Aeronautics and Space Report of the President

Fiscal Year 2023 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, 2022, through September 30, 2023. 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.** NASA astronaut and Expedition 68 Flight Engineer Woody Hoburg rides the Canadarm2 robotic arm while maneuvering a rollout solar array toward the International Space Station's truss structure on June 9, 2023. Credit: NASA. **2.** On December 5, 2022, the 20th day of the Artemis I mission, the Orion spacecraft captured this image of Earth rising behind the Moon following the return powered flyby. Credit: NASA. **3.** Joe Adams (NUSO) positions a UAS over a calibration panel to capture an image with the attached MicaSense Dual multispectral sensor. This calibration image will be used to post-process the imagery in support of radiometric calibration research conducted at the Denver Federal Center in Colorado. Credit: U.S. Geological Survey (USGS). **4.** A fast-moving wildfire that devastated the town of Lahaina on Maui, HI, is shown on August 8, 2023, as seen by the Operational Land Imager (OLI) instrument on the Landsat 8 satellite. Credit: NASA Earth Observatory image by Lauren Dauphin, using Landsat data from the USGS. **5.** An F-16 Fighting Falcon pilot assigned to the 113th Wing, Joint Base Andrews, Maryland, taxis out for a Red Flag 23-3 mission at Nellis Air Force Base, Nevada, July 19, 2023. Credit: U.S. Air Force/William R. Lewis. **6.** The James Webb Space Telescope captured this image of around 50 young stars in Rho Ophiuchi, the closest star-forming region to Earth. Credit: NASA, ESA, CSA, STScI, Klaus Pontoppidan (STScI); image processing: Alyssa Pagan (STScI).

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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.[1] The National Space Council membership, which includes the heads of the agencies, departments, and offices responsible for the United States space enterprise, supports the Council's Chair, Vice President Kamala Harris.

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 nonfederal representatives of industries and other persons involved in aeronautical and space activities.[2] 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. These subcommittees meet regularly to produce recommendations for consideration by the National Space Council. The UAG held a public meeting on December 1, 2023 to announce and deliberate recommendations across its six subcommittees in advance of that month's National Space Council meeting.

1 https://www.whitehouse.gov/spacecouncil/

2 https://www.nasa.gov/usersadvisorygroup/

Meetings of the National Space Council

On December 20, 2023, Vice President Kamala Harris convened the Biden-Harris Administration's third National Space Council meeting at the Andrew W. Mellon Auditorium in Washington, DC. The meeting was the first ever to focus on international partnerships and included topics such as the role of space in promoting American leadership and strength abroad, the contribution of space capabilities to improving life here on Earth, and how the United States is leading an unprecedented coalition of nations in the return to the Moon. As part of a larger set of announcements across the civil, commercial, and national security space sectors, the Vice President released the U.S. Novel Space Activities Authorization and Supervision Framework, a companion executive action to the proposed legislation that the National Space Council transmitted to Congress in November 2023.[3] Vice President Harris also declared that, alongside American astronauts, the United States intended to land an international astronaut on the surface of the Moon by the end of the decade as part of the Artemis Program.

Key Announcements

Supporting International Rules and Norms for Outer Space. On December 7, 2022, 155 nations voted in support of a United Nations Resolution welcoming the commitment announced by Vice President Harris in April 2022 not to conduct destructive, direct-ascent anti-satellite missile testing, and encouraging all nations to make such a commitment. At the end of Fiscal Year 2023 (FY 2023), 35 countries had done so.

Broadening and Deepening International Space Partnerships. The Artemis Accords stand at the center of the Biden-Harris administration's civil space diplomatic efforts. Under Vice President Harris's leadership, 20 nations joined the Artemis Accords, bringing the current total to 29 signatories at the end of FY 2023. As Chair of the National Space Council, the Vice President led specific engagements with President Emmanuel Macron, President Yoon Suk Yeol, and Prime Minister Narendra Modi that bolstered U.S. international space cooperation with France, South Korea, and India.

Strengthening the U.S.-Africa Partnership in Space. In December 2022, the National Space Council led the first-ever U.S.-Africa Space Forum as part of the U.S.-Africa Leaders Summit. The Forum reaffirmed the United States' commitment to collaborating with African partners on the peaceful use and exploration of outer space to meet shared priorities here on Earth.

3 https://www.whitehouse.gov/wp-content/uploads/2023/12/Novel-Space-Activities-Framework-2023.pdf

The Forum highlighted the U.S.-Africa space partnership and cooperation to address 21st century challenges and opportunities, including responding to the climate, biodiversity, and global food crises; promoting responsible behavior in outer space; and reinforcing U.S.-African scientific and commercial space cooperation.

Leading the Return to the Moon. At the direction of Vice President Harris, NASA published an initial lunar surface architecture in April 2023, including areas for international partnerships. The architecture addressed science, transportation and habitation, lunar and Mars infrastructure, and operations by incorporating extensive stakeholder feedback from the NASA workforce, international partners, U.S. industry, academia, and other U.S. government agencies.

Coordinating Whole-of-Government Efforts to Develop a Diverse and Robust Aerospace STEM Workforce. The National Science and Technology Council established the Space STEM Task Force to coordinate space-related STEM Education activities across federal departments and agencies. Co-chaired by the National Space Council, the Task Force published the Interagency Space STEM Roadmap, which guided the whole-of-government approach. The Task Force launched a space careers awareness campaign that included a webinar and social media campaign to highlight the breadth of space-related career paths. The U.S. Department of Education created the Your Place in Space Career and Technical Education Challenge to introduce students to space STEM careers. The Department of Labor and National Space Council cohosted a Registered Apprenticeship Accelerator focused on growing the skilled technical workforce in the space sector.

National Aeronautics and Space Administration

NASA

Exploration Systems Development Mission Directorate

The Exploration Systems Development Mission Directorate (ESDMD) programs provide the foundation for humanity's return to the Moon and exploration beyond. ESDMD manages the human exploration systems development for deep space launch, lunar orbital, lunar surface, and Mars exploration.

Strategy and Architecture Office

The ESDMD Strategy and Architecture Office translates NASA's Moon to Mars Objectives into an integrated portfolio that leverages diverse government, academic, industry, and international stakeholders.[1] 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 each objective is traced to relevant systems throughout execution.[2] The office also develops potential concept solutions, conducts analyses, and empowers preformulation activities to identify the human exploration campaign elements needed in the architecture to fulfill the needs of Moon to Mars exploration.

In FY 2023, the Strategy and Architecture Office:

- Hosted its first Architecture Concept Review in January 2023 where agency leadership reviewed the results of the 2022 Strategic Analysis Cycle. These analyses inform architecture decisions by decomposing functions, use cases, and elements from overarching

1 https://www.nasa.gov/wp-content/uploads/2022/09/m2m-objectives-exec-summary.pdf

2 https://www.nasa.gov/wp-content/uploads/2023/04/m2m_strategy_and_objectives_development.pdf

objectives while identifying capability gaps. This activity unifies the entire agency around a consistent architecture that addresses the agency Moon to Mars Objectives.

