in August and September 2023 that authorize more complex BVLOS operations, including infrastructure inspection and package delivery. In granting these petitions, the FAA enabled new operations in FY 2024 using a layered mitigation approach. Rather than rely on a single mitigation, the FAA utilizes several mitigations put together when approving operational petitions. Data gathered by operations conducted under these exemptions informs efforts for repeatable and scalable operations. The FAA also worked with its public safety stakeholders to enable UA operations that allow for multiple types of operations, such as First Responder Beyond Visual Line of Sight (e.g., emergency response), Tactical Beyond Visual Line of Sight (e.g., short-notice incident response), and Beyond Visual Line of Sight Using Obstruction Shielding (e.g., operating within 50 feet of a structure).

The FAA recently revealed initiatives aimed at realizing UTM, outlining both long-term and short-term plans while identifying policy gaps that need resolution to achieve the "full operational capability" of the UTM ecosystem. Collaboration between industry, NASA, the FAA's Centers of Excellence, academia, and the FAA is ongoing to test and enhance capabilities for managing unmanned aircraft to unmanned aircraft (UA-UA) collision risk across different airspace environments. The necessity to implement UTM services to facilitate safe drone deliveries, thereby enabling increased operations for compensation and hire, is consistently emphasized by industry stakeholders. Under existing regulations, the FAA does not have a framework for independently recognizing or approving third-party automated data or UTM services. This has hindered the industry from developing and marketing these services. To address this gap, in 2022 and 2023, the FAA developed the UTM Near-Term Approval Process (NTAP), which utilizes existing FAA operational approval processes to facilitate the review, testing, evaluation, and acceptance of UTM third-party services. The NTAP provides a pathway for evaluating and accepting UTM services supporting BVLOS operations of multiple operators and is foundational to informing the evolving regulatory framework and future service qualification, as well as providing data to support future rulemaking. In August 2023, the FAA, in collaboration with the industry, announced the UTM Key Site Operational Evaluation. This initiative permits industry and government to gather data from coordinated, real-life UAS operations in North Texas, which will be instrumental in validating the effectiveness of strategic deconfliction services for managing UA-UA collision risk.

Research is foundational for UAS and AAM integration. Research enables informed policies, procedures, regulations, and operations to support the safe and secure integration of UAS and AAM into the NAS. The FAA maintains a comprehensive strategic outlook for UAS and AAM research that captures the FAA's UAS and AAM integration research landscape over the near, mid-, and far term. This landscape is rooted in completed research that yielded data and results that contributed to significant UAS integration advancements. For example, collision severity research yielded thresholds and metrics that informed the development of the Operation of Unmanned Aircraft Systems Over People Final Rule. Additionally, research and analysis into operational data from Part 107 waivers led to the identification of trends characterizing the sufficiency of information provided in those waivers that resulted in approvals and the insufficiency of information provided in those waivers that did not receive approval.

Integration of UAS and AAM operations is a multifaceted global challenge, requiring coordinated efforts within the FAA, across multiple agencies, with international partners, and in international forums, such as the International Civil Aviation Organization. Enabling industry objectives while maintaining the security and safety of the public requires meeting multiple objectives in different domains. The FAA is leveraging an evolving spectrum of UAS and AAM research and analyses being conducted by government agencies, industry, academia,

international organizations, standards bodies, and others to inform rulemaking and operational changes that will enable full UAS and AAM integration into the NAS.

The FAA remains committed to finding innovative, new pathways to enable the next level of safe, secure, and efficient drone and new entrant operations so the United States may continue its global leadership in innovation, safety, and international air transportation systems.

Commercial Space

The FAA's Office of Commercial Space Transportation (AST) continued to achieve new records in FY 2024 with 148 licensed operations (142 launches and 6 reentries) by multiple operators, 35 more than in FY 2023. The FAA maintained its perfect record of ensuring zero fatalities, serious injuries, or significant property damage to the uninvolved public during licensed or permitted space launch and reentry activities, further enabling safe space transportation.

In addition to the growth in the number of commercial space operations, the complexity of the missions seeking FAA approval continues to evolve and increase. The FAA continues to prepare for a dynamic and rapidly maturing set of future missions, which include orbital and suborbital space operations and innovative new designs for traditional launch systems.

Over FY 2024, the FAA licensed ten launches and three reentries carrying human space participants. Virgin Galactic, Blue Origin, and SpaceX operated private astronaut and spaceflight participant operations. Additionally, SpaceX continued to provide spaceflight capability to NASA astronauts and the International Space Station (ISS) by conducting two launches and one reentry carrying ISS crewmembers in addition to three cargo resupply missions. This capability eliminates U.S. dependence on high-cost Russian transportation to the ISS. Boeing continued to develop its commercial crew capsule to provide additional resilient and reliable space transportation for NASA programs.

In FY 2024, commercial space transportation expanded with the following FAA activities:

- Issued two new vehicle license determinations.
- Issued 37 license modifications and ten renewals.
- Conducted a record number of safety inspections—over 800—exceeding the FY 2023 record of 754.
- Granted a license to Stratolaunch for its Roc/Talon hybrid launch vehicle from Mojave, California. The Roc carrier aircraft has the world's largest wingspan of 384 feet. This is the first hybrid vehicle to obtain a Part 450 license.
- Granted a reentry license to Varda for its Winnebago reentry vehicle landing at the Utah Test and Training Range. This is the first reentry vehicle to obtain a Part 450 license.

- Granted three license modifications authorizing SpaceX to conduct test flights of its Starship Super Heavy launch vehicle. This program supports NASA's Artemis Program to develop a fully reusable transportation system designed to carry both crew and cargo to the Moon.
- Granted license modifications to the SpaceX Falcon 9 launch vehicle and Dragon reentry capsule enabling the Polaris Dawn mission. Polaris Dawn private astronauts conducted research with the aim of better understanding the effects of spaceflight and space radiation on human health and included the first-ever private spacewalk.

As more rocket launch operators seek to share the Nation's airspace, the FAA has continued to support airspace efficiency programs to facilitate the integration of space activities throughout the NAS. Launch and reentry vehicle operators provide information relevant to hazard area timeframes, which allows the use of time-based launch/reentry procedures at launch sites in Boca Chica, Texas; Cape Canaveral, Florida; Vandenberg, California; Spaceport America, New Mexico; and Wallops Flight Facility, Virginia. Certain operators voluntarily provide the FAA with telemetry information, which is used by Air Traffic Organization Space Operations to enhance mission awareness and facilitate the accelerated release of launch and reentry airspace or aircraft hazard areas, back to the National Aerospace System. SpaceX voluntarily provides the FAA with certain operational information to implement dynamic launch and reentry windows that the FAA uses at launch sites in Vandenberg, Kennedy Space Center, and Cape Canaveral. These are both ways the FAA uses data about launch and reentry operations to minimize the amount of time airspace is closed to other users.

In FY 2024 specifically, here are a few of AST's accomplishments:

- Publishing eight new Advisory Circulars[1] (ACs) and two revised ACs providing the commercial space transportation industry with guidance on how to comply with regulations.
- Publishing a final rule to incorporate changes required by the Commercial Space Launch Competitiveness Act of 2015 into FAA regulations.[2] It updates definitions for commercial space launch and reentry vehicles and occupants, expands the applicability of permitted operations to include certain reusable vehicles, and clarifies financial responsibility requirements. It also provides clarity to applicants seeking licenses for operations involving government astronauts.
- Completing the work of an Aerospace Rulemaking Advisory Committee (commonly referred to as a SpARC) to gain industry advice and recommendations on

1 https://drs.faa.gov/browse/AC/doctypeDetails?Status=Current&Office%20of%20Primary%20Responsibility=AST-1

2 https://www.federalregister.gov/documents/2024/09/19/2024-20900/us-commercial-space-launch-competitiveness-act-incorporation#:~:text=This%20final%20rule%20provides%20regulatory,safety%2Dcritical%20roles%20on%20board

improvements to 14 CFR Part 440, Financial Responsibility, to include Maximum Probable Loss determinations, responsive reciprocal waiver of claims regime for launch and reentry operators, standards that should apply for means of financial responsibility other than insurance, and changes to the cost of a casualty.

- Continuing the work of a SpARC Safety Framework for Commercial Human Spaceflight Aerospace Rulemaking Committee to gain industry advice and recommendations on the structure of a new regulatory framework for human occupant safety that aligns with mitigating risks while allowing the industry to continue to rapidly innovate and economically prosper while also setting the standard for space travel safety.
- Publishing a policy on payload reviews to specifically address secondary or hosted payloads.[3]
- Publishing a policy on the licensing of reentry vehicles prior to launch.[4]

3 https://www.federalregister.gov/documents/2024/03/14/2024-05384/policy-on-requiring-disclosure-of-payload-contents

4 https://www.federalregister.gov/documents/2024/04/17/2024-08156/launch-of-a-reentry-vehicle-as-a-payload-that-requires-a-reentry-authorization-to-return-to-earth

Department of Commerce

DOC

During FY 2024, the Department of Commerce (DOC) continued to prioritize its Strategic Objective 1.7 to "Advance U.S. leadership in the global commercial space industry." The Department employed its multifaceted tools to strengthen the competitiveness of U.S. businesses, build up the U.S. space workforce and communities, measure the space economy, engage international partners, promote industry standards, encourage technological innovation, bolster cybersecurity, advance space situational awareness for safety and sustainability, and enhance global security. In addition, the Department continued to utilize space technologies to forecast weather and space weather, monitor climate change, support disaster response, and advance scientific understanding.

Deputy Secretary of Commerce Don Graves continued to lead the Department's Commercial Space Coordinating Committee (CSCC) to coordinate and guide efforts across the bureaus to further Strategic Objective 1.7. He participated in multiple space engagements throughout the year to demonstrate the Department's support for the commercial space industry, including the U.S. Chamber of Commerce's Global Aerospace Summit, the inaugural meeting of the Advisory Committee on Excellence in Space, the National Space Council's Black Space Week celebration, and a Women in Space Commerce event that he convened during Women's History Month. The Deputy Secretary also met with many space industry executives and others from the space community to ensure that the Department was aware of their priorities and perspectives.

Deputy Secretary Graves represented the Department at the December 2023 meeting of the National Space Council, where the vice president released the U.S. Novel Space Activities Authorization and Supervision Framework. The Department took steps to support the initial implementation of the framework and promote congressional support for related legislation that would provide regulatory clarity and certainty for future commercial activities in space.

Office of Space Commerce

The National Oceanic and Atmospheric Administration's (NOAA) Office of Space Commerce (OSC) continued to fulfill its statutory responsibilities to 1) foster the conditions for the economic growth and technological advancement of the U.S. space commerce industry and 2) license private-sector parties to operate private remote sensing space systems. In addition, the Office made significant strides to fulfill the Department's responsibilities under Space Policy Directive–3, the National Space Traffic Management Policy. The Office successfully fielded the initial version of its Traffic Coordination System for Space (TraCSS), engaged in dialogues with international partners and industry stakeholders, and continued to license commercial remote sensing satellites.

Space Situational Awareness (SSA)

On September 30, 2024, OSC officially launched the initial phase of TraCSS, which began delivering spaceflight safety services to a beta user group of satellite owners/operators representing approximately 1,000 satellites in orbit. TraCSS is a modern, cloud-based information technology system that notifies space operators of potential collisions to promote space safety, sustainability, and international cooperation.

The launch of TraCSS Phase 1.0 represented the culmination of many significant efforts throughout FY 2024, including hiring actions, milestone approvals, contract awards, and pathfinder projects. Collaboration among the DOC, NOAA, and OSC teams and industry enabled rapid progress. From receiving Authority to Proceed from DOC on March 5, 2024, to the TraCSS system integrator contract award later in March 2024, to achieving Authority to Operate from NOAA in August 2024, TraCSS 1.0 achieved on-schedule fielding. In addition, the office hired the first TraCSS program manager, filled other key positions, and established an Independent Review Board that met twice in FY 2024 to provide direct and impactful feedback from renowned space experts. OSC held six stakeholder listening sessions on various aspects of TraCSS throughout FY 2024 to ensure that the system's development reflects user requirements.

During FY 2024, OSC executed the TraCSS Consolidated Pathfinder project, a limited-term effort to inform the office on contractual and operational metrics, methods, and structures that will enable use of commercial Space Situational Awareness (SSA) capabilities to support spaceflight safety in low Earth orbit (LEO). A secondary goal was to explore the commercial sector's capabilities to maintain a LEO object catalog. The office placed a total of $15.5 million in orders with five commercial SSA companies to execute the project. Lessons learned are informing OSC's development of the plan to procure and integrate sustained commercial

SSA data and capabilities for the operational TraCSS system. In September 2024, NOAA invited vendors to participate in another TraCSS pathfinder project that will examine the efficacy of generating improved satellite positional data, or ephemerides, based on data provided by satellite owners/operators.

In FY 2024, OSC entered into a no-exchange-of-funds Cooperative Research and Development Agreement (CRADA) with SpaceX for research and development activities related to automated collision avoidance and satellite conjunction assessment screenings. Under the CRADA, OSC started an astrodynamics evaluation of SpaceX software.

In April 2024, OSC released a document titled "Global Space Situational Awareness Coordination" that outlined its vision for a global, coordinated system of SSA providers, with a series of national or regional hubs providing SSA information and services to spacecraft operators. The office spent much of FY 2024 promoting this vision with allies, partners, and international bodies, including the United Nations and the International Astronautical Federation. To take initial steps toward international SSA coordination, the Office conducted a joint analysis with the European Union Space Surveillance and Tracking (EU SST) program to compare the SSA services provided by TraCSS and EU SST, respectively, and published the results at the 2024 Advanced Maui Optical Surveillance Conference.

Fostering International Space Business Partnerships

OSC helped organize and lead two international events to promote commercial space partnership with African nations, including the U.S.-Africa Commercial Space Stakeholders Meeting in October 2023 and the U.S.-Africa space cooperation session of the NewSpace Africa Conference in April 2024. These events, involving government and industry participants from the United States, the African Union Commission, and many African nations, provided an opportunity for African stakeholders to better understand the U.S. space landscape, gain insight into key U.S. priorities, share the state of African space institutions, and identify areas of potential partnership.

In October 2023, OSC collaborated with the State Department and the government of Singapore to hold the first U.S.-Singapore Space Dialogue in Washington, DC. The office organized a commercial roundtable that brought together over 20 space companies and research organizations from the two countries. The session allowed industry representatives to better understand how the United States and Singapore promote their respective commercial space sectors and to outline their interests in bilateral cooperation.

In November 2023, OSC collaborated with the State Department and the Republic of Korea (ROK) to hold a ROK-U.S. Space Week in Seoul, including a ROK-U.S. Space Forum and a ROK-U.S. Space Industry Symposium. NOAA leadership participated in the Forum to highlight mutual cooperation across civil, commercial, and security space. OSC co-organized a

space startup pitching session at the Forum. The office also organized the Industry Symposium, involving dozens of U.S. and ROK companies exploring ways to facilitate business-to-business space partnerships. The Industry Symposium fulfilled directions from the two nations' presidents to strengthen U.S.-ROK commercial space cooperation.

In December 2023, OSC collaborated with the government of Italy and the Space Foundation to organize a U.S.-Italy space business roundtable at the Italian Embassy in Washington. Dozens of space companies participated to pursue space partnership opportunities. The event was organized pursuant to the direction of the two nations' leaders during the Italian prime minister's state visit to the United States in July 2023.

In February 2024, officials from OSC and the International Trade Administration (ITA) joined the India Department of Space director for a fireside chat to discuss the ongoing U.S.-India Civil Space Joint Working Group's Commercial Space Sub-Working Group, highlighting U.S.-India discussions on market access, export control, government procurement, and investment regulation.

In March 2024, OSC participated in the second U.S.-France Comprehensive Dialogue on Space in Washington. The office organized the second-ever government-industry "Track 1.5" session to take place under this Dialogue, involving some 50 U.S. and French companies to discuss market access, regulation and policy, spaceflight safety and SSA, and emerging space activities. Deputy Secretary Graves participated in the Track 1.5 preparatory session for U.S. industry.

In April 2024, OSC and the Department of State's Office of Space Affairs co-chaired a U.S.–New Zealand Track 1.5 commercial space roundtable in Colorado Springs, Colorado, to strengthen bilateral partnerships between the two nations' industries. The event supported the inaugural U.S.–New Zealand Space Dialogue, which OSC attended in Washington, DC, to underscore the robust cooperation between the United States and New Zealand in outer space.

In June 2024, OSC participated in the inaugural U.S.-Germany Space Dialogue in Berlin to advance bilateral space cooperation as declared by the two nations' leaders. The office organized a Track 1.5 commercial roundtable that brought together over two dozen space companies and highlighted existing partnerships. The session allowed industry representatives to better understand how the United States and Germany promote their respective commercial space sectors and to outline opportunities and challenges for stronger bilateral cooperation.

In August 2024, OSC participated in the ninth U.S.-Japan Comprehensive Dialogue on Space in Washington, DC. The office organized the second-ever U.S.-Japan "Track 1.5" event to develop ideas for expanding bilateral commercial space partnerships. During the government-to-government "Track 1.0" session of the Comprehensive Dialogue, the office shared a readout of the Track 1.5 session, an update on TraCSS, and an update on its regulation of the U.S. commercial remote sensing industry. Concurrently, Deputy Secretary Don Graves

addressed the first-ever "Track 2.0" (industry-industry) session affiliated with the U.S.-Japan Comprehensive Dialogue on Space.

Promoting Industry Standards

From April 29 to May 6, 2024, OSC collaborated with the National Institute of Standards and Technology (NIST) to cohost the Consultative Committee for Space Data Systems (CCSDS) Technical Plenary Spring Meetings at the Commerce Department headquarters. The committee is a multinational forum for the development of communications and data systems standards for spaceflight. Deputy Secretary of Commerce Don Graves welcomed delegations from 11 international space agencies, with about 200 people attending in person and more virtually from around the world, to develop voluntary, consensus-built standards for space data exchange. These standards are proven to be well-suited for global adoption and use for the exchange of SSA data between SSA platforms and satellite operators.

In June 2024, OSC collaborated with NIST to publish a compendium of existing space industry technical standards, including standards relevant to SSA and space traffic coordination. The compendium provides a consolidated reference to space-related standards, best practices, reports, and other relevant documents compiled up to and current as of June 2024 and has received over 29,000 views as of November 1, 2024.

Novel Space Mission Authorization

OSC led the Department's work on "novel space activities," working with interagency partners, the White House, and industry to design legal, policy, and regulatory tools to support the growth of industry while protecting vital national interests. As part of that work, the office helped design draft legislation—the "Authorization and Supervision of Novel Private Sector Space Activities Act"—released by the White House in November 2023, as well as the "United States Novel Space Activities Authorization and Supervision Framework" released in December 2023.

Commercial Remote Sensing Regulation

OSC's Commercial Remote Sensing Regulatory Affairs (CRSRA) Division continued to regulate the operation of private remote sensing space systems subject to the jurisdiction or control of the United States, while preserving essential national security interests, foreign policy, and international obligations. In March 2024, CRSRA issued a Request for Information regarding its licensing requirements on spacecraft disposal at end of life. CRSRA also held a virtual listening session in July 2024 to gather input from the regulated community and the public regarding insights, challenges, concerns, and recommendations pertaining to U.S. commercial remote sensing regulations and their implementation.

Advisory Committee on Excellence in Space

In March 2024, NOAA rechartered the former Advisory Committee on Commercial Remote Sensing as the Advisory Committee on Excellence in Space (ACES). The new federal advisory committee has an expanded scope covering any matters within OSC's statutory purview, to include commercial space mission authorization, licensing of private remote sensing space systems, and space sustainability. NOAA appointed 17 members to ACES in August/September 2024 and supported its inaugural meeting (held October 3, 2024).

National Executive Committee for Space-Based Positioning, Navigation, and Timing

OSC continued to host the offices of the National Executive Committee (EXCOM) for Space-Based Positioning, Navigation, and Timing, the senior body established by presidential directive to advise and coordinate federal departments and agencies on policy issues related to the Global Positioning System (GPS) and related topics. This included hosting the EXCOM's website, http://www.gps.gov, which remained a leading internet resource for public information about GPS.

National Environmental Satellite, Data, and Information Service

NOAA continued to manage and operate geostationary environmental satellites, low Earth orbiting satellites, and a deep space satellite for weather and space weather monitoring and forecasting. Twenty-four-hour global coverage from these satellites provides the public and NOAA's partners with continuous information used to prepare for events impacting weather, oceans, and climate.

Geostationary Satellites

NOAA's current generation of Geostationary Operational Environmental Satellites, known as the GOES-R Series, continued to provide advanced imagery and atmospheric measurements of Earth's Western Hemisphere, real-time mapping of lightning activity, and monitoring of solar activity and space weather. Together, the GOES East and GOES West satellites provided continuous, real-time monitoring and tracking of hurricanes, thunderstorms, flooding, snow, ice, fog, wildfires, smoke, dust, volcanic eruptions, and other severe weather conditions and environmental hazards for more than half the globe. The GOES program also monitored the Sun and detected space weather hazards that disrupted communications, navigation systems, and power grids on Earth.

GOES-19, the final satellite in the GOES-R Series, successfully launched in June 2024 from Cape Canaveral Space Force Station and began on-orbit testing. This brought the total number of GOES satellites in orbit to five, with two maintained as backups.

NOAA's follow-on to the GOES-R Series, the Geostationary Extended Observations (GeoXO) mission, saw important progress in FY 2024. NOAA awarded four GeoXO development system contracts: Ocean Color to BAE Systems (May 2024), Atmospheric Composition to BAE Systems (May 2024), Spacecraft to Lockheed Martin (June 2024), and the Lightning Mapper to Lockheed Martin (September 2024).

Low Earth Orbiting Satellites

NOAA's current generation of LEO operational environmental satellites, the Joint Polar Satellite System (JPSS), provided full global coverage twice a day with advanced sensors for weather and climate data, collecting information on temperature, atmospheric conditions, wind speed, cloud formation, and drought conditions over the entire Earth.

NOAA-21 and NOAA-20 continued to serve as NOAA's primary LEO operational environmental satellites, with the 13-year-old Suomi National Polar-orbiting Partnership (Suomi NPP) satellite providing an additional tertiary level of support. All major numerical weather prediction (NWP) centers around the world used data and observations from JPSS as the basis of nearly every medium-term (three to seven days in advance) weather forecast, protecting lives and property. NOAA continued to acquire and distribute Japan Meteorological Agency and European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) data for operational users, and NOAA continued to maintain operational backup agreements with those agencies.

The JPSS-3 satellite spent FY 2024 in environmental testing in preparation for storage prior to launch in FY 2033. The instruments for JPSS-4 were entering their final stages of development at the end of FY 2024. The launch sequence for JPSS-4 and JPSS-3 was switched to minimize the schedule and cost risk to the satellites while an Earth radiation budget measurement instrument called Libera is integrated.

NOAA awarded the launch vehicle contract for the QuickSounder mission in September 2024, with launch scheduled for April 2026. QuickSounder will fly an existing Advanced Technology Microwave Sounder engineering development unit on a NASA-procured spacecraft operating in the late afternoon/early morning polar Sun-synchronous orbit. The QuickSounder mission serves as a pathfinder for operational Near Earth Orbit Network (NEON) program acquisitions. NEON is NOAA's planned satellite portfolio to complement the current program of record (i.e., JPSS), fund gap mitigation and risk-reduction activities, and support continuity of observations from LEO.

In March 2024, the NEON program received Milestone 1 approval and Authorization to Proceed from DOC. NEON Series 1 consists of a block of small satellites providing microwave sounding observations essential to the performance of the NWP models. The Series 1

microwave sounding instrument, called the Sounder for Microwave-Based Applications, completed its Phase A studies in August 2024.

In November 2023, NOAA successfully transitioned operations of the legacy Polar Operational Environmental System (POES) constellation to a contractor-provided ground system through the POES Extended Life program. This achievement enabled NOAA to

- allow for a gradual ramp-down of POES operations through FY 2025 using a commercial ground system;
- incentivize growth of commercial industries' cloud-based command and control capabilities to further understand evolving approaches to achieve strategic National Environmental Satellite, Data, and Information Service (NESDIS) cloud development goals; and
- allow re-use of the legacy POES Command and Control ground system for other LEO missions (in progress).

Partner Missions

NOAA continued its cooperation with Taiwan in operating the follow-on to the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC), known as COSMIC-2/FORMOSAT-7. The system provided radio occultation soundings from equatorial orbit to support improved NWP model forecasts and space weather monitoring. NOAA utilized the six COSMIC-2/FORMOSAT-7 satellites heavily during the 2023 and 2024 Atlantic hurricane seasons.

NOAA continued its collaboration with EUMETSAT on the development and operation of polar-orbiting satellites. EUMETSAT's Metop series constellation is part of a joint commitment between NOAA and EUMETSAT to fly complementary polar-orbiting satellites. NOAA continued to work with EUMETSAT to ensure that future programs for both organizations, including NEON and European missions like Sterna, will be able to rely on partners for support.

NOAA continued to collaborate with the Japan Aerospace Exploration Agency (JAXA) on Earth and climate observation. JAXA transmitted data from its Global Change Observation Mission (GCOM) program to NOAA ground receiving sites in the Arctic Circle and the United States. This program supports the tracking of water cycle changes across the globe.

NOAA combined data from its historical LEO and geostationary Earth orbit (GEO) operational satellites together with that from the current satellites to extend its satellite Climate Data Records (CDR)—co-calibrated multi-decadal time series datasets using data from the full periods-of-record. The approximately 45-year seamless records are important to many climate applications, including modeling, detecting and quantifying trends, and supporting

U.S. industry in understanding business risks and opportunities affected by climate. In 2024, NOAA continued the transition of CDR algorithms from using data feeds from legacy POES and GOES instruments to that from JPSS and GOES-R Series instruments. NOAA also continued to work collaboratively with EUMETSAT on an early GOES instrument data recovery and reprocessing effort to support development of a global "Geo-Ring" CDR by combining geostationary data from NOAA, EUMETSAT, and the Japanese Meteorological Agency.

NOAA partnered with the European Union to support the launch of the Sentinel 2c satellite on September 5, 2024. Including Sentinel 2c, NOAA supported operations of a total of 17 European satellites during FY 2024.

Space Weather Observations

NOAA continued to develop the Space Weather Follow On (SWFO) Program to maintain observational continuity of real-time solar imagery and solar-wind events from geostationary orbit and the unique Earth-Sun Lagrange Point 1 (L1) region. The program completed its System Integration Review and other pre-mission reviews for the various instruments and sensors. SWFO-L1 is intended to replace the legacy Deep Space Climate Observatory (DSCOVR) mission, America's primary operational warning system for geomagnetic storms and solar wind data, while giving Earth scientists a unique vantage point for studies of the planet's atmosphere and climate.

As part of the SWFO Program, NOAA partnered with the Naval Research Laboratory (NRL) to build three Compact Coronagraph (CCOR) instruments for future space weather observations. The first CCOR launched in June 2024 on the GOES-19 (GOES-U) satellite and was completing post-launch checkout at the end of FY 2024.

Throughout 2024, NOAA continued to develop the Space Weather Next (SW Next) Program, which will provide NOAA with space weather observations through a comprehensive architecture and coordinated multi-mission program to ensure that space weather products are available to meet user requirements. SW Next will collect observations in multiple locations, such as L1 orbit and Lagrange Point 5 (L5), the latter of which is off the Sun-Earth line, to maintain data continuity and provide enhanced space weather products. As of FY 2024, the program is in the Implementation phase, and NOAA has formulated its first two projects to address observations in the L1 and L5 regions.

In July 2024, the L1 Series Project successfully completed DOC Milestone 2/3, allowing the project to proceed with necessary contracting actions and establishing the project's baseline. The L1 Series Project includes the development and deployment of two dedicated space weather observatories to meet continuity of observations at L1 beyond the SWFO-L1 mission.

In March 2024, the L5 Project successfully completed DOC Milestone 2/3, allowing the project to proceed with necessary contracting actions and establishing the project's baseline.

The L5 Project, in partnership with NRL, is working to build and deliver the third CCOR to the European Space Agency for flight on its Vigil mission to L5.

In addition to the space weather instruments on the GEO and LEO satellites listed above, NOAA continued to operate three dedicated space weather satellites on orbit: DSCOVR, the Advanced Composition Explorer, and the Solar and Heliospheric Observatory.

Commercial Data Program

NOAA's Commercial Data Program (CDP) continued to successfully engage with the private sector to obtain commercial satellite data that helps meet NOAA's observing system objectives. CDP assesses and acquires value-added space-based commercial environmental observation data to augment existing data streams in support of NOAA's operations and research. CDP manages two lines of effort: the Commercial Weather Data Pilot projects, which demonstrate the quality and impact of commercial data on environmental applications, and the Commercial Data Purchases, aimed at supporting operational weather applications.

In FY 2024, CDP continued to manage an Indefinite Delivery/Indefinite Quantity contract with two commercial space companies, Spire and PlanetiQ, to acquire commercial Global Navigation Satellite System (GNSS) Radio Occultation (RO) data, allowing the companies to compete for Delivery Orders (DOs). In September 2024, NOAA concluded its eight-month Radio Occultation Data Buy Delivery Order-3 (DO-3) with Spire for 3,000 RO profiles per day. Upon conclusion of DO-3, on September 18, 2024, NESDIS CDP began its 12-month Delivery Order 4 (DO-4) with both Spire and PlanetiQ for a total of 3,000 RO profiles per day in total. These data, which contain unrestricted distribution rights, were used in operational weather forecast models to enhance forecasting accuracy and effectiveness.

CDP also includes Commercial Weather Data Pilots to evaluate new commercial data sources with the goal of transitioning the piloted capabilities into operations. CDP completed a pilot involving commercial space weather data and published a final report. CDP initiated a GNSS Reflectometry (GNSS-R) Ocean Surface Winds Pilot and at the end of FY 2024 was evaluating commercial reflectometry data gathered during the pilot period to evaluate a range of GNSS-R applications. Additionally, NOAA awarded a new Pilot for Microwave Sounding to Orbital Micro Systems and Tomorrow.io.

NASA Partnership to Enhance Earth Data Management

On August 22, 2024, NOAA and NASA announced a strategic partnership to advance the implementation of the Common Metadata Repository, a continually evolving metadata system for Earth observation data within the NESDIS Common Cloud Framework. The partnership aims to streamline the process of transferring NOAA's valuable data into NASA's repositories, enhancing data accessibility and interoperability for research and operational use.

Office of Marine and Aviation Operations

Aircraft Acquisition Updates

In FY 2024, NOAA exercised a $105.9 million contract option with Gulfstream Aerospace Corporation to purchase a second fully modified G550 aircraft. The state-of-the art jet will be specially configured to support hurricane and tropical storm forecasts, atmospheric research, and other NOAA missions. The fully instrumented aircraft, expected to join NOAA's fleet in 2028, is funded primarily by the Inflation Reduction Act. The new aircraft, along with another to be delivered in 2025, will greatly enhance NOAA's ability to gather data critical to hurricane research and forecasting, atmospheric river research and forecasting, climate studies, and other missions.

In FY 2024, NOAA awarded a contract to Lockheed Martin Aeronautics for two specialized C-130J Hercules aircraft to become the next-generation NOAA Hurricane Hunters.

Funded in part by the 2023 Disaster Relief Supplemental Appropriations Act, the fully instrumented aircraft are expected to join NOAA's fleet in 2030. The four-engine C-130J Hercules aircraft are proven platforms for hurricane reconnaissance and will be modified as replacements for NOAA's two current WP-3D Orion aircraft. The new aircraft will allow NOAA to accommodate larger science payloads as well as enable the launch and control of uncrewed aircraft systems. With expanded research and emergency response demands, modernizing NOAA's aircraft fleet is critical.

National Institute of Standards and Technology

In FY 2024, NIST continued to provide wide-ranging contributions to the aerospace industry, academia, and federal agencies with the research, standards, products, services, and guidance needed to advance the president's aeronautics and space agenda. As detailed in the following sections, NIST's primary contributions are in the areas of advanced manufacturing; systems and supplies; calibrations and sensor development; standards and guidance for reliable and secure space commerce; and support for lunar, cislunar, and extraterrestrial research.

Advanced Manufacturing for Aerospace Applications

NIST utilizes measurement expertise in mass, force, networking, and other areas to provide calibration support to the aerospace industry. Additionally, NIST's broad portfolio in advanced manufacturing helps aerospace manufacturing companies address needs in many sectors, including additive manufacturing (AM), collaborative robotics, smart manufacturing, cybersecurity in manufacturing environments, supply-chain logistics, and large-scale manufacturing.

NIST founded and leads the Additive Manufacturing Benchmark Series (AM Bench) that partners with DOD, the Department of Energy (DOE), NASA, academia, and industry to

produce rigorous measurement data that the industry uses to validate AM simulation codes.[1] Throughout FY 2024, NIST disseminated 18 archival AM Bench measurement publications and eight reference datasets. NIST additionally established a new Manufacturing Science domain for the storage and accessibility of AM Bench datasets on the SciServer system, complementing the existing Configurable Data Curation System.[2]

NIST established an Interagency Agreement with NASA Langley Research Center in 2024 to collaborate on AM data management and process control. This collaboration aims to advance capabilities and reduce risk for metal-based AM processes. In 2024, NIST also collaborated with NASA on research and standards development of digital twins for manufacturing applications. Both NASA and NIST contribute to federal planning and coordination through the Networking and Information Technology Research and Development Fast Track Action Committee on Digital Twins.[3]

The NIST Manufacturing Extension Partnership (MEP) continued to support the expansion and diversification of the advanced manufacturing talent pool for space manufacturing by promoting awareness of advanced manufacturing careers, engaging underrepresented communities, and addressing social barriers for underserved groups.[4] In FY 2024, approximately 15 MEP Centers across the United States worked to increase awareness of the Advanced Manufacturing sector and supported initiatives, including public-private partnerships that enable workforce development programs, such as apprenticeships, internship programs, and boot camps. MEP Centers also worked to recruit students at minority-serving educational institutions and encourage student-led projects for aerospace and defense-related manufacturers.

In April 2024, NIST MEP hosted "Out of This World Manufacturing and More," a virtual event in support of the National Space Council's "Find Your Place in Space Week."[5] The webinar featured a former NASA astronaut and current NIST employee who discussed their experiences in the space program, MEP Center support for small manufacturers in the space supply chain, and the substantial number of MEP Center small manufacturing clients in the space industry.

Aerospace Systems and Supplies

Throughout FY 2024, NIST continued to support the design, development, and calibration of aerospace systems and supplies, including optimization of the supply chain. Contributions

1 https://www.nist.gov/ambench

2 https://cdcs.nist.gov/; https://www.sciserver.org/

3 https://www.nitrd.gov/

4 https://www.nist.gov/mep

5 https://www.nasa.gov/organizations/national-space-council-users-advisory-group-nspc-uag/find-your-place-in-space-week/

include but were not limited to collaborative robotics, material development for advanced applications, fuel development, and thrust calibrations.

NIST maintains a range of Standard Reference Materials (SRMs) used by NASA and the aerospace industry to ensure the quality, safety, and durability of materials used for space-based structures.[6] In FY 2024, NIST supplied Charpy reference materials to NASA to help provide a measure of fracture toughness, which can be used as a direct indicator of material quality for materials ranging from plastics to very-high-strength steels.[7]

In FY 2024, NIST worked with NASA's Marshall Space Flight Center to identify new equations of state and models for thermodynamic properties for future rocket propellants and aviation fluids. This work focused on REFPROP, a reference database for fluid properties and associated models, with NASA collaborators identifying needs for future modeling activities and data products.[8]

In FY 2024, NIST collaborated with NASA's Jet Propulsion Laboratory (JPL) to share methods and tools for collecting, archiving, and storing large datasets to facilitate artificial intelligence/machine learning (AI/ML) approaches to biotechnology research. This effort focuses on the development of data-driven science architectures and standards to help harness the power of large volumes of data for the advancement of bioengineering and bioscience research. This collaboration has accelerated NIST's programs in these fields while also promoting fair data standards.

The 2023 launch of the NIST MEP Supply Chain Optimization and Intelligence Network (SCOIN) has allowed the aerospace industry to gain access to a broad network of domestic small and medium manufacturers (SMMs), bolstering its supply-chain resilience and efficiency. In support of SCOIN, MEP Centers provide specialized training and consulting services, conduct on-site risk assessments, and host group classes for SMMs that focus on best practices in cybersecurity and risk management. As of 2024, there are approximately eight to ten MEP Centers involved in this activity with the aerospace industry.

Additionally, MEP Centers provide lean services, specific technical assistance, and training to help small and medium manufacturers achieve ISO 9001 and 9100 quality management system certifications. FY 2024 survey data show that 17 MEP Centers engaged in this activity.

In FY 2024, approximately 15 MEP Centers helped SMMs achieve certifications under the National Aerospace and Defense Contractors Accreditation Program, an industry-managed certification program that assesses the quality of products and services from suppliers in the aerospace and defense industries.[9]

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6 https://www.nist.gov/srm

7 https://www.nist.gov/programs-projects/charpy-machine-verification-program

8 https://www.nist.gov/srd/refprop

9 https://www.p-r-i.org/nadcap

Calibrations and Sensor Development for Aerospace Applications

NIST contributes to satellite hardware and other space hardware in both technology development and measurement calibration.

NIST provides 30–40 laser power and energy meter calibrations each year to the aerospace industry and DOD customers, supporting both laser weapons systems and target designation systems. In support of government agencies and the broad aerospace industry, NIST provided calibration services and material properties research in areas such as temperature readings, vacuum testing, humidity, and traceable measurements of thermal leaks throughout FY 2024.

A microfabricated photonic accelerometer recently developed at NIST provides exceptional precision and accuracy; it is compact and does not require external calibration—a critically important advantage for navigational guidance in satellites and spacecraft. NIST is currently collaborating with the Air Force Research Laboratory on developing this and other advanced navigational systems for use in the aerospace industry and for the development of resilient positioning and navigation technologies when GPS services are unavailable or denied.

Throughout FY 2024, NIST has developed new technology standards for spaceborne weather monitoring to enhance instrument evaluation, increase data repeatability among instruments, and enable constellations of small satellites. NIST is additionally developing traceable measurement techniques to validate new on-orbit calibration targets and potentially establish a calibration service that supports the remote-sensing community.

NIST continues to work with a commercial developer of high-efficiency solar photovoltaic cells for space applications to "space-qualify" their solar cells. In FY 2024, a company sent batches of solar cells for irradiation by an electron beam from the NIST Van de Graaff accelerator, where the equivalent electron exposure experienced by a satellite over several decades in Earth orbit may be delivered in less than one hour.[10] Characterizing the degradation in performance of the solar cells caused by irradiation is necessary to validate the performance of the cells in a space-radiation environment. The knowledge gained by irradiation of these devices assisted the company in the development of its technology in terms of product reliability and functionality.

NIST is currently collaborating with NASA JPL on the development of superconducting nanowire single-photon detectors, which are photon detectors with extremely low noise and very-high-speed response. These devices are of interest to JPL for space communications and to NIST for various quantum information experiments.

NIST is collaborating with the Laboratory for Atmospheric and Space Physics, NASA's Earth Science Technology Office, and NASA's Langley Research Center to extend the Earth Radiation Budget data record. The Earth Radiation Budget refers to the overall balance

10 https://www.nist.gov/history/radiation-physics-building/facilities/positive-ion-van-de-graaff-accelerator

between incoming energy from the Sun and the outgoing radiation from Earth, which can include heat or other reflected wavelengths. In FY 2024, NIST completed the fabrication of detectors for the Libera mission, which will provide data continuity for this essential climate variable. NIST additionally built a portable, room-temperature, primary standard for optical radiance measurements that is being used to validate the calibration of Earth Radiation Budget instruments.

In FY 2024, NIST designed and fabricated cryogenic readout circuitry, contributing to several of NASA's projects, including the Athena x-ray satellite mission. NIST also began the fabrication of time-domain multiplexer readout circuitry for the demonstration model of the Athena X-ray Integral Field Unit. NIST additionally contributed gamma-ray sensors and readout circuitry for NASA's mini-Dilution Refrigerator and a Transition Edge Sensor (DR-TES) balloon mission. Furthermore, NIST continues to develop a variety of future-looking technologies relevant to several early-stage or potential space missions, as well as far-infrared probe concepts.

NIST continued to provide calibration support to NASA's Goddard Space Flight Center for spectral/radiometric calibration of several Earth-observing instruments through a facility that provides a source of tunable, high-power, uniform radiance for calibrating satellite sensors. NIST develops accurate greenhouse gas (GHG) measurements and primary GHG concentration standards linked to the International System of Units. NIST continues to integrate ground-based and remote-sensing data for GHG concentration measurements as part of the Urban Dome project in order to better understand the complexities of GHG measurements obtained from satellites in orbit.[11]

Standards and Guidance for Reliable and Secure Space Commerce

NIST contributes significantly to two critical technical standards heavily utilized by the aerospace industry: managed model-based 3D engineering (ISO 10303-242) and Systems Analysis Integration, an open-source effort led by NASA's JPL and Boeing.[12] In 2024, NIST presented its research to JPL, Boeing, and members of the Open Model Based Engineering Environment project.

NIST is working on an international comparison for 6G antenna metrology and developing new broadband antenna metrology standards in order to best unlock the potential of 6G internet. NIST is also tackling challenges such as spectrum management, interference mitigation, and data privacy. This research is part of NIST's Robotically Enhanced Antenna

11 https://www.nist.gov/greenhouse-gas-measurements/urban-test-beds

12 http://www.ap242.org/; https://www.nist.gov/programs-projects/systems-analysis-integration

Laboratory for Metrology, which uses industrial robots and radio frequency (RF) sources for satellite antenna measurements.[13]

NIST's cybersecurity work applicable to aerospace is driven by Space Policy Directive 5, Cybersecurity Principles for Space Systems; and EO 13905, Strengthening National Resilience Through Responsible Use of Positioning, Navigation, and Timing Services. NIST has applied the NIST Cybersecurity Framework for space systems to position, navigation, and timing (PNT) systems (Foundational PNT Profile: Applying the Cybersecurity Framework for the Responsible Use of Positioning, Navigation, and Timing Services),[14] commercial satellite operations (Introduction to Cybersecurity for Commercial Satellite Operations),[15] satellite ground segments (Satellite Ground Segment: Applying the Cybersecurity Framework to Assure Satellite Command and Control),[16] and hybrid networks (Cybersecurity Framework Profile for Hybrid Satellite Networks).[17] NIST is also collaborating with other government agencies to advance zero-trust architecture implementation, as well as research to improve GPS navigation message resiliency.

In FY 2024, NIST released three Federal Information Processing Standards regarding cybersecurity and post-quantum cryptography that ensure the confidentiality and integrity of digital communications for all industries, including aerospace.

In FY 2024, NIST collaborated with Red Hat to host the third annual Cybersecurity Open Forum, which brought together cybersecurity experts to address newfound vulnerabilities, discuss strategies to ensure data compliance in open cloud-based environments, and highlight approaches to help safeguard space commerce data.[18] These efforts are in support of DOC Strategic Objective 1.6 in the DOC Strategic Plan: Improve the Nation's Cybersecurity and Protect Federal Government Networks.

Through cooperative agreements and calibration services, NIST is working with companies providing space-based PNT services to incorporate newly developed laser frequency comb techniques that could improve the accuracy of synchronizing distant clocks by 10,000 times compared to the state of the art.

Support for Lunar, Cislunar, and Extraterrestrial Research

NIST supported lunar/cislunar and extraterrestrial research by providing data and measurement techniques and developing equipment that enables relevant mission operations.

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13 https://www.nist.gov/ctl/antenna-communication-and-metrology-laboratory-acml

14 https://csrc.nist.gov/News/2021/nistir-8323-foundational-pnt-profile

15 https://www.nist.gov/news-events/news/2023/07/introduction-cybersecurity-commercial-satellite-operations-nist-ir-8270

16 https://csrc.nist.gov/pubs/ir/8401/final

17 https://www.nccoe.nist.gov/projects/hybrid-satellite-networks-cybersecurity

18 https://events.redhat.com/profile/form/index.cfm?PKformID=0x1063526abcd&sc_cid=7015Y000003tCFcQAM#overview

In FY 2024, NIST provided support for a series of international workshops in conjunction with OSC, including hosting the CCSDS/NIST Technical Plenary Spring Meeting and Lunar Interoperability Forum.[19] These two meetings, held in Washington, DC, in April and May of 2024, brought together international experts in space communications and navigation standards to develop a multi-national approach to interoperability to lunar orbit satellites.

NIST continues to provide expertise in timescales and relativistic clock corrections to advise NASA and other Government agencies on establishing time standards for the Moon and in cislunar space. This expertise is needed to implement the National Cislunar Science & Technology Strategy and implement GPS-like navigation on the lunar surface and in the cislunar region.

In 2024, NIST completed the development of an automated data analysis pipeline for lunar flux measurements and made progress on a similar pipeline in support of accurate measurement of the flux from the standard stars used by astronomers for flux calibration.

In collaboration with NASA and various universities, NIST researchers completed the preliminary design of an artificial starlight source in 2024 through the Calibration using an Artificial star with NIST-traceable Distribution of Luminous Energy project, which aims to provide an entirely new calibration method for astronomical telescopes.

NIST continues to collaborate with NASA's JPL to assess the survivability of microbes in ultra-cold environments and embedded within ice cores in a radiation environment, aiming to determine if the moons of Jupiter and other planetary bodies can potentially support microbial life.

International Trade Administration

The International Trade Administration's (ITA) Office of Transportation and Machinery (OTM) participated in multiple forums on industry development and operations of unmanned aerial systems (UAS). OTM participated in the interagency UAS Executive Committee, which addresses UAS policy issues, and the UAS Security Senior Steering Group (SSG), which implements initiatives derived from the Executive Committee. OTM provided industry perspective through the SSG and participated in a working group to address testing and evaluation of counter-UAS systems to be operated by the U.S. Government. Additionally, OTM supported the development of standards and conformity assessment programs through participation in the UAS Standards Collaborative, a working group hosted by the American National Standards Institute. OTM also supported rulemaking through participation in the Beyond Visual Line of Sight Aviation Rulemaking Committee.

19 https://www.nist.gov/news-events/events/ccsdsnist-technical-plenary-spring-meetings-lunar-interoperability-forum

OTM continued to support the National Security Council–led effort to create and implement the Domestic Counter-UAS National Action Plan. OTM continued to collaborate with DOD on facilitating exports of Blue small UAS and other proven commercial capabilities, as appropriate. In September 2024, ITA led a trade mission to Taiwan encouraging exports of UAS and counter-UAS to Taiwan.