- Released the Moon to Mars Architecture Definition Document in April 2023. The document established the process, framework, and decomposition of the Moon to Mars Objectives, empowering executing systems, programs, and projects to successfully achieve human exploration of the cosmos.[3]
- Hosted workshops in London and Washington in June 2023 to solicit inputs from international space agencies, industry, and academic institutions on NASA's exploration architecture.[4] Unique insight and feedback during the office's iterative feedback solicitation process gave rise to several crucial changes and additions to the objectives. This activity further deepened the stakeholder engagement, understanding, buy-in, and cooperation on the architecture.
- Hosted a Moon to Mars Interagency Architecture Workshop in August 2023 at NASA Headquarters following a similar format to the workshops held in June. Representatives from more than 20 U.S. government agencies participated in discussions on NASA's architecture approach and gained insight into the Moon to Mars Objectives.
- Released a new draft of the Moon to Mars Architecture Definition Document for review in advance of this year's Architecture Concept Review, scheduled for November 14–16, 2023, at NASA's Kennedy Space Center (KSC) in Florida. The revision incorporated the results of the 2023 Strategic Analysis Cycle and further discussions with government, industry, and international stakeholders.
- Made significant progress on several 2023 Strategic Analysis Cycle actions for NASA's lunar architecture, including refinement of the sub-architecture, use cases, and functions, as well as maturation of the power, logistics, communications, positioning, navigation, and timing sub-architectures. These refinements are the result of the workshops, meetings, and Strategic Analysis Cycle described above. It represents a natural evolution in the maturity of the architecture.
- Identified four additional subarchitectures for inclusion in NASA's lunar architecture: in situ resource utilization, data systems and management, infrastructure support, and robotics.
- Expanded the decomposition of the Moon to Mars objectives beyond the Human Lunar Return segment of the Moon to Mars architecture. Analyzed the return of large

3 https://ntrs.nasa.gov/citations/20230002706

4 https://www.nasa.gov/feature/insights-from-workshops-fuel-nasa-s-moon-to-mars-architecture-approach/

A night field test with simulated lunar lighting conditions during the Desert RATS mission in October 2022. A white NASA rover illuminates NASA astronauts Jessica Meir and Artemis Surface Systems Integration Lead Sarah Shull.

quantities of cargo (200–1,200 kg) from the lunar surface to Earth to understand current options and limitations.

- Completed an integrated lunar surface logistics study, comparing performance of pressurized logistics carrier interfaces with habitable elements and the associated carrier size-class. Assessed approaches and recommended further evaluation of a hybrid system for the delivery of pressurized logistics.
- Conducted a ten-day Desert Research and Technology Studies (Desert RATS) mission in October 2022 at Black Point Lava Flow, 40 miles outside Flagstaff, Arizona.[5] This analog mission followed an 11-year hiatus and focused on pressurized rover operations. It included three, two-person crews living, working, and sleeping inside a prototype rover from the Constellation Era on three-day rotations. Operations were primarily conducted at night, with simulated lighting conditions of the lunar South Pole.
    - The Japan Aerospace Exploration Agency joined NASA, sending astronauts and engineers under a study agreement supporting their potential to provide a pressurized rover for Artemis.
    - During the mission, NASA personnel visited a Navajo Nation school; spoke at the Lowell Observatory; and hosted more than 190 students, 22 media outlets, and several congressional stakeholders.

5 https://www.nasa.gov/mission/desert-research-and-technology-studies-desert-rats/

- Received approval for the Frozen Return Of Samples To Earth (FROSTE) team to proceed to pre-formulation activities. The effort meets a high-priority Artemis objective: returning frozen material preserving the environmental conditions in which they originated, namely the lunar South Pole.
- Exported, published, and presented a preprocessed solid terrain model of the 84 South Latitude of the lunar South Pole. The model can be ingested into common simulation and visualization tools directly for general use across the agency.
- Developed an architecture decision process and a suite of modeling tools to identify and prioritize key decisions needed to define NASA's human exploration architecture. This new process will provide value to the agency by:
    - Assessing flow-down impacts to subsequent decisions that may avoid costly reworks or disruptions.
    - Defining inter-organizational critical paths and dependencies for each decision to foster smoother implementation across the agency.
    - Establishing the logical order of decision-making to better inform technology development and implementation investment strategies.
- Developed a government reference, all-chemical propulsion Mars transportation concept and identified the necessary Mars surface infrastructure required to enable it. This effort will aid the agency in making informed assessments of future transportation concepts.
- Coordinated studies with four International Partners under separate study agreements, garnering key technical contributions to the Moon to Mars Architecture. These collaborating agencies included the Italian Space Agency (lunar habitation elements), the European Space Agency (lunar logistics and cargo delivery), the Canadian Space Agency (lunar rovers for science and logistics), and the Japan Aerospace Exploration Agency (lunar cargo lander concepts). In FY 2024, NASA expects technical development activities under three of these agreements to reach Element Initiation and Mission Concept Review, key milestones for official inclusion in the Moon to Mars Architecture.
    - Potential International Partner contributions to the Moon to Mars Architecture developed via these study agreements extend beyond the items mentioned above. Other technical areas to be explored in these agreements could include mobility systems, science instrumentation, sample return, nuclear power generation, communications and navigation, surface habitation, in situ resource utilization, and crew health and performance systems.

- In addition to the studies pursued in FY 2023, NASA made significant progress developing new study agreements with the French Space Agency and the Israeli Space Agency. NASA expects formal initiation of activities under these study agreements in FY 2024, alongside continued activity under current study agreements.

- Sponsored a competition for university teams from across the country from June 12 to 14 in Cocoa Beach, Florida, as part of NASA's annual Revolutionary Aerospace Systems Concepts–Academic Linkage.[6] The competition challenged university teams to develop new concepts for operation on the Moon, on Mars, and beyond. Finalist teams responded to themes ranging from supporting lunar operations and tourism to enabling long-term survival on the surface of Mars.

Moon to Mars Program Office

After the successful launch of the Artemis I mission in November 2022, NASA unified all developmental human spaceflight programs under the Moon to Mars Program Office. This organizational structure allows for a mission-focused approach to systems engineering, risk management, safety, and mission assurance, and supports the integration of science objectives to answer some of humanity's most complex questions. Further, the new organization answers some key stakeholders' concerns regarding the need for clear lines of authority and integration for the entire Moon to Mars enterprise. The Moon to Mars Program Office includes the Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program (EHP), Space Launch System (SLS), Orion, Exploration Ground Systems (EGS), Human Landing System (HLS) and Gateway programs.[7] Collectively, these programs provide the foundation for humanity's return to the Moon and exploration beyond. Progress steadily continues toward the first crewed Artemis mission and sustainable lunar exploration.

Orion

Orion will serve as the exploration vehicle 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 2023, NASA launched an uncrewed Orion aboard Artemis I to test the capsule's propulsion systems, software, navigation, and communications capabilities. The Orion crew capsule performed exceptionally well, meeting all flight objectives throughout the mission around the Moon, and was successfully recovered from the Pacific Ocean on December 11, 2022. In FY 2023, NASA achieved milestones for the following Artemis missions:

6 https://www.nasa.gov/learning-resources/nasa-announces-winning-collegiate-teams-at-2023-rasc-al-forum/

7 https://www.nasa.gov/humans-in-space/space-launch-system/

- On the Artemis I mission, NASA's Orion spacecraft was successfully launched, flown a record-setting 1.4 million miles around the Moon, and returned to Earth safely. The Artemis I mission took place from November 16 to December 11, 2022. The 25.5-day uncrewed mission tested Orion in the harsh environment of deep space in preparation to fly astronauts on Artemis II.
- For the Artemis II mission, the Orion spacecraft will carry a crew of four astronauts around the Moon. The spacecraft is in work to support a late 2024 launch. The Crew Module underwent preparations for mating with the Service Module. The Service Module will propel and power the spacecraft.
- The Artemis III and IV missions are planned to take astronauts to the surface of the Moon. Those Orion spacecraft are currently in production at KSC in Florida and at Airbus facilities in Bremen, Germany. The Service Modules for the Artemis V and VI missions are also in production in Germany, and the Crew Module for Artemis V is being welded together at NASA's Michoud Assembly Facility (MAF) in New Orleans.