Throughout FY 2024, OTM organized and led three meetings of the Industry Trade Advisory Committee on Aerospace Equipment, which provides advice to the Secretary of Commerce and the U.S. Trade Representative (USTR) on aerospace-related trade policy issues. The Committee provided feedback on the following topics: the Indo-Pacific Economic Framework; the U.S.-Taiwan Trade Initiative for the 21st Century; the U.S.-EU Trade and Technology Council; EU defense policies that impact U.S. aerospace trade with Europe; current priorities vis-à-vis China; critical materials trade agreements; supply-chain issues; per- and polyfluoroalkyl substance issues affecting access to the EU market; and aerospace industry initiatives that positively impact the environment.

ITA continued to support USTR on issues relating to the enforcement of U.S. rights under the World Trade Organization Agreement on Trade in Civil Aircraft. Following the 2021 resolution of the case between Boeing and Airbus, ITA has supported USTR in working group meetings with European Union and United Kingdom counterparts to verify agreement compliance and to monitor competition from non-market economies.

ITA's Office of Finance and Professional Services continued to participate in the Group on the Sector Understanding on Export Credits for Civil Aircraft (the "Aircraft Sector Understanding" or ASU) at the Organization for Economic Cooperation and Development. The ASU establishes rules for aviation export credit agencies and ensures that government financial support does not negatively affect the civil aviation market. As a member of the U.S. delegation, ITA participated in negotiations of potential ASU adjustments and represented the interests of the U.S. airline industry during the ASU discussions. Furthermore, ITA also worked closely with interagency partners to monitor conditions in the aircraft finance market and supported Export-Import Bank's ongoing initiatives to provide financing support to the U.S. aerospace industry and its supply chain.

In 2024, ASU participants discussed the need to develop procedures for adding and removing countries from the Cape Town Convention Discount List, which determines eligibility for a fee discount under the ASU. The group created a new Cape Town Convention Experts Group to begin work on related procedures, and the group held its inaugural meeting in March 2024. ASU participants also discussed proposals for clarifying rules related to maintenance contracts and helicopter sales. In light of the satisfactory functioning of the ASU, the group decided that a full review of the ASU was not necessary until at least 2027.

ITA actively participated in the implementation of the National Space Council's policies, which included industrial base, supply-chain risk, and competitiveness issues. Throughout FY 2024, ITA and NOAA continued to ensure that the policies' implementation actions would improve the U.S. industry's competitiveness, stimulate the American economy, increase exports, and create U.S. jobs.

ITA continued to play an important role in promoting U.S. aerospace trade interests as the industry faced mounting competition from abroad. At the close of FY 2024, ITA's Advocacy Center had 38 active space-related cases with a total project value of $10.4 billion and U.S. export content of $9.7 billion. At the same time, the Advocacy Center had 511 active cases in the aerospace and defense sectors valued at $664.2 billion with $566.9 billion of U.S. export content. ITA organized and participated in multiple trade events, advocating for U.S. companies in international aerospace competitions for the sales for aircraft, helicopters, airport construction, communications, remote sensing satellites, commercial projects, and air traffic management projects.

Industry and Trade Promotion

The Aerospace & Defense team achieved unprecedented performance levels in FY 2024, driven by a diverse portfolio of team members, events, services, and partners. The team organized 51 trade promotion events for 3,062 company representatives, achieving approximately 168 success stories. The team conducted approximately 2,826 in-depth export counseling sessions with over 1,271 U.S. companies, reflecting exceptional client demand and participation. The team also led four trade missions, 12 Trade Expansion Missions, four Trade Enhancement Partnership Programs, and 11 webinars promoting U.S. exports.

In June 2024, ITA organized a panel at the Select USA Summit to increase foreign investment in the U.S. commercial space industry. Moderated by ITA's Deputy Assistant Secretary for Manufacturing, the panel provided guidance to potential investors, highlighted market opportunities, and shared success stories from previous investors.

Bureau of Economic Analysis

In FY 2024, the Bureau of Economic Analysis (BEA) published revised and new statistics quantifying the U.S. space economy for 2017–22.[20] The new statistics included more detail than previous estimates and new price index data tables.

In March 2024, BEA held a Space Economy Measurement Workshop that brought together space economy experts and stakeholders from government, private industry, nonprofits,

20 Tina Highfill, Patrick Georgi, and Chris Surfield, "SCB, New and Revised Statistics for the U.S. Space Economy, 2017–2022," June 2024, bea.gov.

and academia for the purpose of demonstrating, expanding, and improving BEA's space economy statistics.

United States Patent and Trademark Office

The United States Patent and Trademark Office (USPTO) continued to develop and engage in initiatives to support commercial space innovation. In May 2024, USPTO hosted an all-day "Dialogue on Intellectual Property (IP) and Space Commercialization" that focused on the intersection of IP and the expanding commercial space sector. The dialogue was the first event at the USPTO dedicated to an in-depth discussion of the convergence of IP and space law, as well as the specific challenges and opportunities for small and medium-sized enterprises and startups in the commercial space sectors.

Additionally, the USPTO continued to utilize IP attachés stationed around the world to engage both domestically and abroad in commercial space innovation. In March 2024, the IP attachés participated in a Space Florida Roundtable engaging in IP discussions with private companies, IP practitioners, and the Economic Development Commission of Florida's Space Coast to address IP concerns in foreign jurisdictions. Finally, IP attachés expanded their participation in international air shows throughout FY 2024 to engage U.S. businesses actively expanding into international markets.

Bureau of Industry and Security

The Bureau of Industry and Security (BIS) administers and enforces export controls on dual-use technologies, including certain space-related technologies. Export controls are a national security tool designed to protect critical U.S. technologies that could contribute to weapons of mass destruction proliferation, destabilizing accumulations of conventional weapons, and human rights abuses.

During FY 2024, the BIS continued working with interagency partners, including the Department of State, which designates and controls the export of defense articles and services, among which are certain space-related technologies, to review U.S. space-related export controls to ensure that items that do not provide the United States with a critical military or intelligence advantage are controlled under the proper authorities. BIS also engaged with its Transportation Technical Advisory Committee, which convenes experts in industry, academia, and government, to discuss aerospace-related topics such as controls on emerging technology for national security reasons in coordination with international export control partners.

Advancing Export Control for U.S. Businesses

On December 20, 2023, the vice president directed the Departments of State and Commerce to conduct a review of space export controls to enable a globally competitive U.S. industrial base while protecting U.S. national security and foreign policy interests. Throughout the fiscal year, the Departments of State and Commerce, in coordination with other interagency partners, reviewed public comments on spacecraft and related items enumerated and described therein submitted in response to published notices of proposed rulemaking. The feedback received informed interagency discussions on streamlining export control regulations for both the U.S. commercial space industry and those of international partners. Consistent with the objectives of Space Policy Directive–2, the Departments of State and Commerce seek to bolster the U.S. commercial space sector by lowering the administrative burden, decreasing regulatory compliance costs, and increasing U.S. exports. BIS and NOAA's OSC advocated for, with adequate technical justification, updating the existing regulations and the transfer of certain U.S. space-related technology from the International Traffic in Arms Regulations (ITAR) to the DOC-administered Export Administration Regulations (EAR).

In April 2024, BIS released a rule significantly streamlining secure trade with Australia and the United Kingdom in light of the AUKUS Trilateral Enhanced Security Partnership. As part of these regulatory revisions, BIS removed license requirements for most commercial satellite and spacecraft parts and components, reducing licensing burdens on industry and promoting joint development of space-related technologies across the U.S., Australian, and British industrial bases. BIS also completed a significant interagency review effort to modernize space-related export controls to ensure a globally competitive U.S. industrial base while protecting national security and foreign policy interests. This effort is expected to result in significant updates to space-related export controls in FY 2025.

Civil Space Industrial Base Assessment

The BIS Office of Strategic Industries and Economic Security, under authority of the Defense Production Act Section 705, executed an industrial base survey and assessment of the Civil Space Industrial Base (CSIB). This assessment was performed in collaboration with NOAA and NASA. In September 2024, BIS concluded its assessment and analysis from more than 1,000 participating survey respondents.

The principal goal of this multi-year study was to evaluate the health and competitiveness of the civil segment of the domestic space supply chain and to inform the planning and execution of U.S. civil space policy. The study aimed to gain a deeper understanding of the interconnectedness of the multi-tiered composition of the U.S. government space systems supply chain network and help identify any constraints and challenges to the strength and resilience

of the U.S. space sector. Key findings relevant to the U.S. space industrial base composition, behavior, overall health and competitiveness, and policymaking include:

- Small businesses of fewer than 100 employees make up approximately half of the U.S. civil space supply chain.
- Most participants in the CSIB are diversified in their sector participation, with 90 percent of respondents deriving less than 50 percent of their revenue from space applications.
- An acute business challenge in the sector is finding and retaining qualified workers, despite most organizations in the CSIB being in good or fair financial health.
- Both the adoption and pursuit of emerging technologies are robust among space-sector suppliers, with pronounced participation in additive manufacturing, advanced materials, and artificial intelligence.

The resulting data also included respondents' views on current export control regulations as well as suggestions for revisions. BIS is utilizing the data from the CSIB assessment to inform proposed changes to export controls for spacecraft and related items under the Export Administration Regulations (EAR). BIS is also continuing to engage in discussions with relevant interagency partners on prospective data sharing and follow-on analytics agreements to bring additional supply chain visibility to both defense and intelligence community stakeholders.

National Telecommunications and Information Administration

In FY 2024, the National Telecommunications and Information Administration (NTIA) promoted and enabled space-based connectivity in the United States and globally in its capacity as the president's principal advisor on telecommunications and information policy and manager of the federal government's use of scarce wireless spectrum.

NTIA advanced the global standing of the U.S. satellite and space industries by securing favorable outcomes on spectrum access, orbital access, and space sustainability as a core member of the U.S. delegation to the International Telecommunications Union (ITU)'s 2023 World Radiocommunication Conference and Radio Assembly.

NTIA paved the way for growth in the commercial space sector by successfully coordinating more than 1,000 Federal Communications Commission (FCC) applications for satellites, earth stations, launches, and other space uses, thereby allowing both federal and commercial missions to thrive. Additionally, NTIA released proposed guidance to further clarify participation from LEO satellite networks in the Broadband Equity, Access, and Deployment program.

Throughout FY 2024, NTIA advanced the deployment of space-based connectivity globally, and from LEO satellite systems in particular, by engaging bilateral and multilateral partners jointly with the State Department and the FCC. NTIA advocated for space-based connectivity, particularly to unserved and underserved communities, through the G7 Industry and Technology Working Group; the G20 Digital Economy Working Group; the UN General Assembly's Pact for the Future; the International Telecommunication Union's Radiocommunication, Development, and Standardization Sectors; and the Inter-American Telecommunications Commission. NTIA additionally advocated in support of global connectivity, including via LEO constellations in several bilateral trade missions. During her April 2024 visit to Kenya, Secretary Gina Raimondo announced AST SpaceMobile's African testing plans.

NTIA helped preserve the stability of the international regulatory regime for satellite networks by partnering with the State Department and the FCC to neutralize efforts to reshape and broaden the mandate of the International Telecommunications Satellite Organization (ITSO), culminating in success at the October 8–10, 2024, ITSO Assembly of 149 governments. ITSO's role is limited to oversight of Intelsat corporation's public service obligations for global connectivity using geostationary satellites, and no other corporation or orbits. At the Assembly, NTIA developed a U.S. position for the terms of reference to guide a new Working Group on ITSO's Future (funding and scope), striking efforts to broaden ITSO to oversee all non-geostationary orbital usage worldwide by any company. NTIA also pushed for the U.S. delegation to denounce formally proposed threats to market access for Intelsat, especially as it undergoes an acquisition by SES corporation. The African bloc continues to seek the redistribution of FCC geostationary licenses that transferred to Intelsat in 2001.

NTIA improved the global regulatory environment for U.S.-based satellite companies by strengthening international capacity to license satellite networks through specialized trainings on satellite spectrum management conducted via the United States Telecommunications Training Institute and the Carnegie Mellon Executive Training Program (among other forums).

NTIA worked to facilitate and promote the deployment of novel satellite "direct-to-handset" technologies by proposing a methodology for coordinating spectrum use with radio astronomy and seeking comment on the role of satellite networks in 6G as part of a broader Request for Comment on 6G technology.

NTIA, in partnership with NASA and DOD, commenced a study under the National Spectrum Strategy to expand use of the 18-GHz band for satellite and space-to-space communications.

Minority Business Development Agency

In December 2023, the Minority Business Development Agency (MBDA) signed a memorandum of understanding with NASA to help connect minority business enterprises (MBEs) to NASA acquisition and development opportunities. Through this effort, NASA and MBDA aim to boost equitable participation of MBEs in aerospace technology and scientific discovery by identifying and addressing barriers and policy gaps. MBDA and NASA share an interest in fostering collaboration, capacity building, and business development, as well as increasing knowledge, awareness, and engagement, between and among MBDA Business Centers and Projects in space commerce.[21]

21 https://www.nasa.gov/news-release/nasa-us-department-of-commerce-expand-minority-business-efforts/

Department of the Interior

DOI

Remotely sensed data and derived information contribute substantially to mission-critical work across the Department of the Interior (DOI).[1] This DOI section highlights a sample of DOI remote sensing applications and illustrates a range of technology, platforms, and specialized sensors employed.

Bureau of Land Management

The Bureau of Land Management (BLM) leverages ground, air, and spaceborne remote sensing technologies to support its mission to sustain the health, diversity, and productivity of public lands for the use and enjoyment of present and future generations. These technologies include aerial and close-range photography; multispectral, hyperspectral, and thermal infrared camera/imaging systems; and radar and lidar. The BLM also utilizes passive and active imaging system information collected by uncrewed aircraft systems (UAS). Remote-sensing data and products are currently used to address a host of BLM monitoring requirements, including energy development, mine production verification, assessment of land cover condition through time, and wildfire response and mitigation. Finally, the BLM requires field-based measurements to support management decisions covering vast expanses of land. Through the integration of remote sensing into the BLM's Assessment, Inventory, and Monitoring strategy, field-based data can be used to generate information and maps that would otherwise be too expensive to produce. The BLM leverages remote sensing to provide an integrated, quantitative monitoring approach to efficiently and effectively document the impacts from authorized and unauthorized disturbance and land treatment activities at local and regional scales.

1 Disclaimer: Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Combining Satellite and Terrestrial Lidar to Improve Disturbance and Mining Monitoring

Over the past few years, southeastern New Mexico saw unprecedented oil and gas development, creating a need for the BLM Carlsbad Field Office (CFO) to monitor surface disturbances related to energy development and mineral mining. Of particular importance was finding a method to identify illegal mining, where minerals owned by the Federal Government were being removed without a permit or royalty payments. Historically, the BLM has relied on incidental observations in the field and reports from the public to discover these mineral trespasses.

In collaboration with CFO, the BLM's National Operations Center (NOC) developed the Change and Disturbance Event Detection Tool (CDEDT), a web-based tool for finding satellite imagery over an area of interest and highlighting surface change between two user-specified dates. Currently, CDEDT includes Sentinel-2, Landsat (missions 5, 7–9), Sentinel-1, and National Agriculture Imagery Program (NAIP) datasets. The tool allows users to identify change by using various remote-sensing indices, and easily export data into usable Geographic Information System (GIS) formats.

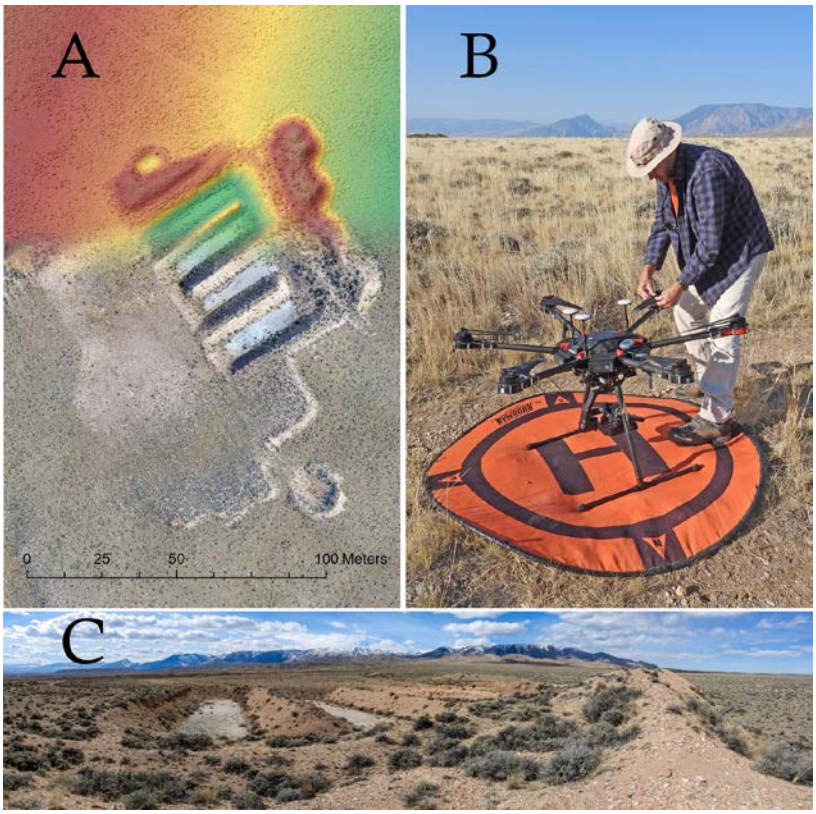
NOC completed the development of CDEDT after several years of evaluation and integration. CFO staff use CDEDT to identify new disturbances using a brightness index, then compare the resulting polygons to known disturbances and permits using a custom geoprocessing tool. If the presence of a disturbance on BLM lands cannot be explained by a known permit, geologists conduct a field visit. If a mineral trespass is found, geologists will also walk the perimeter of the pit and scan it using a handheld lidar scanner during the visit. Using a variety of data sources, such as 2018 U.S. Geological Survey (USGS) 3D Elevation Program lidar, geologists can use GIS to estimate the volume of material removed. The CDEDT tool does not require a license and is open to all users online.[2]

Clarks Fork Pit Reclamation

Along the Wyoming-Montana border, within the view of the Nez Perce Historic Trail and the stunning Clarks Fork Canyon, lies the Clarks Fork Pit, which comprises four excavations, each about 100 by 25 feet. There is no record of when or why these pits were excavated, though they are likely associated with old oil and gas leases in the area. Using Bipartisan Infrastructure Law (BIL) funding for revegetation and hazard mitigation on mined lands, the BLM Cody Field Office is reclaiming this site in 2024 by restoring the disturbed area to contour, spreading topsoil, and seeding native plant species, thus restoring the view of the area to a natural state.

BLM remote pilots acquired aerial images pre-mitigation and plan to reacquire the area post-mitigation to quantify and document landscape changes. The BLM collected natural-color

2 https://blm-gee-cdedt.projects.earthengine.app/view/change-and-disturbance-event-detection-tool-cdedt



(A) The Clarks Fork Pit 1.5-centimeter digital surface model (top) fades into the 0.75-centimeter orthomosaic (bottom), both created from UAS imagery. (B) A BLM remote pilot prepares the M600 UAS for a mapping flight. (C) Excavated pits and tailings pile at the site. (Photos taken by Lisa Marks)

aerial images over 20 acres with stereo overlap using a Sony RX1RII digital camera mounted underneath a DJI M600 UAS. The M600 overflew the site at a height of 200 feet above ground level, triggering the camera by an intervelometer every 2 seconds. The stereo overlap of the imagery allowed for the creation of a 3D model of the site, a digital surface model, and an orthomosaic with spatial resolution of 0.75 centimeters. BLM Wyoming Cadastral installed and surveyed permanent aluminum structures so that future spatial products of this site can be precisely aligned with the current output.

Mapping Abandoned Mine Lands in Oregon with Uncrewed Aerial Systems

An estimated 1 million abandoned mine land (AML) features exist on BLM lands, but scientists have inventoried and characterized only a small fraction of these features in the field. The BLM works to mitigate both physical hazards, like mine openings, and environmental hazards commonly present at AML sites. The BLM Oregon and Washington AML Unit, as well as the Prineville District Offices, plan to do an extensive characterization of AML features at

the Maury and Platner complexes near Prineville, Oregon. Both sites were previously mercury mines and therefore have the potential to escalate to Comprehensive Environmental Response, Compensation, and Liability Act, or Superfund, sites. Remote-sensing data, particularly from UAS, is crucial for providing baseline data quickly, efficiently, and safely, thus minimizing the need for on-site time and reducing or eliminating contact with contaminated waste and equipment.

In July 2024, BLM NOC joined field staff from both offices to collect high-resolution 3D geospatial data at these mine sites using UAS. To map approximately 100 acres at Maury and 400 acres at Platner, field staff collected 948 and 1,510 stereo images, respectively, using a combination of nadir and oblique flights. The BLM photogrammetrically processed the stereo imagery to produce high-resolution 3D data using Agisoft Metashape.[3] By surveying precise control points with a global navigation satellite system (GNSS) receiver at each site, these 3D data can serve as a baseline for comparison to any data collected in the future. Detailed orthomosaic imagery, high-resolution elevation surfaces, and estimated material volumes derived from this mapping effort will support environmental remediation of the site.

Streamlining Vegetation Mapping: The Transition to Multidimensional Multivariate Rasters

The availability of various Fractional Vegetation Cover products, such as the Rangeland Analysis Platform (RAP), developed by the U.S. Department of Agriculture (USDA), and the Rangeland Condition Monitoring Assessment and Projection (RCMAP), created by the USGS, mark a new era in vegetation mapping. These products leverage training data from the BLM Assessment, Inventory, and Monitoring (AIM) program, gathered on the ground and integrated with the Landsat satellite archive. The resulting models effectively describe the annual cover of major plant functional types—such as trees, shrubs, perennial grasses, and sagebrush—across the western United States from the mid-1980s to the present.

These products empower managers to assess the status and trends of land management areas concerning disturbance, treatment, restoration projects, and more. However, a significant challenge remains: presenting these data in a format that is easily digestible for managers and users. Traditionally, using these products required a separate raster for each year and variable—resulting in 228 rasters for RAP (covering 38 years and 6 variables) and 351 rasters for RCMAP (spanning 39 years and 9 variables). This fragmentation led to excessive time spent by users gathering the data into a single location. To address this, the BLM adopted modern Multidimensional Multivariate Raster formats, successfully consolidating all 579 files into just two rasters. These "all-in-one" rasters can be directly used in various new tools, including time

3 https://www.agisoft.com/

sliders, the Multidimensional toolbar in Esri's ArcGIS Pro, and the Multidimensional viewer in the Esri Web Map Viewer.[4] Data from all 579 layers can now be integrated into user projects with a single click, and users can easily toggle between them.

A major advantage of this approach is the ability to swiftly create Temporal Profiles using the ArcGIS Pro Multidimensional toolbar. Users can chart a single variable at multiple locations or multiple variables at a single location across all years, all within a few clicks and with near-instant response times. This efficiency leads to substantial time savings while also reducing network and server loads, analysis times, and training costs. Additionally, these Multidimensional Multivariate Rasters can be seamlessly utilized across a broad range of tools, including time animations, zonal statistics, trend rasters, anomaly detection, change detection, time cubes, and more.

Bureau of Reclamation

The Bureau of Reclamation (BOR) uses Landsat data to help monitor consumptive water use throughout the western United States. BOR analysts use Landsat imagery to map irrigated crops for estimating water demand and to monitor interstate and inter-basin water compact compliance. The BOR also takes part in ecological restoration of several rivers in the West. Scientists use lidar, multispectral aerial imagery, and sonar data to generate maps of topography, vegetation, and river channel bathymetry, which help guide restoration activities.

Use of NDVI to Determine the Irrigation Status of the Newlands Project Lands

The BOR administers the Operating Criteria and Procedures (OCAP) for the Newlands Project (Project), located near Fallon, Nevada. Annually, OCAP directs BOR to determine the allocated irrigation status for approximately 77,000 acres of agricultural fields and wetlands. Remote-sensing techniques help to ensure regular and effective monitoring of the irrigation status of these lands in the Project.

Each month during the growing season, the BOR collects orthorectified and radiometrically corrected surface reflectance imagery. This four-band multispectral imagery product enables temporal analysis and monitoring applications. Scientists download and process the imagery into color infrared and Normalized Difference Vegetation Index (NDVI) products. This allows the monitoring of the irrigation status of the fields in the project with respect to the water allocation that has been provided to the field. The BOR derives the average NDVI value per field each month and uses the maximum value to establish whether the field was

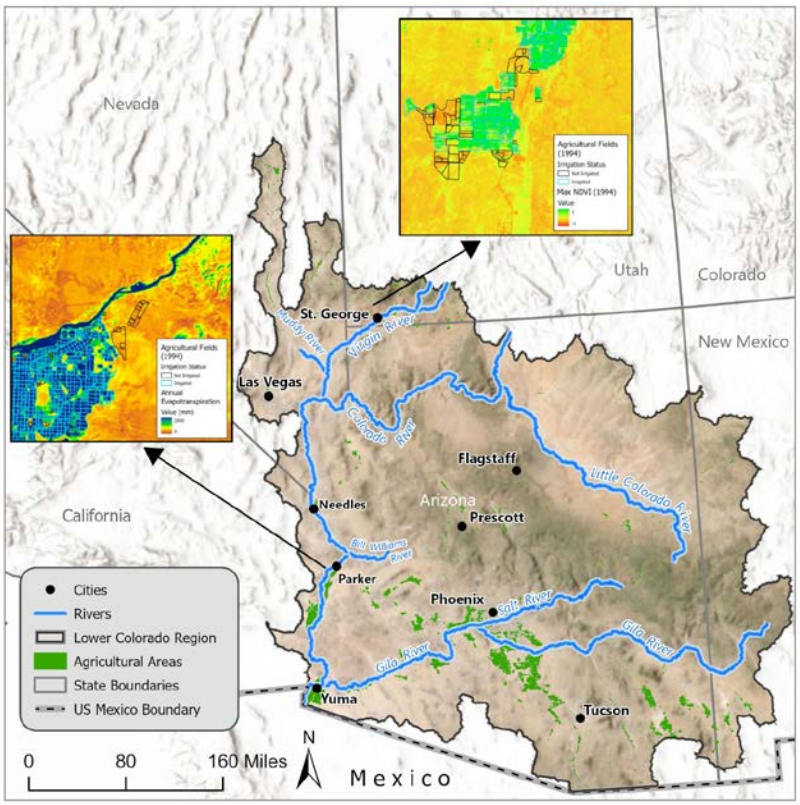
4 https://www.esri.com/en-us/c/product/arcgis-online; https://www.arcgis.com/home/webmap/viewer.html?useExisting=1

irrigated and estimate Project water demand. Stakeholders then review results using a web app developed in ArcGIS Online.

This program serves as an example of leveraging remote-sensing-based techniques to meet the BOR's water management responsibilities. By adopting new technologies, the BOR and its partner organizations can follow more streamlined processes that improve data collection accuracy and water use estimates.

Estimating Consumptive Use of Irrigated Agriculture in the Lower Colorado River System

The Department of the Interior is tasked with reporting the annual consumptive uses and losses of water from the Colorado River System on a five-year basis. The largest category of consumptive use in the five-year reports is consistently irrigated agriculture. Because the study area is so vast (around 132,000 square miles) with around 600,000 to 900,000 acres irrigated annually, the BOR relies upon remotely sensed data to estimate the consumptive uses and losses of irrigated agriculture.



Example of 1994 data showing irrigated fields and annual evapotranspiration in St. George, Arizona, and Parker, Arizona.

In the 2012 Colorado River Basin Water Supply and Demand Study, the BOR agreed to recalculate consumptive uses and losses data for the lower Colorado River System from 1971 to 2005 using updated and consistent methods.[5] To do so, the BOR contracted with the USGS to produce monthly and annual images of NDVI and net evaporation raster files based on the Operational Simplified Surface Energy Balance (SSEBop) method for the entire lower Colorado River System. The NDVI and SSEBop evapotranspiration data were used to calculate the consumptive use of irrigated agriculture.

The BOR developed a logistic regression model based on known non-irrigated fields to predict the irrigation status of each field within the lower Colorado River System for each year. Scientists manually checked the model's predictions using the historical NDVI data and imagery. For each year, BOR used evapotranspiration data from the irrigated fields to estimate consumptive use by irrigated agriculture across the lower Colorado River System. The estimated consumptive use for irrigated agriculture was between 2.4 million and 3.4 million acre-feet depending on the year. The data appear in BOR's Lower Colorado River System Consumptive Uses and Losses Report, Recalculated 1971–2005, as well as the associated dataset and data visualization tool, which include consumptive uses and losses data through 2015.[6]

Fish and Wildlife Service

The U.S. Fish and Wildlife Service (USFWS), in concert with its international, federal, tribal, state, local, and non-government organization partners, uses many remote-sensing technologies to find optimal solutions to monitor and manage fish and wildlife populations, habitats, waters, wetlands, and landscapes. The USFWS utilizes acoustic Global Positioning System (GPS), as well as radio telemetry sensors on fish and wildlife for time and location information tied to a variety of remote-sensing image products such as aerial and satellite optical imagery, as well as thermal, radar, sonar, and lidar imagery. This time and geospatial system of imagery and location enables the USFWS to map habitats, find invasive plants, determine flight paths of birds and bats, conduct fish and wildlife inventories, watch over refuge lands, and monitor trust species.

Land Surface Phenology for Assessing Habitat Differences of an Endangered Prairie Grouse

The Attwater's greater prairie chicken (*Tympanuchus cupido attwateri*) was once a common inhabitant of coastal tallgrass prairie from Louisiana southward along the Texas Gulf Coast. Overhunting and habitat loss from conversion of native prairie to cropland and monocultures

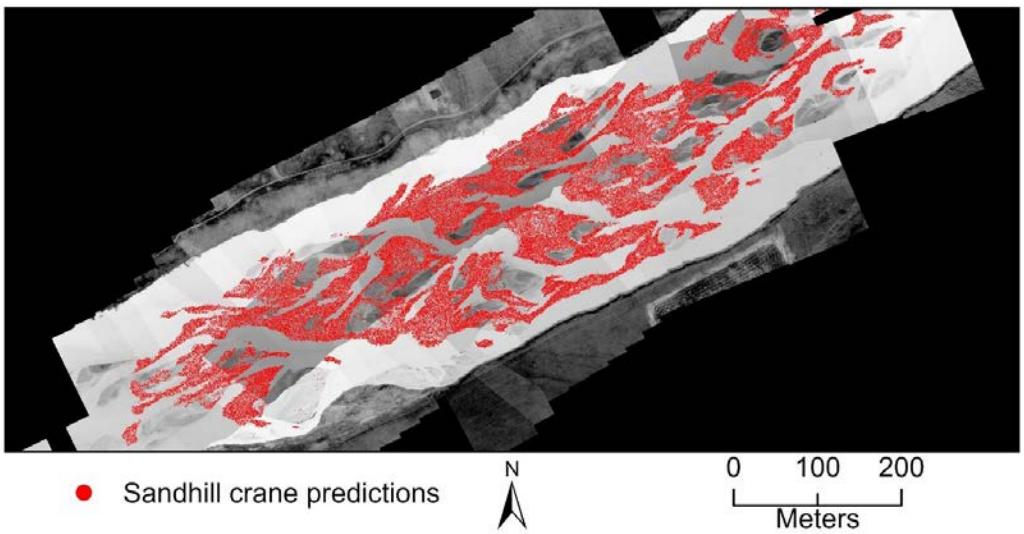
5 https://www.usbr.gov/lc/region/programs/crbstudy/finalreport/index.html

6 https://www.usbr.gov/lc/region/g4000/wtracct.html

for livestock pastures led to widespread population declines by the early to mid-1900s. The species persists in two remnant native prairie grasslands in Texas, one of which is the 43-square-kilometer Attwater Prairie Chicken National Wildlife Refuge located 100 kilometers west of Houston. To assess habitat conditions, researchers from USFWS worked with Boston University's Center for Remote Sensing to extend the annual high-resolution (30-meter) land surface phenology metrics from 2016 to 2022. This was achieved using Harmonized Landsat 8 and Sentinel-2 (HLS) imagery covering the study area. To assess the phenology of prairie chicken habitat, the team conducted a preliminary comparison of georeferenced lek—breeding ground—locations from 2016 to 2022 within native prairie against nearby randomly selected nonnative prairie. The team evaluated all locations using digital biomass data (30-meter Landsat) from the USDA Agricultural Research Service's Rangeland Analysis Platform to assess annual productivity. The team linked greater land surface phenology differences between lek locations in native prairie and nonnative pastures with periods of low productivity. Annual and interannual land surface phenology metrics showed high potential for distinguishing critical habitat differences that could help identify locations capable of supporting population recovery efforts. Future work could pair GPS telemetry data with phenology and other environmental data to understand habitat selection and population parameters such as survival, abundance, and reproductive rates at additional sites.

Enhancing Migratory Bird Surveys with Thermal Imagery and Deep Learning

The USFWS Division of Migratory Bird Management aims to improve migratory bird surveys by using aerial remote sensing combined with deep learning analyses to automate survey counts. The goal is to provide accurate wildlife counts while simultaneously reducing risk to pilots by allowing aerial surveys to occur at higher altitudes. In partnership with the College of William and Mary, USFWS previously demonstrated that thermal remote-sensing technology, coupled with deep learning, can provide accurate counts of sandhill cranes (*Antigone canadensis*) at night during their critically important migratory stopover in the Platte River Valley of Nebraska. In 2023, the collaboration expanded to include the USGS Northern Prairie Wildlife Research Center, the Crane Trust, and the International Crane Foundation. In March 2023, the project moved from a demonstration to a full, operational survey of areas used by sandhill cranes in the region, including the collection of more than 75,000 nighttime thermal images while the birds were roosting on or near the Platte and North Platte Rivers. In addition, researchers collected thermal imagery in places where ducks and geese were congregating to help distinguish these species from cranes. A You Only Look Once detection model was developed to predict and count sandhill cranes. The detection model was initially based on the laborious manual labeling of birds in imagery, but a semiautomatic "human-in-the-loop" approach was then used to rapidly increase these labels and improve the model. The results



An example mosaic of thermal images shows sandhill crane predictions, indicated by red circles, on the Platte River of Nebraska.

predicted that 1.088 million (± 6.4 percent) sandhill cranes were present during this survey. This detection model also resulted in georeferenced locations of sandhill cranes, which has implications for understanding their habitat as well as their response to management.[7] This study is the first complete survey of roosting sandhill cranes on the Platte River and shows that these innovative surveys can be accomplished at a broad spatial scale. Emerging remote-sensing and deep learning technologies offer opportunities to improve on traditional surveys used by harvest managers, and the enhanced spatial information provided by these approaches fosters new applications in habitat management and other environmental management areas.

Applying Deep Learning to Detect and Classify Ocean Wildlife

The USFWS uses airborne remote-sensing technologies to improve aerial migratory bird surveys of ocean wildlife. These technologies enhance the safety of aircrews by allowing flight at higher altitudes and improve the quality of wildlife population data by minimizing errors and quantifying uncertainty. Deep learning methods are being advanced to automate data processing and improve the cost-efficiency of remote-sensing technologies for surveys covering broad geographic areas and generating very large image datasets. The USFWS is partnering with the Bureau of Ocean Energy Management (BOEM), USGS, academic institutions, and private contractors to accomplish these objectives. The initial focus is on marine bird and other wildlife surveys given overlapping agency requirements for these data. The project is part of the Atlantic Marine Assessment Program for Protected Species. Because of the focus on

7 For more information, see https://www.fws.gov/story/using-cutting-edge-technology-monitor-sandhill-cranes.

marine wildlife, the project has implications for informing renewable energy development and may increase the efficiency of both public and private environmental monitoring programs. The collaboration produced a collection of more than three million images in the marine environment, spanning from Maine to Florida. A workflow is in development to advance the imagery data from the sensors to an artificial intelligence (AI) detection model in the aircraft and to a species classification algorithm that distinguishes and counts each species. From there, a georeferenced location is obtained for each bird. More specifically, a cutting-edge AI/deep learning algorithm has been developed to automatically detect seabirds in imagery. This detection algorithm has 80 to 90 percent accuracy across a wide range of seabird species. The efficiency gained by these technologies will help inform diverse management decisions, such as the development of renewable energy in Outer Continental Shelf systems, population monitoring for species of concern, and the setting of harvest limits for species that utilize these habitats.

Mapping Phragmites Using Lidar at Fish Springs National Wildlife Refuge

In 2022, the USFWS partnered with the USGS National Geospatial Technical Operations Center to collect Quality Level 1 lidar data to support topobathymetric mapping activities at Fish Springs National Wildlife Refuge in western Utah. Data were collected on September 24, 2022, using fixed-wing aircraft, and delivered to USFWS in spring 2023. In addition to hydrologic applications, USFWS staff used the high-quality lidar data to map patches of invasive phragmites (*Phragmites australis*) across the 17,922-acre refuge so that effective control strategies could be developed.

Phragmites, a tall robust plant, can form monotypic dense patches that commonly crowd out native wetland vegetation and provide little in terms of wildlife habitat or food resources. USFWS staff used the classified lidar point data to construct height above ground rasters. To minimize confusion with native marsh plant communities, which tend to be shorter-stature plants, raster cells were filtered and aggregated (by height) to include only pixels greater than 1.5 meters. Concurrent with lidar collection, high-resolution (10-centimeter) true-color imagery was also collected. This imagery, in conjunction with ongoing ground visits by refuge staff, was used to investigate if lidar can be used to accurately map phragmites patches. Refuge staff are currently developing strategies to address high-priority areas, including those scheduled for future marsh enhancement projects slated to begin in 2025.

Precision Monitoring of Colonial Nesting Islands Using UASs and Machine Learning

Monitoring colonial waterbirds at nesting sites is necessary for tracking population trends, informing conservation decisions, and understanding ecosystem health. However, censusing nesting sites takes considerable effort and risk. Traditional colonial waterbird monitoring

includes traversing the colony on foot; surveying via boat; or surveying aerially using aircraft operated by an onboard human pilot. Each of these methods presents challenges and consequences. Widely available small UASs are a useful wildlife management and research tool. UASs provide more precise count estimates than traditional ground surveys and other methods. Manually counting and digitizing the very large sets of photos or videos, however, is a time-consuming task. To reduce the time needed to generate accurate counts from waterbird colony imagery, researchers from the USFWS developed guidelines for acquiring UAS footage of colonial waterbird nesting islands and a deep learning tool that can be applied to precisely, accurately, and efficiently count and digitize multi-species waterbird colonies. These machine learning algorithms were trained to identify 16 classes of waterbirds nesting together on islands along the Texas coast using convolutional neural network-based object detectors. These algorithms can also be trained to detect and identify other species and be applied to monitoring efforts in a variety of habitats. Using UAS-collected aerial imagery and deep learning can substantially improve the accuracy of monitoring events while reducing staff processing time and colony disturbance. This tool is undergoing updates for use in other ecosystems and on additional bird species.

National Park Service

The National Park Service (NPS) has a substantial investment in, and a long history of, using aerial and spaceborne remote-sensing and GPS technologies. The NPS Inventory and Monitoring Program conducts baseline inventories for more than 270 parks across the Nation. Remote-sensing data are a critical source of information regarding geology, soils, vegetation, and infrastructure. Aerial photography and satellite imagery are utilized to compile vegetation maps; a monumental task given that the agency has responsibility for over 30 million acres. These data are particularly critical for NPS activities in Alaska given its remoteness. The NPS takes advantage of the open and freely available Landsat archive to quantify decadal changes in glacier ice cover and document land-cover change in national park units. The NPS has been the DOI's sponsoring agency to map all large wildland and prescribed fires as part of the DOI Monitoring Trends in Burn Severity project, using the Landsat archive. GPS supports field data collection, navigation, and search-and-rescue operations conducted by the agency.

Monitoring Permafrost Thaw Slumps in Arctic Alaska

Retrogressive thaw slumps (slumps) are dramatic features of the Arctic landscape caused by thaw and subsidence of permafrost, followed by downslope flow of liquefied sediment and water. The National Park Service Arctic Inventory and Monitoring Network monitors the growth of select slumps in northwestern Alaska. Researchers studied the growth in area, the

rate of advance of the main thaw escarpment, and the amount of subsidence using three-dimensional models created from small-format (35-millimeter) aerial photographs in multiple years from 2010 to 2020, supplemented with high-resolution satellite images from 2006 to 2023.

Thirteen of the study slumps were present before 2016, and most were initiated in the years 2004–05. Eight slumps had largely stabilized by the previous sample date (2014 or 2016) and grew little from then to the most recent sample date (2019 or 2020). Four slumps continued growing uniformly from 2016 through 2020, with scarp migration rates of 7 to 37 meters per year in 2019–20. Just one of these older slumps showed markedly increased growth in recent years. Sediment transport into nearby water bodies from these slumps was greatly reduced relative to the early years in the slumps' lives because either they were growing very little, or the growth had progressed hundreds of meters from adjacent water bodies and the sediment mobilized at the advancing scarp was being deposited on the slump floor.

The most striking development was the re-initiation of slump activity in the vicinity of a previously stabilized slump near Douglas Creek in Gates of the Arctic National Park and Preserve. Four new slumps were first visible in 2016 satellite images and grew rapidly through 2023, with scarps advancing at rates of up to 60 meters per year and elevation loss at the scarp of up to 10 meters. Approximately 137,000 cubic meters of material was lost from the slump footprints of three of the slumps as of 2020.

UAS Lidar for American Revolutionary War Landscape Analysis

Established in 1959, Minute Man National Historical Park in Massachusetts preserves cultural resources associated with the first day of the American Revolution, April 19, 1775, a running battle of episodic skirmishes between British soldiers and Provincial forces. The sites of these skirmishes, beginning at the North Bridge in Concord and moving through Miriam's Corner, Elm Brook Hill, and Parker's Revenge, are interpreted for their connection with events at the dawn of the American Revolution.

One of the bloodiest battles that day occurred at Elm Brook Hill in the town of Lincoln. While the general area of the battle is known from historical documentation, the exact location of the battle is not. In preparation for the 250th anniversary of the Revolution, the NPS Northeast Archeological Resources Program partnered with Minute Man National Historical Park, Advanced Metal Detecting For Archaeologists, the American Veterans Archaeology Recovery Program, the Friends of the Minute Man National Historical Park, and the NPS Midwest Archeological Center to investigate Elm Brook Hill using an integrated archeological approach to identify the location of the fighting, interpret the tactical engagement between the British and Provincial forces, and uncover details about the men that fought on that first day of the Revolution.

The team deployed a suite of scientific archaeological methods and tools to map evidence of the battle. UAS lidar obtained a high-resolution 3D terrain model of the battlefield and surrounding area. Complementary data from systematic metallic survey, soil coring, and ground-penetrating radar surveys were integrated in GIS software. To interpret and visualize the Elm Brook Hill battle, data were queried based on KOCOA principles: tactical assessment of the historic terrain using key terrain (K), observation and field of fire (O), cover and concealment (C), obstacles (O), and avenues of approach and egress (A).

The results of the project provide the park with evidence-based information for the restoration of the 1775 Elm Brook Hill Battlefield and enhance interpretation of the battle through newly developed programs and public exhibits. Importantly, the results of this investigation provide a tangible foundation for effective and sustainable resource protection and management of the Elm Brook Hill Battlefield.

Office of Surface Mining Reclamation and Enforcement

The Office of Surface Mining Reclamation and Enforcement (OSMRE) remote-sensing program provides OSMRE offices, states, and Tribes with the necessary tools to use remote-sensing technologies to support Titles IV (Abandoned Mine Lands) and V (Regulation of Current Mining) of the Surface Mining Control and Reclamation Act of 1977. As part of this support, the OSMRE remote-sensing program provides high-resolution satellite imagery, aerial photography, and lidar data to conduct analysis of terrain, vegetation, and hydrologic function on active mine sites to ensure that reclamation is consistent with the approved mining permit. These data are also used to support inventory, monitoring, and assessment of abandoned mine land features to ensure the absence of threats to the environment or to human health and safety.

Storytelling with Satellite Imagery: Coal Mining and Reclamation in the Southwest

The GIS Branch within OSMRE uses commercial satellite imagery to tell the story of surface coal mines via Esri's ArcGIS StoryMap web-based application. Although OSMRE keeps most of its published image services and geospatial content available to internal users only, they have made the StoryMaps available publicly. The Navajo Mine StoryMap features the Navajo Mine situated in the northwestern corner of New Mexico. Owned and operated by the Navajo Transitional Energy Company, LLC, whose sole shareholder is the Navajo Nation, the mine continues its over-60-year history of coal production and provides energy to hundreds of thousands of homes across the American Southwest. The StoryMap provides an overview of the mine's origin, starting prior to the Surface Mining Control and Reclamation Act of 1977 and continuing through the present. It uses various geospatial features to illustrate its geographical location and extent, active coal mining operations and reclamation, and historical and

current visual comparisons. One of the features of the Navajo Mine StoryMap is a time-lapse video that uses PlanetScope scenes to show the growth of the Dixon Coal Pit as active mining progresses south and east over the span of eight years. The StoryMap also has an integrated web scene that allows viewers to explore the mine site in three dimensions. The main view features an orthorectified 2024 Maxar image. The image is draped over a digital surface elevation model. Users can zoom in/out, rotate, and tilt the view. They can also click on the feature points on the scene to view the corresponding geotagged photos that were taken on-site along with a brief site description.

Supporting Field Personnel with Remotely Sensed Data

OSMRE inspectors conduct four complete inspections and 12 partial inspections at every surface coal mine where the Office serves as the regulatory authority. The state and Tribal lands that possess coal regulatory programs perform their own inspections; however, OSMRE personnel conduct oversight inspections at a percentage of those sites. This means the limited number of OSMRE inspectors must travel often and cover sites in several states. To help ease this workload, OSMRE field personnel began using remotely sensed data and geospatial support from the GIS Branch to reduce travel and field time.

The GIS Branch within OSMRE leverages a multitude of resources to support field personnel with remotely sensed data. Under the NextView contract, the GIS team requests new monthly commercial high-resolution Maxar satellite imagery over several surface coal mines. In addition, the GIS team has access to the imagery archive containing all existing Maxar imagery. This is a valuable resource, as the organization incurs no additional cost. In addition, OSMRE has a small contract in place with Planet, which provides access to medium-resolution daily images and the ability to task a limited number of high-resolution SkySat imagery acquisitions to help fill in the data gaps. The GIS team can also collect data with UAS over smaller sites that require detailed photogrammetric and mapping support. The GIS Branch compiles these remotely sensed datasets onto web maps and shares them with OSMRE staff and interested state and Tribal partners. The maps can be used in an office environment to conduct virtual partial inspections, or they can be loaded onto mobile devices to assist with a physical inspection in a remote location lacking cell service. These tools reduce the number of physical visits to the sites, and inspectors can use these tools to plan their time in the field more effectively and efficiently.

U.S. Geological Survey

The USGS is both a user and a provider of remotely sensed data. The USGS manages the Landsat satellite series and a web-enabled archive of global Landsat imagery that dates back

to 1972. Landsat represents the world's longest continuously acquired collection of spaceborne moderate-resolution land remote-sensing data, and the entire archive became available for download at no charge in December 2008. The USGS also distributes aerial photography through the National Map. It archives and distributes historical aerial photography; lidar data; declassified imagery; hyperspectral imagery; data collected by UAS; and imagery from a variety of government, foreign, and commercial satellites. These data are used for a wide range of applications, such as mineral resource development; monitoring the health of U.S. and global ecosystems; land-use change; emergency response; and assessments of natural hazards such as fires, hurricanes, earthquakes, droughts, and floods.

Satellite-Derived Fire Intensity in Alaskan Boreal Forests

A central question in wildfire research is how increasingly frequent and severe fires will alter landscapes. Will these changes promote the regrowth of different species, or will burned landscapes eventually recover to their original state? USGS researchers from the Western Geographic Science Center are investigating this question in Alaska's boreal forests, where vegetation is closely tied to soil characteristics. Deciduous trees such as aspen (*Populus tremuloides*) and birch (*Betula neoalaskana*) thrive in thin, mineral soils, while conifers such as black spruce (*Picea mariana*) do best in thick, organic layers. Unusually severe or frequent wildfires that consume organic soil material may disrupt cycles of conifer regeneration, potentially leading to a shift toward deciduous dominance.

To better understand conditions that influence wildfire intensity in boreal environments, the researchers use data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the Terra and Aqua satellites. MODIS provides measurements of fire radiative power (FRP), a proxy for fire intensity that is largely determined by the amount and condition of available fuel. By combining 20 years of MODIS FRP data across Alaska with a long-term record of fire perimeters (1940–present) and a contemporary map of land-cover species, researchers examine how fire history—that is, the number and timing of previous burns—and vegetation type have influenced fire intensity over the past two decades. This analysis provides insights into the potential future appearance of boreal landscapes, both in Alaska and beyond.

United States–Mexico Borderland and Vegetation Community Map

People on both sides of the United States–Mexico border need a high-resolution, binational vegetation community map that spans the entire United States–Mexico borderlands. Traditionally, mapping efforts in this region were impeded by complex logistics related to the international border, differing national needs and plans, and resource allocations and priorities. To address this need, scientists from the USGS Southwest Biological Science Center partnered

with the Sonoran Joint Venture, the USFWS Migratory Bird Program, data engineers from the Department of Biosystems Engineering at the University of Arizona, and collaborators from the Wildlands Network and the Borderlands Program to produce the first prototype land-cover map within the overlapping Mojave Desert, Sonoran Desert, and North American Bird Conservation Initiative's Bird Conservation Region 33 (BCR33) using Landsat satellite data. BCR33 is an area of high biodiversity, providing habitat for bird species of concern and other wildlife. The land-cover map supports USFWS recovery plan efforts related to conservation planning activities for many species, including yellow-billed cuckoo, cactus ferruginous pygmy-owl, southwestern willow flycatcher, Yuma Ridgway's rail, Bendire's and LeConte's thrashers, masked bobwhite, jaguar, and endangered plants such as Bartram's stonecrop and the Pima pineapple cactus. In 2024, a Phase-II map for the full BCR33 region was completed, increasing the understanding of the binational nature of natural communities.[8]

Rangeland Condition Monitoring Assessment and Projection

Rangelands occupy huge swathes of land in the United States, typically where climate and soils are too harsh for either forest or agriculture. Rangeland ecosystems provide critical wildlife habitat, forage for livestock, carbon sequestration, provision of water resources, and recreational opportunities. At the same time, rangelands are sensitive to change through fire and anthropogenic disturbances. The arid-semiarid climate in most rangelands fluctuates widely, impacting livestock forage availability, wildlife habitat, and water resources. Many of these changes can be subtle or evolve over long time periods, responding to both climate and anthropogenic driving forces.

Scientists from the USGS Earth Resources Observation and Science (EROS) Center and the BLM developed the Rangeland Condition Monitoring Assessment and Projection (RCMAP) project. This project quantifies the percent cover of rangeland components across the western United States using Landsat imagery from 1985 to 2023 in the current generation. The RCMAP product suite includes ten fractional components (annual herbaceous, bare ground, herbaceous, litter, non-sagebrush shrub, perennial herbaceous, sagebrush, shrub, tree, and shrub height) and the temporal trends of each.

Data show that much of the rangelands of the western United States has experienced change, although most of this change is gradual. Weather variation is the leading driver of change, followed by fire. The time series can track increased herbaceous cover and decreased bare ground cover in wet years, and the opposite in dry years. Deeper root systems in shrubs and trees insulate these components from interannual weather variation to some extent.

8 The published map and associated paper are available at https://doi.org/10.3390/rs15051266.

The RCMAP team is currently evaluating enhanced AI methods such as convolutional neural networks that leverage spatial and/or temporal patterns to reduce mapping errors. Additionally, hyperspectral imagery, such as that from the Earth Surface Mineral Dust Source Investigation, has been tested and found to increase classification accuracy by providing more information for separating out rangeland targets.

RCMAP fractional component time-series data spanning 1985–2023 and trends analysis products are now available for download and on the rangelands viewer application.[9] This dataset is designed for out-of-the-box application and provides a foundation for both historical and future monitoring at ecosystem scales. Land managers and scientists can use annual fractional cover maps to monitor changes to vegetation composition, evaluate past management practices, target future improvements, determine locations of critical wildlife habitat, assess effects of highly variable weather changes, and appraise landscape health and fragmentation.

UAS 3D Model for Geoheritage Sites of the Nation Project

The USGS National Cooperative Geologic Mapping Program's Geoheritage Sites of the Nation project is developing an initial inventory of geoheritage sites—geologic features and landforms with scientific, educational, cultural, economic, and aesthetic significance. These geoheritage sites showcase the natural heritage on federal public lands across the United States and its territories. To allow the public to remotely explore geologic sites of significance, the project is building an interactive web application, the Geoheritage Sites of the Nation Viewer, to provide an educational and outreach tool to 1) raise awareness of significant geologic sites, 2) communicate the role of geology in our natural heritage, and 3) increase the accessibility and relevance of geologic mapping and geoscience topics more broadly to the public.

The Marsh-Felch Dinosaur Quarry site at the BLM Garden Park Fossil Area north of Cañon City has been selected as the highlight site for Colorado. One of the most complete dinosaur skeletons ever unearthed was found there. The fossil discoveries around present-day Garden Fossil Park Area sparked the "Bone Wars" of the late 1800s and inspired the selection of the Colorado state fossil, the Stegosaurus. In July 2024, the USGS National Uncrewed Systems Office conducted flights using a Skydio X10 UAS to safely and efficiently obtain high-resolution imagery of this famous fossil site. Using its 3D Scan capability, the Skydio X10 autonomously determines where to capture photos to achieve coverage across a volume of interest. The aircraft is equipped with multiple collision-avoidance cameras and can maneuver through areas with complex terrain to capture imagery. Over the course of three flights, the UAS captured nearly 3,000 photos across the quarry. Using structure-from-motion software, these images will be processed to generate a 3D model of this world-renowned fossil site for

9 See https://www.mrlc.gov/ and https://www.mrlc.gov/rangeland-viewer/.

inclusion in the Geoheritage web application. This project marks the first time that USGS remote pilots have utilized the Skydio X10's technologically advanced 3D scan capabilities for a geologic feature.

Central California Crop Type Mapping of Trends and Patterns from 2005 to 2020

California's croplands are some of the most economically important, productive, and diverse in the United States. This agricultural landscape can be dynamic, as farmers alter crop types and acreage in response to market trends, highly variable weather changes, and natural hazards such as floods and droughts. To better understand these changes, researchers from the USGS are developing accurate, long-term crop type data to support monitoring trends and patterns in croplands across time. The USGS team used high-resolution aircraft-based aerial imagery from the USDA's NAIP and moderate-resolution satellite imagery from Landsat to build a machine learning model to identify nine different crop types. This model was applied to remotely sensed images of California croplands beginning in 2005 and ending in 2020. The results showed a decline in total area of field crops and pasture crops across the date range. Deciduous fruit and nut crops, citrus and subtropical crops, and fallow/young perennial crop types were all found to have increased in total area during the study date range. In general, these results suggest a shift from crops that are replanted every year (annual) to crops that keep growing or regrow every year (perennial). The results also showed that crop types in the southwestern Central Valley and the Sacramento–San Joaquin River Delta changed frequently between map dates, while the Salinas, Napa, and Santa Maria Valleys had more enduring crop types. The developed crop type maps and dataset can aid managers and decision makers for resource planning.[10]

Airborne Magnetic and Radiometric Surveys Unlock Earth's Secrets for Science and Resource Exploration

The USGS Mineral Resources Program is taking to the skies with high-resolution airborne magnetic and radiometric surveys via helicopter as part of the Earth Mapping Resources Initiative (Earth MRI).[11] This ambitious undertaking, covering parts of the conterminous United States, Alaska, and Puerto Rico, not only supports critical mineral resource assessments, both in subsurface deposits and in mine waste, but also fuels a broader range of geophysical, geological, and geochemical research, with additional applications such as earthquake hazards. The survey data are publicly accessible, promoting scientific collaboration and discovery. Magnetic surveys measure the subtle variations in Earth's magnetic field, revealing differences in the magnetic properties of rocks and minerals beneath the surface. Radiometric surveys detect natural low-level radioactivity emitted by rocks and soils, providing information

10 For more information, visit https://doi.org/10.1002/agg2.20553.

11 See https://www.usgs.gov/special-topics/earth-mri.

on the distribution of potassium, uranium, and thorium, which indicate specific rock types. Scientists employ specialized software to analyze the magnetic and radiometric signatures from the surveys to make map products that unveil hidden patterns not readily seen with other methods. The Earth MRI Acquisitions viewer offers a user-friendly interface to explore where surveys have been conducted and are planned.[12] This interactive tool also provides direct links to download the magnetic and radiometric survey data, complete with full citations, streamlining access for researchers.

The First Annual National Land Cover Database: 39 Years of Land-Cover Change

Improving information on characteristics of land cover, understanding drivers of change, and identifying potential consequences of change on human and natural systems can provide greater insight into the impacts and feedback of human activity, highly variable weather changes, and other land-change drivers. The geospatial community has called for a new generation of monitoring data and information: land-cover and land-change products need to span larger geographic extents, over longer time periods, at higher spatial resolutions, and provide more systematic and consistent information on change than ever before. To meet these growing demands, the USGS has developed the Annual National Land Cover Database (NLCD) Collection 1 Science Products.

The NLCD and Land Change Monitoring, Assessment, and Projection (LCMAP) merged methodologies to produce Land Cover and Fractional Impervious Surface (along with other derived products) at annual time steps, called Annual NLCD. The legacy methodologies from NLCD and LCMAP were combined with modern innovations in geospatial deep learning and harmonic modeling to create the next generation of land-cover and land-change information from Landsat Collection 2 satellite observations (U.S. Landsat Analysis Ready Data).

The initial release in 2024 of Annual NLCD Collection 1.0 includes six geospatial raster products for the conterminous U.S. (CONUS) for 1985–2023: land cover, land-cover change, land-cover confidence, fractional impervious surface, impervious descriptor, and spectral change day of year.[13] The thematic land-cover product depicts land cover using the legacy NLCD classes. The product suite provides powerful time-series information at a 30-meter spatial resolution about annual land cover and its change across time. Future annual updates of these products for CONUS are planned.

Annual land cover and other related products are intended to meet a growing user need for information at higher temporal frequency and over a longer record for the United States. Many types of scientific studies have applied annual land-cover information, including estimating biological carbon emissions, projecting future land use, documenting forest fragmentation or

12 https://ngmdb.usgs.gov/emri/#3.2/40/-96

13 See https://www.sciencebase.gov/catalog/item/655ceb8ad34ee4b6e05cc51a.

conservation practices, modeling wildfire hazards, tracking water quality and quantity, and understanding change in wildlife habitat and ecosystem disturbance/disease.

Landsat-Derived Global Rainfed and Irrigated Area Product

Climate variability and ballooning populations put unprecedented pressure on agricultural croplands and their water use, which are vital for ensuring global food and water security in the 21st century. In addition, the COVID-19 pandemic, military conflicts, and changing diets have added to looming global food insecurity. Therefore, there is a critical need to produce consistent and accurate global cropland products at high spatial resolution (farm-scale, 30-meter or better) that are generated consistently, accurately, and routinely (for example, every year). The Global Food-and-Water Security-support Analysis Data (GFSAD) produced the world's first Landsat-derived global cropland-extent product at 30-meter resolution, which is funded by NASA and the USGS. The overarching goal of GFSAD is to develop comprehensive data and products in support of global food and water security. This is achieved by developing cropland models, maps, and monitoring tools leading to a wide array of products using machine learning algorithms, satellite sensor–based big-data analytics, and cloud computing. This new GFSAD project focuses on producing three distinct Landsat-derived global cropland products: Landsat-Derived Global Rainfed and Irrigated-Cropland Products, Global Cropping Intensity Product, and Global Crop Type Products.

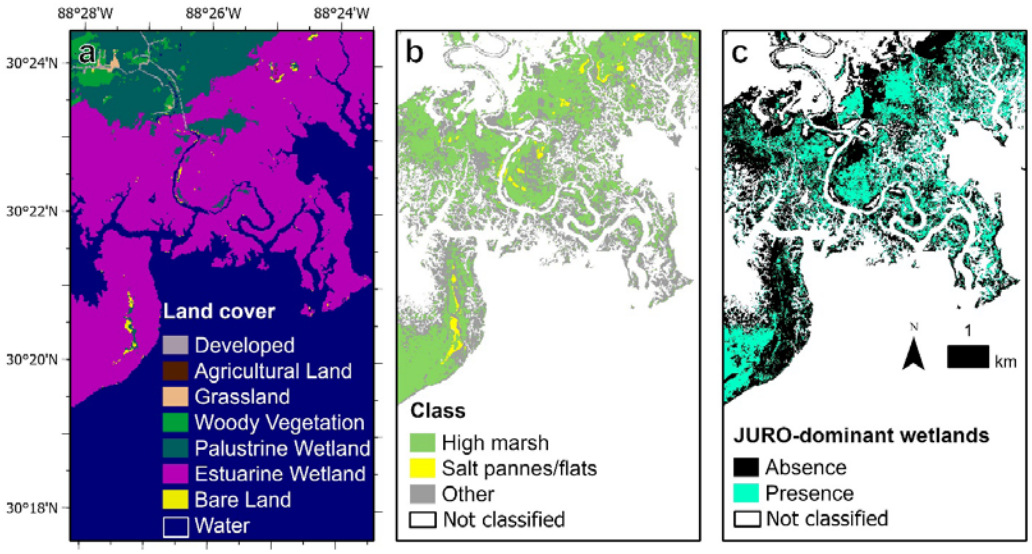
Mapping Irregularly Flooded Wetlands, High Marsh, and Salt Pannes/Flats

Irregularly flooded wetlands provide important ecosystem services, such as offering habitat for fish and wildlife, enhancing water quality, ameliorating flooding impacts, supporting coastal food webs, and protecting coastlines from erosion. Mapping irregularly flooded wetlands is a daunting challenge given their expansive coverage and dynamic nature. Furthermore, coastal wetlands are expected to change drastically over the coming century due to accelerated sea-level rise and changes in the frequency and intensity of extreme storms. Consequently, coastal managers need baseline information on the current spatial distribution of wetlands, along with efficient repeatable methods for observing change in these important and dynamic environments.

Researchers from the USGS Wetland and Aquatic Research Center and Mississippi State University jointly produced geospatial datasets of irregularly flooded wetland probability and high marsh and salt panne/flat habitats across the northern Gulf of America coast, from Texas to Florida. Additionally, the data publication produced through this effort includes 1) a map from Lake Pontchartrain, Louisiana, to the Florida Big Bend delineating the coverage of irregularly flooded wetlands dominated by black needlerush (*Juncus roemerianus*); 2) a supplemental map with a second high marsh class in Texas dominated by succulents and desert saltgrass (*Distichlis spicata*); 3) a project-specific field reference dataset; and 4) spatial metadata showing

the elevation data used to create these products. These products are the first regional map of elevation-based, irregularly flooded wetland probability and high marsh and salt panne/flat along the northern Gulf of America coast that provides a baseline condition from which future changes can be compared.

This effort is the result of financial support by NOAA's RESTORE Science Program to fund research conducted by Mississippi State University and the USGS. Many other agencies assisted with the development of these products, including the USFWS, Tall Timbers Research Station, Texas Tech University, Louisiana State University, Grand Bay National Estuarine Research Reserve, Weeks Bay National Estuarine Research Reserve, Embry-Riddle Aeronautical University, and the Forbes Biological Station. The maps are publicly available online and can also be viewed via ArcGIS Online.[14] The elevation-based, irregularly flooded wetland probability map produced via this study was published in *Remote Sensing of Environment*, and the high marsh and salt pannes/flats map was published in *Geocarto International*.[15]



Example of high marsh and salt pannes/flats map products for the Grand Bay estuary, Mississippi. a) Land-cover map modified from NOAA's Coastal Change Analysis Program 30-meter layer; b) map of high marsh, salt pannes/flats, and other irregularly flooded wetlands; and c) map of irregularly flooded wetlands dominated by *Juncus roemerianus*. White areas in panes b and c represent areas outside the coastal wetland mask.

14 See https://www.sciencebase.gov/catalog/item/628cf979d34ef70cdba3c03b and https://usgs.maps.arcgis.com/home/item.html?id=98d03a92d84940b9ac67e5c339c6eb2b.

15 See https://doi.org/10.1016/j.rse.2023.113451 and https://doi.org/10.1080/10106049.2023.2285354.

Hyperspectral Imaging Supports Natural Resource Evaluations

In 2024 the USGS Earth Mapping Resources Initiative (Earth MRI) funded NASA to collect high-altitude airborne hyperspectral imagery above over 400,000 square kilometers of the southwestern United States (roughly the size of California).[16] Earth MRI has now developed the largest airborne hyperspectral dataset in the world. Hyperspectral imagery collects light reflecting from Earth using a spectrometer flown on an aircraft or spacecraft. Hyperspectral imagers have hundreds of narrow spectral channels, allowing for the comparison of spectral patterns in each pixel of an image to patterns in a spectral library of materials that have been measured in a laboratory. This pattern matching allows a material to be detected and its distribution across a landscape to be mapped.

The Earth MRI program is updating the Nation's geologic framework and identifying areas with the potential for critical mineral resources. Earth MRI is using hyperspectral data to map minerals at Earth's surface, including previously mined areas to assess the potential to re-mine mineral resources from waste. Hyperspectral data acquired in 2024 include more than 1 billion spectral measurements to assist the Earth MRI program. The four-year acquisition program, 2023–26, aims to acquire more than 1 million square kilometers of data for portions of California, Nevada, Arizona, Utah, Idaho, Wyoming, Colorado, New Mexico, and Texas.

Gathering and analyzing hyperspectral data over such a large area is only possible through partnerships with other federal agencies and state geological surveys. Through an interagency agreement, the NASA Armstrong Flight Research Center flies a high-altitude aircraft (the ER-2 at 65,000 feet) with a hyperspectral sensor measuring reflected sunlight and a multispectral sensor measuring infrared energy. Pairing the ER-2 with these sensors allows collection over large areas with finely detailed images. NASA has branded the data collection as the Geological Earth Mapping experiment. In studies with the California State Geological Survey (CGS), images from the hyperspectral dataset are analyzed to support the mapping of potential lithium resources. USGS and CGS are cooperating to apply the hyperspectral data to aid field sampling and resource evaluations. Beyond minerals, hyperspectral data have many demonstrated uses, for example, mapping native and nonnative vegetation species and detecting hydrocarbon contamination from oil spills. Earth MRI regional hyperspectral data are available online.[17]

Aerial Imagery Provides High-Quality Coastal Maps

Sandy coasts, like those on Cape Cod, are constantly changing, making the maintenance of current maps a challenge. Researchers in the USGS Remote Sensing Coastal Change Project, part of the Coastal and Marine Hazards and Resources Program, National Hazards Mission

16 See https://www.usgs.gov/special-topics/earth-mri.

17 See https://aviris.jpl.nasa.gov/GEMX/.

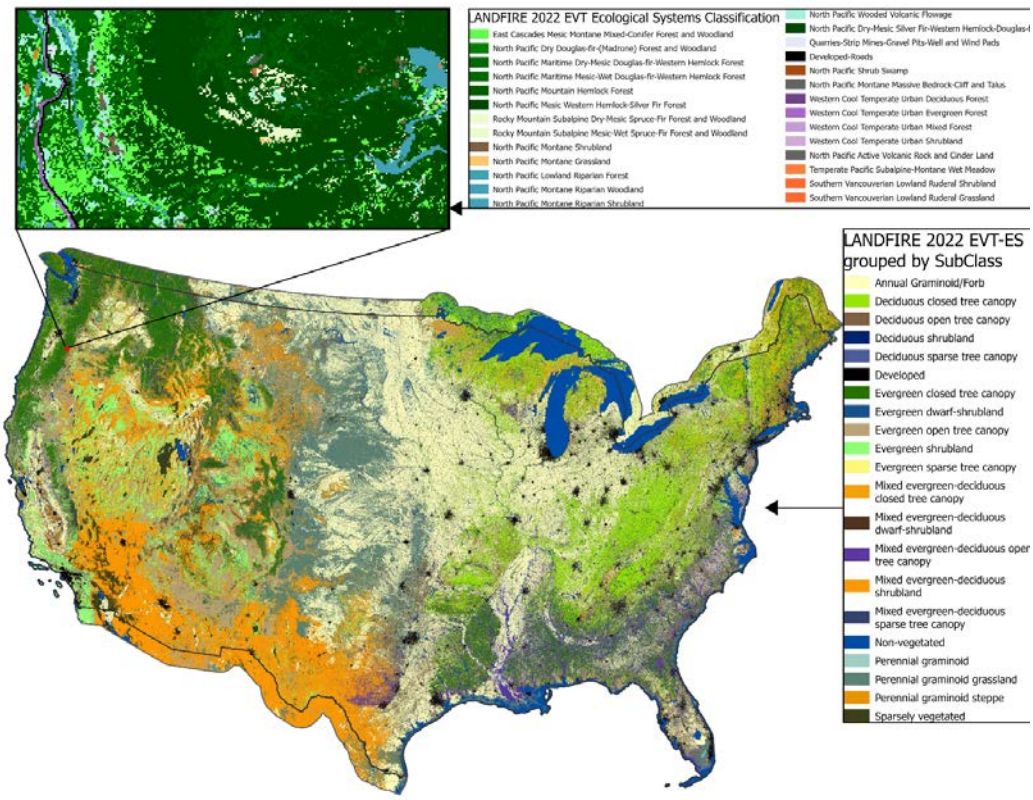
Area, use aerial imagery to study coastal change. The gold standard for mapping is airborne lidar, which provides high accuracy over large survey areas. Yet lidar surveys are expensive and infrequent, with the last regional survey on Cape Cod completed in 2018. Surveys derived from aerial imagery using structure-from-motion photogrammetry can provide comparable accuracy and coverage at a fraction of the cost. In November 2023, about 14,420 images were acquired on four overlapping flightlines along 135 kilometers of Cape Cod shoreline during four hours of flying. The resulting digital elevation models (accurate to about 0.15 meter) and orthomosaics allow scientists to chart shoreline locations, measure beach slopes (for use in wave-runup forecasts) and determine land cover for coastal habitat assessment. These data will be used to manage natural resources by NPS partners at the Cape Cod National Seashore and as input to the USGS Total Water Level Coastal Change forecasts.

The LANDFIRE Program at 20

The Landscape Fire and Resource Management Planning Tools (LANDFIRE) program celebrated its 20th anniversary in 2024. This anniversary reflects years of work dedicated to producing hundreds of Landsat-based, 30-meter geospatial layers that are integral in capturing vegetation and wildland fuel dynamics for the United States and its territories. LANDFIRE is mapping more than 700 vegetation types within the conterminous United States, and 90 kilometers into Canada and Mexico, to understand wildland fire fuel characteristics. This effort supports fuel management projects; helps identify at-risk communities; and produces standardized datasets that support the management of fire to help protect people, natural resources, and property. LANDFIRE maps also provide spatial fuels data needed for fire behavior modeling on large wildfires and for prescribed fire planning.

LANDFIRE recently developed innovative compositing processes that leverage Harmonized Landsat and Sentinel-2 (HLS) data to make a single set of seasonal disturbance and vegetation products (four per year) simultaneously. In years past, separate compositing campaigns were needed for disturbance and vegetation composites. The HLS-based composited imagery provides much clearer images, eliminating a time-intensive manual cleaning process. All compositing processes are automated and optimized to run on the USGS high-performance computing environment. Current efforts aim to transition these methods to the cloud for even greater efficiencies.

LANDFIRE actively tests and implements new machine learning and AI classifiers with methods to tune the models for these products. All methodologies have been developed to scale from the desktop computer to the cloud. The newest algorithms often require large amounts of data to model continuous and thematic variables more accurately. To address this challenge, LANDFIRE has been actively engaged in obtaining new 3D remotely sensed data sources, including satellite, airborne, and terrestrial lidar datasets. Additionally, LANDFIRE



LANDFIRE 2022 Existing Vegetation Type (EVT) Ecological Systems Classifications (ES) were produced for the conterminous United States and 90 kilometers into Canada and Mexico. The inset map shows a zoomed-in EVT-ES map of a forested area in Oregon.

has tackled challenges caused by data inconsistencies by adjusting the data distribution and removing outliers, ultimately minimizing product errors, and ensuring continued data quality.

Earth MRI Magnetic Data Assist with Earthquake Hazards in South Carolina

Airborne magnetic survey data, which measure subtle variations in Earth's magnetic field, can be used to image geology and faults at Earth's surface and up to several kilometers below. In South Carolina, a magnitude 7 earthquake in 1886 nearly destroyed the city of Charleston, and the region is considered at risk for future earthquakes. Data collected collaboratively through the Earth MRI and USGS Earthquake Hazards Program are being used to image faults that have slipped in recent geologic time and may pose risk today. The magnetic methods work by imaging contrasts between rocks that have different amounts of magnetic minerals, such as iron-rich basalts vs. sandstones. Such contrasts could be generated by a fault that juxtaposes different rocks. For example, in December 2021, a swarm of relatively low-magnitude earthquakes (magnitude less than 3.6) started near Elgin, about 30 kilometers from South Carolina's capital city, Columbia. These earthquakes are well-aligned with a lineament visible

in the aeromagnetic data, which is interpreted as the causative fault. These earthquakes continue today. A few other lineaments are visible near Charleston. Comparisons to other datasets, such as seismic reflection data, show that these faults have been active in the last two million years and may continue to be active in the future.[18]

The 3D National Topography Model: Integrating High-Resolution Elevation and Hydrography Data

The USGS 3D National Topography Model (3DNTM) is a new initiative that updates and integrates USGS lidar elevation and hydrography data to model the nation in three dimensions. The 3DNTM comprises three components: an ongoing effort to complete the National 3D Elevation Program (3DEP) baseline dataset; the development of the next-generation hydrography and elevation programs; and a longer-term goal to fully integrate hydrography, elevation, and other data from The National Map in a 3D data model.[19] All three components are in progress. At the end of FY 2024, 3DEP data were available or in progress for 94.7 percent of the Nation. FY 2024 also marks the first full year of production of the 3D Hydrography Program that is using the 3DEP baseline to derive all new surface water maps for the Nation.

18 For more information, see https://doi.org/10.1029/2022GC010803.

19 See https://www.usgs.gov/programs/national-geospatial-program/national-map.

Federal Communications Commission

FCC

The Federal Communications Commission (FCC), primarily through its Space Bureau, formulates rules to facilitate the provision of commercial satellite services in the United States. It also issues licenses for the deployment and operation of all non-federal U.S. satellites. During FY 2024, the Space Bureau led complex policy analysis and rulemakings, authorized satellite and earth station systems used for space-based services, streamlined regulatory processes to provide maximum flexibility for operators to meet customer needs, and fostered the efficient use of scarce radio frequency spectrum and orbital resources. The Space Bureau also served as the FCC's focal point for coordination with other U.S. Government agencies on matters of space policy and governance and collaborated with the FCC's Office of International Affairs for consultations with other countries, international and multilateral organizations, and foreign government officials that involve satellite and space policy matters.

External Engagement

In FY 2024, the FCC supported bilateral and multilateral engagements regarding routine licensing and policy matters and also provided subject matter expertise on space-related items for planning and participation in working parties related to the most recent International Telecommunication Union World Radiocommunication Conference in 2023 (WRC-23). FCC staff participated as part of the U.S. delegation for WRC-23, which was held from November 20 to December 15, 2023, in Dubai, United Arab Emirates. Some key outcomes from WRC-23 included adopting regulatory actions for the provision of inter-satellite links to allow data to be made available in near-real time to enhance weather forecasting and disaster risk reduction, approving resolutions to allocate additional frequencies for passive Earth exploration-satellite services to enable better climate monitoring, and allocating new frequencies to the aviation

industry for aeronautical mobile satellite services to enhance bi-directional communication via non-geostationary satellite systems for pilots and air traffic controllers. To prepare for future world radiocommunication conferences, the WRC-23 also adopted several resolutions to conduct further studies on specified topics including possible new or modified space research service radio frequency allocations for future development of communications on the lunar surface, technical and regulatory provisions that may be necessary to protect radio astronomy operating in specific Radio Quiet Zones from radio frequency interference, and possible new allocations to the mobile-satellite service for direct connectivity between satellites and mobile user equipment to complement terrestrial mobile network coverage, among other topics.

During FY 2024, the Space Bureau developed public documents and held events as part of its ongoing Transparency Initiative, with the goal to provide interested parties with accessible guidance on the FCC's application and authorization procedures for satellites and earth stations communicating with satellites.[1] On November 1, 2023, the FCC hosted its first open house dedicated to discussing the Transparency Initiative, which not only highlighted the need to keep pace with rapid technological innovation but also emphasized benefits of the initiative, such as reducing administrative burdens on both applicants and staff and expediting the processing of applications. In addition to hosting open house events, the Bureau placed additional information on the FCC's website, including event recordings, checklists, presentations, and responses to frequently asked questions. Event recordings were also placed on the FCC's YouTube channel.[2] The FCC continued to hold open houses in FY 2024 with topics including earth station licensing, satellite radio frequency spectrum coordination, and interagency review of satellites prior to launch. On February 29, 2024, the FCC held another public event of special note to recognize 20 years since the establishment of the orbital debris mitigation rule for commercial satellite operators and presented a retrospective on the rules and the future of orbital debris mitigation.

Administrative and Rulemaking Proceedings

The FCC promoted the development of space-based communications through significant actions in administrative and rulemaking proceedings. In the past year, the FCC adopted new rules to streamline satellite rules and expedite the processing of space and earth station applications. It also updated rules on orbital debris mitigation and established a new framework for the coming convergence of satellite and terrestrial networks in the future.

1 https://www.fcc.gov/space/transparency-initiative

2 https://www.youtube.com/FCC

Among the FCC actions in these and other areas in FY 2024 are the following:

- On January 26, 2024, the FCC adopted an Order on Reconsideration addressing petitions regarding the Commission's orbital debris mitigation rules. The Order on Reconsideration upheld changes to orbital debris mitigation rules adopted in 2020 as part of the first comprehensive update of the rules since their adoption in 2004 and included guidance to satellite operators on compliance with the modified rules. Specifically, the Order addressed questions related to satellite maneuverability disclosure requirements, methods for addressing risks from "free flying" deployment devices, assessment of satellite disposal reliability for large satellite systems, release of persistent liquids in space, and how the FCC's orbital debris rules apply to non-U.S.-licensed space stations. The FCC also issued a public notice related to orbital debris mitigation on May 2, 2024, to update the record in order to keep its regulations aligned with the rapidly evolving space industry and orbital environment.
- On February 16, 2024, the FCC adopted a Notice of Proposed Rulemaking (NPRM), seeking comment on a proposed process for radio frequency spectrum licensing for space station in-space servicing, assembly, and manufacturing (ISAM) activities. The FCC proposed to exempt ISAM applicants from certain requirements that might not be necessary for the radiofrequency operations involved in ISAM, such as those for processing rounds and "first-come-first-served" processes and proposed a grace period for compliance with the FCC's surety bond requirement.
- On March 14, 2024, the FCC adopted a first-of-its-kind framework establishing new rules for Supplemental Coverage from Space (SCS), which leverages satellite technology to extend the reach of wireless networks to remote areas and areas where terrestrial infrastructure is unavailable due to disaster, to make sure smartphone users stay connected even where there is no terrestrial mobile service. The framework allows satellite operators collaborating with terrestrial service providers to seek FCC authorization to operate space stations on certain licensed, flexible-use parts of the radio frequency spectrum currently allocated to wireless services, provided they satisfy certain licensing prerequisites, such as having a radio frequency spectrum lease from a terrestrial licensee. The FCC also adopted a Further Notice of Proposed Rulemaking (FNPRM) to seek further comment on public safety issues to ensure that these services adequately meet consumers' needs and expectations for critical services. The FNPRM also sought comment on issues associated with the protection of radio astronomy services.
- On October 2, 2023, the FCC took its first space debris enforcement action and entered into a consent decree with DISH for failure to properly deorbit its EchoStar-7

satellite. The settlement included an admission of liability from the company and an agreement to adhere to a compliance plan and pay a penalty of $150,000. The FCC's investigation found that the company violated the Communications Act, the FCC rules, and the terms of the company's license by relocating its direct-broadcast satellite service EchoStar-7 satellite at the satellite's end-of-mission to a disposal orbit well below the elevation required by the terms of its license, which raised orbital debris concerns. Additionally, on August 12, 2024, the FCC settled with Intelsat resolving the FCC's investigation into Intelsat's unauthorized operation of its Galaxy 35 satellite. Intelsat admitted to violating the Commission's rules, agreed to implement a compliance plan, and consented to a payment of a $160,000 civil penalty.

- On September 26, 2024, the FCC adopted rules to open 400 megahertz of radio frequency spectrum for nongeostationary orbit fixed-satellite service operations in the 17.3- to 17.8-GHz band. These rule changes enable nongeostationary fixed-satellite services to operate in the 17.3- to 17.7-GHz band in the space-to-Earth (downlink) direction on a co-primary basis with incumbent services and on a shared, co-primary basis with geostationary satellite orbit services. This action provides a contiguous 1,300-megahertz block of radio frequency spectrum for nongeostationary orbit fixed-satellite services downlink operations and will support advanced services, including high-speed broadband access, and allows for a range of use cases from different orbits, bolstering competition in the space economy. These rules also enable nongeostationary-satellite-orbit fixed-satellite service downlink use of the 17.7- to 17.8-GHz band on a co-primary basis with geostationary services and on an unprotected basis with respect to terrestrial fixed services.

Satellite and Spacecraft Licensing and Authorizations

During FY 2024, the FCC took steps to bolster the rapidly evolving space-based communications industry and issued multiple rulings aimed at facilitating the deployment and operation of nongeostationary satellites and satellite systems. Many of these applications were processed under the FCC's streamlined small satellite rules, which offer a more efficient licensing pathway for qualifying operators with a simplified application process and reduced fees, paving the way for a diverse array of satellite-based services. The rulings issued by the FCC included authorizations for entirely new systems as well as the granting of license modifications and special temporary authority for existing satellite licensees.

These satellites and satellite systems are designed to provide a wide spectrum of services, including satellite phone communications, data transmission, high-speed broadband internet, and serving as testing platforms for emerging technologies. Specifically:

- On October 13, 2023, the FCC granted in part Space Exploration Holdings, LLC's (SpaceX) request for license modification, authorizing SpaceX to deploy and operate in the fixed-satellite service (FSS) using V-band frequencies on up to 7,500 satellites of SpaceX's currently authorized "second generation" (Gen2) Starlink constellation rather than deploying a separate V-band system. Later, on March 8, 2024, the FCC authorized SpaceX to also provide FSS in the E-band with its Gen2 Starlink satellites.
- On January 16, 2024, the FCC authorized Spire Global, Inc. (Spire), to construct, deploy, and operate three nongeostationary satellites, Hubble 1, Hubble 2, and Hubble 3, to demonstrate technologies for satellite connections to Bluetooth devices on the ground.
- On May 16, 2024, the FCC granted Iridium Constellation, LLC's request to modify its license for its nongeostationary, mobile-satellite service (MSS) system, the Iridium NEXT System, in order to expand the storage altitude range of the system's spare satellites to facilitate satellite replacement and better ensure continuity of service for users.
- On August 2, 2024, the FCC granted in part AST & Science LLC's request to launch and operate five V-band nongeostationary, low Earth orbit satellites in order to test a system capable of providing SCS, which provides alternative connectivity options in areas where geographic and economic challenges have made it difficult, costly, and sometimes physically impossible to install cell towers or fiber.
- On August 16, 2024, the FCC granted SpaceX's request for modification of its license for the first-generation Starlink constellation consisting of up to 4,408 low Earth orbit, nongeostationary satellites. Specifically, the FCC granted SpaceX the authority to modify its operations due to planned changes in satellite hardware, including modification of beam-forming and digital processing equipment to enable narrower beam capabilities. This modification also reflected updates to SpaceX's orbital debris mitigation plan due to planned deployment of larger satellites.
- Also on August 16, 2024, the FCC granted in part Globalstar Licensee LLC's (Globalstar) request for modification of its license to deploy and operate up to 26 nongeostationary, low Earth orbit satellites to replenish and enhance its constellation in the provision of MSS. Globalstar provides mobile satellite voice and data services, including support for transmitting emergency calls and text messages in areas without traditional cell phone reception and GPS tracking support for vehicles, equipment, and other assets through satellite connectivity.

In FY 2024, the FCC also authorized radio frequency uses for nongeostationary satellites and satellite systems that provide services such as remote sensing, Earth observation and imaging, and related activities, including the following:

- On October 5, 2023, the FCC authorized Umbra Lab Inc. to construct, deploy, and operate six low Earth, nongeostationary satellites for radio frequency operations in the Earth Exploration Satellite Service (EESS) to conduct synthetic aperture radar (SAR) imaging, a technique that uses radar technology to create high-resolution images of Earth's surface.
- On November 6, 2023, the FCC authorized Space Sciences & Engineering LLC (PlanetiQ) to deploy and operate one nongeostationary satellite, GNOMES-4, in low Earth orbit. The satellite derives data from radio occultation using signals transmitted from satellites that operate in the Radionavigation Satellite Service (RNSS). Later, on June 6, 2024, the FCC authorized PlanetiQ to deploy and operate another nongeostationary satellite, GNOMES-5, in low Earth orbit for the same purpose.
- On January 19, 2024, the FCC authorized Loft Orbital Solutions Inc. (Loft) to construct, deploy, and operate one nongeostationary satellite, YAM-6, to service a number of customer needs using imagers, radios, and computing capabilities on the spacecraft. Later, on May 30, 2024, the FCC authorized Loft to deploy and operate another nongeostationary satellite, the YAM-7, for similar purposes.
- On January 20, 2024, the FCC granted in part Quantum Space LLC's request for authority to deploy and operate one satellite, the Quantum Sentry, to demonstrate a sensor that tracks space objects and improve its image-processing algorithms.
- On January 30, 2024, the FCC authorized Muon Space Inc. to construct, deploy, and operate two EESS low Earth orbit, nongeostationary satellites to demonstrate and validate the on-orbit performance of Muon's in-house-built microwave and hyperspectral sensors.
- On March 8, 2024, the FCC granted Kuiper Systems LLC's (Kuiper) request to modify its license to reduce the total number of satellites in its constellation from 3,236 to 3,232 satellites, change the specified orbital parameters of its constellation, and authorize radio frequency communications necessary for Kuiper to conduct launch and early-orbit phase operations, payload testing, and deorbit operations on a non-interference basis. Later, on April 22, 2024, the FCC granted Kuiper's request to modify its authorization and partially waive certain requirements related to international frequency regulations, prior to the initiation of broadband service to unserved and underserved areas of the United States.
- On March 15, 2024, the FCC authorized Capella Space Corp. (Capella) to deploy and operate two EESS low Earth orbit, nongeostationary satellites for the purposes of conducting SAR imaging with reduced latency. Later, on May 24, 2024, the FCC

granted Capella's request to modify its license to deploy and operate two additional satellites for the same purposes.

- On May 10, 2024, the FCC granted in part Planet Labs PBC's request for authority to deploy and operate two nongeostationary satellites as part of a constellation of Earth-observing satellites capable of identifying, quantifying, and tracking the sources of greenhouse gas emissions.
- On May 17, 2024, the FCC granted in part Tomorrow Companies, Inc.'s request for authorization to deploy and operate up to four nongeostationary EESS satellites as part of the Tomorrow.io Weather Constellation, which is designed to improve global weather forecasting and climate monitoring.
- On May 27, 2024, the FCC granted in part Umbra Lab Inc.'s request for authority to deploy and operate two nongeostationary satellites, the Umbra Block 2.1, operating in EESS and conducting SAR imaging.
- On June 7, 2024, the FCC granted the request of Spire to modify its nongeostationary space station license and grant of market access to include operations in the non-voice, nongeostationary MSS system. Spire provides global maritime monitoring data, meteorological monitoring, and Earth-imaging services.

In FY 2024, the FCC also authorized its first applications for commercial radio frequency spectrum for lunar communications. These applications were filed under the FCC's streamlined small spacecraft rules designed for non-Earth orbiting missions, which provide simplified application processing for qualifying missions. FCC actions concerning lunar missions included the following:

- On October 5, 2023, the FCC authorized Intuitive Machines to construct, deploy, and operate a lunar lander for a period of 60 days. This mission was part of the Commercial Lunar Payload Services (CLPS) program sponsored by NASA to explore the surface of the Moon.
- On December 6, 2023, the FCC authorized Astrobotic Technology Inc. to construct, deploy, and operate a lunar lander, the Peregrine Mission 1, and provide communications support and delivery for objects and instruments that would separate from the lander. This mission was also part of NASA's CLPS program.

In addition to these commercial operations, the FCC also granted applications for radio frequency spectrum use for experimental operations by non-federal satellites. The FCC granted many of these authorizations to universities and other teaching institutions conducting space research missions for educational purposes. The FCC also authorized radio frequency spectrum use for a variety of missions pertaining to small-scale testing of propulsion systems,

including different types of propellant, new communication systems, ISAM technologies, or operations supporting other federal missions or programs. Other experimental grants by the FCC included grants for communications associated with launch vehicles and for the testing of new telecommunications satellites and ground terminals, including testing equipment designed to provide services for consumer smartphones when those phones are beyond the range of terrestrial base stations. For example, the FCC authorized SpaceX to conduct testing of radio frequency spectrum related to using its satellites for SCS both in the United States and internationally, via coordination with other governments. A few additional noteworthy experimental authorizations include the following:

- On January 11, 2024, the FCC authorized Northrop Grumman Systems Corporation to deploy and operate the NG-20 Cygnus spacecraft as part of the NASA Commercial Resupply Services 2 (CRS2) program, providing delivery of cargo and supplies to the International Space Station (ISS).
- Also on January 11, 2024, the FCC authorized radio frequency communications for Atomos Nuclear and Energy Corporation to deploy and operate two spacecraft, Gluon and Meson, to demonstrate rendezvous, docking, and refueling technologies. During the mission, the two spacecraft will also attempt to demonstrate additional maneuvers, including release, redocking, and orbital transfer.
- On April 3, 2024, the FCC authorized the Boeing Company to communicate with the Boeing CST-100 Starliner Crew Capsule during its first crewed flight test mission to the ISS.
- On April 12, 2024, the FCC authorized Inversion Space Company to deploy and operate a satellite to test and validate technologies for future reentry vehicles that will return cargo from space to Earth.
- On April 26, 2024, the FCC authorized Varda Space Industries Inc. to communicate with its Winnebago-2 satellite. The Winnebago-2's mission aims to demonstrate technologies for producing pharmaceutical and other materials in microgravity conditions and then returning these space-manufactured products back to Earth.
- On July 19, 2024, the FCC authorized Sierra Space Corporation to deploy and operate the Dream Chaser space plane as part of the NASA CRS2 program to deliver cargo and supplies to the ISS, conduct ISS-attached operations and experiments, dispose of or return cargo from the ISS, and return the Dream Chaser back to Earth at the end of the mission.
- On September 12, 2024, the FCC authorized communications for SpaceX's Dragon capsule supporting its Polaris Dawn mission. This crewed spaceflight mission aimed to advance human space exploration by studying the effects of space radiation and

spaceflight on the human body, evaluating upgraded spacesuits for extended missions, testing laser-based communications systems in space, and conducting the first-ever commercial spacewalk.

In FY 2024, the FCC authorized a range of commercial geostationary satellite operations. These authorizations included various license modifications and grants of special temporary authority, often with respect to facilitating routine testing procedures and the deployment of replacement satellites. The FCC also granted special temporary authority to many licensees for the relocation of satellites to different locations in the geostationary arc and temporarily adjusting beam coverage areas, enhancing the flexibility and responsiveness of satellite networks to evolving market demands and technological advancements. While the majority of these authorizations addressed standard operational needs, several geostationary authorizations warrant particular mention, including the following:

- On July 17, 2024, the FCC authorized Sirius XM Radio Inc. to construct, deploy, and operate two new replacement Satellite Digital Audio Radio Service (SDARS) space stations, authorized to operate at various orbital locations.
- On August 15, 2024, the FCC granted Alascom, Inc.'s request for special temporary authority to conduct telemetry, tracking, and command (TT&C) operations in order to vent the SPACEWAY-2 space station's propellant tanks while maintaining the necessary stationkeeping tolerance and deorbit the space station. Later, on September 25, 2024, the FCC also granted Alascom, Inc.'s request for special temporary authority to perform TT&C operations necessary to de-orbit the SPACEWAY-2 satellite.
- On September 18, 2024, the FCC granted Sirius XM Radio Inc.'s request to modify the license for the SXM-7 and SXM-8 space stations to allow operations in the Wireless Communications Service band immediately adjacent to the SDARS band.