Space Launch System

On November 16, 2022, the Artemis I mission made history by launching the SLS Block 1 rocket. SLS performance exceeded all expectations and provided confidence in its ability to support a crewed capsule on the Artemis II mission. In FY 2023, NASA:

- Delivered Artemis II flight systems to the Kennedy Space Center in Florida for final prelaunch preparations.
- Completed final processing of the Core Stage Engines for Artemis III. The engines will remain at Stennis Space Center until they are needed for installation onto the Artemis III Core Stage at MAF. Additionally, Artemis III solid rocket boosters have been cast and are in storage in Utah.
- Successfully restarted production of the high-performance liquid rocket engines. The first series of engine testing was successfully completed and met all objectives. NASA achieved production cost savings of 30 percent per engine relative to the production costs of the Space Shuttle Main Engine.
- Finalized the Stages Production and Evolution Contract, which will result in construction of SLS core stages for Artemis III and IV, procurement of critical and long-lead material for the core stages for Artemis V and VI, development of the Exploration Upper Stages (EUS) for Artemis V and VI, and as tooling and related support and engineering services.
- Continued planning for a phased implementation of the Exploration Production and Operations Contract (EPOC), which will usher in a new method of

procuring SLS launch services and ultimately save the U.S. Government money for these launch services.

Exploration Ground Systems

The Exploration Ground Systems (EGS), based at KSC, develops and operates the systems and facilities necessary to process and launch rockets and spacecraft during assembly, transport, and launch. 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 2023, EGS successfully completed the following tasks:

- Prepared the Mobile Launcher 1 for the Artemis II mission by conducting repairs necessary after the Artemis I launch and performed functional testing of the Crew Access Arm. The Crew Access Arm will be necessary for the crewed flight on Artemis II.
- Made significant progress on upgrading Pad 39B, including building an Emergency Egress System for crew to use in an emergency during launch. This Emergency Egress System is necessary in preparation for the Artemis II flight with crew.
- Upgraded the Pad Environmental Control System. This system provides conditioned air (temperature, humidity, and flow) to all three segments of the vehicle, including the Orion capsule. The enhancements were needed to meet human rating and Block 1B requirements for Artemis II and beyond.
- Started construction on the Mobile Launcher 2 (ML2), the next capability that will allow for the launching of the SLS Block 1B launch vehicle. The start of construction is a key milestone indicating the bulk of the engineering is complete and significant forward progress has been made in resolving past design difficulties associated with the ML2.

Human Landing System

The Human Landing System (HLS) Program is responsible for the spacecraft that will carry astronauts from lunar orbit to the Moon's surface and safely back to lunar orbit. In FY 2023, the HLS Program completed two procurements and initiated development of the landers that will transport astronauts to and from the Moon's surface beginning with the Artemis IV mission while continuing to mature the design and conduct system testing for the Artemis III lunar lander. Additionally, the agency:

- Awarded contracts to SpaceX and Blue Origin to develop landers for missions beyond Artemis III that meet more advanced sustaining requirements, including capabilities to dock with Gateway, accommodate four crewmembers and longer surface stays, and deliver more mass to the lunar surface. An expansion of SpaceX's existing contract provides for an evolution from their HLS Starship design for Artemis III to also

deliver the Artemis IV lander, and a new contract with Blue Origin provides for their lander for Artemis V. Both lander designs will be available to compete for recurring services on later Artemis missions under a future procurement.

- Worked collaboratively with SpaceX to advance the design of their HLS variants for Artemis III and IV and incorporate them into Artemis mission planning. SpaceX completed specific ground demonstrations of flight-like and prototype HLS subsystems for propulsion (e.g., the Raptor main engine and reaction control thrusters), life support, thermal control, and space communications, and they completed reviews of HLS mission operations and crew training. SpaceX also conducted the first flight test of the integrated Starship/Super-Heavy commercial launch vehicle system that will launch the HLS Starship, and they subsequently matured the designs of both the launch vehicle and launch site infrastructure at Boca Chica, Texas.
- The HLS Program forged cross-program agreements with Orion, EHP, and Gateway to ensure integration of interface designs and sharing of joint test and simulator systems. NASA and SpaceX conducted a Certification Baseline Review to confirm that SpaceX's HLS design, performance, and verification plans for Artemis IV conform to NASA requirements.
- Initiated collaborative work with Blue Origin to develop their Blue Moon lander for Artemis V and incorporate it into Artemis mission planning. Following contract award in May 2023, Blue Origin completed two milestones, delivering a crew module mockup and lander training simulator.

Gateway

Sustainability on the lunar surface can only be accomplished with a sustainable presence in lunar orbit. Gateway will provide multipurpose capabilities to facilitate a long-term human return to the lunar surface. It provides key logistics, staging, docking, and checkout capabilities necessary to complete missions of increasing complexity planned for Artemis IV and beyond. Additionally, it will serve as a proving ground and staging point for sustainable deep space exploration. In FY 2023, the Gateway program moved forward with growing existing and establishing new international and commercial partnerships, while teams around the world began assembling and testing the initial elements of the station.

- Major hardware, test equipment, and software accomplishments occurred in FY 2023, including completing peripheral docking target ground units, creating an S-Band transponder flight unit for the Power and Propulsion Element (PPE) and the Habitation and Logistics Outpost (HALO), shipping the first Communication Test Sets to commercial partners, delivering the HALO mock-up for astronaut training, and completing the formal software release of the Payload System Manager, a

system-level software application that will manage each module's command and data streams to and from their payloads, across Gateway.

- Gateway also made major progress with risk reduction testing for refueling, solar electric propulsion, and other Mars-forward capabilities. For example, Gateway competed the 6kW Busek Thruster Risk Reduction Test in December 2022 at NASA's GRC VF5 facility. The test characterized the BHT-6000 electric propulsion thruster performance, operating characteristics, and plume in a low-backpressure environment. Additional objectives were to demonstrate changes made to the thruster design from the Qualification thruster investigation, obtain more data with the new soft-start approach, and obtain data at lower power operating points. Testing was fully successful in furthering the PPPE team's understanding of the operation and integration of the BHT-6000 thruster for Gateway.
- Gateway completed the program's ninth Integrated Analysis Cycle. This analysis cycle updates with the latest designs and systems information focusing on the Artemis IV mission. The Artemis IV mission includes the International Habitat (I-Hab) delivery to Gateway and a lunar landing mission with the HLS-SpaceX Starship.
- Gateway led an Artemis IV+ Near Rectilinear Halo Orbit (NRHO) integration checkpoint in August 2023. The intent of this NRHO integration checkpoint is to confirm and convey the integration maturity of Gateway, Orion, HLS, EVA, and EHP to jointly meet cross-program objectives that enable a successful mission within NRHO. The checkpoint aligns these programs to a common understanding of the NRHO cross-program technical and mission content.