In FY 2024, the FCC took steps to support space communication by licensing new earth stations. This activity includes earth stations that operate in motion, including on board an aircraft, and that receive from and transmit to geostationary space stations in order to provide broadband data communication services, including internet, to aircraft passengers. While the majority of the authorizations address standard operations, some of these actions warrant mention:

- On April 3, 2024, the FCC authorized Gogo Business Aviation LLC to communicate with OneWeb satellites.
- On May 16, 2024, the FCC granted SpaceX Services, Inc. (SpaceX) authority to communicate with its Starlink system using multiple types of new earth stations in motion.

U.S. Department of Agriculture

USDA

The U.S. Department of Agriculture's (USDA) mission is to provide leadership on food, agriculture, natural resources, rural development, and nutrition through a foundation of public policy, cutting-edge science, and effective management. In its pursuit of growth and progress, USDA fosters resilience in the food system, invests in healthy communities, and advocates for small and mid-sized farms. USDA's mission extends to promoting agricultural production that nourishes Americans and also contributes to feeding the world while safeguarding the Nation's natural resources through conservation, forest restoration, watershed improvement, and the stewardship of private lands. USDA also works with foreign governments, international organizations, and the Office of the U.S. Trade Representative to establish international standards and rules to improve accountability and predictability for agricultural trade worldwide.

Central to this mission is the USDA Geospatial Strategic Plan (GSP), which advances the use of geospatial data and technology as an indispensable tool for achieving USDA's objectives. The GSP outlines a framework for implementing the Geospatial Data Act of 2018,[1] enhancing the value of geospatial information across USDA operations and fostering partnerships that promote cost efficiency and innovation. USDA is solving real-world problems, leading collaboration, and advancing geographic literacy across the Department, with partner federal agencies as well as state, local, and tribal communities. USDA continues to strengthen its ability to deliver on its mission and is positioning itself to become a federal leader in the use of geospatial information and technology.

Through the application of remote-sensing technologies, USDA can monitor agriculture, rangelands, and forests, thus enabling data-driven decision-making that supports mission-critical operations such as fire management, conservation, precision agriculture, rural

1 43 U.S.C. Ch. 46, Geospatial Data Act of 2018, as amended.

development, and food security. These efforts rely on a broad array of platforms, from satellite systems and aerial imagery to ground-based data collection, each playing a vital role in fulfilling USDA's goals for sustainability, resilience, and agricultural innovation.

Agricultural Research Service

The Agricultural Research Service (ARS) is the intramural research branch for USDA involved with Earth science, natural resources monitoring, and advanced analytics. For many years, ARS has been integral to the development, calibration, and validation of Earth science products, including soil moisture, evapotranspiration, land cover, and drought status data products.

Research undertaken by the Long-Term Agroecosystem Research Network has supported field experimentation and remote sensing calibration and validation for satellites like the Soil Moisture Active Passive (SMAP) mission. ARS scientists collaborated with NASA on field experimentation to develop algorithms for the retrieval of cropland coverage and soil moisture estimates for satellites in development, including the NASA-ISRO Synthetic Aperture Radar (NISAR) mission, set to launch in 2025. Other efforts include integrating satellite soil moisture data products into the USDA drought monitoring efforts. ARS scientists served on multiple satellite science teams, including those for SMAP, NISAR, the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), and Landsat, providing invaluable expertise in agricultural monitoring and interpretation.

ARS, in collaboration with NASA's Applied Sciences Water Resources Program under the Grape Remote Sensing Atmospheric Profile and Evapotranspiration experiment project, has generated vegetation indices using the harmonized Landsat and Sentinel-2 data product for study sites across several states, including California, Michigan, Oklahoma, and Wyoming, to support grape, almond, and grazing projects. ARS generated daily evapotranspiration products over the continental United States using GOES thermal imagery in combination with other visible and near-infrared satellite products. These were downscaled to field scale (about 30 meters) and contributed to the OpenET (EvapoTranspiration) project. ARS scientists also used satellite data to map historical and near-real-time rangeland conditions in the Central Great Plains to generate robust models and to track the dynamic nature of herbaceous biomass, forage quality, and fractional ground cover at sub-pasture scales.

Another contribution of note is the study and development of microgreens to improve the diets of astronauts on the ISS with fresh food. ARS scientists in Beltsville, Maryland, have been working on improving the growth and nutritional value of these microgreens, with space-based testing on the horizon. Earth system modeling is also heavily informed by various space-based monitoring systems. For example, the Soil Water Assessment Tool has been incorporating satellite data into its data flow for more up-to-date predictions and understanding of Earth

processes. Carbon monitoring is another focus of research, with ARS leading an effort to provide continental-scale tillage and carbon storage products that will inform assessments of crop yield and conservation management practices. The basis of this monitoring is a combination of remote sensing observations, models, and ground-based monitoring throughout the United States.

ARS serves as the primary point of contact for USDA on Earth observations with respect to NASA collaborations, including serving on the interagency U.S. Group on Earth Observations (USGEO) and the current Earth Observation Assessment Working Group. This group recently completed the Assessment for Agriculture and Forestry, evaluating the impact of specific Earth observations on key products, services, and objectives of USDA.

Foreign Agricultural Service

The Foreign Agricultural Service's Global Market Analysis (FAS-GMA) serves as a major source of objective and reliable global agricultural production information to USDA's monthly World Agricultural Supply and Demand Estimates (WASDE) report, the primary source of USDA's global commodity outlook. The monthly WASDE report provides public access to information affecting world food security and is crucial to decisions affecting U.S. agriculture, trade policy, and food aid.[2] FAS-GMA authors the World Agricultural Production (WAP) circular, and both WASDE and WAP publications are Principal Federal Economic Indicators.[3] FAS also publishes and archives global monthly crop production, supply, and distribution (PSD) data from USDA's monthly WASDE report on the FAS PSD Online website.[4]

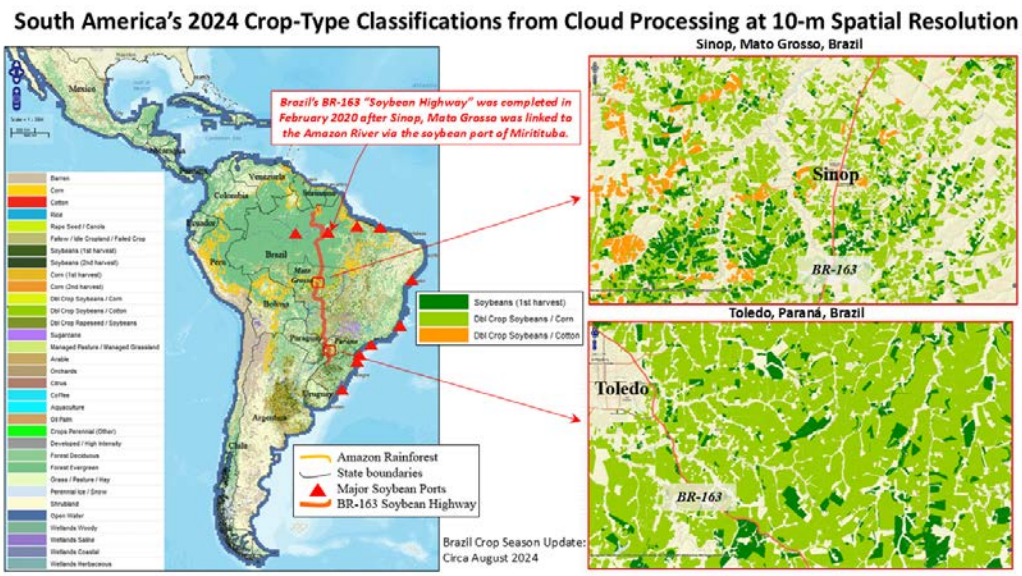
During FY 2024, FAS-GMA's International Production Assessment Division (IPAD) operated the remote-sensing program and operationally estimated monthly changes in global crop production by leveraging daily NASA satellite measurements on cloud-based computing systems at 250-meter (m) spatial resolution to estimate crop yields and estimated national crop area from two cloud-based systems at 10-m spatial resolution. National crop area for numerous crops and countries were primarily estimated from the Google Earth Engine (GEE) cloud and from Geospatial Data Analysis (GDA) Corporation's cloud system that sharpened 30-m Landsat imagery measurements to 10-m spatial resolution.

The cloud-based GEE and GDA systems computed and estimated national crop area for numerous crops at 10-m resolution from cloud-based machine learning algorithms that provided timely crop-type classifications and national crop area estimates before the harvest season was completed. Cloud-based computing at 10-m spatial resolution also allowed crop area

2 USDA WASDE Report, https://www.usda.gov/oce/commodity/wasde.

3 USDA FAS WAP Circular, https://www.fas.usda.gov/data/world-agricultural-production.

4 USDA FAS PSD Online, https://apps.fas.usda.gov/psdonline/app/index.html#/app/home.



Source: GDA GeoChronicles are cloud-free 10-day 10-m imagery composites derived from four satellites (Sentinel-2A/2B and Landsat-8/9).

Example of South America's 2024 crop-type classification at 10-meter spatial resolution, with two close-up views showing crop types grown along Brazil's BR-163 Soybean Highway near the towns of Sinop and Toledo, Brazil. National crop area estimates were extracted from the above 10-m crop-type image on regular and timely intervals during the 2024 growing season. (Image courtesy of Geospatial Data Analysis Corporation)

estimates to be calculated for more countries and crops, as well as at critical time periods during the growing season. In addition, cloud-free GeoChronicles composites at 10-m resolution were derived at regular 10-day time intervals, and all 30-m Landsat 8/9 bands were sharpened to 10-m resolution through an innovative deep learning neural network model that preserved each Landsat band's radiometric properties.

The final cloud-free GeoChronicles composites at 10-m resolution provided nearly global cropland coverage during FY 2024, and the 10-day composites were derived from four satellites: two USGS-NASA Landsat-8/9 satellites with 30-m bands sharpened to 10-m and two Copernicus Sentinel-2A/2B satellites with 20-m bands sharpened to 10-m. The four satellite GeoChronicles 10-day composites sharpened to 10-m resolution also provided unprecedented cloud-free 10-m spatial coverage for most countries, especially for countries with smaller fields such as island nations in the Caribbean or countries with large populations and relatively smaller field sizes such as those in Africa, Asia, and South America.

Cloud computing with 10-m GeoChronicles cloud-free composites also improved the accuracy of national crop area results for all countries in comparison to previous crop area results derived from 30-m Landsat imagery on GEE. Cloud-based machine learning algorithms on both GEE and GDA cloud systems also allowed timely 2024 crop area estimates at 10-m spatial resolution to be delivered to USDA decision makers one month before the harvest

ended. For example, Brazil's 2024 soybean and corn area estimates were computed from GDA's 10-m cloud-based system and the timely soybean area results were provided to USDA's lockup decision makers by early May 2024, or one full month before Brazil's soybean harvest ended on June 15, 2024.

In addition, the four satellite GeoChronicles composites at 10-m resolution were staged on GEE for the 2024 contiguous U.S. (CONUS) crop season from April through October. These 10-day GeoChronicles composites allowed timely cloud-based 10-m crop-type classifications to be computed for the CONUS crop season by leveraging machine learning algorithms for numerous crops on the cloud-based GEE and GDA GeoChronicles systems.

For FY 2024, seasonal crop yields were estimated from the cloud-based USDA-NASA Global Agricultural Monitoring (GLAM) system hosted by NASA's Global Inventory Modeling and Mapping Studies (GIMMS).[5] The USDA-NASA GLAM system provided public users with science-quality Normalized Difference Vegetation Index (NDVI) composites derived from daily satellite measurements retrieved from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor onboard NASA's Terra and Aqua satellites and from the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor on NOAA's S-NPP and NOAA-20 satellites. NASA's MODIS Adaptive Processing System (MODAPS) and Land, Atmosphere Near-real-time Capability for Earth Observing System (EOS) (LANCE) systems also processed eight-day NDVI composites for the cloud-based GLAM-NDVI/MODIS (from 2001) and GLAM-NDVI/VIIRS (from 2012) time series data systems. NASA's MODAPS and LANCE time series NDVI sets also utilized the best available cloud screening and NDVI bidirectional reflectance distribution function science algorithms derived from daily MODIS measurements at 250-m resolution and daily VIIRS measurements at 500-m resolution.

The cloud-based GLAM-NDVI/MODIS (250-m) and GLAM-NDVI/VIIRS (500-m) systems enabled public users to estimate relative crop yields for all major crop-producing countries, as well as for small island nations with limited cropland area. The GLAM-NDVI/MODIS-Terra (250-m) system also provided the most reliable and best available science data for estimating 2024 corn and soybean yields because the GLAM NDVI/MODIS-Terra record has the finest spatial resolution (250-m) and longest NDVI/MODIS long-term record (from 2001); additionally, NDVI spectral characteristics for corn and soybean crops have the greatest NDVI-yield correlations compared to other crop types, as verified by numerous researchers.

For FY 2024, the USDA-NASA Global Reservoir and Lake Monitor (G-REALM) web application displayed reservoir and lake water heights for more than 600 inland water bodies by retrieving near-real-time water height measurements from NASA's Jason-3, Jason Continuity of Service on Sentinel-6 (Jason-CS/S-6), and Surface Water and Ocean Topography (SWOT)

5 USDA-NASA GLAM, https://glam1.gsfc.nasa.gov/.

satellites, as well as from the Copernicus Sentinel 3A/3B satellites.[6] Lake water height measurements from NASA's SWOT were started in 2023 and provided G-REALM with NASA's latest state-of-the-art technological improvements in satellite radar altimetry.

FAS-GMA also hosted online Crop Explorer, 12 Commodity Explorers, and the Global Agricultural and Disaster Assessment System (GADAS) web applications that displayed numerous global crop masks interfaced with multiple Earth observation data streams from NASA, NOAA, and other agencies.[7] Crop Explorer and the 12 online Commodity Explorers are crop-specific and monitored seasonal NDVI, cumulative precipitation, daily temperature, and root zone soil moisture measurements over global croplands for corn, wheat, rice, cotton, soybeans, barley, palm oil, rapeseed, sorghum, sunflower seed, peanuts, and millet. GADAS is a state-of-the-art geographic information system, with geographic information system (GIS) tools and cropland datasets to help further support agricultural and disaster assessment analysis.

Forest Service

As the primary forestry agency of the United States and the largest agency in the USDA, the U.S. Forest Service (USFS) continues to sustain the health, diversity, and productivity of the Nation's forests and grasslands. This work encompasses partnerships with states, tribes, and other federal agencies to address forestry and natural resource issues; administration and management of 155 national forests and 20 national grasslands collectively known as National Forest System (NFS) lands, totaling 193 million acres (146 million forested acres); assistance in the stewardship of approximately 620 million acres of additional forest lands by other federal, state, tribal, and community forest agencies and private land owners; and research and monitoring of forestlands and resources by the Forest Inventory and Analysis (FIA) program.

In FY 2024, the USFS continued their collaboration with NASA, NOAA, the USGS, other agencies, and non-federal partners to apply operational satellite and airborne imagery and the most advanced remote-sensing and geospatial technologies. Specific accomplishments included the following:

- Through the Applied Earth Observations Innovation Partnership, NASA and the USFS conducted a three-day Joint Application Workshop, "Co-Producing EO-Driven Solutions for Fire, Forest, Ecosystem, and Rangeland Management," in April 2024.[8] The workshop, hosted in Ann Arbor, Michigan, focused on co-developing

6 USDA-NASA G-REALM, https://ipad.fas.usda.gov/cropexplorer/global_reservoir/.

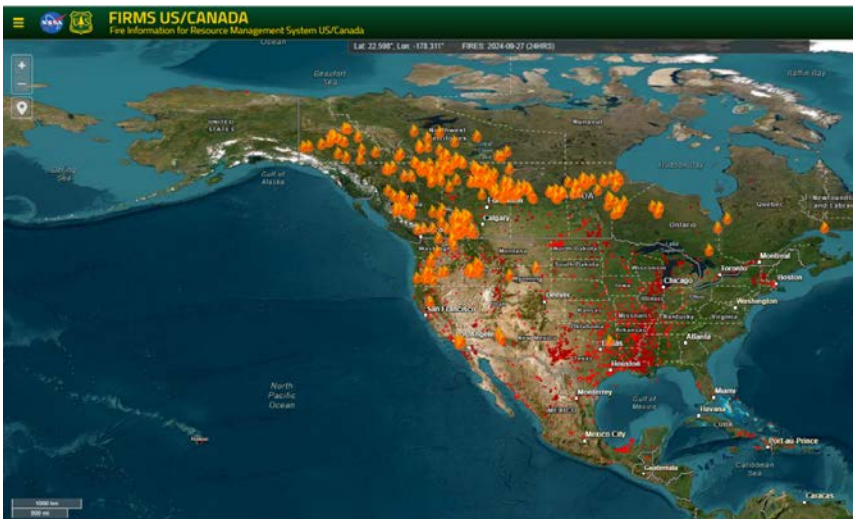
7 USDA FAS-GMA Crop Explorer, https://ipad.fas.usda.gov/cropexplorer/; Commodity Explorer, https://ipad.fas.usda.gov/cropexplorer/cropview/; Global Agricultural and Disaster Assessment System (GADAS), https://geo.fas.usda.gov/GADAS/index.html.

8 https://research.fs.usda.gov/rmrs/projects/applied-earth-observations-innovation-partnership#overview

shovel-ready ideas to better leverage Earth observations to meet science and management priorities of U.S. land and natural resource management agencies.

- The USFS partnered with NASA to provide comprehensive, low-latency remote-sensing products to support strategic wildland fire management needs for the USFS and other agencies in the United States and Canada.[9] This partnership included efforts to develop, maintain, and enhance the availability of key sources of operational remote-sensing data and a web portal to visualize and disseminate these data to support operational needs of federal and state agencies and to inform the public. These efforts included providing multiple sources of near-real-time, real-time, and ultra-real-time imagery and other science data products from sensors onboard multiple polar-orbiting and geostationary satellites. These sources include Terra and Aqua MODIS, S-NPP and NOAA-20 VIIRS, S-NPP Ozone Mapping and Profiler Suite, Landsat 8/9 Operational Land Imager (OLI), Sentinel-2A and 2B MSI, and Geostationary Operational Environmental Satellites (GOES) 16 and 18 ABI.
- In FY 2024, the Forest Service and NASA signed an MOU for joint wildfire technology development, assessment, and transition to operations and management. The MOU established a collaboration for conducting research, developing an interagency concept of operations, and carrying out technology assessments and demonstrations.
- The Fire and Smoke Model Evaluation Experiment (FASMEE), a fire and smoke field campaign led by Forest Service Research & Development, was supported by NASA's Wildland Fire Program. FASMEE is an interdisciplinary collaborative effort to identify and collect critical measurements of fuels, fire behavior, fire energy, meteorology, smoke, and fire effects that will be used to evaluate and advance operational fire and smoke models. NASA provided a B-200 aircraft outfitted with fire and smoke instruments and continued supporting the data archive for the field campaign.
- The USFS collaborated with the NASA Terrestrial Information Systems Laboratory, NASA Land-Atmosphere Near Real-Time Capabilities for EOS, NASA Applied Sciences Program, NASA Global Imagery Browse Services, NOAA, the USGS, and university partners to complete the development of a NASA-hosted computing platform to serve the USFS operational needs for near-real-time satellite data processing; strategic Active Fire Mapping processing, analysis, and product generation; and forest disturbance monitoring and damage mapping. This operational platform, the Fire Information for Resource Management System Fire Map, allows online users to view near-real-time fire vector data within approximately three hours of satellite overpass and raster imagery within four to five hours. Also available for

9 https://firms.modaps.eosdis.nasa.gov/usfs/



The Fire Information for Resource Management System fire map portal: https://firms.modaps.eosdis.nasa.gov/usfs/.

download on this site is the full archive of global active fire detections from MODIS and VIIRS.

- The USFS utilized MODIS imagery to conduct coarse-scale damage assessments for large geographic areas of the continental United States in the immediate aftermath of significant forest disturbance events (e.g., hurricanes) as well as to support broadscale forest health monitoring for the approximately 800 million acres of forested lands throughout the United States. This strategic information supported the agency in targeting areas for fuels management activities and tactical response efforts regarding forest to pest and pathogen outbreaks. This includes providing comprehensive near-real-time, 250-m indices and raster disturbance detection products for CONUS and Alaska throughout the annual growing season derived from eight-day MODIS composite imagery and available for USFS staff download from the online Landscape Automated Monitoring and Detection Algorithm (LAMDA) portal.[10]
- The USFS also utilized Sentinel-2 and Landsat imagery to conduct moderate-scale forest damage assessments, including the tasking and acquisition of commercial high-resolution imagery for calibration/validation purposes and higher-resolution assessment needs in support of planning and response to disaster events affecting National Forest System Lands during FY 2024. This included 10 significant events—five hurricane and three tornado events in the southeast United States, one severe wind event in the Great Lakes Region, and one large landslide event in Alaska.

10 https://rcr-usfs.github.io/LAMDA/Delivery/lamda-downloads#viewer-frame

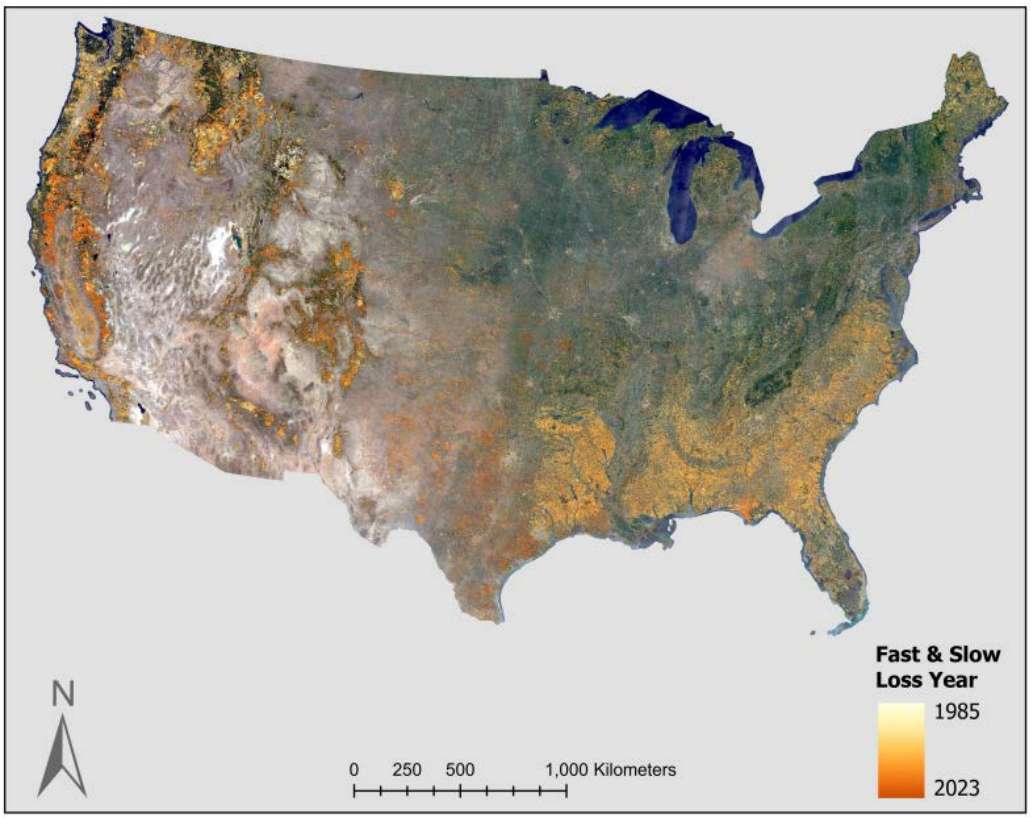
- The USFS continued coordination with NASA Ames Research Center to overhaul and upgrade the Automated Modular Sensor (AMS) electronics and sensor components and to further develop the AMS firmware and software for use on USFS aircraft. The coordination included efforts to renew a multiyear interagency agreement between the USFS and NASA to identify funding support to complete this work and move the AMS sensor into operational support activities.
- Landsat 8 and 9 OLI and Sentinel 2 imagery was operationally applied to provide 158 burn severity mapping emergency assessment products for 145 wildland fire events covering approximately 3.3 million acres (through September 22, 2024), including seven products for one international response for the Slocan Wildfire Complex in southeast British Columbia, Canada. These rapid-response products support post-fire emergency stabilization/hazard mitigation activities conducted by the USFS Burned Area Emergency Response teams in the immediate aftermath of wildland fires. Additionally, two separate burn severity mappings, totaling approximately 690,000 acres, were done for the Hermit's Peak/Calf Canyon fire in order to assess longer-term severity effects and recovery in the fire area that initially occurred in 2022.
- In FY 2024, Landsat 8 and 9 OLI and Sentinel 2 imagery were operationally applied to map and estimate post-fire basal area loss and canopy cover loss for 105 large wildfires occurring in 2023 and 2024 and affecting more than 1.7 million acres. These products support forest restoration planning management activities and efficient use of resources to support those activities.
- In FY 2024, in partnership with the USGS, the USFS continued to operationally apply Landsat 4 and 5 Thematic Mapper (TM), Landsat 7 ETM, Landsat 8 and 9 OLI, and Sentinel 2 imagery to complete new and/or revised mappings of 1,432 current and historical large fires affecting over 13.5 million acres across multiple land ownerships in the United States. This increased the extent of the historical Monitoring Trends in Burn Severity (MTBS) data record to include more than 30,000 fires covering more than 211 million acres of burned lands. The purpose of MTBS is to map and characterize large fires to assess the effectiveness of national fire management policies.
- The USFS coordinated with NASA and the USGS to provide operational Landsat active fire detection data for CONUS, southern Canada, and northern Mexico. This activity leverages the real-time Landsat 8 and Landsat 9 operational data stream collected by the USGS to provide 30-m active fire detection data within 20 minutes of satellite overpass.
- Technical collaboration activities continued between the USFS and NASA Ames Research Center regarding the exchange, technology transfer, and implementation of relevant NASA, USFS, and commercial technologies, capabilities, and emerging

data sources. These collaboration activities supported crewed and uncrewed airborne remote-sensing activities in the USFS and interagency community through the Tactical Fire Remote Sensing Advisory Committee.

- The USFS used imagery from Landsat 8 and Landsat 9 OLI and the USDA National Agriculture Imagery Program (NAIP)[11] to initiate, complete, and update mid-level vegetation mapping, riparian mapping, land-cover change, and Field Sampled Vegetation spatial update products for national forest lands and adjacent land areas throughout the country. Mid-level vegetation mapping areas included two National Forests encompassing more than 24,431,118 million acres. Additionally, three CONUS-level products are currently being produced using national inventory data.
- The USFS used Landsat 7, Landsat 8, and Landsat 9 OLI data to create annual updates of 30-m tree canopy cover data from 2008 to 2022 for CONUS, the interior of Alaska, Hawaii, Puerto Rico, and the Virgin Islands.
- Landsat TM/ETM/OLI and NAIP imagery was used in conjunction with other core geospatial datasets to conduct ecological land-type associations and soil-type mapping on NFS lands in the northeast and western United States. The USFS, Natural Resources Conservation Service, and other agencies use these data for resource management, planning, and decision making.
- The USFS completed and delivered a comprehensive and consistent land-cover/land-use monitoring system, the Landscape Change Monitoring System (LCMS), for the continental United States. LCMS utilizes Landsat TM/ETM/OLI time-series stacks within GEE to detect and monitor land-cover/land-use change from the mid-1980s to the present across all U.S. administrative ownerships, including CONUS, southeast Alaska, Puerto Rico, and the U.S. Virgin Islands. In FY 2024, the 1985–2022 CONUS change product was updated to include 2023 data. This effort is being conducted in collaboration with several federal and academic partners.
- The USFS continued to develop and refine standards and practices for integrating lidar into forest and resource management (i.e., defining acquisition specifications, data-quality assessment, and analysis/modeling procedures for forest parameters) and monitoring.
- The USFS continued to expand its engagement in the USGS 3D Elevation Program (3DEP)[12] as it transitions to the USGS 3D Hydrography Program (3DHP) and the 3D National Topography Model (3DNTM) initiative to ensure consistent acquisition

11 National Agriculture Imagery Program (NAIP) GeoHub, https://naip-usdaonline.hub.arcgis.com/.

12 https://www.usgs.gov/3d-elevation-program



Summary of annual Fast and Slow Loss from the USFS Landscape Change Monitoring System data for all years from 1985 to 2023 with a backdrop mosaic that includes Landsat. This data is derived from Landsat using a machine learning algorithm.

specifications and to minimize redundant collections by partnering with other state and federal entities on data acquisitions.

- In 2024, the USFS, in collaboration with other federal agencies, created the Interdepartmental Imagery Publication Platform (IIPP), now actively serving raster imagery. The IIPP is a new, state-of-the-art cloud-based geospatial imagery hosting platform that replaces the Geospatial Technology and Applications Center (GTAC) Image Services platform that has operated for over 20 years. A large portion of the data services in IIPP include all dates of NAIP imagery and other high-resolution imagery from aerial and satellite sensors, which are essential for daily USDA and partner operational business information needs.
- Forest Inventory and Analysis (FIA) and Forest Health Protection staff continue to utilize Landsat 8, Landsat 9 OLI, Terra and Aqua MODIS, NAIP imagery, NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT), and Global Ecosystem Dynamics Investigation (GEDI) products to support inventory and monitoring of the Nation's forests, including mapping and use in post-stratification to improve forest attribute estimates.

- USFS scientists serve on the GEDI science team. NASA's GEDI instrument on the ISS collects lidar waveform data for assessing the existing biomass of forests and how changes in this biomass caused by human activities or variations in climate may impact atmospheric carbon dioxide concentrations. Additionally, these investigations of the 3D structure of forests help elucidate habitat quality and biodiversity at local to regional scales.
- A USFS scientist contributes as a co-investigator to the NASA Carbon Monitoring System (CMS), which tracks carbon dioxide movements across the globe. Their work focuses on refining CMS flux data, used to monitor carbon emissions and absorption, by conducting precise regional assessments. This process involves comparing CMS data with real-world observations, such as ground or tower measurements, ensuring that the system can accurately inform carbon flux inventories at both regional and global scales. Under the 2020 Resources Planning Act, USFS scientists are analyzing current status and projections for national reporting of carbon, by using FIA and Natural Resources Conservation Service (NRCS) data together with national map products that depend on the Landsat archive.
- The Forest Inventory and Analysis Program continued ongoing work with NASA scientists to use NASA's G-LiHT imager to collect data that augment the forest inventory of interior Alaska, which includes investigations for improving carbon monitoring. This agreement allows the Forest Inventory and Analysis Program to assess and monitor all of Alaska's forests using a reduced set of field plots.
- Remote-sensing scientists often rely on observations from Forest Inventory and Analysis data to calibrate or validate models based on remote sensing or to support scientific studies. For example, the Forest Inventory and Analysis program has an agreement to share USFS data with the LANDFIRE program, in cooperation with the Department of the Interior. LANDFIRE uses Landsat data to create models and maps of vegetation and fire risk characteristics.

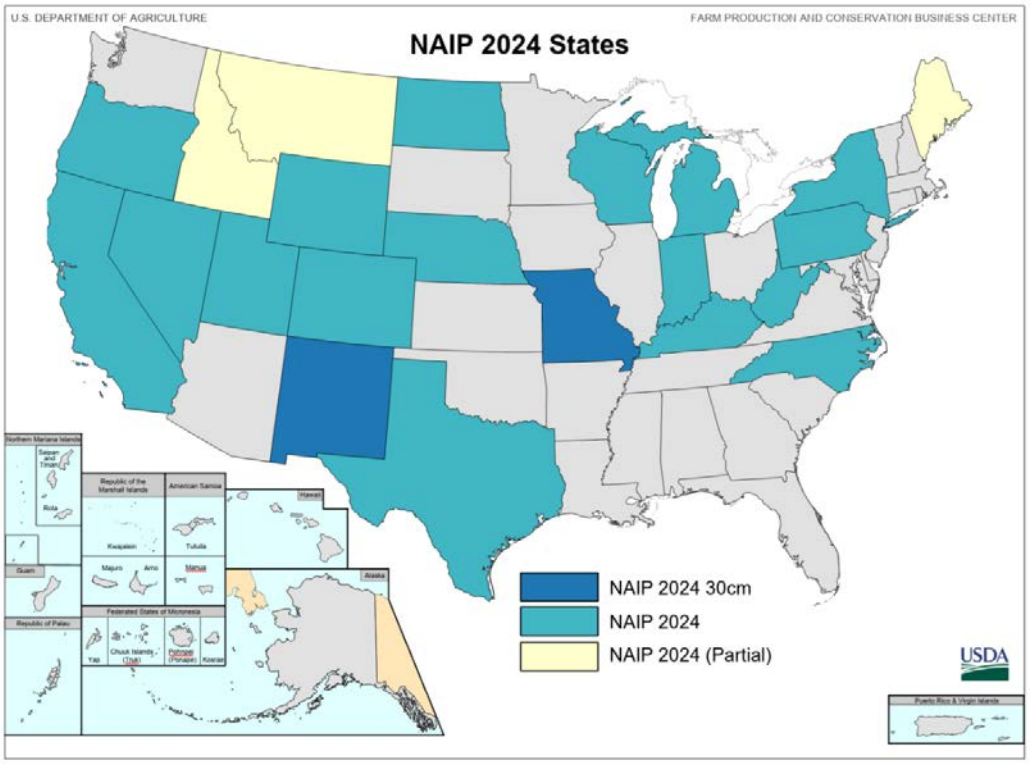
Farm Service Agency

The Farm Service Agency (FSA) administers several safety-net, price-support, conservation, disaster assistance, and loan programs established by Congress through a network of federal, state, and county offices. Land-based information plays a fundamental role in the daily operations and administration of those programs. In FY 2024, FSA used a diverse set of remotely sensed data, typically from traditional aerial images, to support a wide variety of agency activities, including efforts to record producer-reported crop plantings.

FSA did not directly operate any crewed aircraft or uncrewed aerial vehicles this past reporting period; however, the agency issued several remote-sensing contracts to acquire aerial imagery that required the use of the National Airspace System. The main contracts supported orthorectified imagery collection for the NAIP.

NAIP is a multi-department-funded program that provides current high-resolution imagery of CONUS, Hawaii, Puerto Rico, and the U.S. Virgin Islands to the public. An example of high-quality imagery collected is shown on the right. NAIP imagery is collected every two years for CONUS and every four years for Hawaii, Puerto Rico, and the U.S. Virgin Islands. The map, entitled "NAIP 2024 States," shows the current status of data collection by state. Nearly all civilian federal agencies use NAIP as a base layer in their GIS to support a wide variety of activities, such as conservation and land

Example of National Agriculture Imagery Program imagery showing fields of canola in bloom in central North Dakota. (Image courtesy of Farm Service Agency)



Map displaying states and territories where USDA collected imagery through the NAIP in 2024, as of September 10, 2024.

management. Commercial platforms like Google and Apple also utilize NAIP imagery. The FSA, NRCS, USFS, and USGS-DOI have successfully funded and supported NAIP since the program's inception in 2003.

Complete border-to-border coverage under NAIP requires broad access to restricted and other special-use airspace. Data from several military areas are not typically collected due to national security concerns.

In 2024, FSA used high-resolution aerial and satellite imagery, as well as satellite data, to support disaster recovery programs, including Emergency Farm Loans and the Emergency Conservation Programs, on an ad hoc basis. In addition to the civilian-managed space-based systems, FSA incorporated high-resolution Maxar satellite imagery for Alaska, acquired by NRCS and the USGS, into the NAIP imagery services to provide updated imagery to state and county office users. FSA also provided geospatial decision-support products to FSA leadership for situational awareness during natural disasters. The products included impacted program estimates; estimated precipitation; and natural disaster extents for flood events, tornadoes, hurricanes, and wildfires.

National Agricultural Statistics Service

The National Agricultural Statistics Service (NASS) serves as the statistical agency for the USDA, and its data support research, education, and advocacy for the country's agricultural future.

NASS used Earth observation data to construct and sample area frames for agricultural statistical surveys; estimate crop area and yield; monitor crop conditions; build soil moisture via data visualizations; impute for survey non-response; and provide geospatial data products and assessments for disaster events such as tornadoes, hurricanes, and wildfires. NASS used Landsat imagery, digital NAIP imagery, and other Earth observation resources for the CONUS to select the yearly area-based samples for the 2024 June Area Survey, NASS's largest annual statistical survey.

The acreage estimation program used satellite-based Earth observation imagery from the Landsat 8 and 9 and Sentinel-2 A and B missions to produce acreage estimates for crops at state and county levels. Earth observation-based acreage indications for all states were derived from the Cropland Data Layer (CDL), a 30-m-resolution CONUS crop cover product for all market-sensitive crops. The NASS Agricultural Statistics Board (ASB) utilized the Earth observation acreage estimates as independent inputs to set official estimates for monthly crop production reports. In addition, NASS distributed the CDL for the CONUS to stakeholders for the 2023 crop seasons via the USDA Geospatial Data Gateway and CroplandCROS. NASS released

the 2024 CONUS CDL at 10-meter resolution at USDA's Agricultural Outlook Forum in February 2025.[13]

CroplandCROS continued to provide data users with access to a variety of geospatial resources and information, including all historical CDL data, derivative cultivated data-layer, crop-frequency data-layer, and crop sequence boundary products. These web applications offer advanced tools such as interactive visualization, web-based data dissemination, and geospatial queries. These applications use web browsers to deliver crop-specific, land-cover data and visualization tools directly to the lay agricultural community, thus requiring no specialized expertise or GIS software.

NASS used machine learning techniques to continue development on the 30-m crop-type prediction layers and corresponding entropy (uncertainty) layers derived from historic CDLs. These geospatial products are called Predictive CDLs (PCDLs), and, in FY 2024, NASS statisticians utilized them for manual imputation and editing of farmer reports during the June Area Survey. The PCDLs were produced for CONUS and made available for internal use for the June Area Survey.

In FY 2024, geospatial decision-support data products were delivered for disaster inundation and wildfire assessments to estimate impacts on agriculture from the Kentucky and Tennessee tornadoes (December 2023), the Texas wildfires (February 2024), the midwestern floods (June 2024), Hurricane Debby (August 2024), and Hurricane Helene (September 2024). The products included tornado damage assessments; wildfire impact on crops, grasslands, and ranching infrastructure; and flooding over impacted crop and pasture areas.[14] NASS used this information to assess near-real-time storm inundation or wildfire impact over croplands and pasturelands, which it shared with the USDA and the public.

NASS utilized the MODIS NDVI and the NASA GIMMS GLAM application for modeling corn and soybean yield estimates covering the 16 largest corn-producing and 11 largest soybean-producing states. NASS operationally delivered updated yield estimates to the ASB as an independent indication for setting official August, September, and October yield estimates by state and county.

The web-based national vegetation condition geospatial portal VegScape continued to deliver timely crop condition vegetation indices based on MODIS daily, weekly, and biweekly products throughout the growing season.[15] VegScape showed crop condition, vegetation greenness, and drought anomaly assessments. Additionally, NASS continued to monitor the ongoing California drought, providing monthly growing-season CDL-based fallowed-land estimates for California water resource stakeholders.

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13 https://croplandcros.scinet.usda.gov

14 https://www.nass.usda.gov/Research_and_Science/Disaster-Analysis/

15 https://nassgeodata.gmu.edu/VegScape

Crop Condition and Soil Moisture Analytics (CropCASMA) continued to provide both volumetric and categorical topsoil and subsoil moisture conditions for crop land from the NASA SMAP mission.[16] CropCASMA delivers customized daily and weekly updates based on the NASS crop reporting period of Monday through Sunday. The Arkansas and California Regional Field Offices continue to incorporate CropCASMA percentages of soil moisture into their weekly Crop Progress and Condition Reports.

Research efforts continued on the NASA Advanced Information Systems Technology grant titled "Digital Twin Infrastructure Model for Agricultural Applications." The project's purpose is to develop a digital twin infrastructure by integrating land/hydrology process models, agricultural models, and Earth observation information to develop an agricultural productivity modeling system over CONUS. The predicted county-level yield will potentially provide complementary information to in-season NASS Crop Production reporting. The project team developed and tested a software module that loosely coupled NASA's Land Information System (LIS) with Decision Support System for Agrotechnology Transfer and Agricultural Policy/Environmental eXtender crop process models. Iowa model simulation has demonstrated notable geospatial improvement of crop yield prediction by introducing LIS soil moisture data.

Research efforts continued on the USDA National Institute of Food and Agriculture–funded project "DSFAS-AI: Developing an Integrated Deep Learning Modeling and Visualization Framework for County-Level Crop Yield Prediction in Support of USDA NASS Operation."[17] This project aims to produce weekly in-season crop yield predictions over CONUS at the county level by utilizing publicly available Earth observation datasets and state-of-the-art deep learning technologies.

NASS is deriving a first-ever 10-m resolution Hawaiian Cropland Data Layer (HCDL)[18] for 2023 and 2024 from gap-filled 10-day Sentinel-Landsat multi-sensor image composites. This National Institute of Food and Agriculture-funded project is called "AgriWatch: Innovating Agricultural Disaster Response with AI-Empowered Real-Time Monitoring."[19] NASS expects the official release of the HCDL products in spring 2025.

16 https://nassgeo.csiss.gmu.edu/CropCASMA/

17 https://www.nifa.usda.gov/grants/programs/data-science-food-agricultural-systems-dsfas, https://portal.nifa.usda.gov/web/crisprojectpages/1028199-dsfas-ai-developing-an-integrated-deep-learning-model-framework-for-county-level-crop-yield-prediction-in-support-of-usda-nass-operation.html, https://www.mdpi.com/2072-4292/15/18/4562.

18 https://ieeexplore.ieee.org/document/10660811

19 https://portal.nifa.usda.gov/web/crisprojectpages/1031678-agriwatch-innovating-agricultural-disaster-response-with-ai-empowered-real-time-monitoring.html

National Institute of Food and Agriculture

The National Institute of Food and Agriculture (NIFA) provides leadership and funding for programs that advance agriculture-related sciences. The agency invests in and supports initiatives that ensure the long-term viability of agriculture, including funding research, education, and extension initiatives that incorporate remote sensing, geospatial data, and satellite technology. With the focus on leadership and funding, several projects are illustrative of ways in which NIFA's portfolio articulates with aeronautics and space technologies. Examples are listed below.

NIFA grantee South Dakota State University[20] used new-generation satellite observations that make it possible to generate high temporal and high spatial time series data for near-real-time monitoring of crop progress and condition. The team developed a geospatial tool that provides near-real-time monitoring of weekly crop progress and conditions at a 30-m field scale based on land-surface phenology derived from the synthetic time series fused from polar-orbiting satellites (NASA's Landsat-8 and Sentinel-2) and geostationary (GOES-R) satellite observations. This tool significantly improved the temporal and spatial capability of monitoring crop growth and was delivered to USDA's NASS to integrate into its existing operational system, VegScape.

VegScape is a web-based geospatial application that delivers interactive vegetation indices so that users can explore, visualize, query, and disseminate current vegetative cover maps and data without the need for specialized expertise, software, or high-end computers. It also uses data from NASA's MODIS instrument on the Terra and Aqua satellites to provide data on the health of crops in the CONUS, which includes the NDVI of each field. The NDVI indicates how green the plants are, thus giving an indication of their health.

NIFA grantees who receive funding from the Specialty Crop Research Initiative utilize remote sensing, geospatial data, and satellite technology to improve disease detection and sampling protocols, as well as to minimize disease risk of mildew and botrytis in high-value vineyard crops by optimizing sampling and scouting practices. Another application in NIFA's grants portfolio is Integrated Invasive Pest Detection, which incorporates remote sensing, conventional ground surveys, and artificial intelligence (AI). These applications facilitate acquiring and processing big data at multiple spatial and temporal scales to advance invasive pest detection. A current four-year grant integrates satellites, unmanned aircraft systems (UAS, drones), and conventional ground surveys into a system for invasive pest detection, development of image analysis tools using AI for detecting invasive pests, and economic assessment of the developed integrated invasive pest survey system.[21] The economic, environmental, and social impacts of invasive species on agricultural production, native biota, property values, and

20 NIFA funded Proposal #2024-05462; $4,125,422.

21 NIFA funded Proposal #2020-06491, $400,484.

tourism were estimated to be approximately $120 billion annually in the United States, thus exhibiting the paramount importance of leveraging remote sensing, geospatial data, and satellite technology to protect our agricultural ecosystems.

Broadly, NIFA's funding programs provide support for incorporating multiple environmental data at diverse spatial scales. The deployment of new sensors and platforms holds the potential to transform the use of data in agricultural operations. Numerous grants support developing methods for adapting data across platforms, such as translating data collected from satellites to UAS. This approach allowed a grantee to develop an agricultural suitability model using UAS and satellite data under current and future climate conditions. The grantee made use of satellite, UAS data, and machine-learning algorithms to identify agricultural suitability for three specialty crops (grapes, strawberries, and citrus production) in California, thus comparing current and future climate conditions.[22]

Natural Resources Conservation Service

Aerial Imagery

The Natural Resources Conservation Service (NRCS) helps America's farmers, ranchers, and forest landowners conserve the Nation's soil, water, air, and other natural resources. To fulfill this mission, NRCS acquires, develops, interprets, analyzes, and delivers natural-resource information to enable knowledge-based natural-resource planning and decision making at all landscape levels. Various types of geospatial systems, data, and information are crucial to the successful delivery of NRCS services. Aerial imagery, elevation data, and global positioning system data are essential geospatial elements integrated into NRCS program applications, service centers, state offices, and national centers. Today, NRCS offices use geospatial data daily to support conservation programs. The NRCS coordinates acquisitions of aerial imagery and digital elevation data with other federal and state agencies through interagency committees like the National Digital Orthoimagery Program and the USGS 3D Elevation Program. Participation in these programs assists NRCS in maximizing geospatial investments and avoiding duplication of acquisitions for aerial imagery and digital elevation datasets.

Satellite Imagery

NRCS has geospatial imagery requirements for all states and territories, including Alaska, Puerto Rico, the U.S. Virgin Islands, the Hawaiian Islands, Guam, the Commonwealth of the Northern Mariana Islands, American Samoa, and all Federated States of Micronesia and the Marshall Islands. NRCS requires 60-centimeter (cm) or higher resolution imagery for

22 NIFA funded Proposal #2021-10179, $299,911.

most agency programs. Acquisition of imagery in non-CONUS areas remains challenging because of remote locations and difficult weather conditions. NRCS uses commercial high-resolution satellite imagery from Maxar for such areas, as well as lands with restricted airspace. In FY 2024, NRCS acquired high-resolution imagery of the Hawaiian Islands (including the northwestern islands), Guam, the Commonwealth of the Northern Mariana Islands, American Samoa, the Federated States of Micronesia, the Marshall Islands, and Palmyra Atoll.

NAIP

NAIP is a high-resolution imagery program that typically collects data during summer months while leaves remain present. This dataset is the primary base map used for the creation of geospatial data used in USDA field offices. NRCS, the USFS, the USGS-DOI, and FSA (the NAIP leader) have successfully funded and supported NAIP since its 2003 inception. NRCS mission delivery extensively uses NAIP imagery, which remains available for most of its offices in the continental United States.[23]

National Resources Inventory

The National Resources Inventory (NRI) program collects and produces scientifically credible information on the status, condition, and trends of land, soil, water, and related resources on the Nation's non-federal lands in support of efforts to protect, restore, and enhance the lands and waters of the United States. The Rural Development Act of 1972 (P.L. 92-419) mandated the NRI to conduct a "land inventory reflecting soil, water, and related resource conditions." It requires assessments of resource quantity and quality, as well as change and trends, thus allowing for regular resource appraisals on the effectiveness of soil and water conservation practices; irrigation techniques; and farming technologies, techniques, and practices. NRCS executed a contract to acquire high-resolution digital aerial photography (four-inch ground-resolving distance) for more than 71,000 NRI sites in the contiguous United States, Puerto Rico, the U.S. Virgin Islands, Alaska, and Hawaii. The digital imagery is interpreted at one of NRCS's three Remote Sensing Labs. The resulting data are sent to the Center for Survey Statistics and Methodology at Iowa State University for compilation and statistical estimation.

Beyond acquisition of fixed-wing imagery in Alaska, high-resolution satellite imagery from the Maxar constellation is used for data collection in areas difficult to fly aircraft for the collection of imagery.

23 Visit https://naip-usdaonline.hub.arcgis.com/ and the NAIP program section marked FSA-NAIP for more information.

Stewardship Lands

NRCS offers easement programs (Stewardship Lands) to landowners who want to maintain or enhance their land in a way that is beneficial to agriculture and/or the environment. All NRCS easement programs are voluntary. As of FY 2024, NRCS has acquired approximately 24,800 wildlife and agricultural conservation easements totaling nearly 5.7 million acres. The use of high-resolution aerial photography remains a major component of conservation easement monitoring for both on-site monitoring and off-site "remote" monitoring events. NRCS acquires 15-cm, high-resolution direct digital imagery for conservation easements.

Elevation

NRCS requires high-quality elevation data and derivative datasets nationwide. The agency maintains a national strategy to acquire, integrate, and deliver data to meet its geospatial needs. High-quality digital elevation data and derivatives help NRCS employees work more effectively and efficiently to assist customers. NRCS participates in the USGS 3DEP to acquire high-quality 3D elevation data through remote sensing. The map shows areas where NRCS and 3DEP partners have completed or are working on lidar topographic acquisition projects in FY 2024.

By the end of FY 2024, 3DEP and its partners had increased lidar coverage to more than 95 percent of the continental United States and Hawaii. Interferometric Synthetic Aperture Radar coverage for Alaska stands 100 percent complete. NRCS contracted $30.8 million of the $87.6 million total 3DEP investments for FY 2024 awards. Based on the approved national strategy, NRCS obligated $28.2 million in FY 2024 on an Interagency Agreement with the USGS for acquisitions in FY 2025 and FY 2026.

Use of Positioning, Navigation, and Timing Signals from Space

Space-based Positioning, Navigation, and Timing (PNT) signals from the U.S. Global Positioning System (GPS) are essential to all NRCS geospatial activities. The NRCS utilizes GPS signals from space as well as the Federal Aviation Administration's Wide Area Augmentation Service signals to enhance delineation of conservation issues on the ground daily in every state of the United States as well as in the Caribbean and Pacific basins.

Continuously Operating Reference States are organized into ground-based networks that push cellular Real Time Kinematic corrections to GPS signals from space to equipment utilized by NRCS engineers, conservationists, farm and ranch operators, and vendors that support the agriculture industry. NRCS vendors and partners for aerial imagery, small unmanned aerial systems (sUAS), and lidar elevation data acquisition rely on GPS PNT for positioning of aircraft, as well as geolocation of imagery and lidar data that support conservation planning. The use of GPS PNT services continues to support the NRCS mission of "Helping People Help the Land."

Risk Management Agency

The USDA's Risk Management Agency (RMA), created in 1996, serves America's agricultural producers through effective, market-based risk management tools to strengthen the economic stability of agricultural producers and rural communities. RMA manages the Federal Crop Insurance Corporation to provide innovative crop insurance products to America's farmers and ranchers.[24] Geospatial systems and data, including space-based remote sensing systems, have played a fundamental role in RMA's program delivery, particularly in aspects of actuarial rating (sub-county rating), compliance, and program oversight.

Through crop insurance, RMA aided farmers and ranchers impacted by weather and price events often caused by natural disasters. In FY 2024, RMA used moderate-resolution remote-sensing data from Landsat, Sentinel-2, MODIS, and other systems, as well as high-resolution aerial photography and limited commercial satellite imagery. Satellite, aerial photography, elevation data, and GPS information were essential geospatial data integrated into RMA program applications. RMA offices used geospatial data daily to support crop insurance.

Many of these imagery products were available to RMA because of the USDA's interagency coordination. RMA incorporated geospatial data into decision-support products that were furnished to the USDA and agency leadership, thus providing situational awareness. The products support impacted area program estimates, precipitation excess or deficits, and natural-disaster extents for flood events, hurricanes, and wildfires.

RMA staff were active participants in remote-sensing activities, such as the Remote Sensing Coordination Committee, and the USGEO Earth Observation Assessment. As an operational user of remote-sensing products, RMA's participation in these working groups provided insight to scientists developing applications that benefit crop insurance delivery and oversight, as well as benefiting farmers and ranchers across America.

In addition, RMA partnered with scientists and researchers to develop products to meet agency business needs on integrating satellite imagery for enhancing program integrity models.

24 https://www.rma.usda.gov/Federal-Crop-Insurance-Corporation

National Science Foundation

NSF

Established by the National Science Foundation Act of 1950 (P.L. 81-507), NSF is an independent federal agency charged with the mission "to promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense." NSF is unique in carrying out its mission by supporting research across all fields of science, technology, engineering, and mathematics (STEM), and at all levels and settings of STEM education. NSF investments contribute significantly to the economic and national security interests of the Nation, and the development of a future-focused science and engineering workforce.

NSF contributed to the Nation's aeronautics and space activities through awards, cooperative agreements, and interagency agreements that enable, for example, the monitoring of space weather, atmosphere, ionosphere, and magnetosphere; overseeing university-led microsatellite operations; supporting the Nation's long-duration balloon program; conducting planetary defense; and mitigating impacts of satellite constellations upon scientific advancement. NSF investments advanced foundational research for aerospace, communications, electronics, manufacturing, robotics, and vehicle technologies. Ground-based observing facilities continued to survey and improve our understanding of diverse space environments, as well as providing synergistic observations that have motivated or enhanced data collection from the Nation's fleet of space-borne astrophysics and heliophysics observatories, in addition to the formulation and design of new space mission concepts.

Division of Atmospheric and Geospace Sciences

The Division of Atmospheric and Geospace Sciences (AGS) within the NSF Directorate for Geosciences continued to fund research and research infrastructure programs in space science and space weather in FY 2024. AGS invested in basic and use-inspired research through the

Space Weather Research, Solar-Terrestrial Research, Aeronomy, and Magnetospheric Physics programs and in research infrastructure through the Geospace Facilities program.

AGS funding supported several hundred faculty members and students at U.S. universities, research institutes, and small companies and helped grow the current and future space workforce. AGS provided continued funding for seven Faculty Development in Space Sciences (FDSS) awards that support the creation of new tenure-track faculty positions to ensure the health and vitality of solar and space sciences within U.S. universities. Under a revised version of the solicitation, in FY 2024, AGS made an additional six FDSS awards of $1.5 million each, including to two emerging research institutions.

AGS continued to support seven projects awarded through the solicitation issued in FY 2022 titled "Grand Challenges in Integrative Geospace Sciences: Advancing National Space Weather Expertise and Research Toward Societal Resilience" at 17 U.S. universities, research institutes, and women-led private companies.

For the total solar eclipse in April 2024, NSF, NASA, and NOAA collaborated to present a wide variety of outreach to share the excitement of solar science with the U.S. public. AGS also supported unique research possible only during total solar eclipses, including studies of the infrared emissions of the Sun's corona using instruments on the NSF/National Center for Atmospheric Research (NCAR) Gulfstream V aircraft and low-frequency radio observations to discover day-night-day changes in the ionosphere on the scale of a few minutes. AGS provided funds to U.S. scientists to engage with the amateur radio community and the broader public across the Nation on eclipse research.

AGS continued to support research infrastructure and facilities that are the foundation of NSF-supported geospace research. These projects play a crucial role in space research and are also great opportunities to train our future experimentalists. They include advanced radar systems to study the ionosphere and magnetosphere, such as Incoherent Scattering Radars (ISRs) and the Super Dual Auroral Radar Network, ground-based optical and radio instruments to study the upper atmosphere, and ground-based solar telescopes and instruments. Four ISR facilities at Poker Flat, Alaska; at Resolute Bay, Canada; at Millstone Hill Observatory, Massachusetts; and near Jicamarca, Peru, are respectively in the auroral zone, polar cap, subauroral zone, and equatorial region, ideally situated to observe the properties of the ionosphere in these distinct regions.

Another funded project, the Active Magnetosphere and Planetary Electrodynamics Response Experiment, provided global and continuous measurements of the Birkeland currents using magnetic field data from the commercial satellites of the Iridium constellation. AGS also funded the Subauroral Geophysical Observatory near Gakona, Alaska, anchored by the High-Altitude Auroral Research Program facility, an ionospheric heating array used for active space plasma experiments as well as the Extended Owens Valley Solar Array near Big Pine,

California, an interferometer radio array for mapping solar magnetic fields. AGS continued the funding of three large-scale magnetometer networks: the Magnetometer Array for Cusp and Cleft Studies, the Surface Magnetic Assessment in Real Time Network, and the Conjugate Experiment to Investigate Sources of High-Latitude Magnetic Perturbations (a collaboration with the United Kingdom). The combined magnetometer arrays covered large areas in both hemispheres to monitor global magnetic perturbations.

In addition, AGS supported the SuperMAG collaboration in collecting and disseminating vital magnetic measurements to researchers and space weather operators across the country. AGS also ran a second competition in the Distributed Array of Small Instruments (DASI) program that supported the development, deployment, and operation of instruments in distributed arrays to conduct high-spatial- and -temporal-resolution measurements for solar and space physics research. The selected DASI projects range from the development of instrument platforms for remote and harsh environments to student-led development of inexpensive radio receivers suitable for scientific analysis.

AGS continued its support of CubeSat missions that are in stages of advanced development. These include the IMpulsive Phase Rapid Energetic Solar Spectrometer experiment to study hard x-ray emission from solar flares; the Climatology of Anthropogenic and Natural Very Low Frequency (VLF) wave Activity in Space, which will measure VLF wave energy that originates from lightning and ground-based transmitters and propagates to the outer reaches of Earth's magnetic field; the Virtual Super-resolution Optics with Reconfigurable Swarms mission consisting of two satellites that together form an ultraviolet telescope for observing the Sun; and the Space Weather Atmospheric Reconfigurable Multiscale Experiment project that is a pilot to create constellations of small satellites to monitor ionospheric disturbances.

The High-Altitude Observatory (HAO) at NSF's National Center for Atmospheric Research (NCAR), funded by AGS, continued research to better understand and quantify the impact of solar variability on Earth's atmosphere across temporal scales. HAO continued to support Mauna Loa Solar Observatory's instrumentation and its related data-sharing website. HAO also made progress in preparation for the Coronal Solar Magnetism Observatory (COSMO), a proposed synoptic facility to measure magnetic fields and plasma properties in the large-scale solar atmosphere. HAO conducted the COSMO Site and Design Advancement project, site surveys with remote-observing instrumentation to determine scientifically optimal locations for COSMO. HAO also conducted experiments and observations for the total solar eclipse in April 2024 to study the solar corona, including using telescopes in the path of totality in Texas and supporting observations for a partial eclipse at Mauna Loa Solar Observatory in Hawaii. NCAR also played supporting roles on airborne projects that flew through totality.

AGS continued to support the Data Analysis and Archive Center for the six-satellite Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC).

COSMIC was launched in 2006 and fully decommissioned in 2020, producing close to 7 million Global Navigation Satellite System (GNSS) radio occultation (RO) neutral atmosphere soundings and over 4.6 million ionospheric soundings over its lifetime. The COSMIC team continued to conduct a reprocessing campaign to create whole-mission datasets with consistent and state-of-the-art processing for all the observations generated over the mission lifetime. The team also processed data for several other RO satellite missions, including South Korea's KOMPSAT-5 and Spain's Paz. NSF also supported processing for the follow-on COSMIC-2 mission with high-gain RO receivers flying over the tropics, producing over 5,000 occultations per day along with path-integrated electron content above the satellites. The satellites also include ion velocity meters as secondary payloads. The work included the development of new ionospheric products, characterization of ionospheric variability and irregularities, and new retrieval techniques. The mission is operated through a collaboration between NOAA, the U.S. Air Force, and the Taiwan Space Agency (TASA). Currently, the COSMIC team is working on the Radio Occultation Modeling Experiment (ROMEX), an activity of the World Meteorological Organization International Radio Occultation Working Group, which is conducting experiments to determine the value of very large volumes of RO observations. The COSMIC group is jointly supported by NSF and NASA.

AGS continued other interagency collaborations, such as the joint sponsorship of the Community Coordinated Modeling Center located at NASA's Goddard Space Flight Center. AGS and Division of Astronomical Sciences (AST) staff continued to represent NSF on the Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee within the NSTC Committee on Homeland and National Security and implement the goals and objectives identified in the National Space Weather Strategy and Action Plan.

Division of Astronomical Sciences

NSF continued to serve as the lead federal agency for the support of ground-based astronomy and space science. NSF sponsored a broad base of observational, theoretical, and laboratory research aimed at understanding the states of matter and physical processes in the universe. Areas of research covered nearby stars and planets, including our Sun and its planets, as well as Earth's atmosphere and its space environment, all the way to the most distant reaches of the universe and the earliest moments of its existence.

The Division of Astronomical Sciences, within the Directorate for Mathematical and Physical Sciences, supported research in all areas of astronomy and astrophysics, as well as related multidisciplinary studies. Because of the scale of modern astronomical research, the Division engaged in interagency and international collaborations. Areas of emphasis and the priorities of specific programs were guided by community recommendations, which have been

developed and transmitted by National Research Council decadal surveys and by federal advisory committees.

AST supported forefront merit-reviewed research in observational, theoretical, and laboratory astronomy to help ensure the scientific excellence of the U.S. astronomical community. The Division encouraged national understanding of the astronomical sciences by a broad population of scientists, policy makers, educators, and the public at large. While AST's major research awards program is the Astronomy and Astrophysics Grants solicitation, AST participates in 65 solicitations, supporting all aspects of astronomical research, education, engagement, and spectrum management.

AST contributed to funding opportunities that helped develop the future generation of science leaders, including the Partnerships in Astronomy and Astrophysics Research and Education, Research Experiences for Undergraduates, the Graduate Research Fellowship Program, Astronomy and Astrophysics Postdoctoral Fellowships, Launching Early-Career Academic Pathways, and the Faculty Early Career Development Program.

An important component of AST's effort is supporting technology development and instrumentation. AST awards develop technologies, techniques, and ground-breaking research infrastructure for application in astronomy across the electromagnetic spectrum. AST solicits proposals for research projects with a range of scope, including Advanced Technologies and Instrumentation, the Major Research Instrumentation Program, and Mid-scale Research Infrastructure.

Awarded programs delivered, and are developing, forefront capabilities and new facilities in Antarctica, Chile, and the United States for U.S. scientists. New technology and infrastructure to detect and characterize exoplanets generated novel approaches to hyper-spectral imaging (integral-field and speckle imaging); high-contrast (coronagraphic) imaging; and tunable, blue/UV-capable laser-frequency combs for ultra-high-precision radial velocities.

Other advances are being made in reactive ion-plasma etched grating fabrication for application to large, high-efficiency spectroscopic instruments; sub-Kelvin cryogenic testing of photonic and quantum information technologies for far-infrared on-chip spectroscopy via advances in semiconductor fabrication processes; and cryogenic telescopes using unique optical designs. These efforts deepen interactions between U.S. industry and academic U.S. researchers, enabling cutting-edge research capabilities on large telescopes.

The next generation of ground-based telescopes and detectors to map the cosmic microwave background radiation and its polarization at millimeter wavelengths are opening a new window on the very early universe. Mitigation of terrestrial and satellite foreground contamination at optical and radio wavelengths via machine learning and artificial intelligence systems has led to advanced software systems that also serve to harvest multi-messenger signals targeting kilonovae (from gravitational wave events), fast radio bursts, and neutral hydrogen maps at

the epoch of reionization. NSF-supported community access to CHARA, the world's premier optical interferometer, continues with enhanced capabilities.

Through merit review, AST provided community access to world-class, ground-based research facilities. The national astronomical facilities are operated by the NSF National Radio Astronomy Observatory (NRAO), the NSF National Optical-Infrared Astronomy Research Laboratory (NOIRLab), and the NSF National Solar Observatory (NSO). This network of telescopes delivered data that directly tested and challenged our understanding of the space environment while also working in partnership with the Nation's space-based astrophysical observatories to deliver a more complete picture of the universe and our place in it.

NSF's Daniel K. Inouye Solar Telescope (Inouye) continued its operations commissioning phase throughout FY 2024. One of Inouye's main objectives is to study solar magnetic fields at the smallest scales to better explain their behavior. Inouye scientists solidified the telescope's prestige as the world's leading flagship of ground-based solar observatories with a press release this year on the first-ever high-resolution magnetic field maps of the Sun's corona. These maps enhance our understanding of the Sun's atmosphere and how its changing conditions lead to impacts on Earth's technology-dependent society.

Staff from AST and from AGS participated in the National Science and Technology Council's (NSTC) SWORM Working Group under the Space Weather, Security, and Hazards subcommittee. SWORM began carrying out the new implementation plan, approved in late 2023. NSO's Global Oscillations Network Group (GONG), supported by NSF and NOAA, continued their support for operational space weather forecasting. GONG end-of-life is expected in the early 2030s, and SWORM drafted a continuity-of-observations document. Concern about a possible gap in critical data was an ongoing topic within SWORM, with the second next-generation GONG facility proposal under review at NSF.

AST, in partnership with Chile, the European Union, Canada, Japan, the Republic of Korea, and Taiwan, continued science operations of the Atacama Large Millimeter/Submillimeter Array (ALMA), an interferometric array located near San Pedro de Atacama, Chile. ALMA continued to receive a record number of observing proposals and/or requests for time. Capabilities offered to the community included simultaneous observations with arrays of 12- and 7-meter-diameter antennas, observations with antenna separations of up to 16 kilometers, and observations at electromagnetic frequencies of up to 900 gigahertz. ALMA's unique capabilities allowed discoveries in molecular chemistry across the topics of planets and planet formation, protostellar and debris disks, low- and high-mass star formation, stellar evolution, normal galaxies, galaxy centers, and galaxy formation and evolution. Science highlights were the observations of planetary formation distinguishing between two current models of formation, the detection of gas around a supermassive black hole providing details into how these objects grow, and observations showing how young binary stars transfer gas to each other and

the effects that transfer has on the stellar properties. ALMA continued to make complementary observations with the James Webb Space Telescope.

The Very Large Array (VLA), located in New Mexico, continued to offer capabilities to the radio astronomy community with its 28 25-meter-diameter antennas operating in the frequency range 74 megahertz to 50 gigahertz, and with array sizes between 600 meters and 21 kilometers. The VLA investigated a wide range of astronomical objects: radio galaxies, quasars, pulsars, supernova remnants, gamma-ray bursts, stars, the Sun and planets, astrophysical masers, black holes, and hydrogen gas in both the Milky Way galaxy and other galaxies. The ongoing VLA Sky Survey has provided critical support to future observations by the Rubin Observatory and other multi-messenger astronomy projects. Highlights were the discovery of a source of power for the enigmatic fast radio burst objects, new observations of pulsars allowing stronger tests of relativity, and details about magnetars that will assist in the understanding of these extreme objects.

The Very Long Baseline Array (VLBA) consists of ten 25-meter-diameter antennas spread across the continental United States, the U.S. Virgin Islands, and Hawaii. VLBA operates between 0.3 gigahertz and 96 gigahertz and makes ultra-high-resolution observations of astronomical objects. VLBA observations provided accurate distance measurements of distant sources, as well as those in our solar system, and highly accurate measurements of Earth's location in the universe. To determine their exact locations on Earth to within fractions of an inch, the VLBA telescopes observe very distant quasars. With the support of the U.S. Naval Observatory, the VLBA telescopes then act like pins tacked to Earth's crust; any movement of the crust shows up as a change in distances between the telescopes. With the exact ground positioning of the VLBA, scientists helped GPS services improve their accuracy and monitor movements of Earth's crust and learn how they reflect wind patterns. Furthermore, radar facilities beamed radio pulses onto nearby asteroids. The VLBA's telescopes collected the beams as they returned to Earth. The precise timing of reflections received by the VLBA telescopes revealed asteroid spin rates and directions and allowed the prediction of changes of orbit. With the VLBA's timing accuracy, astronomers kept an eye on potentially devastating "killer" asteroids and monitored asteroids targeted for possible future human exploration.

NSF's Green Bank Observatory (GBO) is a federally funded research and development center located in Green Bank, West Virginia. The main instrument at GBO is the 100-meter Green Bank Telescope (GBT), the world's largest fully steerable single-dish radio telescope, operating at frequencies from 0.2 gigahertz to 116 gigahertz. The GBT's large sky coverage, very high sensitivity, wide wavelength coverage, and extensive suite of instruments enabled work in areas of astrophysics from pulsars and long-wavelength gravitational waves to interstellar chemistry and physics. The GBT was a critical element in very-long-baseline interferometry

and served as a bistatic radar receiver for rapid and sensitive imaging of near-Earth objects and asteroids.

Construction of the Vera C. Rubin Observatory continued in FY 2024. The project has been making significant progress along the post-COVID re-baselined plan, with completion now projected late in 2025. The Rubin Observatory will image the entire accessible sky in a multicolor survey that will populate a science-ready database of unprecedented size, enabling breakthrough research in dark energy and dark matter, in galactic structure, and in solar system astronomy. The relentless, repeated observations will also revolutionize the study of transient events. Rubin will also support planetary defense. Assuming that other existing near-Earth object (NEO) efforts continue, by the end of Rubin Observatory's ten-year prime mission, the catalogue for objects larger than 140 meters across should be 75 percent complete for NEOs (80 percent for potentially hazardous asteroids).

Early in 2024, the primary mirror was successfully coated and installed in its support cell. In April 2024, the main telescope mount assembly completed testing, and it is ready for operations. In May 2024, the Legacy Survey of Space and Time (LSST) Camera arrived at the summit in Chile after a long journey from the construction site at SLAC National Accelerator Laboratory. The camera is currently undergoing re-verification and testing. The secondary mirror was installed in its support cell and is ready to be mounted on the telescope mount. Development of the data management system has continued apace. NSF's federal partner, DOE, is funding the camera and maintenance of the U.S. data facility in a project led by the SLAC National Accelerator Laboratory. NSF and DOE support installation and commissioning together. NSF is funding the telescope, building, site, network and software pipelining, and data management systems that allow specialized access separately for research and for education and public outreach. Operations support has been requested from both agencies and will be augmented by negotiated non-federal and international in-kind contributions.

AST continued to fund the operations of a network of optical and infrared observatories situated in Hawaii, Arizona, and Chile, providing competitive, world-class open science opportunities to the U.S. astronomy community. Data from these facilities continued to broaden and deepen our understanding of space environments. For example, in FY 2024, community teams determined that differences in binary stars' composition can originate from chemical variations in the cloud of stellar material from which they formed; discovered merging supermassive black holes during cosmic dawn, providing an unprecedented look at the nature of dark energy and its effect on the universe's large-scale structure; and placed the strongest constraints on the expansion of the universe ever obtained using supernovae and found hints that the universe's dark energy density may vary with time.

AST continued to host NSF's Electromagnetic Spectrum Management Unit (ESMU), allowing NSF to serve as the primary U.S. Government agency responsible for protecting

and enhancing electromagnetic spectrum access for ground-based astronomy and working more broadly to enable the spectrum access needed for research and development endeavors in other disciplines. As challenges in the field and demand for spectrum management on the part of government, private-sector, and scientific applications have increased, ESMU has engaged in domestic and international spectrum management on a daily basis, including interfacing with regulators in advisory committees, responding to legislative and executive initiatives such as the National Spectrum Strategy, leading the U.S. delegation to the International Telecommunication Union–Radiocommunication Sector (ITU-R) Working Party 7D for Radio Astronomy and engaging at all levels in ITU-R efforts (up to and including treaty conferences), working directly with other agencies, and coordinating frequency assignments domestically with ground-based astronomy sites. The ESMU also chairs an NSF-wide Electromagnetic Spectrum Management Coordination group with representatives from all NSF Directorates. The ESMU provides spectrum management support and advice for the entire NSF, as well as the scientific community.

The cross-directorate Spectrum and Wireless Innovation enabled by Future Technologies (SWIFT) program, now in its fourth year, invested significantly in research on effective spectrum utilization and coexistence techniques, and during the past year has focused on satellite coexistence. The multi-disciplinary Spectrum Innovation Initiative (SII) is also in its fifth year, having begun in FY 2020 to promote dynamic and agile spectrum utilization while ensuring innovation and security for all users. SII includes the National Radio Dynamic Zones program to advance dynamic spectrum sharing, building toward a permanent national facility for innovative systems that use or manage spectrum. SII's National Center thrust (SII-Center) funded the first national center for wireless spectrum research (SpectrumX), which began operations in FY 2022 and has rapidly established itself as a "household name" in spectrum matters, catching the attention of and working with regulators, federal agencies, and private-sector entities on research and educational issues. The Integrative Activities part of SII promoted increased and more effective use of the spectrum for passive and active applications, especially of a cross-disciplinary nature. Finally, the Workforce Development thrust encouraged developing a skilled workforce through education and training programs and has during the past year made significant investments in these areas. NSF ESMU also leads cross-government efforts that align with these objectives in accordance with the 2023 National Spectrum Strategy, in which NSF was tasked with developing a National Spectrum R&D Plan and National Spectrum Workforce Plan.

NSF ESMU is also engaged in efforts in the optical domain focused on coexistence issues between ground-based optical/infrared astronomy and satellite constellations, including funding work monitoring and predicting optical reflections from satellites through the SWIFT-SAT program. NSF NOIRLab cohosts the Centre for the Protection of the Dark and

Quiet Sky from Satellite Constellation Interference of the International Astronomical Union (IAU CPS). The CPS aims to mitigate the impact of satellite constellations on ground-based astronomical observations, including those collected by amateur astronomers and the general public, and raises awareness of these issues internationally as Technical Secretariat for the Group of Friends of the Dark and Quiet Sky for Science and Society at the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS).

Division of Physics

NSF's Division of Physics (PHY) operated the Laser Interferometric Gravitational-Wave Observatory (LIGO), which started its fourth observational run at the end of May 2023. This run includes approximately half of the planned instrument upgrade that will lead to an increase in detection sensitivity of about 70 percent. Since the start of the run, LIGO has detected 143 events, more than the total observed in the first three runs combined.

Complementing LIGO, and in partnership with AST, PHY supported the North American Nanohertz Observatory for Gravitational Waves (NANOGrav), which continued to monitor low-frequency gravitational waves permeating the universe. These waves carry a plethora of information about the structure of galaxies and the mergers of the massive black holes at their centers. The team worked within a large international collaboration to refine detections and provide new insights into the structure of galaxies and the mergers of the massive black holes at their centers.

Office of Polar Programs

NSF's Office of Polar Programs supports NASA's Long Duration Balloon (LDB) Program at the U.S. Antarctic Program's McMurdo Station, providing logistical support for the LDB astrophysical and space science payloads assembly and final testing, as well as assisting with the balloon launches and follow-up payload recovery after a flight is terminated in various regions of the Antarctic continent. The 2023/2024 austral summer season had a successful launch and a 57-day flight operation of the NASA Astrophysics Explorer Mission of Opportunity payload instrument Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory (GUSTO). This is a new NASA balloon flight duration record.

Observations continue at the U.S. Amundsen-Scott South Pole Station with the 10-meter off-axis radio South Pole Telescope (SPT) and a battery of small-aperture telescopes called the Background Imaging of Cosmic Extragalactic Polarization (BICEP) Array. The measurements that SPT and BICEP telescopes have produced on primordial gravitational waves continue to

improve, probing models of post–Big Bang Inflation that operate near grand-unified-theory energy scales. Recent results from the SPT and BICEP collaborations included deep multi-frequency sky maps of the *B*-mode polarization of the Cosmic Microwave Background (CMB) radiation that address gravitational lensing and foregrounds to unprecedented precision. In 2024, SPT astronomers demonstrated improved constraints on primordial gravitational waves with delensing, as well as delivered new cosmological constraints from the Dark Energy Survey cluster abundances and SPT multi-wavelength data. Both the SPT and BICEP projects contributed to the sample variance of the gravitational lensing *B*-modes by reducing the cross-correlating against a lensing *B*-mode template.

The IceCube Neutrino Observatory (ICNO), jointly operated at the South Pole by NSF's Office of Polar Programs and Division of Physics, continues collecting observed cosmogenic neutrinos—tiny, ghostlike astronomical messengers—with energies ranging from 100 gigaelectronvolts to tens of petaelectronvolts. The IceCube detector provides us with an entirely new view of our own Milky Way galaxy in "neutrino lights" and characterizes the astrophysical diffuse background neutrino flux using tracked events in the IceCube Neutrino Observatory database. The IceCube Collaboration is an international group of over 450 scientists from 58 institutions in 14 countries. Intriguingly, unlike electromagnetic light of any wavelength, in neutrinos, the universe outshines the nearby sources in our own galaxy.

Directorate for Technology, Innovation and Partnerships

NSF's Directorate for Technology, Innovation and Partnerships (TIP) invests in technologies that can enhance the commercial use of space through a range of programs, including the NSF Small Business Innovation Research (SBIR)/Small Business Technology Transfer (STTR), NSF Innovation Corps (NSF I-Corps™), NSF Regional Innovation Engines (NSF Engines), and NSF Pathways to Enable Open-Source Ecosystems (POSE) programs, among others. The TIP portfolio intersects with the key technology focus areas identified in the CHIPS and Science Act of 2022, as well as the list of Critical and Emerging Technologies recently updated by the White House. NSF's TIP Directorate has played a growing role in funding space start-ups in the United States. Below are examples of individual projects or collections of projects advancing specific and aligned technology thrusts.

Radiation-tolerant computers for space applications: NSF-funded I-Corps teams are investigating ways to shield electronic components from radiation in working environments. This technology ensures that even a single charged particle does not cause electronic noise and signal spikes in digital circuits, resulting in inaccurate or unintelligible data.

Air-breathing small engines for very low Earth orbits: NSF-funded technology from this program is based on the development of an air-breathing plasma thruster that operates in very low Earth orbits. This engine utilizes air as a propellant, eliminating fuel tanks to reduce launch weight and costs with zero carbon emissions, compact design, and simplified manufacturing. Unlike other air-breathing technologies, the self-neutralizing, air-breathing plasma thruster integrates a scramjet-type inlet, actively generating air plasma without compression, thus eliminating the need for a bulky collimator.

Space satellite applications: An NSF-funded I-Corps team is developing an electrostatic actuation technology that enables dynamic reshaping of membrane reflectors for satellite applications on orbit. The technology expands flexibility in commercial satellite communications from geostationary orbit to different geographic areas by allowing the repurposing of existing satellites. The ability to reshape a reflector on orbit allows large reflectors with unprecedented surface precision to be used for innovative atmospheric radar instruments and improved weather monitoring from space, allowing for longer-range and more precise forecasting of tropical cyclones and protecting coastal communities from storms.

Small satellite vehicles: An I-Corps project team is developing an entirely solid-state, flow-controlled, electric thruster system for use in CubeSats. The core technology is a solid-state flow-controlled device developed to offer the same level of fluid control and precision as is available on much larger, pressure-driven mechanical propulsion systems currently used on many, much larger commercial satellites. This technology offers the ability to repeatably flow and stop flow of liquid propellants to electrospray thrusters in a vacuum environment without the need for much larger pressure systems or mechanical valves, minimizing the impact of previous scaling limitations for satellites.

Prequalification of safety software for space: A POSE-funded project team is harnessing the power of open-source development for the safety qualification of space vehicles. Prequalification is the process of preparing hardware, software, and documentation that are shared and reused by multiple systems that go through safety qualification. A successful example of a prequalification process involves the open-source Real-Time Executive for Multiprocessor Systems (RTEMS), a real-time operating system used in satellites and space probes. The prequalification reduces the cost to develop and qualify new spacecraft that use the RTEMS software. These systems are vital to critical infrastructure and national security.

Novel semiconductor manufacturing: SBIR project teams have taken advantage of new opportunities afforded by unique microgravity conditions. The space environment offers a

wealth of resources, and microgravity presents novel environmental conditions conducive to pioneering technologies and yielding unmatched quality and efficiency in semiconductor production. The absence of buoyancy, sedimentation, convection, and hydrostatic pressure, as well as the elimination of containers or substrates in microgravity, foster distinct differences in crystal growth, fluid dynamics, heat transfer, and surface chemistry. Early leadership and forging ahead on designing and manufacturing semiconductors for space applications are critical to U.S. technology leadership and national security.

Propulsion systems and mobility: This SBIR-funded project may revolutionize the space industry by reducing reliance on traditional propellants. Propulsion systems are critical to satellite subsystems and mobility, and the proposed technology will lower space mission costs, increase mission flexibility, and extend spacecraft lifetimes. The plan will enable zero-emission impulse for satellites and facilitate efficient satellite reentry into the atmosphere, mitigating the problem of space debris. The project focused on scaling, strengthening the metamaterial for a more space-like environment, and demonstrating sufficient thrust to move a small satellite.

Bioengineering and rapid drug discovery: An SBIR-funded project team fosters the United States' economic competitiveness while advancing the health and welfare of the American public. Drug discovery is currently costly and time-intensive; however, microgravity environments are being evaluated because they can increase the rate of crystal growth while reducing defect density in the resulting crystal structures that can impact cell and plant growth. This new environment may provide an experimental platform that offers rapid and inexpensive development of post-translational protein-editing therapeutics, creating a pathway for U.S. leadership in future drug discovery.

Space habitat infrastructure: An SBIR-funded project team intends to deploy a commercial space platform in cislunar and deep space to provide fast connectivity, navigation, and positioning to space users. This cislunar network will include nodes in low Earth orbit, geosynchronous orbit, and lunar orbit to create a secure and covert gigabit network for scientific, commercial, and military applications. This project will develop a revolutionary spacecraft that will be a small, yet nimble, spacecraft that uses lasers, a novel architecture, and machine learning software to provide high-data-rate omnidirectional coverage of its surroundings. The project will deploy clusters of these satellites as network nodes. It is envisioned that space users can use these small interplanetary satellites (and their network) for gigabit connectivity and accurate navigation and positioning in cislunar and deep space. Successful deployment supports U.S. leadership in the critical infrastructure required to sustain life and work beyond our planet.

Next-generation wireless communication infrastructure: An SBIR-funded team supports the development of a revolutionary wireless communications technology based on physical layer rateless codes, which could provide high throughput and coverage with low computational costs, minimum latency, and enhanced energy efficiency. The initial target market is space communications, both commercial and government space programs. This innovation addresses the need for cheaper and faster solutions for the data communication systems of commercial and government space customers. Successful deployments are critical to the national defense.

Readily available energy generation: An SBIR-funded project team supports the development of a metal foam electrode-based neutron sensor that can withstand the harsh, high-temperature, radiation-suffused environments in advanced nuclear reactors. Advanced nuclear reactors may be a relevant approach to energy generation in the coming decades, as well as the fuel that sustains life beyond our planet. Since their safety and performance rely on instrumentation and control systems, advanced reactors' successful deployment is contingent on developing commercially viable, adaptable, high-temperature, and high-sensitivity neutron sensors. The proposed sensors could find numerous applications in other industries, including medical diagnostics and treatments, medical isotope production, sterilization, space radiation effects, national security/nonproliferation, manufacturing, industrial processes, oil and gas, and direct (electric) energy conversion power devices. Ultimately, this approach is key to U.S. leadership in technology as well as quality of life, and it underlies our ability to forge new frontiers.

NSF Regional Innovation Engines (NSF Engines): The NSF Engines program catalyzes regional innovation ecosystems throughout the United States, and particularly in regions that have not participated in the technology boom of the past few decades. The program fosters partnerships across industry, academia, government, nonprofits, civil society, and communities of practice. The inaugural portfolio of NSF Engines awards, announced by NSF and the White House on January 29, 2024, includes the development of space technology. As one instance of this emphasis, the Piedmont Triad Regenerative Medicine Engine includes a research and innovation thrust on in-space biomanufacturing. For example, in March 2024, this NSF Engine partnered with Axiom Space to provide access to the world's first commercial space station, leveraging the benefits of microgravity to explore a new frontier for tissue and organ regeneration. This effort is a key step toward a future robust commercial space economy in low Earth orbit.

Division of Chemical, Bioengineering, Environmental and Transport Systems

The NSF Division of Chemical, Bioengineering, Environmental and Transport Systems (CBET) in the Directorate for Engineering supported discoveries in fundamental transport, thermal, and fluid phenomena. CBET-funded research topics included joint funding areas with the Air Force Office of Scientific Research on basic combustion science and turbulence-chemistry interactions and turbulence, boundary-layer transition, and fluid-structure interactions.

In addition, CBET partnered with the Center for the Advancement of Science in Space (CASIS) to support research projects on fluid dynamics, particulate and multiphase processes, combustion and fire systems, thermal transport processes, and nanoscale interactions that utilize the International Space Station (ISS) National Lab to conduct research in microgravity conditions that will benefit life on Earth. Projects have investigated flame spread, the behavior of vapor bubbles, and phase separation.

CBET and the NSF Division of Civil, Mechanical and Manufacturing Innovation also partnered with CASIS to support research projects on tissue engineering and mechanobiology that use the ISS National Lab for studies in microgravity conditions. In 2024, the partners supported new projects to advance fundamental understanding of cardiac aging and sarcopenia, which affect human health on Earth as well as in low-gravity conditions.

Division of Engineering Education and Centers

The NSF Division of Engineering Education and Centers (EEC) in the Directorate for Engineering invested in the development of 21st-century engineers and the discovery of technologies through transformational center-based research, research in education, and research opportunities for students and teachers. EEC supported NSF Research Experiences for Undergraduates (REU) Sites that focus on fluid mechanics; aerospace engineering for unmanned aerial systems; and hypersonic, propulsive, energetic, and reusable platforms. Some of these REU Sites are supported through an NSF partnership with the Department of Defense.

EEC managed the NSF Non-Academic Research Internships for Graduate Students (INTERN) program, which enabled graduate students to acquire core professional competencies and skills in aeronautics and aerospace. NSF partnered with the Air Force Research Laboratory (AFRL) to support INTERN research opportunities at multiple AFRL directorates, such as the Aerospace Systems Directorate and the Space Vehicles Directorate. In 2024, NSF began a partnership with the U.S. Army Combat Capabilities Development Command Army Research Laboratory (ARL) and Ground Vehicle Systems Center (GVSC) to support INTERN research opportunities.

The NSF Industry-University Cooperative Research Center (IUCRC) program, which is NSF-wide and led by EEC, has enabled academic researchers to conduct fundamental, pre-competitive research of shared interest to industry and government members while developing a high-tech, exceptionally skilled workforce. IUCRC investments are driving innovation in aeronautics and space technologies with a focus on in-space manufacturing, guidance-navigation-control, high-performance space computing, advanced materials, smart and autonomous vehicles, microelectronics, and sensors.

Department of State

DOS

In FY 2024, the U.S. Department of State led diplomatic and public diplomacy efforts to strengthen U.S. leadership in space exploration, applications, and commercialization by increasing understanding of, and support for, U.S. national space policies and programs and to encourage the foreign use of U.S. space capabilities, systems, and services.

The Office of Space Affairs within the Bureau of Oceans and International Environmental and Scientific Affairs (OES/SA) directly supports civil and commercial space cooperation by negotiating bilateral and multilateral agreements, conducting diplomatic outreach to partner countries, and leading U.S. participation in international space and technological activities and multilateral organizations. The Office of Emerging Security Challenges within the Bureau of Arms Control, Deterrence, and Stability (ADS/ESC) supports diplomatic and public diplomacy engagements to promote space security cooperation, including the pursuit of space-related transparency and confidence-building measures, as well as bilateral and multilateral space security dialogues. Highlights of OES/SA and ADS/ESC work in FY 2024 included helping recruit 14 new signatories to the Artemis Accords; organizing inaugural U.S. space dialogues with Germany, Italy, New Zealand, the Philippines, and Singapore; hosting the second U.S.-France Comprehensive Dialogue on Space; and hosting the 9th U.S.-Japan Comprehensive Dialogue on Space.

UN Security Council

Following initial announcements in February 2024 about a new Russian anti-satellite threat, the administration subsequently shared its assessment that Russia is developing a new satellite carrying a nuclear device. As part of an integrated administration response to this potential new threat, the Bureau of Arms Control, Deterrence, and Stability supported extensive

diplomatic outreach to underscore the grave implications for international security and stability should Russia place such a weapon into Earth orbit.

This outreach stressed that the placement by States Parties to the Outer Space Treaty of a nuclear weapon in orbit would be a clear violation of Article IV of the Outer Space Treaty, the cornerstone of the legal regime for outer space. It also emphasized that nuclear detonation in outer space could also cause devastating consequences for the world and for the global economy, including all States' ability to use space as a driver for development.

In order to reinforce the clear obligations States Parties of the Outer Space Treaty have under international law, the United States joined with Japan in April 2024 to propose a UN Security Council resolution, which was cosponsored by a total of 65 nations. This resolution would have reiterated States Parties' obligations with respect to the Outer Space Treaty's Article IV. It also included a call for all States not to develop nuclear weapons, or any other kinds of weapons of mass destruction, specifically designed to be placed in orbit around Earth.

On April 24, 2024, Russia vetoed what should have been a noncontroversial, even-handed resolution in the United Nations Security Council.

Despite this veto, State has continued to use diplomatic space security engagements to put a bright spotlight on Russia's troubling actions in space regarding the full range of its counterspace capabilities and their divergence from the Kremlin's rhetoric. These efforts included sponsorship of a UN General Assembly resolution for consideration at the Assembly's 79th session in October–November 2024.

Artemis Accords

OES/SA led the Department's collaboration with NASA to promote international participation in the Artemis Accords. The Artemis Accords are a nonbinding political commitment to the safe, sustainable, and responsible exploration and use of outer space, as the United States and its allies and partners return to the Moon and beyond. In FY 2024, after concerted diplomatic efforts, OES/SA was pleased that 14 new countries decided to join the Artemis Accords, including emerging spacefaring nations like Angola, Armenia, and Peru.

This fiscal year also saw the Artemis Accords signatory group move further into the implementation phase of the ten Accords principles. Most notably, the group agreed on a set of basic mission data that lunar mission operators should share publicly for purposes of deconfliction (or non-interference) and agreed to share that information with the UN. The United States initiated the first-ever such report to the UN Office of Outer Space Affairs in April for two U.S. commercial lunar missions, followed by similar notifications to the UN by Japan and India. The signatory group convened two meetings of Accords signatory countries: a Heads of Agency

meeting on the margins of the International Astronautical Congress in Baku, Azerbaijan, in October 2023, and a working-level meeting in Quebec, Canada, in May 2024.

Multilateral Diplomacy

In FY 2024, OES/SA led U.S. interagency efforts to promote national space policy objectives at the United Nations, primarily through the UN Committee on the Peaceful Uses of Outer Space (COPUOS) and its Scientific and Technical Subcommittee (STSC) and Legal Subcommittee (LSC). Across all sessions, OES/SA utilized negotiations to promote the safe, sustainable, and responsible use of space topics such as the Long-Term Sustainability of Outer Space Activities (LTS), space situational awareness (SSA) and space traffic coordination (STC), and space resource utilization (SRU).

At the 61st session of the STSC, the Subcommittee agreed to establish an agenda item to discuss the potentially detrimental effects of satellite and large satellite constellation brightness on astronomy. This initiative, known as "Dark and Quiet Skies," was advocated for by the United States, which has convened numerous domestic discussions with astronomers, commercial satellite operators, and academics to ensure that all stakeholders have a voice in the process moving forward. This included the release of a Federal Register Notice to solicit private-sector participation in multilateral engagements, including through the formation of a domestic discussion group to gather perspectives from relevant stakeholders on this issue.

At the 63rd session of the LSC, the United States delegation highlighted the U.S. Novel Space Activities Authorization and Supervision Framework endorsed by the National Space Council in December 2023; recent FCC enforcement efforts related to orbital debris; and the Department of Commerce's vision for Global Space Situational Awareness Coordination, among other examples of U.S. efforts to implement international best practices in civil and commercial space activities. Following an international conference on space resource activities, the LSC's Space Resource Working Group set a deadline for additional inputs from member states for an initial set of recommended principles. U.S. experts featured prominently in the international conference, as well as an expert meeting on space resource activities hosted by Belgium and Luxembourg in March 2024.

Between June 19 and 28, 2024, the U.S. delegation helped achieve several milestones at the 67th session of the UNCOPUOS Plenary, including the creation of an Action Team on Lunar Activities Consultations (ATLAC), which creates a multilateral process to identify a potential mechanism to facilitate coordination and communication for lunar surface activities between Moon-faring nations. The Committee also adopted consensus language in the final report that reaffirmed the Outer Space Treaty as the cornerstone of international space law,

and specifically Article IV, which calls on nations "not to place in orbit around the earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction."