Exploration Extravehicular Activity

The Exploration EVA and Human Surface Mobility (HSM) Program (EHP) provides safe, reliable, and effective spacewalking and surface mobility capabilities that allow astronauts to survive and work outside the confines of a base spacecraft. The EHP completed a banner year, wrapping up successful formulation of the program in the agency-level Key Decision Point 1. Each of the projects assigned to the program also progressed through significant formulation or implementation activities. In FY 2023, the agency:

- Awarded task orders to two vendors: the Artemis III task order to Axiom Space and the ISS Task Order to Collins Aerospace. Subsequently, the vendors commenced work toward their proposed milestones. Each vendor has completed its Certification Baseline Review and is working toward completing its Preliminary Design Review. Training hardware is in development for Artemis III and is nearly ready for delivery.
- Completed formulation of the Lunar Terrain Vehicle rover with a successful agency-level Key Decision Point A. Later in the fiscal year, the Vehicle completed its System

Requirements Review and released a services model contract request for proposal in May. Proposals have been received and are under review for selection of vendors.

- The Pressurized Rover team completed a successful Mission Concept Review in partnership with the Japanese Space Agency. The team supported a successful Acquisition Strategy Meeting in which NASA approved acquiring the Pressurized Rover via an international partnership. Details of the design concepts, launch vehicle, and proposed terms of the international agreement were approved at the agency level to proceed with drafting and working through approval of the International Agreement.

Mars Campaign Office

The Mars Campaign Office oversees development projects that demonstrate critical human exploration systems to reduce mission risk, validate operational concepts, leverage partner capabilities, and lower life-cycle costs for future Mars missions. In FY 2023, these projects continued to advance deep space technologies through ground-based prototype testing and utilization in low-Earth orbit destinations.

- **Crew Health And Performance Exploration Analog (CHAPEA):** CHAPEA Mission 1 passed the 100-day mark (toward the total of 378 days) on October 3, 2023. The CHAPEA analog, a 3D printed Mars analog habitat at Johnson Space Center, will provide the first integrated health, cognitive, and physical performance data in relation to a realistic Mars food system. It includes realistic Mars time delays, simulated EVAs, extended isolation and confinement, and other resource constraints to validate food system adequacy and inform vehicle mass and volume requirements and crew health and performance risks. The CHAPEA crew is made up of four non-NASA volunteers that were selected out of over 8,000 applicants.
- **Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE):** The Mars Campaign Office (MCO) CAPSTONE SmallSat, a robotic precursor pathfinder mission, was the first spacecraft to demonstrate the unique lunar orbit intended for NASA's Gateway last November 2022. CAPSTONE, the size of a microwave, successfully entered the near rectilinear halo orbit (NRHO) and has completed its mission objectives. CAPSTONE has directly transferred that experience and lessons to inform NASA Gateway planning activities related to NRHO operations and validate navigation and stationkeeping analysis and simulation.
- **BioSentinel:** The BioSentinel SmallSat is now over 24 million kilometers from Earth. It was launched on Artemis I in November 2022 to detect, measure, and correlate the impact of space radiation on living organisms over long durations. BioSentinel allows scientists to study living cells' response to deep-space radiation, work that will help

astronauts on future missions to Mars. The BioSentinel spacecraft recently advanced new capabilities to benefit future lunar and deep space missions. Demand for the Deep Space Network (DSN) is increasing rapidly. The BioSentinel team, along with Morehead State University and the DSN, conducted a successful Beacon Test. Beacon tones allow space assets to "call home" and provide automated updates as opposed to regularly scheduled communication windows with the ground team. The beacon service is a much more efficient use of DSN resources and is now available for more types of space missions, including SmallSats.

- **MCO ShadowCam:** In a cooperative partnership with South Korea's Korea Aerospace Research Institute (KARI) space agency, M2M/MCO launched the ShadowCam hypersensitive optical camera aboard the KARI Danuri lunar orbiter in August 2022. Built by Arizona State University, the ShadowCam instrument has provided the first high-resolution images of the permanently shadowed regions (PSRs) at the lunar poles and around the future south pole landing site of the Artemis human missions. The instrument uses the minimal light reflected off geologic features such as mountains or the walls of craters to collect images in frozen regions thought to contain water ice—a significant resource for exploration that can be used for fuel, oxygen, and other exploration applications.

  ShadowCam also observes seasonal changes and measures the terrain inside the craters. The high-resolution images will inform how the Moon has evolved and how water is trapped and preserved and helps with site selection and exploration planning for the M2M Artemis missions.

- **Brine Processor:** The Brine Processor Assembly Technology Demonstration on the ISS successfully demonstrated a 98 percent water recovery capability. The legacy ISS humidity condensate recovery and urine processing hardware was capable of recovering 93 to 94 percent of water. The Brine Processor Assembly (BPA) uses heat and pressure to evaporate water from the brine that is left over from the Urine Processor Assembly. This evaporated water is collected by the humidity control hardware and returned to the water system for further processing into potable water. Data from over a year of on-orbit operation of the BPA shows that the additional water harvested by the BPA has increased the total water recovered to greater than 98 percent, an enabling goal for Mars transit life-support systems.

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 22 years of research and 3,700 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 2023, Commercial Resupply Services (CRS) flights from Northrop Grumman and SpaceX launched a total of five cargo flights to the ISS, delivering over 37,000 pounds of science investigations, spacewalking tools, and critical supplies. Also in FY 2023, Northrop Grumman's Cygnus spacecraft completed its second successful reboost of the ISS. 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 complemented by NASA's Partners. Roscosmos provided three Progress cargo missions of nearly nine tons of food, fuel, and supplies. Over 12,000 pounds of 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.

NASA's Commercial Crew Program (CCP) enables NASA to maximize 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.

The core Expedition 68 crew members consisted of NASA astronauts Frank Rubio, Nicole Mann, and Josh Cassada, in addition to Japan Aerospace Exploration Agency (JAXA) astronaut Koichi Wakata and Roscosmos cosmonauts Sergey Prokopyev, Dmitri Petelin, and Anna Kikina. In October 2022, ISS was handed over to the SpaceX Crew-5 astronauts from the SpaceX Crew-4 astronauts and they joined the Soyuz 68S crew.

After 156 docked days onboard the ISS, the SpaceX Crew-5 returned to Earth after handing over their roles to the recently arrived SpaceX Crew-6 team. The SpaceX Crew-6 team carried NASA astronauts Steve Bowen and Woody Hoburg, in addition to astronaut Sultan Alneyadi of the Mohammed bin Rashid Space Centre in the United Arab Emirates and cosmonaut Andrey Fedyaev of Roscosmos. Several weeks after the handover, Expedition 69 began onboard the ISS. The core Expedition 69 crew consisted of the new SpaceX Crew-6, NASA astronaut Rubio and Roscosmos cosmonauts Prokopyev and Petelin.

Following an external coolant leak detected on the Soyuz spacecraft in which they launched, ISS crew members Rubio, Prokopyev, and Petelin had an extended stay onboard the ISS and returned on a different Soyuz spacecraft (69S), which was sent uncrewed to the ISS in February 2023. After spending 371 days in low-Earth orbit, Rubio returned with his crewmates on September 27, 2023, breaking the previous record held by NASA astronaut Mark Vande Hei for the longest single spaceflight by an American astronaut. Rubio experienced approximately 5,936 orbits of Earth and traveled over 157 million statute miles (equivalent to approximately 328 round trips to the Moon).