UN General Assembly Fourth Committee

In October 2023, OES/SA led negotiations in the UN General Assembly's (UNGA) Fourth Committee to ensure the adoption of the UNCOPUOS report under the "international cooperation in the peaceful uses of outer space" agenda item. The 2023 session was particularly contentious due to one delegation's disregard for long-standing precedent by introducing a new and contentious resolution under this agenda item that served as a thinly veiled criticism of private-sector space activities and how nations use outer space. The United States joined numerous other Member States in raising substantive concerns with this draft resolution, which was subsequently withdrawn from negotiation.

International Committee on Global Navigation Satellite Systems

In October 2023, OES/SA led the U.S. delegation to the 17th meeting of the International Committee on Global Navigation Satellite Systems (GNSS) (ICG), hosted by the European Union (EU) in Madrid, Spain. OES/SA also cochaired the ICG Working Group on Systems, Signals and Services, where recommendations were adopted related to system time interoperability; low Earth orbit (LEO) positioning, navigation, and timing (PNT) systems; and international GNSS monitoring. Under the ICG, NASA led a subgroup focused on space service use and continued to make significant progress in their efforts to promote GNSS usage in space. This work also included discussion on lunar PNT issues. The ICG continues to provide a platform for multilateral discussions on important GNSS topics, focused on system compatibility, interoperability, and transparency in service provision.

In January 2024, the ICG held workshops on international GNSS monitoring and precise point positioning (PPP) services on the margins of the Multi-GNSS Asia conference in Chiang Rai, Thailand. In April, the United States hosted the 11th ICG Workshop on Interference Detection and Mitigation in Honolulu, Hawaii. The United States also organized and trichaired a workshop on LEO PNT, held at the UN offices in Vienna in June 2024, which included participation from commercial providers.

Bilateral Diplomacy

OES/SA worked across FY 2024 to empower the Department's regional bureaus and international missions to engage on space issues in bilateral relationships that span the spectrum from friendly to competitive. Primarily through support to Environment, Science, Technology, and Health (ESTH) Officers in the field and regional desk officers, OES/SA was able to augment

the Department's work by bringing space deliverables to relationships and solving challenges generated through previous U.S. Government space initiatives. Examples include the negotiation and follow-up from multiple bilateral space framework agreements (detailed more below), the continued technical operation of the International Space Station following Russia's full-scale invasion of Ukraine in FY 2022, and ongoing space traffic deconfliction with space objects from countries that share less information about their operations.

Bilateral Agreements

In FY 2024, OES/SA coordinated multiple initiatives to negotiate, conclude, and amend international agreements in support of U.S. civil space activities with foreign governments. This included an agreement to extend NASA's cooperation with Australia on ballooning activities and multiple agreements with the European Space Agency and the Italian Space Agency (ASI) for mutually beneficial cooperation on space exploration. NASA also completed an agreement with the United Arab Emirates for cooperation on Gateway and the Artemis program.

In 2024, under authority from OES, the USGS signed a Memorandum of Understanding with Geoscience Australia for cooperation on Earth observation activities under the Landsat Next program. Specifically, Australia agreed to provide operational ground station services and support, which will enhance USGS land remote-sensing data collection under the Landsat program.

Following Russia's illegal, full-scale invasion of Ukraine in FY 2022, the EU ended long-running contracts with Russia for the launch of EU satellites. OES/SA worked with an array of U.S. Government departments and agencies and the European Commission to negotiate and conclude an international agreement providing assurances on the safe handling of sensitive satellites to enable the launch of EU geo-navigation satellites from U.S. territory, a boost for U.S. space launch providers. Two successful launches were conducted in the United States during FY 2024.

Inaugural U.S.-Germany Space Dialogue

This year, OES cochaired the first-ever U.S.-Germany Space Dialogue in Berlin in June 2024. The two sides discussed civil, commercial, and security space cooperation. Before the kick-off, the German delegation hosted a press panel to highlight the NASA–Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center, or DLR) collaboration on the Gravity Recovery and Climate Experiment-Continuity (GRACE-C) mission. GRACE-C will extend a decades-long record of following shifting water masses using gravity measurements—data that is key to characterizing Earth's climate—with a targeted launch of 2028. Additionally, during the dialogue, the USGS and Germany's DLR signed a statement of intent for Germany to host a LandsatNext ground station, which will enable their site to receive data from future LandsatNext satellites, quickly sharing their data to support economic development and

environmental management. The ground station also currently supports Landsat 8 and 9 missions. According to the USGS, the arrangement will save the U.S. Government tens of millions of dollars over the life of the project.

Second Meeting of the U.S.-France Comprehensive Dialogue

The U.S.-France Comprehensive Dialogue underscores the importance of the U.S.-France alliance's more than 60-year relationship in space and recognizes the growing nexus of civil, commercial, and national security space activities and the increasingly interconnected nature of all three sectors. At this year's dialogue, both countries reiterated their strong determination to build upon the inaugural dialogue and further expand cooperation in a variety of areas, including enabling a sustainable space economy that preserves the benefits of space for future generations, advancing the security and resilience of space, increasing consultation in multilateral forums related to outer space affairs, and improving cooperation in maritime domain awareness.

Inaugural U.S.-Singapore Civil Space Dialogue

The inaugural U.S.-Singapore Space Dialogue highlighted several promising areas for U.S. cooperation with Singapore's emerging and fast-growing space program and sector, particularly in Earth observation for uses such as fire and haze monitoring, as well as maritime domain awareness. A "Track 1.5" session included representatives from both government and the private sector from both countries. The session highlighted Singapore's commercial ambitions and talent in the space technology sector and brought together U.S. and Singaporean private space firms for a frank and productive discussion on bilateral business partnerships.

Inaugural U.S.–New Zealand Space Dialogue

The United States and New Zealand held their inaugural Space Dialogue in Washington, DC, on April 12, 2024. The first space dialogue between the United States and New Zealand underscored growing and important bilateral cooperation in space and reinforced New Zealand's close partnership across the civil and commercial space sectors, with the opportunity to grow in the space security sector. The United States and New Zealand issued a joint statement published on the Department of State's website, summarizing their work and announcing their continued collaboration. Prior to the April 12 government-to-government dialogue, the United States also hosted a roundtable with New Zealand on April 10 on the margins of the annual Space Symposium conference in Colorado, where government and industry representatives from both countries discussed challenges and opportunities for U.S.–New Zealand commercial space collaboration.

Inaugural U.S.-Philippines Space Dialogue

The inaugural U.S.-Philippines Space Dialogue highlighted several areas for U.S. cooperation with this key treaty ally in East Asia, particularly in Earth observation satellite data applications, including weather pattern monitoring and maritime domain awareness. This dialogue highlighted the growing use of Earth observation satellite data by emerging space nations for socioeconomic and security applications and served to enhance broader ties with a critical U.S. partner and ally.

Ninth Meeting of the U.S.-Japan Space Comprehensive Dialogue

The United States and Japan reaffirmed shared values of openness and transparency and pledged to continue to expand cooperation on civil, commercial, and security aspects of outer space at a two-day Comprehensive Dialogue on Space hosted in Washington on August 26–27. Both sides noted the historic agreement at the April 2024 leaders' summit in Washington for cooperation in lunar surface exploration, including the announcement of a shared goal that a Japanese national would be the first non-U.S. astronaut to land on the Moon on a future Artemis mission. The two sides held a classified space security session and a "Track 1.5" commercial space dialogue and announced U.S. and Japan private companies' formation of a "space industry network" to deepen commercial connections. The two sides pledged to work together to maintain the leadership of the United States and its allies and partners in outer space.

GNSS Technical Working Groups with Japan and the Republic of Korea

The United States and the Republic of Korea (ROK) held a Technical Working Group (TWG) meeting in April 2024 in Honolulu on the margins of the Institute of Navigation Pacific PNT Conference. The two sides discussed technical issues related to development of the Korea Positioning System in an effort to align the system with GPS to the maximum extent possible. The ROK delegation also visited a GPS monitor site at the Space Force facility on Oahu. The United States and Japan held TWG meetings in October 2023 and February 2024 to continue bilateral discussions on spectrum coordination for Japan's Quasi-Zenith Satellite System expansion to 11 satellites.

Africa and the Western Hemisphere

In FY 2024, OES/SA continued to strengthen U.S. space engagements in Africa, Latin America, and the Caribbean, building on the 2022 U.S.-Africa Leaders Summit and 2022 Summit of the Americas. For example, as part of the space workstream of the Americas Partnership for Economic Prosperity, OES/SA worked closely with Chile—the workstream's lead—to support a series of workshops focused on the societal applications of space technologies and data.

In addition, this summer, OES brought the Department's new U.S. Science Envoy, commercial astronaut Dr. Sian Proctor, to Kenya, South Africa, Chile, and Peru to talk about issues important to many of our African and Latin American partners, such as space workforce development and the commercial space sector. During her visits, she met with students, educators, scientists, and policy makers to talk about STEM education and curriculum development, space policy, how to advance space cooperation with the United States, and how "solving problems for space" helps us "solve problems for Earth."

We have promoted responsible behavior in outer space among our African and Latin American partners, encouraging countries to sign the four core outer space treaties, join the UN Committee on the Peaceful Uses of Outer Space, sign the Artemis Accords, and make a national commitment not to conduct direct-ascent anti-satellite missile tests.

Near-Earth Objects

The Department, NASA, and the Federal Emergency Management Agency co-organized the first International Planetary Defense Tabletop exercise with representatives from the U.S. interagency and international counterparts from the European Space Agency (ESA), the Canadian Space Agency, the United Kingdom Space Agency, the Japan Aerospace Exploration Agency, and the United Nations Office for Outer Space Affairs, among others. Exercise participants were confronted with a hypothetical but realistic planetary defense scenario: an asteroid with a significant chance of impacting Earth in approximately 14 years, and numerous large uncertainties in where the asteroid could hit Earth, how severe the consequences would be if impact were to occur, and what it would take to successfully deflect the asteroid away from Earth. Over the course of the two-day exercise, participants explored how decisions might be made collaboratively in the face of these large uncertainties. The exercise revealed gaps in current domestic and international preparedness efforts and will be explored further in the next exercise to identify appropriate ways to address them.

National Space Council Meeting on International Partnerships

On December 20, 2023, Secretary of State Antony Blinken represented the Department at the third meeting of the National Space Council (NSpC), chaired by Vice President Kamala Harris. This session focused on international partnerships, highlighting diplomatic priorities such as expanding the Artemis Accords and promoting U.S. leadership in space. In his remarks, Secretary Blinken highlighted the Department's first-ever Strategic Framework for Space Diplomacy, emphasizing the critical role of diplomacy in facilitating groundbreaking initiatives like the James Webb Space Telescope.

At the third NSpC meeting, Vice President Harris tasked the Department of State with carrying forward key initiatives in FY 2024. These include the following:

- Expanding and strengthening the Artemis Accords, including by developing a plan for deepening implementation of the Accords (see section on Artemis Accords).
- Leveraging programs like Embassy Science Fellows and U.S. Science Envoys to advance space diplomacy objectives. In FY 2024, we worked with OES/Office of Science and Technology Cooperation (STC) to support visits to four countries by the U.S. Science Envoy, Dr. Sian Proctor, focused on the civil use of space. Through the Embassy Science Fellow Program, STC matched scientists from DOE, NASA, NOAA, and USDA to space and Earth observing projects in the Association of Southeast Asian Nations (ASEAN), Indonesia, Iraq, Italy, Egypt, and New Zealand.
- Strengthening outreach to nations to encourage further commitments not to conduct destructive direct-ascent anti-satellite missile testing. To help establish this as a new international norm of responsible behavior in outer space, the United States continues to encourage other countries to make their own commitments along with the United States and 37 other nations.
- Conducting a review of space export controls to enable a globally competitive U.S. industrial base while protecting our national security and foreign policy interests. In June 2024, Department of State delivered to the NSpC a summary of the Department's review, as well as the related actions we are undertaking. Completed actions include submitting, for formal interagency review, a *Federal Register* rule that would propose changes to the Department's export regulations, including changes intended to support the U.S. space industrial base by clarifying and adjusting the International Traffic in Arms Regulations (ITAR). The Department also published an interim final rule establishing an ITAR exemption at 22 CFR 126.7, the first new ITAR exemption in many years. The public comment periods for each of these rules will conclude in November 2024. Separately, the Department provided guidance to industry on how best to interpret ITAR requirements for modern space-related efforts, such as certain temporary satellite imports and reusable rockets that are recovered outside the United States.

Department of Energy

DOE

The Department of Energy (DOE) participates in the national effort to enable U.S. interests in space. Various organizations within DOE, including the National Nuclear Security Administration (NNSA), provide support to NASA via existing programs and capabilities to maximize the use of national investments in science and technology. DOE directly supports research and operations of facilities at its National Laboratories and U.S. universities that contribute to advancing NASA missions. Additionally, DOE's laboratories conduct research activities and technology development activities supported directly by NASA through Strategic Partnership Projects. Finally, DOE's laboratories conduct research selected and supported by their Laboratory Directed Research and Development programs that align with NASA missions.

Overall, DOE supports NASA to accomplish its mission in the following four major areas:

- power the exploration of space,
- support the secure and peaceful use of space,
- solve the mysteries of space, and
- enable the development of space.

A detailed description of DOE's role in each area is provided below.

Power the Exploration of Space

DOE, through its Office of Nuclear Energy (NE), supports NASA's planetary science and human exploration programs by maintaining capabilities needed to develop, produce, and deliver Radioisotope Power Systems (RPS) for space mission applications. RPS convert heat from the radioactive decay of plutonium (Pu)-238 into electricity and reliably operate for

decades in the harsh conditions encountered in space or on the surfaces of other planets where solar energy or stored-energy devices are impractical or impossible to use.

Radioisotope Power Systems Powered Missions

In FY 2024, through NE, DOE

- completed for the Dragonfly mission the Safety Design Strategy, which will be used to prepare the Safety Analysis Report;
- progressed toward the fabrication of an electrically heated Multi-mission Radioisotope Thermoelectric Generator (MMRTG) flight unit with mission-unique features for Dragonfly; and
- supported the development of the Memorandum of Understanding (MOU) between NASA and the European Space Agency (ESA) on the ExoMars Rosalind Franklin Mission. The MOU, signed in May 2024, initiated interagency collaboration between DOE and NASA for the mission.

Constant Rate Production

With funding support from NASA, DOE, through NE, continued to maintain RPS production capability through the Constant Rate Production (CRP) program with the primary focus on scaling up production capacity; optimizing production processes; and maintaining, modernizing, and replacing equipment and infrastructure. DOE conducted activities in FY 2024 to meet CRP goals of 1.5 kilograms per year average annual production rate capacity of heat source plutonium oxide and average annual production capacity of 10–15 fueled clads per year:

- Successfully established long-term target irradiation schedules in the High Flux Isotope Reactor at Oak Ridge National Laboratory (ORNL) and the Advanced Test Reactor at Idaho National Laboratory (INL).
- Manufactured flight-quality fuel clads for the Dragonfly mission.
- Successfully demonstrated a sustainable waste removal process for ion exchange resin waste for heat-source production and made progress on developing sustainable processes for removing liquid organic and solid wastes to streamline production.
- Maintained the production of specialized components, including Carbon-bonded Carbon Fiber, iridium alloy blanks/foils, Clad Vent Sets, and Lightweight Radioisotope Heater Units clad components, at ORNL.
- Performed a comprehensive assessment of the equipment at Los Alamos National Laboratory (LANL) to reduce manufacturing risks and risks from aging systems and equipment.

- Completed the turnover to operations of the Hot Press Furnace Line.
- Conducted equipment replacement and refurbishment activities at INL to reduce risks, including the replacement of the module assembly glovebox windows and glove rings.

RPS Technology Development Activities

In FY 2024, DOE, through NE, continued to provide technical expertise, procurement coordination, and planning and support to NASA in conducting energy conversion research and development to advance state-of-the-art performance in heat-to-electrical-energy conversion. Static energy conversion projects are underway with the goal of providing higher conversion efficiency and improving mission performance over design lifetime.

DOE continued its partnership with NASA to deliver a next-generation radioisotope thermoelectric generator (NGRTG) with higher power output. DOE is refurbishing an existing General-Purpose Heat Source (GPHS)-RTG unit from the 1980s to identify opportunities to enhance its design to meet modern production standards. In FY 2024, DOE completed the go/no-go assessment for the refurbished GPHS-RTG unit and completed the converter subassembly, data package, and certificate of inspection.

Surface Fission System Development

DOE, through NE, provided technical support for fission surface system development. DOE and NASA have selected proposals to design a fission surface power (FSP) system for lunar power applications. The goal of the FSP project is to demonstrate a 40-kilowatt electric nuclear reactor on the Moon by the end of the decade. In September 2022, DOE awarded 12-month design contracts to three teams, Lockheed Martin, Westinghouse Electric Company, and Intuitive Machines and X-energy for their design proposals,[1] which were successfully completed. In FY 2024, NASA provided additional funding to DOE for a follow-on effort for each of the three teams. The Phase 1a effort focuses on lab-scale hardware development of key subsystems and components for each of the three unique designs. The deliverables include test plans, testing results, and concept and schedule updates for delivery of a flight system. This information will be used as a basis for decisions on system requirements and planning for Phase 2. Phase 2 is the next major phase of FSP development to support both a ground demonstration qualification unit and a flight unit.

In FY 2024, DOE successfully completed several milestones in the second year of development as outlined in the FSP Technology Maturation Plan, which provides technical direction for government-funded technology development efforts. These milestones include the

1 Press release: https://inl.gov/article/battelle-energy-alliance-nasa-select-industry-partners-to-design-nuclear-power-system-for-lunar-applications/.

demonstration of hydrogen retention in a baseline Yttrium-Hydride (YH) moderator and the development of an element design with the potential to retain hydrogen at higher temperatures. DOE also completed a technology development plan for FSP instrumentation and control components as well as future scoping for radiation shielding.

Nuclear Thermal Propulsion System Development

DOE, through NE, provided technical support for Nuclear Thermal Propulsion (NTP) system development. In FY 2024, DOE focused on experimental activities and contract design to pursue flight demonstration.

Experimental Activities: In FY 2024, DOE experimental activities included preliminary scoping of a future fuel irradiation test (Sirius 5) aimed at leveraging a new capability for testing fuel in gaseous hydrogen in the Transient Reactor Test Facility (TREAT). DOE laboratories continued to work with non-irradiated fuel material to refine fabrication methods and to characterize thermal properties of the material and coatings. Progress was made on evaluating NTP instrumentation and control and development, which included the investigation of simulations of NTP reactor start-up to help inform future requirements and technology needs. Additionally, DOE progressed the construction of a gaseous hydrogen supply system for TREAT to allow hydrogen exposure during future irradiation experiments. Construction is expected to be completed in early FY 2025.

Contract Design: DOE worked with NASA on the development of the request for proposals (RFP) and contract procurement for NTP reactor design activities. Industry teams led by BWX Technologies, Inc.; General Atomics, Inc. (GA); and Ultrasafe Nuclear Technologies, Inc. (USNC), successfully completed design contracts issued by INL in FY 2022. Each contractor developed reactor design and supporting information for evaluating future development. In FY 2023, DOE supported $5 million award extensions to two of the teams, one led by GA and the other by USNC, for an additional 12 months of design work on their respective designs. Design efforts were extended and are expected to be completed in early FY 2025.

Support the Secure and Peaceful Use of Space

In FY 2024, DOE conducted programs that support NASA missions and are synergistic with national security activities. For example, NASA leverages DOE-unique engineering, scientific, and computing capabilities for analyzing asteroids and planetary defense scenarios. This work helps to develop and exercise capabilities that are relevant to the weapons program, including

high-performance computing, two- and three-dimensional simulations, weapon effects, systems engineering, and weapon component design.

Planetary Defense

DOE continued to work with NASA, the Department of Defense, the Department of Homeland Security, and other agencies to develop and implement the actions outlined in the National Near-Earth Object Preparedness Strategy and Action Plan. This Strategy and Action Plan was developed to help improve our Nation's preparedness to address the hazards of near-Earth object (NEO) impacts. The NEO plan has six strategic goals. The two pertaining to DOE focus on improving NEO modeling, predictions, and information integration and developing technologies for NEO deflection and disruption missions.

In FY 2024, DOE collaborated with NASA to

- characterize the potentially hazardous asteroid target sets, define mission requirements, and identify capability gaps;
- examine the effects of either a kinetic impactor and/or a nuclear detonation, either at the surface or at a standoff distance from a model asteroid, using simulations from peta-scale computers at the National Labs;
- define additional development and system engineering requirements to address technical gaps such as arming, fusing, and firing a deflection device;
- participate in planetary defense tabletop exercises and technical interchange meetings;
- advise on risk-assessment analysis and effectiveness of mitigation approaches;
- conduct impact and airburst effects studies, which will serve as the initial conditions for FEMA emergency response planning if mitigation approaches fail; and
- partner with NASA scientists and engineers to publish refereed technical papers.

NASA's Environmental Continuous Air Monitors

DOE maintained the NASA-owned Environmental Continuous Air Monitors for deployment around launch sites to provide indication of a radioactive release, should one occur. NASA agreed to loan these sensors in support of DOE/NNSA's nuclear incident response mission when those devices are not being used for mission launch support. These devices were upgraded to provide real-time associated data telemetry systems and will be interoperable with NNSA's existing data telemetry capability.

Global Nuclear Monitoring

DOE builds the Nation's operational sensors to monitor the entire planet from space to detect and report surface, atmospheric, or space nuclear detonations. DOE develops, builds, and

delivers these satellite payloads to meet interagency performance and schedule commitments and provides launch and on-orbit operational support for the current generation of the U.S. Nuclear Detonation Detection System (USNDS). This information helps to characterize space weather, which helps NASA to characterize the radiation environments that NASA space exploration vehicles must endure. DOE also provides much of the underlying science and technology capability for space-based detection of foreign nuclear weapon detonations to meet test ban treaty monitoring needs.

The DOE weapons laboratories—LANL, Sandia National Laboratories (SNL), and Lawrence Livermore National Laboratory (LLNL)—supply the science, technology, and engineering required for USNDS. LANL and SNL lead the production of sensors, and LLNL contributes to the end-to-end modeling of USNDS. These laboratories have a unique and comprehensive understanding of nuclear weapons, as well as the observables associated with nuclear detonations and the propagation of signals to sensors. Moreover, these laboratories have extensive capabilities in the design, construction, calibration, deployment, and operation of satellite-based instruments, along with detailed modeling and analysis. To support continuous global monitoring, the operations communities routinely receive analysis, insights, and computer codes based on this research.

Two distinct sensor suites are built at DOE laboratories to accomplish the nuclear detonation reporting mission: the Global Burst Detector (GBD) and the Space and Atmospheric Burst Reporting System (SABRS). The GBD is hosted on all GPS satellites, and SABRS is carried on satellite hosts in geosynchronous orbit.

In FY 2024, DOE continued full-scale production of both sensor suites as needed to meet national security requirements. To ensure that the technologies and capabilities developed for the program support the stakeholder needs, DOE actively engaged in intergovernmental working groups to reduce duplication of effort, refine user requirements, and improve the quality of relevant technologies across funding agencies. To maintain a vital capability to design and implement these systems, DOE supported demonstration-validation payloads both to explore new technologies and new sensing modalities and to increase the Technology Readiness Level for parts that might be used in future payload designs.

Solve the Mysteries of Space

In FY 2024, DOE, through the Office of Science, supported numerous activities that contributed to a broad range of space interests. These activities included fundamental research of mutual interest to NASA and DOE, collaborative research efforts with NASA, and the operation of DOE scientific facilities that are available to NASA and the broader scientific community for space-related research. Coordinated and collaborative activities in basic science that are

undertaken by DOE and NASA are performed under the 2020 MOU. The MOU established the Science and Innovation Working Group, co-led by the Director of DOE's Office of Science and the Associate Administrator of NASA's Science Mission Directorate, with the purpose of identifying areas of mutual interest in science and technology development that would benefit from greater coordination and collaboration between the agencies. The working group meets on an ad hoc basis to discuss new opportunities for collaboration, receive updates on existing joint efforts, and discuss other agency activities of mutual interest.

DOE, through the Office of Science, is also a member of the National Science and Technology Council's Low-Earth Orbit (LEO) Research and Development (R&D) Interagency Working Group (IWG), co-led by NASA, the National Science Foundation, and the Office of Science and Technology Policy (OSTP). In early FY 2024, members of the IWG participated in a convening of federal departments and agencies to explore opportunities for collaborative LEO research.

Plasma Science

DOE, through its Fusion Energy Science program in the Office of Science, supports frontier plasma science research that contributes to DOE-NASA mutual interests in the knowledge of heliospheric and astrophysical systems. In FY 2024, DOE continued to support plasma science research activities at the Large Plasma Device at the Basic Plasma Science Facility at the University of California, Los Angeles (controlled studies of Alfvén waves); the Big Red Plasma Ball and Madison Symmetric Torus experiments at the Wisconsin Plasma Physics Laboratory at the University of Wisconsin–Madison (high-fidelity measurements of magnetic reconnection, dynamo, turbulence, and particle-energization processes); and the Magnetorotational Instability Experiment (MRI) (accretion or accumulation processes involving star and planet formation) device at the Princeton Plasma Physics Laboratory (PPPL). PPPL researchers have continued to perform computer simulations and validation using MRI data related to the recently discovered instability mechanism believed to be behind astrophysical disk accretion rates. PPPL, which has been collaborating with NASA's Magnetospheric Multiscale mission since it was launched in 2015, is now commissioning the Facility for Laboratory Reconnection Experiment, a new and more powerful version of the PPPL's Magnetic Reconnection Experiment.

New knowledge and data derived from these experiments and research activities not only contributed to DOE's mission to advance fusion energy and plasma science, but also contributed to greater understanding of complex space weather phenomena, enabling more accurate models and predictions of this behavior and mitigating the risk to both humans and equipment operating in the space environment.

High Energy Physics (HEP), Cosmology, and Astrophysics

In FY 2024, DOE Office of Science, through its High Energy Physics (HEP) program, continued to support fundamental physics, cosmology, astrophysics, and high-priority national science objectives. These efforts included the Alpha Magnetic Spectrometer (AMS), located on the International Space Station; the Lunar Surface Electromagnetics Experiment at Night (LuSEE-Night) mission; and the Fermi Gamma-ray Space Telescope (FGST) mission. In addition, data from the ground-based Vera C. Rubin Observatory will enable a broad range of physics, astrophysics, and astronomy measurements and will be used in coordinated studies with data from space.

The AMS science goals include a search for evidence of dark matter and cosmic domains of antimatter, and the measurements of cosmic nuclei as a function of location in Earth's atmosphere. The AMS can determine the types and locations of cosmic nuclei, e.g., finding differing amounts of lithium, carbon, and oxygen inside and outside the South Atlantic anomaly, where the Van Allen radiation belt comes closest to Earth. NASA and other agencies have expressed a strong interest in the AMS measurements of space radiation as a function of location in Earth's atmosphere, which is of interest for astronaut safety considerations. Currently, data on more than 225 billion cosmic-ray events has been collected. During FY 2024, DOE began coordination with NASA and the AMS Collaboration to ensure that the AMS scientific data is stored in a publicly accessible archive, and in a common format with other data, to maximize the scientific return to the greater science community.

An extravehicular activity (EVA) was carried out by NASA in FY 2020 to replace the AMS cooling system, enabling it to operate beyond 2028. In December 2021, a DOE review considered the scientific case for a potential upgrade to AMS, which would add another silicon layer on top of the detector to increase science return and to install new radiators to ensure continued, successful operations until 2030. Following DOE and NASA discussions, NASA approved this upgrade, which requires an additional EVA orbital crew for installation, with a launch in 2026 or after. NASA is conducting a series of technical reviews to ensure that the upgrade can be installed safely and efficiently, with minimal impact on other ISS science payloads. A follow-on review was held in December 2023, upon which DOE determined that the status of AMS and the planned upgrade is meeting or exceeding expectations. As such, in 2024, DOE began executing its responsibilities on this upgrade.

The Large Area Telescope (LAT), the primary instrument on FGST in orbit approximately 565 kilometers above Earth, entered its 17th year of successful operations and data analysis on such topics as searches for dark matter and high-energy particle acceleration mechanisms. In FY 2024, the LAT collaboration team published results on indirect detection searches for dark-matter annihilation or decay in observations of dwarf spheroidal satellite galaxies of the Milky Way, extending previous results to dark-matter masses of 10^3–10^{11} gigaelectron volts (GeV).

Six possible annihilation or decay channels into standard model particles, with subsequent cascades, were considered. No evidence was found, though this analysis provided constraints on annihilation cross-sections and dark-matter particle lifetimes of several factors stronger than from ground-based atmospheric Cherenkov (MAGIC, VERITAS) and water Cherenkov (HAWC) telescope observations of the Draco dwarf spheroidal galaxy. DOE continues to support data processing and storage at the Shared Science Data Facility at the SLAC National Accelerator Laboratory (SLAC).

DOE continued its role building and operating ground-based observatories (in partnership with NSF) to carry out microwave, optical, and near-infrared imaging, as well as spectroscopic surveys that have complementary data with the space missions. HEP-supported scientists at DOE National Labs and U.S. universities continue to carry out simulations and data analysis for these surveys. Of interest to all three agencies is combining simulations and data analyses from the Vera C. Rubin Observatory, the Euclid Mission, the Nancy G. Roman Space Telescope, and others to enhance the scientific impact for studies such as the nature of dark energy, dark-matter searches, and the inflationary era in the early universe. Scientists supported by all three agencies continue working together toward this goal.

Of particular interest to NASA will be the comprehensive census of near-Earth objects, including asteroids and comets, from the ground-based Vera C. Rubin Observatory.[2] As a survey telescope, the Rubin Observatory will observe and take images of the entire southern night sky every three nights. Due to its large mirror size, the 3-billion-pixel camera, and the large field of view, Rubin Observatory will identify about 10 million changes in the sky every night. Scientists have already found most of the near-Earth objects larger than 1 kilometer in size, but less than 30 percent of those larger than 140 meters in size. The Rubin Observatory will increase that to 60 to 90 percent, many having a high probability of crossing Earth's path someday.

In FY 2024, DOE and NASA continued the development of the LuSEE-Night mission, a partnership with the Space Sciences Laboratory (SSL) in Berkeley, California. LuSEE-Night will deliver a new instrument package, developed by Brookhaven National Laboratory (BNL) with contributions from Lawrence Berkeley National Laboratory (LBNL), that will be capable of observing and characterizing the long-wavelength radio signal in the ultra-low noise environment of the lunar far side at night. Such measurements are not possible on Earth or in low Earth orbit due to interference from Earth's ionosphere. This pathfinder mission will potentially make the first measurement of the predicted 21-centimeter signal from the cosmic Dark Ages, a time between when the first atoms formed and when stars and galaxies formed (approximately 370,000 years to approximately 1 billion years after the Big Bang). All DOE

2 NASA was directed in 2005 to catalog 90 percent of potentially hazardous asteroids.

deliverables will be sent to SSL for integration and testing within the full LuSEE-Night instrumentation by October 2024. The LuSEE-Night mission will be sent to the Moon at the end of 2025 via a Commercial Lunar Payload Services launch.

Finally, NASA, through its Strategic Astrophysics Technology program, initiated funding in FY 2020 for a project at SLAC to further develop readout and low-noise signal-processing electronics for cryogenic detector arrays for far-infrared and x-ray space missions, as well as other broadband radio frequency (RF) applications in space. The work builds on HEP-funded research at SLAC to demonstrate and deploy an RF/signal-processing system with 4,000-times multiplexing for cosmic microwave background observation experiments at the South Pole. In FY 2023, the Radio Frequency System on Chip (RFSoC) electronics board was tested for effects from an exposure to 590 krad on the silicon. This radiation hardness test yielded encouraging results, indicating it as a strong candidate for space-based RF observatories. Potential applications for the RFSoC have been identified, including the proposed Cryptomaria Explorer and Cosmic Ray Lunar Sounder space missions.

High-Performance Scientific Computing for Cosmology and Astrophysics

DOE Office of Science, through the Advanced Scientific Computing Research (ASCR) and HEP programs, continued to support the analysis of data from the European Space Agency–NASA Planck Cosmic Microwave Background mission, which collected data from 2009 to 2013.

The National Energy Research Scientific Computing Center (NERSC) at LBNL made significant contributions to science funded by NASA, conducted by NASA researchers, and of direct relevance to NASA projects and missions. In FY 2024, NERSC hosted 28 researchers from NASA research centers, 20 projects that received NASA funding, and an additional nine with direct relevance to NASA programs. Among the projects were Roman Supernova Cosmology, Particle Acceleration and Transport in Solar Flares, Mapping the Signatures of Shock Breakout, six projects with continued studies on magnetic reconnection in various space environments, and a continuing project to support the Extreme Universe Space Observatory Super Pressure Balloon telescopes. Since 2020, more than 400 refereed scientific publications have referenced both NERSC and NASA.

In FY 2024, 12 projects at the Oak Ridge Leadership Computing Facility supported campaigns from NASA programs. These included four Innovative and Novel Computational Impact on Theory and Experiment projects, four projects in the Director's Discretionary program, three projects in the SummitPLUS allocation program for the final year of the Summit supercomputer, and one NASA-funded university project that was allocated time under the ASCR Leadership Computing Challenge. The Rocky Mountain NASA Space Grant Consortium, the NASA Astrophysics Theory Program, and the Hubble Fellowship Program

were cited as collaborators. The principal investigators (PIs) and users included personnel from NASA research centers, such as Langley Research Center, Goddard Space Flight Center, Marshall Space Flight Center, and Stanford University. The areas of inquiry included the formation and evolution of galactic winds via supernovae, the building of emulators to forecast extreme weather events, aerodynamic performance degradation, and advanced computational fluid dynamics for the development of high-lift vehicles for retro-propulsion of crewed Mars landers. A collaborative project between NASA and DOE investigators and IBM resulted in the release of a new AI foundation model called Prithvi, which offers a scalable way to address challenges in short-term weather as well as long-term climate prediction.

In FY 2024, the Argonne Leadership Computing Facility worked closely with NASA to port and optimize the performance of code that benefits aeronautics, space technology, and exploration by modeling fluid flow onto Intel Graphics Processing Units on the Aurora high-performance computer.

NASA research teams bring to the Office of Science's quantum research efforts expertise on quantum algorithms and systems, and two newly funded efforts in the Accelerated Research in Quantum Computing program include collaborators from NASA. Research efforts led by ORNL and North Carolina State University include collaborators from Ames Research Center.

Atmospheric Science and Terrestrial Ecology

DOE, through the Office of Science's Biological and Environmental Research program, engaged in many collaborative research efforts with NASA in the areas of atmospheric science and terrestrial ecology. During FY 2024, DOE's Atmospheric Radiation Measurement User Facility (ARM) and Environmental System Science (ESS) activity continued to support measurements of atmospheric trace gases in Oklahoma to improve understanding of the influence of atmospheric and terrestrial processes on atmospheric chemistry and chemical composition. ARM provided support for ground-based measurements in Oklahoma as part of the Total Column Carbon Observing Network and supported the launch of dedicated radiosonde observations during satellite overpasses at the Southern Great Plains, Oklahoma; Graciosa Island, Azores; and Utqiagvik, Alaska, ARM sites to obtain profiles of temperature and moisture for the validation of algorithms for two sounding instruments on the Suomi National Polar-orbiting Partnership satellite and Joint Polar Satellite System satellites. The ARM Director participates in the NASA Atmospheric Observing System mission suborbital working group to help identify ways that ARM ground sites can be used for validation of NASA measurements.

DOE's Atmospheric System Research (ASR) activity also supported collaboration with NASA scientists at Goddard Space Flight Center, the Goddard Institute for Space Studies, and the Jet Propulsion Laboratory on studies using ARM and NASA observations to investigate

aerosol and cloud processes and their role in Earth's energy balance. ASR and NASA scientists are collaborating on several model intercomparison studies using ARM data.

The ESS activity supported the Next Generation Ecosystem Experiment–Arctic, which continued to collaborate (through a Memorandum of Agreement) with the NASA Arctic-Boreal Vulnerability Experiment to couple real-time ground-based and airborne-based measurements of soil moisture, temperature, and atmospheric chemical composition over Utqiagvik and Nome, Alaska.

Finally, the ESS-supported AmeriFlux Network continued to collaborate with the NASA ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) mission by sharing flux tower measurements such as vegetation cover data and soil moisture data that are coupled with water flux/evapotranspiration measurements to serve as validation sites. The AmeriFlux community is collaborating with several NASA project teams as part of the Year of Remote Sensing, which provides an enhanced focus on remote-sensing capabilities, data products, community-driven analyses and syntheses, early-career training events, and webinars.

Nuclear Astrophysics and Nuclear Data

In FY 2024, DOE, though the Office of Nuclear Physics (NP) in the Office of Science, supported high-priority nuclear astrophysics research strongly aligned with the NASA mission through facilities operations, nuclear astrophysics experiments, and basic research leveraging nuclear theory with computational techniques and capabilities.

Astrophysics depends on nuclear physics observables such as the type of element produced in events, the energy of those elements, and their mass. Multiple factors have converged in just a few years to play a role in advancing our understanding of astrophysical processes to a new level. Techniques increasing the precision and accuracy of mass measurements, and the Facility for Rare Isotope Beams (FRIB), have led to more accurate and precise mass data. High-performance computing capabilities and innovations in nuclear modeling, along with the improved mass data, have accelerated research output.[3]

Nuclear astrophysics experiments employ diverse techniques, including the use of active target detectors with high efficiency to measure direct alpha and proton-induced reactions, as well as novel measurements of neutron capture reactions using accelerator mass spectrometry. Several experimental campaigns took place in FY 2024 of particular significance for nucleosynthesis in the mass A=10 to 100 range, utilizing stable and radioactive beams generated via the in-flight method. The in-flight method involves producing short-lived radioisotopes through reactions between stable beams interacting with a hydrogen or helium target and requires

3 F or a recent overview of technical, theoretical, and computational developments related to mass measurements, see "Precise Mass Measurements of Radioactive Nuclides for Astrophysics," *The European Physical Journal A (EPJ A)*.

specific detection techniques to conduct the measurements. Expertise for these kinds of experiments is found at Argonne National Laboratory (ANL), FRIB, and ORNL.

Experimentalists at the premier stable beam facility, the Argonne Tandem Linac Accelerator System (ATLAS) at ANL, directly measured reaction cross-section to improve our understanding of the nucleosynthesis flow in Type-I x-ray bursts.[4] Other nuclear reaction studies are planned at ATLAS and at FRIB. Related scope is to identify astrophysics-relevant isomers, called "astromers," which play a key role in rapid neutron-capture processes. New experimental results provided the first key nuclear data input for understanding the role of antimony-128 in nucleosynthesis. Various alpha and proton-induced reactions are important in multiple quiescent and explosive stellar environments. Having demonstrated that specific detector systems can measure relevant reaction rates using beams of mass number A~100, experimental campaigns are planned to study some of the most important reactions for the understanding of the weak r-process in neutrino-driven winds.

NP-supported computational and theoretical scope also supports NASA-supported research. Of note are several efforts to develop and field realistic simulations of core collapse supernovae and neutron star mergers. ORNL, LBNL, and several university partners are world-class leaders in this area. Simulations require high-performance computing to address the cosmic origin of the elements, the nature of dense matter, the physics of neutrinos in astrophysical environments, and the origin of gravitational waves. For example, the DOE Exascale Computing Project's ExaStar program drove improvements in the physics while optimizing the performance of nuclear astrophysics codes on new exascale architectures. In FY 2024, progress was made to improve the fidelity and expand the breadth of simulations of astrophysical explosions. Extending simulations to their late stages to join with experimental data (i.e., observations of supernovae and mergers of electromagnetic and nucleosynthetic signals) is high-impact and high-priority.

DOE and NASA continued to work together in the Nuclear Data InterAgency Working Group (NDIAWG), a federal-level working group led by NP, to coordinate and prioritize nuclear data needs for federal programs. In FY 2024, DOE continued discussion on addressing nuclear data needs for human spaceflight safety, planetary exploration, and electronics protection from radiation, including from cosmic-ray interactions with spacecraft. An award was made last year through the NDIAWG funding opportunity announcement to examine neutron-induced reactions for elements found in the solar system. This project provides data and reduces uncertainties for elements relevant for the NASA Dragonfly mission to Saturn's moon Titan. Nuclear data opportunities for space applications were included in the final report

4 A recent paper highlighting this research at https://doi.org/10.1103/physrevlett.131.112701 describes the first direct measurement of the 22Mg(α,*p*)25Al reaction rate, performed at Argonne National Laboratory.

from the Nuclear Science Advisory Committee, published in September 2022, as well as the 2023 Long Range Plan for Nuclear Science.

Experimental Facilities for Space Science and Technology Development

DOE continued to work with NASA in several areas to help support NASA's mission interests, providing scientific user facilities, including particle accelerators and ion beams, for biological and electronic systems radiation studies. The NASA Space Radiation Laboratory (NSRL) at BNL continued to study the effects of cosmic radiation exposure on astronauts, using beams of heavy ions extracted from BNL's Booster accelerator, part of the Relativistic Heavy Ion Collider complex.[5] The work advances the understanding of the link between ionizing radiation and cell damage. NASA continued to provide funding in FY 2024 to support the operation of the 88-inch cyclotron at LBNL for electronics space-radiation effects testing, which is necessary for NASA mission assurance.

DOE's scientific user facilities continued to contribute to NASA's missions in space science and technology development in FY 2024. Representative techniques and their applications used in FY 2024 included neutron diffraction at the Spallation Neutron Source at ORNL and high-energy x-ray diffraction and x-ray tomography at the Advanced Photon Source at ANL to comparatively assess the structure of glasses processed in microgravity versus terrestrial gravity,[6] as well as scanning transmission x-ray microscopy measurements at the Advanced Light Source at LBNL on samples from the asteroid Bennu returned by the OSIRIS-REx mission.[7]

Isotope R&D and Production

DOE Office of Science, through the Office of Isotope R&D and Production (DOE IP), supplied critical isotopes for NASA space-related R&D and applications in FY 2024. The DOE IP supplied helium-3 to NASA for use in detectors and cryogenics; mercury-199 and mercury-202 for atomic clock research; rubidium-87 for navigation satellite systems; nickel-63 for novel space weather sensors; americium-241 for radioisotope heater units; and chlorine-35, chlorine-37, silicon-29, aluminum-26, and curium-244 for astrophysics research. DOE IP has also been supporting research and technical efforts to increase the availability of radioisotopes for next-generation nuclear power sources that could support applications in space, including americium-241, promethium-147, nickel-63, and strontium-90.

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5 A recent paper highlighting research at https://doi.org/10.1016/j.lssr.2022.09.001 describes the development of a galactic cosmic-ray simulator for modeling space missions.

6 The paper published by an international, multi-institutional team (https://www.nature.com/articles/s41526-024-00371-x#Sec8) found that the atomic structure of neodymium titanate glass processed on Earth was strikingly similar to that processed in microgravity aboard the International Space Station, but substantial differences are observed in microstructure, grain size, and crystalline phases due to differences in the melt process.

7 https://conf.goldschmidt.info/goldschmidt/2024/meetingapp.cgi/Paper/23152

Enable the Development of Space

The Office of Nuclear Incident Response's Consequence Management (CM) Program devoted a small amount of funding to supporting Space Nuclear Systems (SNS)–related tasks in FY 2024. The Federal Aviation Administration (FAA) included DOE in its review of the draft Advisory Circular, "Launch and Reentry of Space Nuclear Systems." The CM Program continues to support SNS and maintains communication with the DOE/NNSA Office of Non-Proliferation and Arms Control.

In FY 2024, DOE, through the Solar Energy Technologies Office (SETO), worked on reducing the cost and increasing the efficiency of III-V photovoltaic cells, as well as improving the efficiency and stability of perovskite solar cells, including perovskite cells on lightweight and flexible substrates. In FY 2024, the National Renewable Energy Laboratory (NREL) optimized III-V multijunction cell efficiency for terrestrial applications and reduced the cell costs through substrate reuse and alternative metallization. NREL continued to provide cell calibrations and measurements, including those under the AM0 (extraterrestrial) solar spectrum. In FY 2024, SETO served as Chair of the Interagency Advanced Power Group's Renewable Energy Conversion Working Group with focus groups on space solar and perovskite photovoltaics.

In FY 2024, DOE, through the Hydrogen and Fuel Cell Technologies Office, continued work to advance fuel cell technologies for heavy-duty terrestrial transportation applications with transferable benefits for aeronautical applications. Research, development, and demonstration activities focused on reducing cost and enhancing efficiency and durability for fuel cells. Efforts included the development of proton-exchange membrane fuel cells that can efficiently operate at higher temperatures to facilitate heat rejection during fuel cell operation, of particular interest to aeronautical applications.

Smithsonian Institution

The Smithsonian Institution continued to make internationally recognized contributions to national aerospace programs, discoveries, and public education in FY 2024. During that fiscal year, Smithsonian scientists wrote over 1,000 papers, more than half of which were completed with support from NASA. The Smithsonian Units contributing to this effort include the Smithsonian Astrophysical Observatory (SAO), the National Museum of Natural History, and the National Air and Space Museum (NASM). These efforts demonstrate the longstanding commitment of the Smithsonian to building world-leading space technology, producing groundbreaking discoveries, and disseminating knowledge about space through major education and public engagement programs.

The Smithsonian Astrophysical Observatory is a partner of the Center for Astrophysics | Harvard & Smithsonian (CfA) in Cambridge, Massachusetts, and represents the largest component of the Smithsonian's space contributors. The organization has over 500 scientists, engineers, and telescope staff engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education.

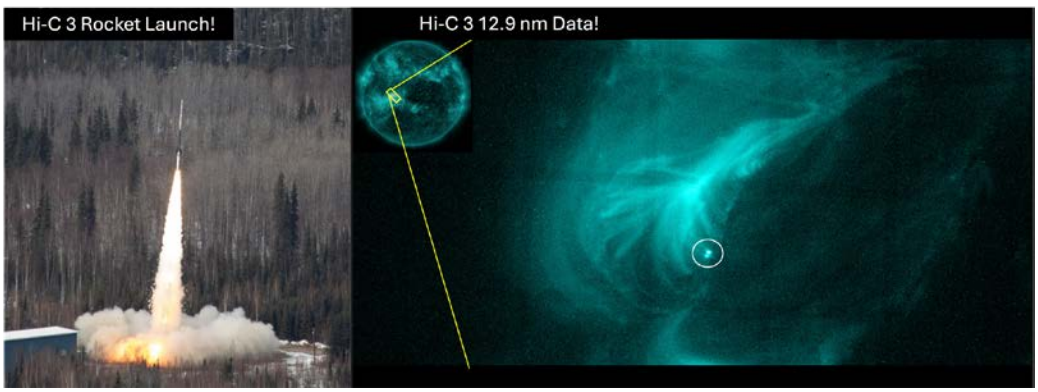
SAO has been a leader in x-ray astronomy since the field's inception several decades ago and operates the Chandra X-ray Observatory on behalf of NASA. Chandra—one of NASA's "Great Observatories" since its launch in 1999—continues to return significant revelations to scientists and the public alike as the world's preeminent x-ray observatory. This year, Chandra celebrated 25 years of successful operations in exploring the universe. Chandra results were shared widely in the press (over 3,900 articles since October 1, 2023) and across social media. Chandra data were made accessible to large audiences through a sonification project that translates astronomical data into sounds. These projects included concerts at the Las Vegas Sphere and an original documentary that premiered at the Smithsonian's Hirshhorn. Chandra images

were displayed prominently at stations in the Washington, DC, Metro system and in a special educational insert in *USA Today*.