Upon the undocking of the Soyuz 69S spacecraft in September 2023, the ISS transitioned to Expedition 70, whose core crew consisted of members from the recently arrived SpaceX Crew-7 and Soyuz 70S missions. The SpaceX Crew-6 team handed over the ISS to the SpaceX Crew-7 team consisting of astronaut Jasmin Moghbeli of NASA, astronaut Andreas Mogensen of the European Space Agency (ESA), astronaut Satoshi Furukawa of JAXA, and cosmonaut Konstantin Borisov of Roscosmos. The Soyuz 70S crew consisted of NASA astronaut Loral O'Hara and Roscosmos cosmonauts Oleg Kononenko and Nikolai Chub.

In FY 2023, there were a total of 14 spacewalks supported by the onboard crew and ground teams, eight of which were U.S. extravehicular activities (EVAs). Each of the U.S. EVAs played a critical part toward the augmentation of the ISS's power supply through the preparation for, or installation of, ISS Roll-Out Solar Arrays (iROSAs). The new arrays are approximately 60 feet long by 20 feet wide and shade a little more than half of the original arrays, which are 112 feet long by 39 feet wide. Each new iROSA produces more than 20 kilowatts of electricity, and together they enable a 30 percent increase in power production over the ISS's current arrays. NASA and Boeing have a plan in place for a fourth set of roll-out arrays to further augment the ISS's power supply. These arrays, which would be the seventh and eighth installed on the ISS, are targeted for delivery to the orbital outpost in 2025.

The five spacewalks on the ISS's Russian Segment tackled a variety of objectives, many of which were related to the integration of hardware associated with the Nauka Multipurpose Laboratory Module, including the European Robotic Arm. The last spacewalk in FY 2023 marked the 267th spacewalk for ISS assembly, maintenance, and upgrades.

The ISS National Laboratory continued to fly science experiments, technology demonstrations, and education programs for the benefit of humanity. In FY 2023 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 Igniting Innovations solicitation. The partnership sought proposals for flight research to address the goals of the Cancer Moonshot initiative and accelerating the translation of stem cell– and organoid-based disease models and advanced technologies for biomanufacturing. The response from the community was high, and more than 50 proposals were received. In FY 2023 the first-ever knee meniscus was successfully 3D bioprinted in orbit using Redwire's BioFabrication Facility enabled through the ISS National Laboratory. This milestone is the first step to improved treatment for meniscal injuries, one of the most common for U.S. Service Members. In FY 2023 the ISS National Laboratory hosted one of the most successful ISS Research and Development Conferences in Seattle, Washington, with 905 registrants, the most since the COVID pandemic began. In FY 2023, Stanford University launched a semiconductor investigation through the National Laboratory to the ISS to improve the synthesis of materials for photovoltaic devices, renewable energy sources designed to convert sunlight into electricity for solar energy applications.

Following Congress's FY 2022 consent to operate the ISS through 2030, as well as the commitment of ESA, JAXA, and the Canadian Space Agency (CSA) to the extension of ISS operations through 2030, and Roscosmos's commitment to operations through 2028, NASA is working with these partners to strategize what future international cooperation in LEO would look like in future commercial low-Earth orbit destinations (CLD).

Commercial Space Division

Commercial Crew Program

During FY 2023, NASA's Commercial Crew Program (CCP) and partners continued flying ISS crew rotation missions as well as readying a launch vehicle and spacecraft for a planned crewed demonstration flight to and from the ISS.

As described in the previous section, in FY 2023, NASA's Commercial Crew Program partner SpaceX flew two operational crew rotation flights to and from the ISS.

The fifth operational mission of SpaceX (Crew-5) in the CCP launched on October 5, 2022, and returned to Earth on March 11, 2023. This mission marked two significant milestones. Nicole Mann was the first Native American woman to travel to space, and she also served as the first female mission commander for a SpaceX crewed mission. Also, it was the first time a Russian cosmonaut, Anna Kikina, flew aboard a Crew Dragon spacecraft.

Following Crew-5's successful docking to the ISS, SpaceX's Crew-4 mission concluded with a successful landing on October 14, 2022.

The SpaceX Crew-6 mission launched on March 2, 2023, and docked with the ISS the following day.

The final ISS crew rotation mission to the ISS during FY 2023, Crew-7, launched on August 26, 2023, docking with the ISS the following day. Crew-7 represented the first time that astronauts representing four ISS International Partners (U.S., Russia, ESA, and JAXA) flew on a single CCP mission.

After Crew-7's successful ISS docking, Crew-6 undocked from the ISS on September 3, 2023, and landed in the Atlantic Ocean off the coast of Jacksonville, Florida, after 186 days in space.

A summary of NASA's Commercial Crew Missions by SpaceX Spacecraft

Spacecraft Name	ISS Crew Missions
Dragon Resilience	Crew-1
Dragon Endeavour	Demo-2, Crew-2, Crew-6
Dragon Endurance	Crew-3, Crew-5, Crew-7
Dragon Freedom	Crew-4

NASA CCP's partner, Boeing, continued spacecraft issue mitigation efforts and launch vehicle processing in preparation for their upcoming Crew Flight Test (CFT). CFT will be the first crewed flight of Boeing's Starliner Commercial Transportation System. NASA astronauts Butch Wilmore and Suni Williams are assigned to fly Starliner and United Launch Alliance's Atlas V rocket to the ISS. Starliner will remain docked at the orbiting laboratory for about two weeks to evaluate the new spacecraft and its systems before returning to Earth, landing in the western United States.

Launch Services Office

In FY 2023, NASA's Launch Services Office (LSO) successfully launched a weather satellite for the National Oceanic and Atmospheric Administration (NOAA) and a science mission. The Joint Polar Satellite System 2 (JPSS-2) satellite launched aboard an Atlas V along with the Space Technology Mission Directorate's (STMD's) technology demonstration mission, Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID), as a secondary payload. The Surface Water and Ocean Topography (SWOT) satellite launched aboard a Falcon 9 in December 2022. Both JPSS-2 and SWOT launched from Vandenberg Space Force Base (VSFB) in California. In addition to launching NASA's science and technology spacecraft, LSO acquired a new launch service for NASA's Science Mission Directorate (SMD). The

launch service for the Sentinel-6B mission is a competitively awarded launch services task order under the NASA Launch Services II contract. Sentinel-6B will launch aboard a Falcon 9 in November 2025.

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 2023, the program provided these advisory services to several programs and missions, including the ISS Cargo Resupply Services missions; the 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) 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 2023, LSO acquired four new science VADR Class D launch services through competitively awarded VADR launch service task orders. In November 2022, NASA selected Rocket Lab to provide a VADR launch service for the Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) mission. The pair of TROPICS-2 and TROPICS-3 spacecraft successfully launched aboard two Electron rockets from Rocket Lab's Launch Complex 1 Pad B in Mahia, New Zealand, in May 2023, completing the constellation. In February 2023, the Escape and Plasma Acceleration and Dynamics Explorers (ESCAPADE) launch service was awarded to Blue Origin launching on a New Glenn VADR launch vehicle. ESCAPADE is planned for launch from Cape Canaveral Space Force Station (CCSFS) in August 2024. In August 2023, the Polar Radiant Energy in the Far-InfraRed Experiment (PREFIRE) mission launch service was awarded to Rocket Lab launching on an Electron VADR launch vehicle. PREFIRE is planned for launch from New Zealand in May 2024. In September 2023, NASA selected SpaceX to provide a VADR launch service for the Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites (TRACERS) mission. TRACERS is planned to launch aboard a Falcon 9 from VSFC no earlier than April 2025. There are currently 12 companies providing launch services for VADR missions.

NASA and LSO continue to partner with universities, nonprofits, and NASA Centers to launch small research satellites through the CubeSat Launch Initiative (CSLI). As of the end of FY 2023, more than 150 CubeSats from 34 states, the District of Columbia, and Puerto Rico have been launched, with 55 CSLI-sponsored CubeSats preparing for upcoming launches on

NASA, other U.S. agencies, ESA, and commercial missions. In FY 2023, nine CSLI-sponsored CubeSats were launched.

In January 2023, SpaceX completed certification of its Falcon Heavy launch vehicle, and preparations were made for the first LSO-managed mission on a Falcon Heavy, Psyche, which is scheduled to launch from Kennedy Space Center (KSC) in October 2023. Rocket Lab's Electron launch vehicle was also certified in May 2023. Certification activities are currently ongoing with United Launch Alliance's Vulcan, Alpha's Firefly, and Blue Origin's New Glenn launch vehicles.

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 in the human exploration plan, in 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, HRP developed collaborations with universities, industry, the U.S. Government, and International Partners to leverage its research funding and accelerate risk mitigation development to enable space exploration.

In FY 2023 HRP implemented ISS operations of the Complement of Integrated Protocols for Human Exploration Research (CIPHER) study, the most complex human life science experiment ever performed on the ISS. Through CIPHER, astronauts participate in an integrated set of 14 studies sponsored by NASA and International Partner agencies. CIPHER integrates data across all the studies, and those integrated data will be evaluated to identify patterns and gain a deeper understanding of how the human body reacts to long durations in space. It is expected that astronauts flying both six-month missions and year-long missions will participate. These different durations will provide longitudinal physiological and psychological response curves to inform future Mars Crew Health and Performance systems.

Two Human Exploration Research Analog (HERA) campaigns to simulate the isolation and confinement environment of a space mission were conducted by HRP. The campaigns included a variety of research studies, including team functioning and behavioral health, effects of crew autonomy on performance and behavior, lack of privacy, and the effectiveness of tools and technologies in supporting an autonomous team. Planning for the next series of missions is ongoing and will include studies and crew from the United Arab Emirates.

HRP collaborated with the Naval Medical Research Unit Dayton (NAMRU-D) and Langley Research Center (LaRC) to develop a motion-based training platform to provide Human Landing System (HLS) risk mitigation by testing potential countermeasures for landing, egress, and early EVAs. The partnership uses the Navy's Disorientation Research Device, better known as "the Kraken." 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.

HRP completed an international collaboration with the Deutsches Zentrum für Luft- und Raumfahrt (DLR; German Aerospace Center) to conduct a series of 30-day strict head-down-tilt bed rest campaigns at the :envihab (Environment and Habitat) Facility in Cologne, Germany, to study potential countermeasures for Spaceflight Associated Neuro-ocular Syndrome (SANS). The SANS countermeasures studies consisted of four campaigns, with the final two campaigns (3 and 4) finishing in March and June 2023, respectively.

A study was implemented by HRP for "Validation of Multisystem Countermeasures Protocol for Spaceflight during Antarctica Winter-over at Palmer Station." At the National Science Foundation's Antarctic base at Palmer Station, a suite of immune countermeasures is being evaluated to mitigate the negative effects of isolation and confinement on human immune system functionality. A validation study conducted previously demonstrated similar immune dysfunction comparing long-duration astronauts and Antarctic winter-over participants.

HRP completed data collection on an ESA parabolic flight campaign. Five NASA-sponsored investigations were conducted to characterize physiological and functional performance changes in the sensorimotor and cardiovascular systems during weightlessness (0-g) and partial-gravity (0.25-g, 0.50-g, and 0.75-g) using parabolic flight. These data will be used to improve our understanding of the dose-response relationship between gravity level and physiological function.

HRP upgraded the NASA Space Radiation Laboratory at Brookhaven National Laboratory to produce a space radiation environment using particle beam accelerators that enable greater versatility and lower operating costs than the previous system. A total of 20 NASA-funded teams completed radiation biology and health studies, utilizing approximately 152 hours of beam time. These unique dose and dose-rate studies are critical for adequate characterization of space radiation health risks, as our understanding of how the space radiation environment impacts health is still evolving.

HRP coordinated with NASA's White House Liaison and the Office of Science and Technology Policy to support President Biden's Cancer Cabinet as part of the Moonshot Initiative. NASA enabled prioritized access to the NASA Space Radiation Research Lab for National Cancer Institute grant awardees to study effects of heavy ion therapeutics.

HRP supported the commercial space Axiom-2 crew mission by integrating human research studies that included HRP Spaceflight Standard Measures and Spacecraft Occupant Risk research. In addition, HRP supported the Translational Research Institute for Space Health (TRISH) and its Essential Measures, Enhancing eXploration Platforms and Analog Definition (EXPAND) research program, Space Omics (pre- and postflight genetic analyses), and SANS surveillance studies during the Axiom-2 mission. The NASA–commercial provider collaboration helps to build the commercial spaceflight research abilities while helping HRP obtain additional important medical data.

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 2023, RPT test facilities continued to support 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 700 tests (over 57,000 seconds).

RPT placed priority on testing rocket engines and components for NASA and its collaborative commercial partners for the Artemis Program in 2023 and continued to provide testing of the Space Launch System RS-25 core stage engines in the A-1 Test Stand at Stennis Space Center (SSC) in Mississippi. This testing provided performance data on redesigned engines to be used beginning with Artemis V. Modifications to the SSC B-2 Test Stand continued throughout FY 2023 in support of an integrated four-engine stage test of the Exploration Upper Stage (EUS) and its plume management system. The interstage test article, an important element of this planned test, arrived and was mounted into the test stand in preparation for integration of the RL-10 EUS engines. Elsewhere at SSC, test activity in the E-Complex, a versatile multi-user complex for development testing, supported a variety of commercial engine, turbo-pump, thruster, and component test requirements.

Test stands at other NASA Centers also tracked significant activity in 2023. At Marshall Space Flight Center (MSFC), testing supported both NASA internal and NASA collaborative projects to advance manufacturing and development techniques through the testing of engine components, including rocket nozzles. MSFC conducted testing in evaluation of liquid rocket engines for landers, on-orbit stages, and spacecraft, as well as solid rocket motors. White Sands Test Facility (WSTF) supported NASA, International Partner, commercial and defense customers with hot firings, acceptance testing, and qualification of thrusters and thruster system components. Testing at WSTF supported developmental thrusters that advanced low-temperature operations and nano-satellite propulsion. Demilitarization support

for Minuteman III propulsion stages deactivation also continued. At Glenn Research Center's Armstrong Test Facility, preparatory work for proto-qualification testing of the Sierra Space Dream Chaser Cargo System (DCCS) in the In-Space Propulsion Facility (ISPF) continued, as well as vacuum testing to support a Federal partner.

Space Communications and Navigation

In FY 2023, NASA's Space Communications and Navigation (SCaN) program focused on its primary mission of providing reliable space communications to its user community in near and deep space while ensuring its network was maintained and developed for future needs. The program also focused on demonstrating optical communications in near and deep space to provide vastly increased communication speeds for both robotic and crewed missions, including Artemis.

SCaN operated networks above the required network proficiency of 95 percent, with both the Deep Space Network (DSN) and the Near Space Network (NSN) achieving 99 percent or better. The program also continued to work its key plans to build, augment, or upgrade critical network assets, particularly in support of NASA's future Artemis missions. Additional support is required to provide near continuous space communications for both Artemis and the ISS, as well as 100 robotic missions in near and deep space.