In November 2023, SAO scientists announced the discovery of the most distant black hole ever found in x-ray light. By combining Chandra data with those from the James Webb observatory, astronomers probed the growth of a black hole just 470 million years after the Big Bang. This result may explain how some of the very first supermassive black holes in the universe formed. Chandra teamed up again with Webb in January 2024 to produce a spectacular new view of the Cassiopeia A supernova remnant. This stellar debris field 11,000 light-years from Earth shows how some stars end their lives and seed interstellar space with elements that are critical to the next generation of stars and planets.

SAO leads the Solar Wind Electrons, Alphas, and Protons (SWEAP) experiment, which is one of four instrument suites on board the NASA Parker Solar Probe mission. Parker is in the penultimate phase of its mission, and this year it approached the solar surface four times, each within a distance of about five times the Sun's diameter. For the solar eclipse of April 8, SAO coordinated with other solar observatories to study the features of the Sun's corona that then became visible to the naked eye during totality. SAO scientists conducted extensive outreach efforts, visiting schools, museums, and events along the path of totality to educate the public about the Sun, the SWEAP experiment, and other solar programs. In August 2024, the SAO team published a landmark finding in the journal *Science* showing that the wind permeating interplanetary space is heated and accelerated by powerful magnetic waves from the Sun. SAO provides experimental data and open-source data analysis tools for SWEAP, supporting nearly 100 academic publications this year alone.

SAO has partnered with NASA's Marshall Space Flight Center to lead a NASA sounding rocket telescope program that captures the sharpest images of the Sun in extreme ultraviolet

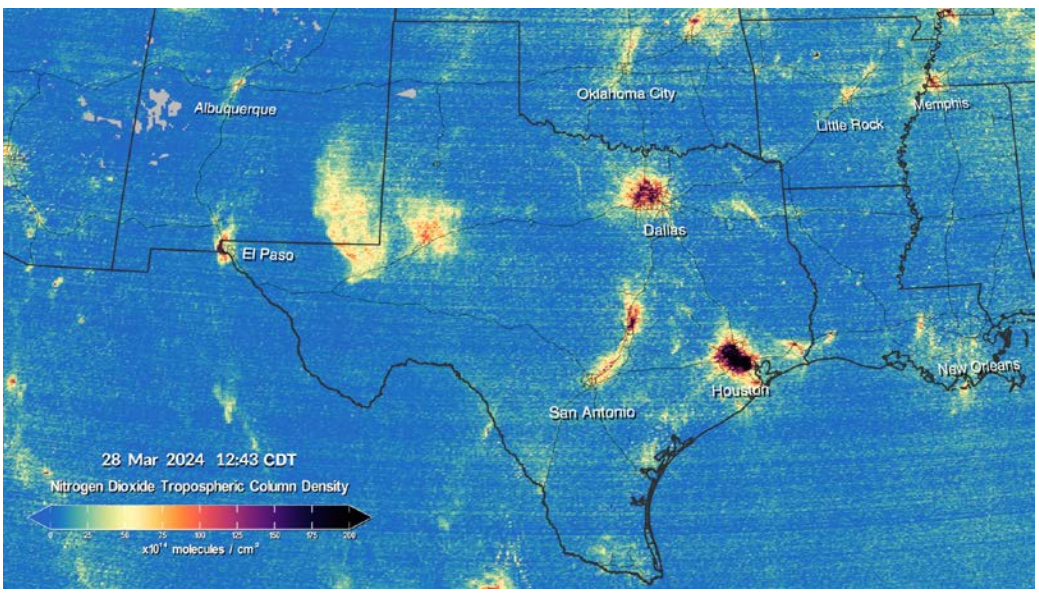


Left: Hi-C Flare rocket launch from Poker Flat, Alaska, on April 17, 2024. (Credit: NASA/LEE Wingfield) Right: Hi-C 3 high-resolution image of the Sun in the extreme ultraviolet. (Credit: Hi-C Flare Team at NASA Marshall Space Flight Center, Center for Astrophysics | Harvard & Smithsonian, and Montana State University)

light. The High-Resolution Coronal Imager (Hi-C 3) had its third launch on April 17, 2024, to observe x-ray and ultraviolet emission during a large solar flare.

The Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission is another SAO-NASA partnership with notable successes in FY 2024. TEMPO started its nominal operations in October 2023, kicking off a new era of air-quality monitoring over North America with hourly atmospheric pollution measurements at the neighborhood scale. Since then, TEMPO has remained in the public spotlight. TEMPO was selected as one of *TIME* magazine's 200 Best Inventions of 2023 that change how we live. The TEMPO team showcased TEMPO on White House Demo Day in November 2023 and again for the President's Council of Advisors on Science and Technology in January 2024.

TEMPO's high-quality, near-real-time air pollution data were released to the public in May 2024 through NASA's Atmospheric Science Data Center. The CfA's Cosmic Data Stories team released a new web-based tool to visualize TEMPO data and expand its use for education and public outreach. In addition to daytime pollution measurements, the TEMPO team developed the capability to perform nighttime observation of light pollution from city lights as a science bonus, which provides the unique capability to measure lighting types from space.

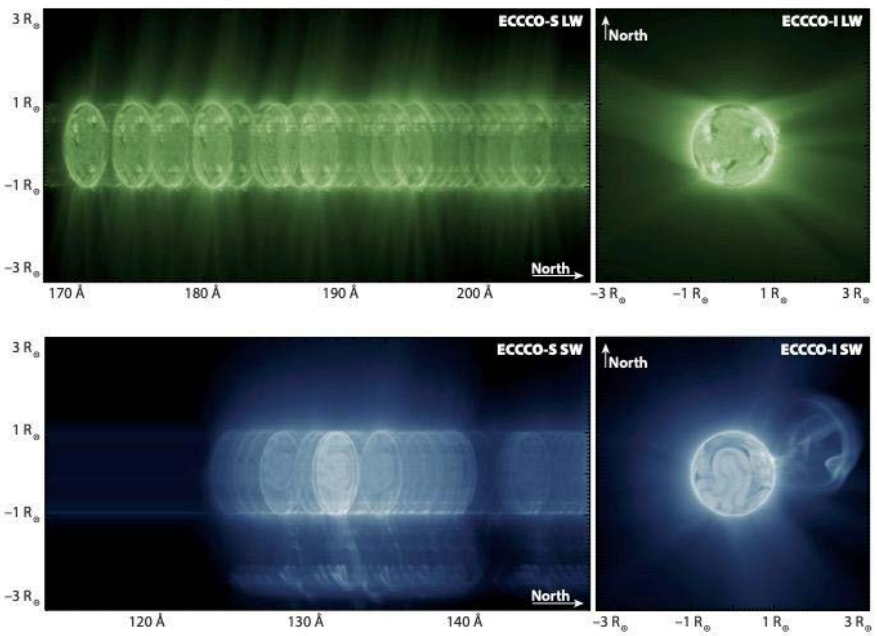


TEMPO has been measuring hourly scans of atmospheric pollution over North America at neighborhood scale since August 2, 2023. The image shows elevated nitrogen dioxide levels on March 28, 2024, along major traffic corridors, including the I-35 in Texas, across cities, from prescribed burns across East Texas and adjacent states, from the Permian basin (a large oil and natural-gas-producing area), and from coal-fired power plants in the rural areas far west and northwest of Houston and far east of Dallas. (Credits: NASA's Scientific Visualization Studio. Data provided by the Smithsonian Astrophysical Observatory at the Center for Astrophysics | Harvard & Smithsonian)

SAO plays a leading role in MethaneSAT, a mission funded by philanthropic donors to address climate change, and its airborne precursor MethaneAIR. MethaneAIR flew on a dedicated Learjet during May–October 2023 and measured methane emissions over 70 percent of U.S. oil and gas production areas. Data processing has been developed on the cloud platform from raw data, to radiance, to methane concentrations, and to methane emissions. MethaneAIR data are made publicly available on Google Earth Engine. MethaneAIR results show over four times higher emissions from oil and gas producers than estimates from the Environmental Protection Agency, and eight times those of oil and gas operators' emissions goals. MethaneSAT was successfully launched on March 4, 2024. MethaneSAT commissioning was completed in August 2024, with first light and initial ground targets collected. MethaneSAT will begin releasing public data in early 2025.

SAO leads the Extreme ultraviolet Coronal mass ejection and Coronal Connectivity Observatory (ECCCO), a mission developed for NASA's Heliophysics Small Explorer program. ECCCO is designed to study the rarely observed "middle corona," a region between 1.5 and 3 solar radii away from the surface of the Sun that is thought to be where the solar wind and solar eruptions are accelerated. The ECCCO Team submitted a Concept Study Report to NASA in September 2024.

The Smithsonian National Museum of Natural History continued, through the Department of Mineral Sciences and the Offices of Education and Exhibits, its mission of



Simulated ECCCO images. Top: Long-wavelength (LW) spectrograph (left) and imager (right). Bottom: Short-wavelength (SW) spectrograph (left) and imager (right) during a simulated coronal mass ejection. (Credit: ECCCO Concept Study Report to NASA)

(Credit: James DiLoreto, Smithsonian Institution)

education, research, and curation related to space exploration. In a regular year, approximately 1 million people visit the Moon, Meteorites and Solar System Gallery of the Geology, Gems and Meteorites Hall, where they can see one of the finest displays of meteorites anywhere in the world.

After a three-year hiatus due to COVID, the Antarctic Search for Meteorites resumed in FY 2024 (austral summer 2023–24) with a collection of meteorites on the blue ice fields of Antarctica. This effort, part of the joint NASA-NSF-Smithsonian U.S. Antarctic Meteorite Program, has been collecting meteorites since 1977 and has recovered nearly 24,000 individual meteorites. The Smithsonian provides classification of all meteorites and long-term curation, providing both information and samples to the scientific community.

In November 2023, the Smithsonian exhibited the first public sample of asteroid (101955) Bennu, less than six weeks after their return to Earth by NASA's OSIRIS-REx Discovery mission. NASA Administrator Sen. Bill Nelson attended the case unveiling, which was widely covered by national and international media. An accompanying video at the exhibit highlights both the mission and the cutting-edge science occurring on Bennu samples by Smithsonian scientists.

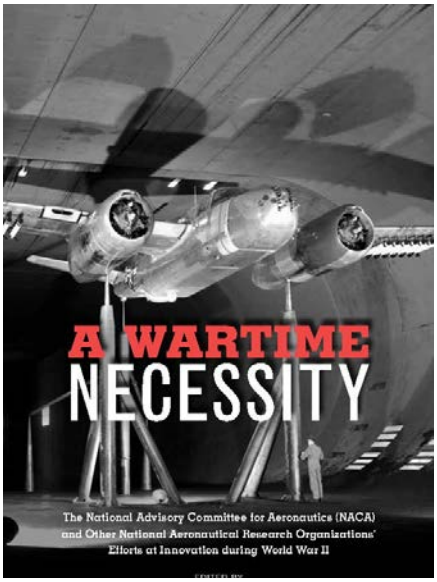
In FY 2024, National Air and Space Museum curators, scientists, and educators advanced their respective fields during the major Transformation project, which is opening new exhibit galleries throughout the Museum's National Mall Building (NMB).

The Aeronautics Department concentrated on aviation-related galleries in the center and east end of the NMB. The Boeing Milestones of Flight Hall and Barron Hilton Pioneers of Flight gallery are scheduled to open in 2025. The new World War I: The Birth of Military Aviation, Jay I. Kislak World War II in the Air, and Modern Military Aviation galleries will follow, along with the How Things Fly interactive gallery, which was developed by the NASM Education Department in cooperation with the Aeronautics Department. New permanent and temporary exhibitions in the Flight in the Arts gallery complement these efforts.

In support of these endeavors, the Aeronautics Department collected several new artifacts. Dr. Roger Connor collected several remotely piloted drones for the forthcoming Climate Change gallery, including a Yamaha RMAX Type II G Agricultural Spray Drone, an AgEagle eBee X Drone, an AeroVironment Quantix Mapper Drone, and an XAG V50 Agricultural Spray and Seeding Drone. Dr. Alex Spencer collected a rare Royal Air Force sector clock and plotting map pieces for the new World War II gallery. Dorothy Cochrane acquired personal effects, memorabilia, and archival material from famed female pilot and astronaut Wally Funk, as well as an archival and memorabilia collection from Matilde Moisant, an early pioneer female aviator who flew before the First World War. She acquired the Brunner-Winkle Bird Model BK aircraft in which Anne Morrow Lindbergh learned to fly. Associate Director Jeremy Kinney collected the Mong Sport Biplane Racer Full Tilt Boogie #40 homebuilt aircraft that won nine National Championships, including the first National Championship won by a woman in air racing in 1993. Another significant acquisition by Dr. Alex Spencer was the prestigious Navy Cross awarded to Lt. (j.g.) Rollin Batten Jr. for rescuing two downed aviators off the coast of Guam on July 4, 1944.

Scientific research at the Museum's Center for Earth and Planetary Studies included roles on nine current and future planetary mission teams. Active missions include the Lunar Reconnaissance Orbiter, the Mars Reconnaissance Orbiter, the Curiosity Mars rover, OSIRIS-APophis EXplorer, the Jupiter Icy Moons Explorer, and the Europa Clipper mission to Jupiter's second-largest moon. Museum scientists are contributing to the development of the upcoming VERITAS and DAVINCI missions to Venus, along with the Dragonfly mission to Saturn's moon Titan.

The Aeronautics Department supported the Aviation Adventures Lecture Series, which featured prominent authors and participants. Their presentations spoke to the important role played by Pan American flight attendants during the Cold War and the Vietnam War; the life story of pioneer female aviator Jerrie Mock, who became the first woman to fly solo around the world; and the successful struggle of female military pilots to gain full equality with the right to fly combat aircraft.



Edited by curator Dr. Alex Spencer and published by NASA, *A Wartime Necessity: The National Advisory Committee for Aeronautics (NACA) and Other National Aeronautical Research Organizations' Efforts at Innovation During World War II* included four chapters by NASM Aeronautics Department scholars. (Credit: NASA)

Aside from meteorites that fall to Earth randomly, direct analysis of solar system materials has required explorers—both human and robotic—to collect and return samples from other planetary bodies. The four 2024 Exploring Space Lectures spotlighted the sample return missions that have helped humanity to better understand the origin and evolution of Earth and other planets. A total of 891 people attended on-site, and the online offering had 1,013 peak views across the series.

NASM Education continued to spark curiosity and empower learners to imagine possibilities of the future. The corps of paid youth, the Explainers, facilitated drop-in, hands-on learning experiences for over 780,000 visitors. Facilitated activities range from understanding life and work in space to exploring the principles of flight through a paper-airplane-flying contest.

On April 8, 2024, for the astronomical event of the year, more than 15,000 people gathered on the National Mall to attend the Solar Eclipse Festival. About 25,000 solar eclipse glasses were distributed on-site at each Museum location the day of the festival, on top of more than 35,000 pairs distributed in the weeks leading up to the eclipse. NASM educators gave 12 radio and television interviews, and the event was spotlighted on the evening news and garnered national attention. In addition to on-site outreach the day of the eclipse, 154,938 individuals tapped into the digital resources on https://airandspace.si.edu.

The Museum's podcast, AirSpace, cultivates young professionals who have not traditionally seen themselves as a NASM audience by adding creativity and depth to regular air and space content with new, unexpected, and inspirational stories. Topics explored during the past year included Moon rocks, celebrities with ties to air and space, and the Chandra X-ray Observatory, with over 170,000 views across the year.

Appendices

Appendix A-1

U.S. Spacecraft Record

(Includes spacecraft from cooperating countries launched by U.S. launch vehicles.)

Calendar Year	Earth Orbit[a]		Earth Escape[b]	
	Success	Failure	Success	Failure
1957	0	1	0	0
1958	5	8	0	4
1959	9	9	1	2
1960	16	12	1	2
1961	35	12	0	2
1962	55	12	4	1
1963	62	11	0	0
1964	69	8	4	0
1965	93	7	4	1
1966	94	12	7	1[b]
1967	78	4	10	0
1968	61	15	3	0
1969	58	1	8	1
1970	36	1	3	0
1971	45	2	8	1
1972	33	2	8	0
1973	23	2	3	0
1974	27	2	1	0
1975	30	4	4	0
1976	33	0	1	0
1977	27	2	2	0
1978	34	2	7	0
1979	18	0	0	0
1980	16	4	0	0
1981	20	1	0	0
1982	21	0	0	0
1983	31	0	0	0
1984	35	3	0	0
1985	37	1	0	0
1986	11	4	0	0
1987	9	1	0	0
1988	16	1	0	0
1989	24	0	2	0
1990	40	0	1	0
1991	32[c]	0	0	0
1992	26[c]	0	1	0
1993	28[c]	1	1	0
1994	31[c]	1	1	0
1995	24[c, d]	2	1	0
1996	30	1	3	0
1997	22[e]	0	1	0
1998	23	0	2	0
1999	35	4	2	0
2000	31[f]	0	0	0
2001	23	0	3	0
2002	18	0	0	1[b]
2003	28[c, f]	0	2	0
2004	8[c]	0	1	0
2005	10	0	2	0
2006	20[d]	0	2	0
2007	16	2	2	0
2008	22[f]	0	0	0

(continued)

Appendix A-1: U.S. Spacecraft Record (continued)

Calendar Year	Earth Orbit[a]		Earth Escape[b]	
	Success	Failure	Success	Failure
2009	24[f]	1	0	0
2010	15	0	0	0
2011	16	1	3	0
2012	13	0	0	0
2013	18	0	1	0
2014	22	1	0	0
2015	12	1	1	0
2016	27	3	2	0
2017	20	1	0	0
2018[g]	33	0	3	0
2019[g]	21	0	0	0
2020[f,g]	32	3	2	0
2021[f,g]	45	3	3	0
2022[f,g]	81	2	4	0
2023[f,g]	108	6	2	0
2024[f,g,h]	153	0	5	0
TOTAL	**2,268**	**177**	**132**	**16**

a. The criterion of success or failure used is attainment of Earth orbit or Earth escape rather than judgment of mission success. "Escape" flights include all that were intended to go to at least an altitude equal to lunar distance from Earth.
b. This Earth-escape failure did attain Earth orbit and, therefore, is included in the Earth-orbit success totals.
c. This excludes commercial satellites. It counts separately spacecraft launched by the same launch vehicle.
d. This counts various sets of microsatellites as a single payload.
e. This includes the Small Spacecraft Technology Initiative (SSTI) Lewis spacecraft that began spinning out of control shortly after it achieved Earth orbit.
f. This includes American spacecraft not launched in the United States.
g. Totals indicate number of launches rather than enumerating individual objects launched.
h. Includes four near-orbital Starship test launches.

Appendix A-2

World Record of Space Launches Successful in Attaining Earth Orbit or Beyond

(Enumerates launches rather than spacecraft; some launches orbited multiple spacecraft.)[a]

Calendar Year	United States[b]	USSR/CIS	France[c]	Italy[c]	Japan	People's Republic of China	Australia	United Kingdom[c]	European Space Agency	India	Israel	Iran	North Korea	South Korea	New Zealand
1957		2													
1958	5	1													
1959	10	3													
1960	16	3													
1961	29	6													
1962	52	20													
1963	38	17													
1964	57	30													
1965	63	48	1												
1966	73	44	1												
1967	57	66	2	1			1								
1968	45	74													
1969	40	70													
1970	28	81	2	1	1	1									
1971	30	83	1	2	2	1		1							
1972	30	74		1	1										
1973	23	86													
1974	22	81		2	1										
1975	27	89	3	1	2	3									
1976	26	99			1	2									
1977	24	98			2										
1978	32	88			3	1									
1979	16	87			2				1						
1980	13	89			2					1					
1981	18	98			3	1			2	1					
1982	18	101			1	1									
1983	22	98			3	1			2	1					
1984	22	97			3	3			4						
1985	17	98			2	1			3						
1986	6	91			2	2			2						
1987	8	95			3	2			2						
1988	12	90			2	4			7						
1989	17	74			2				7		1				
1990	27	75			3	5			5		1				
1991	20	62			2	1			9	1					
1992	31	55			2	3			7	2					

(continued)

Appendix A-2: World Record of Space Launches Successful in Attaining Earth Orbit or Beyond (continued)

Calendar Year	United States[b]	USSR/CIS	France[c]	Italy[c]	Japan	People's Republic of China	Australia	United Kingdom[c]	European Space Agency	India	Israel	Iran	North Korea	South Korea	New Zealand
1993	24	45			1	1			7						
1994	26	49			2	5			6	2					
1995	27	33			1	2			12		1				
1996	32	25			1	3			10	1					
1997	37	28			2	6			12	1					
1998	34	24			2	6			11						
1999	32	26				4			10	1					
2000	30	34				5			12						
2001	23	23			1	1			8	2					
2002	18	23			3	4			11	1	1				
2003	26	21			2	6			4	2					
2004	19	22				8			3	1					
2005	16	26			2	5			5	1					
2006	15	16			5	3			5						
2007	25	33			3	13			8	3	1				
2008[d]	19	26			1	11			7	3					
2009	25	29			3	4			9	4		1			
2010	15	30			2	15			6	1	1				
2011	17	33			3	18			7	3		1			
2012	13	27			2	19			10	2		1	1		
2013	19	29			3	14			7	3				1	
2014	22	31			4	16			10	4	1				
2015	18	24			4	19			11	5		1			
2016	22	16			4	21			11	7	1		1		
2017	29	18			6	17			11	4					
2018	31	16			6	38			11	7					3
2019	21	22			2	32			8	6					6
2020	34	15			4	35			6	2	1	1			6
2021	43	24			3	52			7	1					5
2022	76	21				62			5	4		1		1	9
2023	104	19			2	66			3	7	1	1	1	2	6
2024	145[f]	17			4	66			3	5		4			13
TOTAL	**1,866**	**3,198**	**10**	**8**	**123**	**609**	**1**	**1**	**307**	**89**	**10**	**11**	**3**	**4**	**48**

a. This includes commercial expendable launches and launches of the Space Shuttle as well as launches to useless orbit.
b. Launches from U.S.-Russia joint platform are included in U.S. totals.
c. Since 1979, all launches for ESA member countries have been joint and are listed under ESA.
d. Since 2008, the ESA statistics include the Soyuz launches from Guiana Space Centre.
e. Electron launches from New Zealand are listed under New Zealand.
f. Includes four near-orbital Starship test launches.

Appendix B-1

Successful Launches to Orbit or Beyond on U.S. Vehicles

October 1, 2023–September 30, 2024 (FY 2024)

Launch Date COSPAR[a] Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
October 5, 2023 2023-153 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-21-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
October 6, 2023 2023-154 *Atlas-5(501)*	KuiperSat P1 and P2	Technology Demonstration	Launch of two initial prototype satellites in Amazon's Project Kuiper satellite constellation.
October 9, 2023 2023-156 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-4-1 to -21	Communications	Launch of 21 Starlink v2-Mini satellites.
October 13, 2023 2023-157 *Falcon-Heavy Block 5(px)*	Psyche	Asteroid Exploration	NASA mission to the asteroid Psyche.
October 13, 2023 2023-158 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-22-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
October 18, 2023 2023-160 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-23-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
October 21, 2023 2023-161 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-5-1 to -21	Communications	Launch of 21 Starlink v2-Mini satellites.
October 22, 2023 2023-162 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-24-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
October 29, 2023 2023-166 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-6-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
October 30, 2023 2023-167 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-25-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
November 4, 2023 2023-170 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-26-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
November 8, 2023 2023-171 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-27-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
November 10, 2023 2023-173 *Falcon-9 v1.2 Block 5*	Dragon CRS-29 AWE ILLUMA-T BEAK Clark-sat 1 (AMBITIOUS)	ISS Logistics Earth Observation Communications Technology Demonstration Education	Resupply mission to the ISS with two instruments to be mounted on the exterior of the station and two CubeSats deployed the following month.

a. U.N. Committee on Space Research.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
November 11, 2023 2023-174 *Falcon-9 v1.2 Block 5*	ICEYE X31, X32, X34, X35 Umbra-SAR 07 and 08 Pelican 1 (Pelican 3001) FalconSat 10 (FS 10) SPIP Aether 1 and 2 ION-SCV 013 (Ultimate Hugo) EPICHyper 3 Intuition 1 Crypto3 OSW Cazorla Ymir 1 (AAC-AIS-SAT 3) Pico 1A-1 to 9 Unicorn 2J and 2K Hydra 1 (HADES D) ROM 3 SpaceANT-D Tartan Artibeus 2 Mira SN2 (LEO Express 1) Time We'll Tell SpaceVan 001 EXO 0 GHGSat C9, C10, and C11 Observer 1A ProtoMéthée MANTIS BRO 10 and 11 Connecta T3.1 and T3.2 GENMAT 1 NinjaSat OrbAstro PC1 and TR1 PEARL 1C and 1H Platero Platform 5 Tiger 5 and 6 Lemur-2 174 to 181 Aman 1 (STORK-7) Barry 1 (B1B2) Flock-4q 1 to 36 Heron Mk.2 IRIS C2 KAFASAT OMNI-LER1 Outpost Mission 2 JinjuSat 1 Djibouti 1A Picacho Veronika Hello Test 1 and 2	Earth Observation Earth Observation Earth Observation Technology Demonstration Earth Observation Communications CubeSat Deployer Earth Observation Earth Observation Blockchain Astrobiology Technology Demonstration Internet of Things Earth Observation Amateur Radio Amateur Radio Internet of Things Technology Demonstration CubeSat Deployer Navigation Space Tug Technology Demonstration Earth Observation Earth Observation Earth Observation Earth Observation Signals Intelligence Internet of Things Earth Observation X-ray Astronomy Technology Demonstration Technology Demonstration Earth Observation Payload Hosting Internet of Things Technology Demonstration Earth Observation Debris Removal Earth Observation Amateur Radio Technology Demonstration Earth Observation Technology Demonstration Technology Demonstration Earth Observation Meteorology Technology Demonstration Earth Observation Technology Demonstration	Dedicated SmallSat ride-share mission. Picacho, JinjuSat 1, and Aman-1 failed to deploy.
November 12, 2023 2023-175 *Falcon-9 v1.2 Block 5*	O3b mPower 5 and 6	Communications	Part of a second-generation terabit-per-second constellation on inclined equatorial orbit.
November 18, 2023 2023-177 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-28-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
November 20, 2023 2023-178 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-7-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
November 22, 2023 2023-180 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-29-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
November 28, 2023 2023-183 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-30-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
December 1, 2023 2023-185 *Falcon-9 v1.2 Block 5*	425 Project EO/IR Sat 1 (KORSAT 7) *μ*HETsat GNOMES 4 KOYOH Bane ION-SCV 015 ALISIO 1 LOGSATS NanoFF A and B (Tubsat 28) Unicorn 2L, 2M, and 2N MDQube-SAT 1 SpIRIT EIRSAT 1 Lilium 1 ENSO (ROBUSTA 1E) Hayasat 1	EO/IR Reconnaissance Technology Demonstration Radio Occultation X-ray Astronomy Technology Demonstration CubeSat Deployer Earth Observation Internet of Things Technology Demonstration Earth Observation Internet of Things Gamma-Ray Astronomy Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration	Dedicated rideshare mission with 25 total spacecraft aboard, including South Korea's reconnaissance satellite and first Irish satellite. Remaining 9 payloads unknown.
December 3, 2023 2023-186 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-31-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
December 7, 2023 2023-191 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-33-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
December 8, 2023 2023-192 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-8-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
December 15, 2023 2023-196 *Electron KS*	QPS-SAR 5 (Tsukuyomi 1)	Earth Observation	First successful launch in a constellation of Japanese SAR satellites.
December 19, 2023 2023-200 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-34-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
December 22, 2023 2023-202 *Firefly-Alpha*	Tantrum (ESA-Demo, Tyvak 1015)	Technology Demonstration	Electronically Steerable Antenna demonstration.
December 23, 2023 2023-203 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-32-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
December 24, 2023 2023-204 *Falcon-9 v1.2 Block 5*	SARah 2 and 3 (SARah-Passiv FM 1 and 2)	Reconnaissance	Antennas on both satellites failed to deploy.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
December 29, 2023 2023-210 *Falcon-Heavy Block 5(px)*	X-37B OTV-7 (USA 349, USSF 52)	Military Communications	Flight of the X-37B spaceplane for USSF-52, lasting 434 days.
December 29, 2023 2023-211 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-36-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
January 3, 2024 2024-002 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-9-1 to -15 Starlink v2-Mini-D2C T1-1 to -6	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
January 3, 2024 2024-003 *Falcon-9 v1.2 Block 5*	Ovzon 3	Communications	Swedish broadband satellite.
January 7, 2024 2024-005 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-35-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
January 8, 2024 2024-006 *Vulcan Centaur VC2S*	Peregrine 1 (CLPS 1) Celestis 20	Lunar Lander Memorial Spaceflight	Propellant leak from lander prevented lunar landing.
January 14, 2024 2024-011 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-10-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
January 15, 2024 2024-012 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-37-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
January 18, 2024 2024-014 *Falcon-9 v1.2 Block 5*	Crew Dragon Axiom 3	Space Tourism	Private crewed mission carrying four crewmembers to the International Space Station (see Appendix C).
January 24, 2024 2024-017 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-11-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
January 29, 2024 2024-019 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-38-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
January 29, 2024 2024-020 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-12-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
January 30, 2024 2024-021 *Falcon-9 v1.2 Block 5*	Cygnus CRS-20	ISS Logistics	Delivered scientific research, crew supplies, and hardware to the ISS.
January 31, 2024 2024-022 *Electron KS (R)*	Skylark 1 to 4 (Lemur-2 182 to 185)	Space Situational Awareness	Detects other satellites and debris in orbit to provide more data on the growing orbital debris problem.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
February 8, 2024 2024-025 *Falcon-9 v1.2 Block 5*	PACE	Earth Observation	Plankton, Aerosol, Cloud, Ocean Ecosystem satellite used to understand carbon dioxide exchange between oceans and atmosphere.
February 10, 2024 2024-027 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-13-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
February 14, 2024 2024-028 *Falcon-9 v1.2 Block 5*	HBTSS 1 (USSF 124) and 2 T0TR 5 to 8 (Raptor 1 to 4)	Early Warning Missile Tracking	Track and target threats and target enemy missiles, including hypersonic missile systems (Space Development Agency).
February 15, 2024 2024-030 *Falcon-9 v1.2 Block 5*	Nova-C IM-1 (CLPS 2, TO2-IM, Odysseus) EagleCam	Lunar Lander Education	Intuitive Machines lunar landing mission for NASA's Commercial Lunar Payload Services (CLPS) program. First soft lunar landing by a private company.
February 15, 2024 2024-031 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-14-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
February 18, 2023 2024-034 *Electron KS*	ADRAS-J	Space Debris Removal	Japanese spacecraft to demonstrate core technologies to be used in active debris removal.
February 20, 2024 2024-035 *Falcon-9 v1.2 Block 5*	Merah Putih 2 (HTS-113BT)	Communications	Indonesian broadband access satellite.
February 23, 2024 2024-036 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-15-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
February 25, 2024 2024-038 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-39-1 to -24	Communications	Launch of 24 Starlink v2-Mini satellites
February 28, 2024 2024-041 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-40-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 4, 2024 2024-042 *Falcon-9 v1.2 Block 5*	Crew Dragon 8	Crewed Spaceflight	Eighth operational NASA Commercial Crew flight to the International Space Station (see Appendix C).

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
March 4, 2024 2024-043 *Falcon-9 v1.2 Block 5*	MethaneSAT Jackal X-1L-001 and -002 Aries 1 (Call to Adventure) Quark-Lite Gluon Lizzie Sat 1 MuSat 2 ICEYE X36, X37, X38 GHOSt 4 and 5 ÑuSat 44 YAM 6 Rose (VSP Rose) Fifi, Loulou, Riri (VSP RF A1, B1, C1) Lynk Tower 05 and 06 Optimus OTV 2 Pyxis Scout 1 (Sentry) ContecSat 1 (Oreum) HORACIO Hubble 1 and 2 (Lemur-2 182 and 183) EWS-RROCI 2 Pony Express 2A and 2B BRO 12 and 13 HAMMER (IOD 6) LaCE 1 and 2 OrbAstro TR2 SONATE 2 Tiger 7 and 8 IRIS F1 M3 Lemur-2 184 and 185 AEROS MH-1 PY4 1 to 4 Veery 0E ONDOSAT-OWL 1 and 2	Earth Observation Technology Demonstration Payload Hosting Space Docking Space Docking Technology Demonstration Technology Demonstration Earth Observation Earth Observation Earth Observation Payload Hosting Signals Intelligence Earth Observation Communications Space Tug Technology Demonstration Space Domain Awareness Earth Observation Earth Observation Earth Observation Technology Demonstration Technology Demonstration Signals Intelligence Earth Observation Technology Demonstration Technology Demonstration Technology Demonstration Internet of Things AIS Ship Tracking Technology Demonstration Earth Observation Earth Observation Technology Demonstration Meteorology Amateur Radio	Dedicated rideshare mission carrying 53 payloads into orbit.
March 4, 2024 *2024-044* *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-41-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 10, 2024 2024-045 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-43-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 11, 2024 2024-046 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-17-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 12, 2024 2024-047 *Electron KS*	StriX 3	Earth Observation	Launched from New Zealand.
March 14, 2024 2024-U01 *Starship B10/S28*	Starship S28	Flight Test	Third Starship vehicle test.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
March 16, 2024 2024-049 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-44-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 19, 2024 2024-050 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-16-1 to -20 USA 350 and 351	Communications Unknown	Launch of 20 Starlink v2-Mini satellites and two small military satellites of unknown purpose.
March 21, 2024 2024-053 *Electron KS*	USA 352 (NROL 123) AeroCube 16A and 16B Mola	Technology Demonstration/ Unknown Technology Demonstration Technology Demonstration	Launched from Wallops Island.
March 21, 2024 2024-054 *Falcon-9 v1.2 Block 5*	Dragon CRS-30 Burstcube HyTI SNoOPI Big Red Sat 1 (BRS 1) CURTIS MicroOrbiter 1 (MO 1) Kashiwa Killick 1 QMSat (UdeSat) VIOLET (CubeSat NB)	ISS Logistics Gamma-Ray Burst Study Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Earth Observation Technology Demonstration Space Weather	NASA/SpaceX cargo resupply mission to ISS with 10 CubeSats for deployment from the station in April 2024.
March 24, 2024 2024-056 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-42-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 25, 2024 2024-057 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-46-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
March 30, 2024 2024-059 *Falcon-9 v1.2 Block 5*	Eutelsat 36D	Communications	Satellite placed in geostationary transfer orbit.
March 31, 2024 2024-060 Falcon-9 v1.2 Block 5	Starlink v2-Mini G6-45-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 2, 2024 2024-062 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G7-18-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
April 5, 2024 2024-064 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-47-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 7, 2024 2024-065 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-1-1 to -15 Starlink v2-Mini-D2C T2-1 to -6	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
April 7, 2024 2024-066 *Falcon-9 v1.2 Block 5*	425 Project SAR Sat 1 Capella 14 (Capella Acadia 4) QPS-SAR 7 (Tsukuyomi 2) Centauri 6 Hawk 8A, 8B, 8C, 9A, 9B, and 9C TSAT 1A	Reconnaissance Earth Observation Earth Observation Internet of Things Signals Intelligence Earth Observation	Initial "Bandwagon" rideshare mission carrying 11 payloads.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
April 9, 2024 2024-067 *Delta-4H (upg.)*	USA 353 (NROL 70)	Reconnaissance	Final ignition of the Delta-4H rocket.
April 10, 2024 2024-068 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-48-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 11, 2024 2024-070 *Falcon-9 v1.2 Block 5*	WSF-M 1 (USSF 62)	Space Weather	First satellite in the Weather System Follow-on program.
April 13, 2024 2024-071 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-49-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 17, 2024 2024-073 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-51-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 18, 2024 2024-074 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-52-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 23, 2024 2024-076 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-53-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
April 23, 2024 2024-077 *Electron KS*	NEONSAT 1 ACS3	Earth Observation Technology Demonstration	Launch from Rocket Lab Launch Complex 1 in Mahia, New Zealand; both Korean payloads.
April 28, 2024 2024-079 *Falcon-9 v1.2 Block 5(ex)*	Galileo 29 and 30	Navigation	First of two planned launches to deploy new European Galileo constellation in medium Earth orbit.
April 28, 2024 2024-080 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-54-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 2, 2024 2024-081 *Falcon-9 v1.2 Block 5*	WorldView-Legion 1 and 2	Earth Observation	First of a planned six-satellite network.
May 3, 2024 2024-082 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-55-1 to G6-55-23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 6, 2024 2024-084 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-57-1 to G6-57-23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 8, 2024 2024-086 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-56-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
May 10, 2024 2024-088 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-2-1 to -7 Starlink v2-Mini-D2C G8-2-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
May 13, 2024 2024-090 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-58-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 14, 2024 2024-091 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-7-1 to -7 Starlink v2-Mini-D2C G8-7-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
May 18, 2024 2024-093 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-59-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 22, 2024 2024-096 *Falcon-9 v1.2 Block 5*	USA 354 to 374 (NROL 146)	Reconnaissance	Undisclosed number of small spacecraft.
May 23, 2024 2024-097 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-62-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 24, 2024 2024-098 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-63-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 25, 2024 2024-099 *Electron KS*	PREFIRE 1	Meteorology	Launched from Mahia, New Zealand.
May 28, 2024 2024-100 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-60-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
May 28, 2024 2024-101 *Falcon-9 v1.2 Block 5*	EarthCARE (Earth Explorer 6, Hakuryu)	Earth Observation	European climate satellite.
June 1, 2024 2024-106 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G6-64-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
June 5, 2024 2024-107 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-5-1 to -7 Starlink v2-Mini-D2C G8-5-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
June 5, 2024 2024-108 *Electron KS*	PREFIRE 2	Meteorology	Launch from Mahia, New Zealand; second of two planned launches.
June 5, 2024 2024-109 *Atlas-5(N22)*	Starliner CFT	Crewed Flight Test	Space Force Station, Cape Canaveral, FL; first crewed mission (see Appendix C).
June 6, 2024 2024-U02 *Starship B11/S29*	Starship S29	Flight Test	Fourth flight test of Starship.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
June 8, 2024 2024-111 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-1-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
June 8, 2024 2024-112 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-8-1 to -7 Starlink v2-Mini-D2C G8-8-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
June 19, 2024 2024-113 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-1-1 to -7 Starlink v2-Mini-D2C G9-1-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
June 20, 2024 2024-114 *Electron KS*	Kinéis 1A to 1E	Internet of Things	First launch of European constellation of 25 satellites.
June 20, 2024 2024-115 *Falcon-9 v1.2 Block 5*	Astra 1P/SES 24	Communications	European TV satellite; 250th droneship landing of Falcon first stage.
June 23, 2024 2024-117 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-2-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.
June 24, 2024 2024-118 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-2-1 to -7 Starlink v2-Mini-D2C G9-2-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
June 25, 2024 2024-119 *Falcon-Heavy Block 5(px)*	GOES 19 (GOES U)	Meteorology	Fourth and final NOAA GOES-R series.
June 27, 2024 2024-120 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-3-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
June 29, 2024 2024-121 *Falcon-9 v1.2 Block 5*	USA 375 to 395 (NROL 186)	Reconnaissance	Second mission launch of proliferated satellite system.
July 3, 2024 2024-124 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-9-1 to -7 Starlink v2-Mini-D2C G8-9-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
July 4, 2024 2024-125 *Firefly-Alpha*	CatSat R5 S2-2.0 R5 S4 TechEdSat 11 (TES 11) KUbeSat 1 MESAT 1 Serenity (3) SOC-i	Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Ionospheric Research Earth Observation Education Technology Demonstration	Payload deployment sequence as part of Venture-Class Launch Services Demonstration 2 contract with NASA.
July 8, 2024 2024-127 *Falcon-9 v1.2 Block 5*	Türksat 6A	Communications	First Turkish indigenous and national communication satellite.
July 12, 2024 2024-129 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-3-1 to -7 Starlink v2-Mini-D2C G9-3-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
July 27, 2024 2024-131 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-9-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
June 28, 2024 2024-132 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-4-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
June 28, 2024 2024-133 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-4-1 to -21	Communications	Launch of 21 Starlink v2-Mini satellites.
July 30, 2024 2024-134 *Atlas-5(551)*[2]	USA 396, 397, and 398 (USSF 51)	National Security	Fifty-eighth and final national security launch on Atlas and Delta rockets.
August 2, 2024 2024-136 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-6-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
August 2, 2024 2024-137 *Electron KS*	StriX 4	Communications	Japanese satellite in low Earth orbit; launched from New Zealand.
August 8, 2024 2024-138 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G11-1-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.
August 8, 2024 2024-139 *Falcon-9 v1.2 Block 5*	Cygnus CRS-21 CySat 1 DORA Binar 2, 3, 4 Emma Sagansat 0 Sakura Wisseed Sat	ISS Logistics Education Education/Amateur Radio Education Amateur Radio? Education Communication Education	ISS resupply mission with 9 CubeSats for deployment from the space station.
August 10, 2024 2024-141 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-3-1 to -8 Starlink v2-Mini-D2C G8-3-1 to -13	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
August 11, 2024 2024-142 *Electron KS*	Capella 13 (Capella Acadia 3)	Earth Observation	"A Sky Full of SARs" mission launch honoring support and dedication to synthetic aperture radar (SAR) imagery in Europe.
August 12, 2024 2024-143 *Falcon-9 v1.2 Block 5*	ASBM 1 and 2 (GX 10A, EPS-R 1) and (GX 10B, EPS-R 2)	Communications	Arctic Satellite Broadband Mission 1 and 2 provide enhanced coverage to the Arctic region for U.S. Space Force and Space Norway.
August 12, 2024 2024-144 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-7-1 to -23	Communications	Launch of 23 Starlink v2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
August 15, 2024 2024-146 *Falcon-9 v1.2 Block 5*	WorldView-Legion 3 and 4	Earth Observation/ Intelligence	Maxar's newest fleet of satellites, 30-cm resolution.
August 16, 2024 2024-149 *Falcon-9 v1.2 Block 5*	Capella 15 (Capella Acadia 5) Tyche AWS (Arctic Weather Satellite) QPS-SAR 8 (Amateru 4) YAM 7 (VanZyl 1) Tanager 1 EagleEye Umbra-SAR 09 and 10 ICEYE X33, X39, X40, X43 ŇuSat 48 to 50 GNOMES 5 Hawk 10A, 10B, 10C LUR 1 ION-SCV 012 Lemur-2 190 to 196 Sedna 1 ERNST CAKRA 1 BRO 14 and 15 Connecta-IoT 1 to 4 CUAVA 2 Hyperfield 1 HYPSO 2 Iperdrone.0 (David, Tyvak 0415) Kanyini (SASAT 1) Lemu Nge Φ-sat 2 (PhiSat 2) PTD 4 (LISA-T) PTD R (PTD 5) Sateliot 1 to 4 Tomorrow MS1 and MS2 TROOP F2 (Celestis 24) WaratahSeed 1 (WS 1) WREN 1 Flock-4be 1 to 36 Nightjar (Nanoavionics SDR) QUBE SATORO T2 TORO (Nanoavionics RGB) Deimos (Aethero) OreSat 0.5 GaindéSat 1A Pico 1B-1 to 9 GNA-3 UM5-EOSat UM5Sat-Ribat	Earth Observation Military Technology Demonstration Earth Observation Earth Observation Earth Observation Earth Observation Earth Observation Earth Observation Earth Observation Meteorology Transportation Technology Technology Demonstration Earth Observation Traffic/ Meteorology Traffic Monitoring Technology Earth Observation Maritime Surveillance Communications Navigation Earth Observation Earth Observation Technology Demonstration Earth Observation Earth Observation Technology Demonstration Technology Demonstration Technology Demonstration Communication Meteorology Technology/Memorial Spaceflight Technology Earth Observation Earth Observation Internet of Things Amateur Radio Technology Demonstration Earth Observation Technology Demonstration Technology Demonstration Earth Observation Internet of Things Technology Demonstration Earth Observation Technology Demonstration	Transporter-11 rideshare mission with 116 payloads.
August 20, 2024 2024-150 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G10-5-1 to -22	Communications	Launch of 22 Starlink v2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2023–September 30, 2024 (FY 2024) (continued)

Launch Date COSPAR Designation Launch Vehicle	Spacecraft	Mission Objectives	Remarks
August 28, 2024 2024-152 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-6-1 to -8 Starlink v2-Mini-D2C G8-6-1 to -13	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
August 31, 2024 2024-154 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-10-1 to -8 Starlink v2-Mini-D2C G8-10-1 to -13	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
August 31, 2024 2024-155 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-5-1 to -8 Starlink v2-Mini-D2C G9-5-1 to -13	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
September 5, 2024 2024-158 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G8-11-1 to -8 Starlink v2-Mini-D2C G8-11-1 to -13	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
September 5, 2024 2024-159 *CZ-6*	GeeSAT 3-01 (GeeSat 21 to 30)	Navigation/Communication	Chinese constellation providing automotive and marine navigation and UAV applications.
September 6, 2024 2024-160 *Falcon-9 v1.2 Block 5*	USA 400 to 420 (NROL 113)	Reconnaissance	Starshield constellation.
September 10, 2024 2024-161 *Falcon-9 v1.2 Block 5*	Crew Dragon Polaris Dawn	Crewed Spaceflight	First flight of Polaris program mission carrying a crew of four (see Appendix C).
September 12, 2024 2024-163 *Falcon-9 v1.2 Block 5*	BlueBird 1 to 5 (SpaceMobile 001 to 005)	Communications	Launch of five large smartphone broadband satellites.
September 13, 2024 2024-164 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-6-1 to -8 Starlink v2-Mini-D2C G9-6-1 to -13	Communications Communications	Launch of 21 Starlink v2-Mini satellites.
September 18, 2024 2024-167 *Falcon-9 v1.2 Block 5*	Galileo 31 and 32	Navigation	European Space Agency.
September 20, 2024 2024-171 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-17-1 to -7 Starlink v2-Mini-D2C G9-17-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
September 20, 2024 2024-172 *Electron KS*	Kinéis 2A to 2E	Internet of Things	Second of five launches for Kinéis constellation.
September 25, 2024 2024-175 *Falcon-9 v1.2 Block 5*	Starlink v2-Mini G9-8-1 to -7 Starlink v2-Mini-D2C G9-8-1 to -13	Communications Communications	Launch of 20 Starlink v2-Mini satellites.
September 28, 2024 2024-178 *Falcon-9 v1.2 Block 5*	Crew Dragon 9	Crewed Spaceflight	Ninth operational NASA Commercial Crew flight to the International Space Station (see Appendix C).