A Program Independent Review (PIR) led by NASA's Office of the Chief Engineer reviewed the program's risks and challenges related to providing its internal and external customers with reliable space communications capabilities. SCaN responded to the PIR's key findings and has developed a plan to resolve any issues.

Throughout FY 2023, SCaN enabled the launch and operations of multiple high-profile science and human exploration missions by providing critical space communications and telemetry. The program also partnered with the Space Technology Mission Directorate (STMD) and the Jet Propulsion Laboratory for the launch of the Deep Space Optical Communications (DSOC) payload onboard the Psyche mission, which was delayed into the beginning of FY 2024 due to delayed flight. In addition to previous near space optical communications demonstrations, DSOC was developed to demonstrate optical communication capabilities for deep space missions.

The Integrated Laser Communication Relay Demonstration (LCRD) Low-Earth Orbit User Modem and Amplifier Terminal (ILLUMA-T) payload, designed to provide astronauts and experiments aboard the International Space Station with enhanced data capabilities, was developed by SCaN. Due to launch delays, ILLUMA-T was scheduled to launch in FY 2024.

SCaN coordinated with the interagency spectrum community, led by the National Telecommunications and Information Administration (NTIA) to reach agreement on key spectrum policies issues. The program engaged with the international community through

the Space Frequency Coordination Group, in preparation for the international spectrum treaty negotiation during the 2023 World Radiocommunication Conference (WRC-23).

SCaN organized the Interoperability Plenary (IOP), which meets approximately every four years to provide oversight guidance to the 15 member and observer international space agencies of the Interagency Operations Advisory Group (IOAG). The IOAG met regularly to prepare for discussion of key topics, including 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.

SCaN collaborated with NASA's Office of the General Counsel (and the Office of International and Interagency Relations) to negotiate with the Kingdom of Spain the renewal of both the government-to-government treaty and the 10-year contract, expiring in 2024, to operate the DSN site in Madrid.

SCaN participated in the Quantum Information Science and Technology (QIST) Workforce Development Interagency Working Group managed by the Office of Science and Technology Policy's National Quantum Coordination Office. It also coordinated video and related outreach materials to engage American students and the public on World Quantum Day (April 14).

Science Mission Directorate

NASA's Science Mission Directorate (SMD) increases our understanding of Earth, the Sun, our solar system, and the universe. Through its partnerships with government organizations, industry, and research institutions, including academia and nonprofits, both in the United States and globally, SMD develops and utilizes space-, air-, ground-, and sea-based observatories to gather and analyze data that further our knowledge in the areas of Earth and planetary science, heliophysics, astrophysics, and biological and physical sciences.

At the end of FY 2023, SMD operated 76 missions across its five science divisions: Earth Science, Planetary Science, Heliophysics, Astrophysics, and Biological and Physical Sciences. Earth Science missions study Earth as a system to advance scientific understanding of our home planet and identify and address societal challenges caused by climate change. 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. Heliophysics missions study the Sun and how its activity affects Earth and interplanetary space, while 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 on living systems, while physical science research enables scientists to understand the effects of microgravity on physical phenomena, such as fluid physics and combustion science.

SMD's Science Activation program leverages unique science infrastructure, content, and experts to engage with learners of all ages. In FY 2023 it reached over 52 million people worldwide, more than double the previous year! Working with community-based institutions such as libraries, museums, science centers, and planetariums, the Science Activation program continued its work through 37 competitively selected cooperative agreements, leveraging more than 525 partners and 745 subject matter experts in all 50 states, territories, and the District of Columbia. In addition, the Citizen Science Initiative has 40 active projects that harness the energies of the public and use the rigors of science to create new discoveries. There have been 91 refereed publications with 468 named coauthors who are NASA citizen scientists. In fact, 121 peer-reviewed Science Activation publications have been cited over 1,000 times to date.

Earth Science

Earth is a dynamic, interconnected, living planet that continues to change. The Earth Science Division 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 inform policy and decision makers

to benefit life on Earth in areas such as agriculture, water and food security, urban planning, disaster preparedness and response, transportation, climate and weather, and many others. The Earth Science Division seeks to continue to identify and make the observations necessary to understand our rapidly evolving planet through the coming decades. Below are significant highlights from FY 2023.

Earth System Observatory

Following guidance from the most recent National Academies Decadal Survey, NASA is designing the next generation of integrated Earth missions called the Earth System Observatory (ESO). Each mission will deliver critical measurements on its own, but taken together as a single observatory, the ESO will deliver unprecedented understanding of our Earth, providing key data to inform decisions on how we address climate 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). A trailblazer for the ESO's Surface Deformation and Change mission, the NASA-ISRO synthetic aperture radar (NISAR) mission will assist planners and decision makers with managing hazards and natural resources. NISAR's radar systems were delivered to India for integration with the satellite bus and performance testing. Atmosphere Observing System (AOS-Storm and AOS-Sky), Surface Biology and Geology, and Mass Change components of the Earth System Observatory passed Key Decision Point-A and are now in formulation.

Earth Information Center

The Earth Information Center, a physical and virtual space to show people Earth as NASA sees it, opened its first physical location at NASA Headquarters. 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.

Next Earth Ventures Instrument Selected

In May 2023, NASA selected a new Earth Venture Instrument to better understand Earth's dynamic atmosphere—specifically, ice clouds that form at high altitudes throughout tropical and subtropical regions. The Polarized Submillimeter Ice-cloud Radiometer (PolSIR) instrument, led by Vanderbilt University, will provide crucial information about how to accurately simulate high-altitude ice clouds in global climate models. The investigation consists of two identical CubeSats—each just a little bigger than one foot tall—flying in orbits separated by three to nine hours.

Scientific Discovery: Coupling of Water and Energy Cycles

Climate change and human activities increasingly threaten lakes that store 87 percent of Earth's fresh surface water. More than half of the world's largest lakes showed significant declines from 1992 to 2020. Yet, recent trends and drivers of lake volume change remain largely unknown globally. In a paper published in the May 2023 edition of *Science*, researchers used satellite data from a variety of sources, including NASA's ICESat and ICESat-2, to find that the net volume loss in natural lakes is largely attributable to climate warming and human water consumption.

Increased Airborne Research Capability

NASA took delivery of a Boeing 777 in December 2022 to replace a DC-8 that was beyond end-of-life. The replacement plane responds to the National Academies of Sciences, Engineering, and Medicine recommendation for large aircraft studies: the 777 dramatically improves research capability, doubling range and endurance (~9,000 nautical miles, ~19 hours) and tripling science capacity.

TEMPO Air Quality Mission Launches

The April 2023 launch of the Tropospheric Emissions: Monitoring of Pollution (TEMPO) mission was a significant milestone, as it is the first funded Earth Venture Instrument (EVI-1). Resulting from scientific collaboration among multiple U.S. and international organizations, TEMPO's near-real-time air quality measurements—hourly measurements of pollutants like nitrous dioxide, ozone, and formaldehyde—will benefit both scientific research and operational work of other Federal agencies: both NOAA and EPA are early adopters of TEMPO science applications.

TROPICS Cyclone Study Mission Launches

Launched in May 2023, Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats (TROPICS) is a constellation of innovative CubeSats, each the size of a loaf of bread, that will improve our forecasts of the intensity and landfall of hurricanes. The TROPICS mission is NASA's first successful Venture-Class Acquisition of Dedicated and Rideshare (VADR) engagement (with the secondary goal of fostering the development of new, more affordable options for access to space). The mission partners include MIT Lincoln Labs, Blue Canyon Technologies, Rocket Lab, NOAA, and a coalition of universities.