Appendix C-1

Human Spaceflights

October 1, 2023–September 30, 2024 (FY 2024)

Spacecraft/ Mission	Launch Date	Crew	Flight Time (d:h:min)	Highlights
Shenzhou 17	October 26, 2023	Tang Hongbo Tang Shengjie Jiang Xinlin	187:6:32	Flight to Tiangong space station. Two spacewalks.
Axiom Mission 3 "Freedom"	January 18, 2024	Michael Lopez-Alegria Walter Villadei Alper Gezeravcri Marcus Wandt	21:15:41	Private spaceflight to the International Space Station.
SpaceX Crew-8, "Endeavour" Expedition 70/71/72	March 3, 2024	Matthew Dominic Michael Barratt Jeanette Epps Aleksandr Grebyonkin	235:3:35	First spaceflight for three of the four crewmembers, including the mission commander.
Soyuz MS-25 Expedition 70/71	March 23, 2024	Oleg Novitsky Maryna Vasileuskaya Tracy Caldwell-Dyson	183:23:22	Novitsky and Vasileuskaya spent 13 days in space during this mission, while Caldwell-Dyson spent roughly six months aboard the International Space Station. Oleg Konenko and Nikolai Chub joined Caldwell-Dyson for landing on September 23, 2024.
Shenzhou 18	April 25, 2024	Ye Guangfu Li Guangsu Li Cong	191:12:40	Flight to Tiangong space station. Two spacewalks.
Starliner CFT "Calypso"	June 5, 2024	Barry E. Wilmore Sunita Williams	93:13:9	First crewed mission of Starliner to the International Space Station. The mission was meant to last eight days, but problems with the spacecraft led to the decision to have it return to Earth without its crew. The crew is scheduled to return with SpaceX Crew 9 in early 2025.
SpaceX Polaris Dawn	September 10, 2024	Sarah Gillis Jared Isaacman Anna Menon Kidd Poteet	4:22:13	Reached highest Earth orbit since the Apollo program. First EVA from Dragon craft wearing SpaceX-designed suits. Thirty-six research studies conducted. First human spaceflight mission of the Polaris Program.
Soyuz MS-26 Expedition 71/72	September 11, 2024	Aleksey Ovchinin Ivan Vagner Donald Pettit	Ongoing	Flight to International Space Station. Planned six-month mission.
SpaceX Crew-9, "Endurance" Expedition 71/72	September 28, 2024	Nick Hague Aleksandr Gorbunov	Ongoing	Flight to International Space Station. Barry E. Wilmore and Sunita Williams are to return to Earth on this spacecraft.

Note: Suborbital human spaceflights are not included.

Appendix D-1A

Space Activities of the U.S. Government

Historical Table of Budget Authority (in millions of real-year dollars)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	331	261	490	34	34						785
1960	524	462	561	43	43						1,066
1961	964	926	814	68	68						1,808
1962	1,825	1,797	1,298	199	148	51					3,294
1963	3,673	3,626	1,550	257	214	43					5,433
1964	5,100	5,016	1,599	213	210	3					6,828
1965	5,250	5,138	1,574	241	229	12					6,953
1966	5,175	5,065	1,689	214	187	27					6,968
1967	4,966	4,830	1,664	213	184	29					6,707
1968	4,587	4,430	1,922	174	145	28	0.2	1			6,526
1969	3,991	3,822	2,013	170	118	20	0.2	1	31		6,005
1970	3,746	3,547	1,678	141	103	8	1	1	28		5,366
1971	3,311	3,101	1,512	162	95	27	2	1	37		4,775
1972	3,307	3,071	1,407	133	55	31	6	2	39		4,611
1973	3,406	3,093	1,623	147	54	40	10	2	41		4,863
1974	3,037	2,759	1,766	158	42	60	9	3	44		4,683
1975	3,229	2,915	1,892	158	30	64	8	2	54		4,965
1976	3,550	3,225	1,983	168	23	72	10	4	59		5,376
TQ*	932	849	460	43	5	22	3	1	12		1,352
1977	3,818	3,440	2,412	194	22	91	10	6	65		6,046
1978	4,060	3,623	2,738	226	34	103	10	8	71		6,587
1979	4,596	4,030	3,036	248	59	98	10	8	73		7,314
1980	5,240	4,680	3,848	231	40	93	12	14	72		8,759
1981	5,518	4,992	4,828	234	41	87	12	16	78		10,054
1982	6,044	5,528	6,679	313	61	145	12	15	80		12,520
1983	6,875	6,328	9,019	327	39	178	5	20	85		15,674
1984	7,458	6,858	10,195	395	34	236	3	19	103		17,448
1985	7,573	6,925	12,768	584	34	423	2	15	110		20,277
1986	7,807	7,165	14,126	477	35	309	2	23	108		21,768
1987	10,923	9,809	16,287	466	48	278	8	19	112	1	26,562
1988	9,062	8,322	17,679	741	241	352	14	18	115	1	26,742
1989	10,969	10,097	17,906	560	97	301	17	21	121	3	28,563
1990	12,324	11,460	15,616	506	79	243	31	25	124	4	27,582
1991	14,016	13,046	14,181	772	251	251	29	26	211	4	27,999
1992	14,317	13,199	15,023	798	223	327	34	29	181	4	29,020
1993	14,310	13,064	14,106	731	165	324	33	25	180	4	27,901
1994	14,570	13,022	13,166	632	74	312	31	31	179	5	26,820
1995	13,854	12,543	10,644	759	60	352	31	32	278	6	23,946
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911

(continued)

Appendix D-1A: Space Activities of the U.S. Government Historical Table of Budget Authority (in millions of real-year dollars) (continued)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1997	13,709	12,457	11,727	789	35	448	42	39	219	6	24,973
1998	13,648	12,321	12,359	839	103	435	43	39	213	6	25,519
1999	13,653	12,459	13,203	982	105	575	59	37	200	6	26,644
2000	13,601	12,521	12,941	1,056	164	575	60	44	207	6	26,518
2001	14,230	13,304	14,326	1,062	145	577	60	36	232	12	28,692
2002	14,868	13,871	15,740	1,180	166	644	64	28	266	12	30,791
2003	15,364	14,360	19,388	1,305	191	649	74	42	337	12	35,053
2004	15,379	14,322	19,115	1,464	209	745	71	61	366	12	34,901
2005	16,198	15,234	19,690	1,551	229	807	70	73	360	12	36,475
2006	16,623	15,765	22,114	1,647	245	860	82	84	364	12	39,526
2007	16,285	15,568	22,418	1,680	200	912	87	65	404	12	39,666
2008	17,117	16,502	24,795	1,698	195	862	90	59	479	13	42,995
2009	17,775	17,275	26,528	1,868	200	1,078	64	27	485	14	45,671
2010	18,725	18,228	26,463	2,057	203	1,261	67	27	484	15	46,748
2011	18,432	17,898	27,234	2,186	229	1,444	66	20	412	15	47,318
2012	17,773	17,203	26,677	2,580	199	1,876	76	7	406	16	46,460
2013	17,395	16,865	10,818	2,578	185	1,865	84	20	409	15	30,261
2014	17,647	17,081	10,400	2,839	174	2,087	82	19	461	16	30,320
2015	18,010	17,359	10,325	3,010	182	2,223	83	19	485	18	30,694
2016	19,285	18,645	6,967	3,159	178	2,346	87	19	508	22	28,771
2017	19,653	18,993	10,316	2,995	172	2,214	85	20	480	24	32,305
2018	20,736	19,976	7,861	2,953	175	2,099	79	16	556	29	30,790
2019	21,500	20,775	9,970	2,604	217	1,667	84	19	581	36	33,349
2020	22,629	21,845	11,900	2,401	195	1,507	84	20	543	52	36,146
2021	23,271	22,443	15,100	2,459	211	1,516	84	27	576	44	40,002
2022[e]	24,041	23,161	15,500	2,538	236	1,596	85	30	547	45	41,199
2023[f]	25,384	24,442	22,800	2,771	234	1,793	92	50	555	47	50,013
2024	24,880	23,945	24,462	2,825	231	1,886	95	56	512	45	51,232

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.
b. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.
c. DOE has recalculated its space expenditures since 1998.
d. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.
e. Budget Authority amounts do not include supplemental or emergency-designated funding.
f. FY 2023 NASA Agency Total includes $367 million of "emergency funding" for Construction, Environmental Compliance and Restoration appropriated in Division N of PL 117-358.
* Transition Quarter

Appendix D-1B

Space Activities of the U.S. Government

Historical Table of Budget Authority (in millions of inflation-adjusted FY 2024 dollars)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	2,733	2,155	4,045	281	281						6,481
1960	4,269	3,764	4,570	350	350						8,684
1961	7,746	7,440	6,541	546	546						14,527
1962	14,517	14,295	10,325	1,583	1,177	406					26,203
1963	28,878	28,508	12,186	2,021	1,682	338					42,715
1964	39,590	38,938	12,413	1,653	1,630	23					53,004
1965	40,064	39,210	12,012	1,839	1,748	92					53,060
1966	38,662	37,841	12,618	1,599	1,397	202					52,058
1967	36,006	35,020	12,065	1,544	1,334	210					48,629
1968	32,138	31,038	13,466	1,220	1,016	196	1	7			45,724
1969	26,742	25,609	13,488	1,142	791	134	1	7	209		40,239
1970	23,825	22,559	10,672	897	655	51	6	6	178		34,128
1971	20,039	18,768	9,151	980	575	163	12	6	224		28,900
1972	19,108	17,745	8,130	771	318	179	35	12	228		26,645
1973	18,866	17,132	8,990	816	299	222	55	11	229		26,938
1974	15,702	14,265	9,131	817	217	310	47	16	228		24,213
1975	15,132	13,660	8,866	739	141	300	37	9	252		23,266
1976	15,552	14,128	8,687	737	101	315	44	18	260		23,553
TQ*	3,965	3,612	1,957	183	21	94	13	4	51		5,751
1977	15,599	14,054	9,854	791	90	372	41	25	264		24,699
1978	15,540	13,867	10,480	865	130	394	38	31	272		25,212
1979	16,278	14,273	10,753	878	209	347	35	28	258		25,904
1980	17,069	15,245	12,535	753	130	303	39	46	235		28,532
1981	16,369	14,808	14,322	695	122	258	36	47	232		29,825
1982	16,766	15,335	18,528	867	169	402	33	42	221		34,730
1983	18,272	16,819	23,971	869	104	473	13	53	226		41,659
1984	19,137	17,597	26,160	1,013	87	606	8	49	264		44,771
1985	18,804	17,195	31,703	1,449	84	1,050	5	37	272		50,347
1986	18,956	17,398	34,300	1,158	85	750	5	56	262		52,855
1987	25,945	23,299	38,685	1,106	114	660	19	45	266	2	63,090
1988	20,850	19,147	40,676	1,705	554	810	32	41	265	2	61,529
1989	24,255	22,327	39,594	1,238	214	666	38	46	268	7	63,159
1990	26,288	24,445	33,310	1,079	169	518	66	53	264	9	58,833
1991	28,867	26,869	29,207	1,590	517	517	60	54	435	8	57,667
1992	28,768	26,522	30,187	1,603	448	657	68	58	363	8	58,311
1993	28,094	25,648	27,694	1,435	324	636	65	49	353	8	54,776
1994	27,995	25,020	25,297	1,215	142	599	60	60	345	10	51,532
1995	26,067	23,600	20,027	1,428	113	662	58	60	523	11	45,054
1996	25,641	23,213	21,264	1,529	85	872	66	68	426	11	46,006

(continued)

Appendix D-1B: Space Activities of the U.S. Government Historical Table of Budget Authority (in millions of inflation-adjusted FY 2023 dollars) (continued)

FY	NASA Total	NASA Space	DOD[a]	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1997	24,876	22,604	21,280	1,433	64	813	76	71	398	11	45,316
1998	24,460	22,082	22,150	1,505	185	780	77	70	383	11	45,736
1999	24,168	22,054	23,371	1,738	186	1,018	104	65	354	11	47,164
2000	23,584	21,712	22,440	1,831	284	997	104	76	358	10	45,982
2001	24,091	22,523	24,254	1,798	245	977	102	61	393	20	48,575
2002	24,780	23,118	26,233	1,967	277	1,073	107	47	443	20	51,318
2003	25,126	23,484	31,707	2,134	312	1,061	121	69	551	20	57,326
2004	24,551	22,863	30,515	2,337	334	1,189	113	97	584	19	55,715
2005	25,096	23,603	30,507	2,403	355	1,250	108	113	558	19	56,513
2006	24,943	23,655	33,182	2,471	368	1,290	123	126	546	18	59,309
2007	23,783	22,736	32,740	2,454	292	1,332	127	95	590	18	57,930
2008	24,488	23,608	35,472	2,429	279	1,233	129	84	685	19	61,509
2009	25,173	24,465	37,570	2,645	283	1,527	91	38	687	20	64,680
2010	26,290	25,592	37,154	2,887	285	1,770	94	37	680	21	65,634
2011	25,367	24,633	37,481	3,008	315	1,987	91	27	567	21	65,122
2012	24,020	23,250	36,054	3,486	269	2,535	103	9	549	22	62,790
2013	23,087	22,383	14,358	3,422	246	2,475	111	27	543	20	40,163
2014	22,977	22,240	13,541	3,696	227	2,717	107	25	600	21	39,477
2015	23,184	22,346	13,291	3,875	234	2,862	107	24	624	23	39,511
2016	24,621	23,804	8,895	4,033	227	2,995	111	24	648	28	36,732
2017	24,651	23,823	12,939	3,757	216	2,777	107	25	602	30	40,519
2018	25,412	24,481	9,634	3,619	214	2,573	96	20	681	36	37,734
2019	25,842	24,971	11,984	3,130	261	2,003	101	22	698	44	40,084
2020	26,841	25,911	14,115	2,849	231	1,788	100	24	645	62	42,876
2021	26,706	25,755	17,328	2,822	242	1,740	97	31	661	51	45,905
2022[e]	25,801	24,856	16,635	2,724	253	1,596	91	32	587	48	44,215
2023	25,984	25,020	23,339	2,836	240	1,835	94	51	568	48	51,195
2024	24,880	23,945	24,462	2,825	231	1,886	95	56	512	45	51,232

a. DOD reported that improvements to the estimating methodology resulted in a change in estimated budget authority and outlays starting in FY 2013.
b. The Other column is the total of the non-NASA and non-DOD budget authority figures that appear in the succeeding columns. The total is sometimes different from the sum of the individual figures because of rounding. The Total Space column does not include the NASA Total column because the latter includes budget authority for aeronautics as well as space. For the years 1989–97, this Other column also includes small figures for the Environmental Protection Agency (EPA), as well as $2.1 billion for the replacement of Space Shuttle Challenger in 1987.
c. DOE has recalculated its space expenditures since 1998.
d. The NSF has recalculated its space expenditures since 1980, making them significantly higher than reported in previous years.
e. Budget Authority amounts do not include supplemental or emergency-designated funding.
* Transition Quarter

NOTE: Inflation factors calculated using data from Table 10.1—Gross Domestic Product and Deflators Used in the Historical Tables: 1940–2028 available at https://www.whitehouse.gov/omb/budget/historical-tables/.

Appendix D-2

Federal Space Activities Budget

(in millions of dollars by fiscal year)[a]

Federal Agencies	Budget Authority				Budget Outlays			
	2022 actual	2023 actual	2024 actual	2025 est.	2022 actual	2023 actual	2024 actual	2025 est.
NASA[b]	23,161	24,442	23,945	24,418	22,196	24,459	24,069	24,092
DOD[c]	15,500	22,800	24,462	25,217	16,700	21,700	25,553	25,105
DOE	236	234	231	222	241	194	213	191
DOC[d]	1,651	1,793	1,886	2,234	1,626	1,670	1,593	1,981
DOI[e]	85	92	95	111	85	86	44	44
USDA[f]	30	50	56	58	32	38	46	46
NSF[g]	559	555	512	535	543	548	541	533
DOT[h]	45	47	45	67	49	42	44	62

a. Amounts rounded to the nearest million.
b. FY 2023 and 2024 NASA Outlay amounts are based on MAX A-11 actuals.
c. DOD submitted FY 2022 and 2023 amounts in billions of dollars, so the figures are rounded to the nearest hundred million.
d. DOC space activities budget authority and outlays include the NOAA–National Weather Service Space Weather Prediction Center; all of the NOAA–National Environmental Satellite, Data, and Information Service; and the NOAA–Office of Space Commerce. Supplemental funding is excluded. An average of FY 2023 and FY 2024 outlays was applied to the FY 2025 budget authority to calculate the FY 2025 outlay estimate.
e. The USGS reports on actual and estimated funding levels (budget authority and outlays) for Satellite Operations (space category). Budget Authority amounts do not include supplemental or emergency funding. The DOI revised prior-year outlays to reflect an updated methodology.
f. Total budget authority for the Forest Service going into each new FY is unknown; these numbers use actual outlays for the retrospective estimate.
g. NSF Actual Obligations for FY 2022 include American Rescue Plan (ARP) supplemental funds.
h. For DOT Outlays, FY 2023 funding has obligation plans for $5.0M identified for F&E BLI 2A18 (Commercial Space); the funding has not been obligated; therefore, the outlays are correctly identified at zero. For FY 2024, funding has preliminary obligation plans for $1.0M identified for F&E BLI 2A18 (Commercial Space); the funding has not been obligated; therefore, the outlays are correctly identified at zero. FY 2025 funding includes funding for a new start (SpORT), which cannot be funded under a CR; additionally, remaining funding has preliminary plans for obligation; therefore, the outlays for F&E BLI 2A17 (Commercial Space) are correctly identified at zero.

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)[a]

Federal Agencies	Budget Authority				Budget Outlays			
	2022 actual	2023 actual	2024 actual[2]	2025 est.	2022 actual	2023 actual	2024 actual	2025 est.
NASA[b]	881	942	935	966	883	860	946	967
DOD[c]	56,200	62,600	65,444	61,167	52,400	56,500	61,641	62,242
DOE	3	6	27	28	2	4	5	4
DOC[d]	—	50	48	69	—	43	43	40
DOI[e]	40	43	43	37	40	43	43	20
USDA[f]	85	142	105	114	88	125	93	97
DOT	3,119	3,179	3,450	3,829	3,228	3,285	3,547	3,593

a. Amounts rounded to the nearest million.
b. FY 2023 and 2024 NASA Outlay amounts are based on MAX A-11 actuals.
c. DOD submitted FY 2022 and 2023 amounts in billions of dollars, so the figures are rounded to the nearest hundred million.
d. DOC began reporting NOAA-OMAO aeronautics resources in FY 2025 for the FY 2024 Report.
e. For the Aeronautics and Space Report of the President, the USGS reports on actual and estimated funding levels (budget authority and outlays) for the 3D Elevation Program (3DEP) (aeronautics category). Budget Authority amounts do not include supplemental or emergency funding. The DOI revised prior-year outlays to reflect an updated methodology.
f. Total budget authority for the Forest Service going into each new FY is unknown; these numbers use actual outlays for the retrospective estimate.

Acronyms

3D	three-dimensional
3DEP	3D Elevation Program
3DHP	3D Hydrography Program
3DNTM	3D National Topography Model
4BCO2	Four-bed Carbon Dioxide

A

A2M2	Agile Autonomous Mobile Manipulator
AAM	Advanced Air Mobility
AC	Advisory Circular
ACES	Advisory Committee on Excellence in Space
ACS3	Advanced Composite Solar Sail System
ACSAA	Aircraft Certification, Safety, and Accountability Act
ADS/ESC	Office of Emerging Security Challenges within the Bureau of Arms Control, Deterrence, and Stability
AEPS	Advanced Electric Propulsion System
AFRL	Air Force Research Laboratory
AGS	Division of Atmospheric and Geospace Sciences
AI	artificial intelligence
AI&T	Assembly, Integration, and Test
AIM	Aeronautical Information Management; Assessment, Inventory, and Monitoring
ALMA	Atacama Large Millimeter/Submillimeter Array
AM	additive manufacturing
AM Bench	Additive Manufacturing Benchmark Series
AML	abandoned mine lands
AMM	Autonomous Mobile Manipulator
AMS	Alpha Magnetic Spectrometer; Automated Modular Sensor
ANL	Argonne National Laboratory
API	Application Programming Interface
AppFac	Application Factory
ARC	Aviation Rulemaking Committee
ARL	Army Research Laboratory
ARM	Atmospheric Radiation Measurement User Facility

ARMD	Aeronautics Research Mission Directorate
ARM-I	ARM Institute
ARS	Agricultural Research Service
ASB	Agricultural Statistics Board
ASCR	Advanced Scientific Computing Research
ASE	Aviation Survivability Equipment
ASEAN	Association of Southeast Asian Nations
ASI	Italian Space Agency
ASR	Atmospheric System Research
AST	Division of Astronomical Sciences; FAA's Office of Commercial Space Transportation
ASTRA	Autonomous Satellite Technology for Resilient Application
ASU	Aircraft Sector Understanding
ATLAC	Action Team on Lunar Activities Consultations
ATLAS	Argonne Tandem Linac Accelerator System
ATN	Aeronautical Telecommunications Network
AVS	aviation safety
AWE	Atmospheric Waves Experiment

B

BAA	Broad Agency Announcement
BCR33	Bird Conservation Region 33
BCT	Brigade Combat Teams
BEA	Bureau of Economic Analysis
BICEP	Background Imaging of Cosmic Extragalactic Polarization
BIG	Breakthrough, Innovative, and Game-Changing
BIL	Bipartisan Infrastructure Law
BIS	Bureau of Industry and Security
BLM	Bureau of Land Management
BLOS	beyond-line-of-sight
BMC3	Battle Management Command, Control, and Communications
BNL	Brookhaven National Laboratory
BOEM	Bureau of Ocean Energy Management
BOR	Bureau of Reclamation
BPS	Biological and Physical Sciences
BVLOS	Beyond Visual Line of Sight

C

C2	Collection 2; Command and Control
CADRE	Cooperative Autonomous Distributed Robotic Exploration
CAPS	Cislunar Autonomous Positioning System
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CASIS	Center for the Advancement of Science in Space
CBET	Division of Chemical, Bioengineering, Environmental and Transport Systems
C/C	Carbon-Carbon
CCMD	Combatant Command
CCP	Commercial Crew Program
CCOR	Compact Coronagraph
CCRPP	Civilian Commercialization Readiness Pilot Program
CCSDS	Consultative Committee for Space Data Systems
CCSFS	Cape Canaveral Space Force Station

CDEDT	Change and Disturbance Event Detection Tool
CDL	Cropland Data Layer
CDP	Commercial Data Program
CDR	Climate Data Records; Critical Design Review
CERISS	Commercially Enabled Rapid Space Science
CfA	Center for Astrophysics | Harvard & Smithsonian
CFM	Cryogenic Fluid Management
CFO	Carlsbad Field Office
CFR	Code of Federal Regulations
CFT	Crewed Flight Test; Cross-Functional Team
CF-TPC	carbon-fiber-reinforced thermoplastic composite
CGS	California State Geological Survey
CIF	Center Innovation Fund
CIPHER	Complement of Integrated Protocols for Human Exploration Research
CLD	commercial low-Earth orbit destinations
CLPS	Commercial Lunar Payload Services
CM	Office of Nuclear Incident Response's Consequence Management Program
CMB	Cosmic Microwave Background
CMS	Carbon Monitoring System
CMTC	Composites Manufacturing Technology Center
CMU	Carnegie Mellon University
CNES	Centre National d'Études Spatiales
CNTB	Cloud National Test Bed
COMSATCOM	Commercial SATCOM
CONUS	conterminous United States or contiguous United States
COPUOS	UN Committee on the Peaceful Uses of Outer Space
COSI	Compton Spectrometer and Imager
COSMIC	Consortium for Space Mobility and ISAM Capabilities; Constellation Observing System for Meteorology, Ionosphere, and Climate
COSMO	Coronal Solar Magnetism Observatory
COVID-19	coronavirus disease of 2019
CPR	Changed Product Rule
CRADA	Cooperative Research and Development Agreement
CropCASMA	Crop Condition and Soil Moisture Analytics
CRP	Constant Rate Production
CRS	Commercial Resupply Services
CRSRA	Commercial Remote Sensing Regulatory Affairs
CSA	Canadian Space Agency
CSCC	Commercial Space Coordinating Committee
CSCO	Commercial SATCOM Office
CSDA	Commercial SmallSat Data Acquisition
CSIB	Civil Space Industrial Base
CSLI	CubeSat Launch Initiative
CSP	Communications Services Project
CURIE	CubeSat Radio Interferometry Experiment
CUW	continuous ultrasonic welding
CVN	aircraft carrier

D

DARC	Deep Space Advanced Radar Capability
DASI	Distributed Array of Small Instruments
Data Comm	Data Communications
DAVINCI	Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging

DCCS	Dream Chaser Cargo System
DERISC	Digital Education, Resilience, and Innovation for Supply Chain
DFAIR	Depot-Factory Artificial Intelligence for Repair
DHS	Department of Homeland Security
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DO	delivery order
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOE IP	DOE Office of Isotope R&D and Production
DOI	Department of the Interior
DR-TES	mini-Dilution Refrigerator and a Transition Edge Sensor
DSCOVR	Deep Space Climate Observatory
DSFAS	Data Science for Food and Agricultural Systems
DSN	Deep Space Network
DSOC	Deep Space Optical Communications
DSS	Deep Space Station

E

EAR	Export Administration Regulations
ECCCO	Extreme ultraviolet Coronal mass ejection and Coronal Connectivity Observatory
ECI	Early Career Initiative
ECOSTRESS	ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
EDGE24	Experimentation Demonstration Gateway Event
EEC	Division of Engineering Education and Centers
EESS	Earth Exploration Satellite Service
EGS	Exploration Ground Systems
EHP	Extravehicular Activity and Human Surface Mobility
ELaNa	Educational Launch of Nanosatellites
EM&C	Enterprise Management and Control
EOS	Earth Observing System
EPA	Environmental Protection Agency
EPS	Enhanced Polar System
EPS-R	Enhanced Polar System–Recapitalization
EROS	Earth Resources Observation and Science
ES	Ecological Systems Classifications
ESA	European Space Agency
ESCAPADE	Escape and Plasma Acceleration and Dynamics Explorers
ESD	Earth Science Division
ESDMD	Exploration Systems Development Mission Directorate
ESMU	Electromagnetic Spectrum Management Unit
ESO	Earth System Observatory
ESS	Environmental System Science; Evolved Strategic SATCOM
ESSIO	Exploration Science Strategy and Integration Office
ESTH	Environment, Science, Technology, and Health
ET	evapotranspiration
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EU	European Union
EUS	Exploration Upper Stage
EU SST	European Union Space Surveillance and Tracking
EUV	extreme ultraviolet
EVA	extravehicular activity
EVT	Existing Vegetation Type

EWS	Electro-Optical/Infrared [EO/IR] Weather System
EXCOM	Executive Committee
EXORD	Execution Order

F

FAA	Federal Aviation Administration
FAS-GMA	Foreign Agricultural Service's Global Market Analysis
FCC	Federal Communications Commission
FDSS	Faculty Development in Space Sciences
FEMA	Federal Emergency Management Agency
FFP	Firm-Fixed-Price
FGST	Fermi Gamma-ray Space Telescope
FIA	Forest Inventory and Analysis
FLRAA	Future Long Range Assault Aircraft
FMS	Foreign Military Sales
FNPRM	Further Notice of Proposed Rulemaking
FORGE	Future Operationally Resilient Ground Evolution
FRAME	fixtureless robotic assembly system
FRIB	Facility for Rare Isotope Beams
FRP	fire radiative power
FSA	Farm Service Agency
FSAA	Funded Space Act Agreement
FSP	Fission Surface Power
FSS	fixed-satellite service
FTUAS	Future Tactical Unmanned Aerial Systems
FUAS	Future Unmanned Aerial Systems
FVL	Future Vertical Lift
FVL(MS)	Future Vertical Lift Maritime Strike
FY	fiscal year

G

G	unit of gravity
G-LiHT	Goddard's LiDAR, Hyperspectral and Thermal
G-REALM	Global Reservoir and Lake Monitor
GA	General Atomics, Inc.
GADAS	Global Agricultural and Disaster Assessment System
GBD	Global Burst Detector
GBO	Green Bank Observatory
GBT	Green Bank Telescope
GCD	Game Changing Development
GCOM	Global Change Observation Mission
GDA	Geospatial Data Analysis
GDMS	General Dynamics Mission Systems
GEDI	Global Ecosystem Dynamics Investigation
GEE	Google Earth Engine
Gen2	second generation
GEO	geosynchronous Earth orbit; geostationary Earth orbit
GeoXO	Geostationary Extended Observations
GEP	Ground Entry Point
GeV	gigaelectron volts
GFSAD	Global Food-and-Water Security-support Analysis Data

GHG	greenhouse gas
GIMMS	Global Inventory Modeling and Mapping Studies
GIS	geographic information system
GLAM	Global Agricultural Monitoring
GMI	Ground, Management, and Integration
GNSS	Global Navigation Satellite System
GNSS-R	Global Navigation Satellite System Reflectometry
GOES	Geostationary Operational Environmental Satellite
GONG	Global Oscillations Network Group
GPHS-RTG	general-purpose heat source–radioisotope thermoelectric generator
GPS	Global Positioning System
GPS IIIF	Global Positioning System III Follow-on
GRACE-C	Gravity Recovery and Climate Experiment–Continuity
GSFC	Goddard Space Flight Center
GSP	Geospatial Strategic Plan
GTAC	Geospatial Technology and Applications Center
GUSTO	Galactic/Extragalactic ULDB Spectroscopic Terahertz Observatory

H

HALO	Habitation and Logistics Outpost; Hypersonic Air-Launched OASuW; Hybrid Acquisition for Proliferated LEO
HAO	High-Altitude Observatory
HCDL	Hawaiian Cropland Data Layer
HEP	High Energy Physics
HERA	Human Exploration Research Analog
Hi-C	High Resolution Coronal Imager
HLS	Harmonized Landsat and Sentinel; Human Landing System
HPSC	High Performance Spacecraft Computing
HRP	Human Research Program

I

I-Corps	Innovation Corps
IAU CPS	Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference of the International Astronomical Union
IAWG	International Authorities Working Group
ICAO	International Civil Aviation Organization
ICG	International Committee on Global Navigation Satellite Systems (GNSS)
ICNO	IceCube Neutrino Observatory
IIPP	Interdepartmental Imagery Publication Platform
ILLUMA-T	Integrated Laser Communication Relay Demonstration (LCRD) Low-Earth Orbit User Modem and Amplifier Terminal
IM-1	Intuitive Machines' Nova-C
INL	Idaho National Laboratory
INTERN	Non-Academic Research Internships for Graduate Students
IOP	Interoperability Plenary
IoT	Internet of Things
IP	intellectual property
IPAD	International Production Assessment Division
IPEx	ISRU Pilot Excavator
IPS	Internet Protocol Suite
ISA	Israel Space Agency

ISAM	In-space Servicing, Assembly, and Manufacturing
ISM	In-Space Manufacturing
ISPF	In-Space Propulsion Facility
ISR	Incoherent Scattering Radar; Intelligence, Surveillance, and Reconnaissance
ISRO	Indian Space Research Organisation
ISRU	in situ resource utilization
ISS	International Space Station
ITA	International Trade Administration
ITAR	International Traffic in Arms Regulations
ITE	Improved Turbine Engine
ITSO	International Telecommunications Satellite Organization
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union–Radiocommunication Sector
IUCRC	Industry-University Cooperative Research Center
IVGen Mini	Miniaturized Intravenous Fluid Generation
IWG	Interagency Working Group
IWS	Investigators' Workshop

J

JAHVAA	Joint Acceleration of Hypersonic Vehicle Aerostructure Alternatives
JASD	Joint Agency Satellite Division
JAXA	Japan Aerospace Exploration Agency
JBN	Janus base nanomaterial
JEDI	Joint EUV Diagnostic Investigation
JHUAPL	Johns Hopkins University Applied Physics Laboratory
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JSC	Johnson Space Center
JSF	Joint Strike Fighter
JWST	James Webb Space Telescope

K

KASA	Korean AeroSpace Administration
KDP	Key Decision Point
KSC	Kennedy Space Center

L

L1	Lagrange Point 1
L5	Lagrange Point 5
LAMDA	Landscape Automated Monitoring and Detection Algorithm
LANCE	Land, Atmosphere Near-real-time Capability for Earth Observing System
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANL	Los Alamos National Laboratory
LaRC	Langley Research Center
LAT	Large Area Telescope
LBNL	Lawrence Berkeley National Laboratory
LCMAP	Land Change Monitoring, Assessment, and Projection
LCMS	Landscape Change Monitoring System
LCRD	Laser Communication Relay Demonstration
LDB	Long Duration Balloon

LDS	Laser Detection System
LE	Launched Effects
LEGS	Lunar Exploration Ground Sites
LEO	low Earth orbit
lidar	Light Detection and Ranging
LIGO	Laser Interferometric Gravitational-Wave Observatory
LIS	Land Information System
LISA-T	Lightweight Integrated Solar Array and anTenna
LLNL	Lawrence Livermore National Laboratory
LOX	liquid oxygen
LR	long-range
LRASM	Long-Range Anti-Ship Missile
LS-1	Lizzie Sat-1
LSC	Legal Subcommittee
LSIC	Lunar Surface Innovation Consortium
LSII	Lunar Surface Innovation Initiative
LSO	Launch Services Office
LSST	Legacy Survey of Space and Time
LTE	long-term evolution
LTS	Long-Term Sustainability
LuSEE-Night	Lunar Surface Electromagnetics Experiment at Night
LUX	Luxembourg

M

MAB	Mission Assignment Board
MACS	Multi-layer Acoustics and Conductive-grid Sensor
ManTech	Manufacturing Technology Program
MBDA	Minority Business Development Agency
MBE	minority business enterprise
MBRSC	Mohammed Bin Rashid Space Center
MCO	Mars Campaign Office
MD	missile defense
MDA	Missile Defense Agency
MEO	medium Earth orbit
MEP	Manufacturing Extension Partnership
ML	machine learning
ML2	Mobile Launcher 2
MMRTG	Multi-mission Radioisotope Thermoelectric Generator
MOC3HA	Manufacturing of Carbon-Carbon Composites for Hypersonics Applications
MODAPS	MODIS Adaptive Processing System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSA	Modular Open System Approach
MOU	Memorandum of Understanding
MPL	mission payload
MPLAN	MUREP Partnership Learning Annual Notification
MR	medium-range; mixed-reality
MRI	Magnetorotational Instability Experiment; Mapping Resources Initiative
MRR	Medium Range Reconnaissance
MSD	Mission Support Directorate
MSFC	Marshall Space Flight Center
MSR	Mars Sample Return
MSS	mobile-satellite service
MTA-RP	Middle Tier of Acquisition—Rapid Prototyping

MTBS	Monitoring Trends in Burn Severity
MUOS	Mobile User Objective System
MUREP	Minority University Research and Education Project
MW	missile warning
MW/MT	Missile Warning/Missile Tracking
MxD	Manufacturing x Digital

N

NAIP	National Agriculture Imagery Program
NAMRU-D	Naval Medical Research Unit Dayton
NANOGrav	North American Nanohertz Observatory for Gravitational Waves
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service
NC3	nuclear command, control, and communications
NCAR	National Center for Atmospheric Research
NDIAWG	Nuclear Data InterAgency Working Group
NDL	Navigation Doppler Lidar
NDVI	Normalized Difference Vegetation Index
NE	Office of Nuclear Energy
NEO	near-Earth object
NEON	Near Earth Orbit Network
NERSC	National Energy Research Scientific Computing Center
NESDIS	National Environmental Satellite, Data, and Information Service
NExT	National Defense Space Architecture Experimental Testbed
NextSTEP-2	Next Space Technologies for Exploration Partnerships-2
NFS	National Forest System
NGRTG	next-generation radioisotope thermoelectric generator
NIAC	NASA Innovative Advanced Concepts
NIFA	National Institute of Food and Agriculture
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Database
NMB	National Mall Building
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOC	National Operations Center
NOFO	Notice of Funding Opportunity
NOIRLab	National Optical-Infrared Astronomy Research Laboratory
NOTAMs	Notices to Airmen
NP	Nuclear Physics
NPRM	Notice for Proposed Rulemaking
NPS	National Park Service
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NREL	National Renewable Energy Laboratory
NRI	National Resources Inventory
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSF	National Science Foundation
NSF Engines	NSF Regional Innovation Engines
NSN	Near Space Network

NSO	National Solar Observatory
NSpC	National Space Council
NSRL	NASA Space Radiation Laboratory
NSSL	National Security Space Launch
NSTC	National Science and Technology Council
NTAP	Near-Term Approval Process
NTIA	National Telecommunications and Information Administration
NTP	Nuclear Thermal Propulsion
NWP	numerical weather prediction

O

O&I	Operations and Integration
OASuW	Offensive Anti-Surface Warfare
OC	Operation Center
OCAP	Operating Criteria and Procedures
OCT	Optical Communication Terminal
ODA	Organization Designation Authorization
OEM	original equipment manufacturer
OES/SA	Office of Space Affairs within the Bureau of Oceans and International Environmental and Scientific Affairs
OLI	Operational Land Imager
OMB	Office of Management and Budget
OPIR	Overhead Persistent Infrared
ORNL	Oak Ridge National Laboratory
OSAM-1	On-Orbit Servicing, Assembly, and Manufacturing 1
OSC	Office of Space Commerce
OSIRIS-REx	Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer
OSMRE	Office of Surface Mining Reclamation and Enforcement
OSTP	Office of Science, Technology, and Policy
OTA	Other Transaction Authority
OTM	Office of Transportation and Machinery
OY5	Order Year 5

P

PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PCC	Prizes, Challenges, and Crowdsourcing
PCC4	Project Convergence Capstone 4
PCDL	Predictive Cropland Data Layer
PFP	PWSA Future Programs
PHY	Division of Physics
PI	principal investigator
pLEO	proliferated low Earth orbit
PM-1	Peregrine Mission 1
PNT	Positioning, Navigation, and Timing
POES	Polar Operational Environmental System
POSE	Pathways to Enable Open-Source Ecosystems
PPE	Power and Propulsion Element
PPP	precise point positioning
PPPL	Princeton Plasma Physics Laboratory
PREFIRE	Polar Radiant Energy in the Far-InfraRed Experiment
PSD	production, supply, and distribution

PTD-4	Pathfinder Technology Demonstrator 4
PTD-R	Pathfinder Technology Demonstrator R
PTES	Protected Tactical Enterprise Service
PTS	Protected Tactical SATCOM
PTS-G	Protected Tactical SATCOM global
PTS-R	Protected Tactical SATCOM resilient
PTW	Protected Tactical Waveform
PTWoW	PTW over Wideband Global SATCOM
Pu	plutonium
PWSA	Proliferated Warfighter Space Architecture

R

R&D	Research and Development
RAP	Rangeland Analysis Platform
RASC-AL	Revolutionary Aerospace Concepts Academic Linkage
RCMAP	Rangeland Condition Monitoring Assessment and Projection
RD-OE	Research and Development Operating Environment
REU	Research Experiences for Undergraduates
RF	radio frequency
RFI	Request for Information
RFMG	Radio Frequency Mass Gauge
RFP	Request for Proposals
RFSoC	Radio Frequency System on Chip
RID	Remote Identification
RMA	Risk Management Agency
RNSS	Radionavigation Satellite Service
RO	radio occultation
ROK	Republic of Korea
ROMEX	Radio Occultation Modeling Experiment
RPS	Radioisotope Power Systems
RSLP	Rocket Systems Launch Program
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RTEMS	Real-Time Executive for Multiprocessor Systems

S

SAA	Space Act Agreement
SABRS	Space and Atmospheric Burst Reporting System
SAFE	Sensor Augmented Factory Environment
SAIC	Science Applications International Corporation
SAO	Smithsonian Astrophysical Observatory
SAR	synthetic aperture radar
SATCOM	Satellite Communications
SBIR	Small Business Innovation Research
SBIRS	Space Based Infrared System
SCaN	Space Communications and Navigation
SCN	Satellite Control Network
SCOIN	Supply Chain Optimization and Intelligence Network
SCS	Supplemental Coverage from Space
SDA	Space Development Agency; Space Domain Awareness
SDARS	Satellite Digital Audio Radio Service
SDR	System Design Review

SEATEST 7	Space Environment Analog for Training, Engineering, Science, and Technology 7
SEP	Solar Electric Propulsion
SESAR	Single European Sky Air Traffic Management Research
SETO	Solar Energy Technologies Office
SHINE	Space Health Impacts for the NASA Experience
SII	Spectrum Innovation Initiative
SIIRTD	Space Innovation, Integration, and Rapid Technology Development
SLS	Space Launch System
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SME	subject matter expert
SMM	small and medium manufacturers
SMS	Safety Management Systems
SNL	Sandia National Laboratories
SNS	Space Nuclear Systems
SOTF	Spaceport of the Future
SpARC	Aerospace Rulemaking Advisory Committee
SPHEREx	Spectro-Photometer for the History of the Universe, Epoch of Reionization and Ices Explorer
SpOC	Space Operations Command
SpRCO	Space Rapid Capabilities Office
SPT	South Pole Telescope
SR	short-range
SRM	Standard Reference Materials
SRR	Short Range Reconnaissance
SRT	STMD Restructuring Team
SRU	Space Resource Utilization
SSA	Space Situational Awareness; System Safety Assessments
SSC	Stennis Space Center
SSEBop	Operational Simplified Surface Energy Balance
SSG	Senior Steering Group
SSL	Space Sciences Laboratory
SSN	Space Surveillance Network
SSPICY	Small Spacecraft Propulsion and Inspection Capability
STC	Space Traffic Coordination; Office of Science and Technology Cooperation
STEM	Science, Technology, Engineering, and Mathematics
STMD	Space Technology Mission Directorate
STRG	Space Technology Research Grants
STSC	Scientific and Technical Subcommittee
STTR	Small Business Technology Transfer
SUA	software usage agreement
sUAS	small unmanned aerial systems
Suomi NPP	Suomi National Polar-orbiting Partnership
SV	space vehicle
SW Next	Space Weather Next
SWEAP	Solar Wind Electrons, Alphas, and Protons
SWFO	Space Weather Follow On
SWIFT	Spectrum and Wireless Innovation enabled by Future Technologies
SWORM	Space Weather Operations, Research, and Mitigation
SWOT	Surface Water and Ocean Topography

T

T0	Tranche 0

T0TL	T0 Transport Layer
T0TRK	T0 Tracking Layer
T1	Tranche 1
T1DES	Tranche 1 Development and Experimentation System
T1TL	T1 Transport Layer
T1TRK	T1 Tracking Layer
T2	Technology Transfer; Tranche 2
T2TL	T2 Transport Layer
T2TL-α	Tranche 2 Transport Alpha
T2TL-β	Tranche 2 Transport Beta
T2TL-Gamma	Tranche 2 Transport Gamma
T2TRK	T2 Tracking Layer
T3	Tranche 3
TACSATCOM	tactical satellite communications
TACTOM	Tactical Tomahawk
TALOS	Thruster for the Advancement of Low-Temperature Operations in Space
TAS	Thermal Amine Swingbed
TASA	Taiwan Space Agency
TBO	Trajectory Based Operations
TC	type certificate
TCPS	Trash Compaction and Processing System
TDM	Technology Demonstration Missions
TDP	Technical Data Package
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TFDM	Terminal Flight Data Manager
TIP	Directorate for Technology, Innovation and Partnerships
TM	Thematic Mapper
TraCSS	Traffic Coordination System for Space
TREAT	Transient Reactor Test
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TT&C	telemetry, tracking, and command
TWG	Technical Working Group

U

UA-UA	unmanned aircraft to unmanned aircraft
UAG	Users' Advisory Group
UAM	urban air mobility
UAS	Unmanned Aircraft Systems; Uncrewed Aircraft Systems; Unmanned Aerial Systems
UHF	ultra-high frequency
ULA	United Launch Alliance
ULI	University Leadership Initiative
UN	United Nations
UNCOPUOS	UN Committee on the Peaceful Uses of Outer Space
UND	University of North Dakota
UNGA	UN General Assembly
UNOOSA	United Nations Office for Outer Space Affairs
USAF	United States Air Force
USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USG	U.S. Government

USGEO	U.S. Group on Earth Observations
USGS	U.S. Geological Survey
USNC	Ultrasafe Nuclear Technologies, Inc.
USNDS	U.S. Nuclear Detonation Detection System
USPTO	United States Patent and Trademark Office
USSF	U.S. Space Force
USTR	U.S. Trade Representative
UTM	UAS Traffic Management

V

VADR	Venture-Class Acquisition of Dedicated and Rideshare
VERITAS	Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy
VIIRS	Visible Infrared Imaging Radiometer Suite
VLA	Very Large Array
VLBA	Very Long Baseline Array
VLF	Very Low Frequency
VSFB	Vandenberg Space Force Base
VSRP	Voluntary Safety Reporting Program

W

WAM	Workbench for Additive Materials
WAP	World Agricultural Production
WASDE	World Agricultural Supply and Demand Estimates
WFC	Warfighting Capability
WFOV	wide-field-of-view
WGS	Wideband Global SATCOM
WRC-23	World Radiocommunication Conference
WSF-M	Weather System Follow-On–Microwave
WSTF	White Sands Test Facility

Y

YH	Yttrium-Hydride

Z

ZBOT	Zero Boil-off Tank

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