SWOT Mission Launch

NASA's December 2022 launch of the Surface Water and Ocean Topography (SWOT) mission promises to significantly advance our understanding of the global water cycle, making the first

global survey of Earth's surface water as it measures the height of the water in lakes, rivers, reservoirs, and the ocean. The SUV-size satellite, jointly developed and managed by NASA and the French space agency Centre National d'Études Spatiales (CNES), with contributions from the Canadian Space Agency and U.K. Space Agency, is helping researchers understand how much water flows in and out of freshwater bodies, providing insight into the ocean's role in how climate change unfolds, and how to help mitigate effects of sea-level rise.

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 2023.

OSIRIS-REx Samples Asteroid Bennu

On September 24, 2023, the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REx) successfully returned to Earth NASA's first sample material from an asteroid. This mission collected even more asteroid sample material than anticipated and will help scientists investigate how planets formed and how life began, as well as improve our understanding of asteroids that could impact Earth.[8]

Sample Collection by the Perseverance Rover for Mars Sample Return

NASA's Perseverance Rover, the first element of the Mars Sample Return (MSR) Campaign, collected nine additional diverse, scientifically selected samples from Mars. Two of the samples were depot samples to serve as a backup set while the rest of the collected samples remain cached onboard the Perseverance rover, which serves as the primary means to convey samples to a Sample Retrieval Lander (SRL) as part of the current campaign architecture. Perseverance will continue to gather scientifically compelling samples from other locations, boosting the diversity and scientific value of the collection of samples onboard the rover.

8 https://science.nasa.gov/mission/osiris-rex

DART Crashes into Dimorphos...on Purpose

On September 26, 2022, the Double Asteroid Redirection Test (DART) spacecraft crashed into Dimorphos, the smaller of two asteroids in a binary system (that is no danger to Earth) to test one technique humanity could use to deflect an asteroid heading for Earth. Dimorphos, the size of a football stadium, orbits a larger asteroid, Didymos. Images provided by the ATLAS Telescope in South Africa and the Italian LICIACube, which rode with DART, showed ejecta from the impact. DART's successful autonomous targeting of a small asteroid, with limited prior knowledge, resulted in an orbital period change for Dimorphos of 33 minutes and validates a critical first step on the path to developing kinetic impactor technology as a viable operational capability for planetary defense to prevent future catastrophic asteroid strikes on Earth.

VIPER Begins Assembly and Integration

NASA's Artemis lunar rover, the Volatiles Investigating Polar Exploration Rover (VIPER), will explore the South Pole of the Moon to learn the origin and distribution of water ice on the Moon. VIPER will be the first-ever resource mapping mission on another celestial body. VIPER successfully passed NASA's gate review to begin system assembly and integration, leading up to a launch in 2024.[9]

Crustal and Time-Varying Magnetic Fields at the InSight Landing Site on Mars

After four successful years, NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) mission ended science operations in December 2022, as it gradually lost power due to dust on its solar panels. InSight hosted the first magnetometer deployed to the Martian surface and measured the geology and seismology of Mars throughout its mission. InSight detected over 1,300 Marsquakes, and on May 4, 2022, it measured the largest quake ever detected, estimated to be magnitude 5. InSight also "heard" meteoroids hitting the Mars surface.

Heliophysics

The energy from our Sun enables and sustains life on our home planet while also producing radiation and magnetic energy that can impact that same life. The Heliophysics Division studies the Sun and its influences on the very nature of interplanetary space and, in turn, the atmospheres of planets and the technology that exists there. Solar activity can interfere with satellite electronics, communications, and GPS signals, and it can also impact the radiation fields that spacecraft travel through to get to the Moon, Mars, and other planets. Below are significant highlights from FY 2023.

9 https://science.nasa.gov/mission/viper

Parker Solar Probe Breaks Records and New Ground

The 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 winds and energetic particles.[10] Since its launch in 2018, the spacecraft has set records for the fastest humanmade object and closest approach to the Sun, coming to within 4.51 million miles on September 27, 2023, in addition to producing groundbreaking science and providing valuable information about the structure of coronal mass ejections. To date, Parker has completed 17 orbits around the Sun and six of seven planned flybys of Venus. Solar Cycle 25 began at the end of December 2019, and Parker continues to witness an increasing number of solar events as the Sun's activity ramps up.

Space Weather Program Continues to Grow

The NASA Space Weather Program[11] continued its mission to provide an improved framework to increase our understanding of how the Sun impacts our everyday lives on Earth, to transition NASA research to NOAA and Department of Defense (DOD) operations, and to inform future research goals. Among many other accomplishments in 2023, the Program completed the seventh joint NASA-NOAA Research-to-Operations-to-Research (R2O2R) solicitation to ensure the integration of new science into space weather prediction models, competitively selected its first three Space Weather Centers of Excellence (SWxC) to support multi-institution and multi-/inter-/trans-disciplinary collaboration, and established the Moon to Mars (M2M) Space Weather Analysis Office to support NASA's Space Radiation Analysis Group (SRAG) with human space exploration activities.

Heliophysics Big Year

In FY 2023, NASA completed preparations to launch the Heliophysics Big Year,[12] 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 ending with the Parker Solar Probe's closest approach to the Sun in December 2024, all those interested in sharing the science, art, and beauty of heliophysics will have the opportunity to engage in many solar science events, such as watching solar eclipses, experiencing an aurora, participating in citizen science projects, and other fun Sun-related activities.

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10 https://science.nasa.gov/mission/parker-solar-probe

11 https://science.nasa.gov/heliophysics/focus-areas/space-weather/

12 https://science.nasa.gov/sun/helio-big-year/

Small Explorer Mission Concept Studies Selected

In September 2023, NASA selected four Small Explorer (SMEX) heliophysics missions to conduct concept studies that aim to expand knowledge of the dynamics of the Sun and related phenomena. The Cross-scale Investigation of Earth's Magnetotail and Aurora (CINEMA) mission aims to understand the structure and evolution of Earth's magnetosphere, with particular focus on the magnetotail. The Chromospheric Magnetism Explorer (CMEx) mission's goal is to understand the magnetic nature of solar eruptions and identify the magnetic sources of the solar wind. The Extreme ultraviolet Coronal Mass Ejection and Coronal Connectivity Observatory (ECCCO) intends to contribute to understanding the Sun's middle corona and the dynamics of eruptive events leaving the Sun. The Magnetospheric Auroral Asymmetry Explorer (MAAX) seeks to improve our understanding of how interactions between Earth's magnetosphere and ionosphere influence Earth's aurora. Any missions selected to move forward after the concept studies are conducted will join the current heliophysics mission fleet.

Astrophysics

The Astrophysics Division manages studies of the universe, seeking to better understand the creation and history of stars and galaxies, as well as our place within it. Astrophysics explores how planetary systems can form, how habitable environments develop, and whether other worlds contain the signatures of life. Below are significant highlights from FY 2023.

James Webb Space Telescope (Webb)

The James Webb Space Telescope (Webb) studies every phase in the history of our universe, ranging from the first luminous glows after the Big Bang, to the formation of solar systems capable of supporting life on planets like Earth, to the evolution of our own solar system. Orbiting the Sun 1.5 million kilometers (1 million miles) away from Earth, the world's largest, most powerful, and most complex space science telescope ever built, Webb serves thousands of astronomers worldwide. Among its many accomplishments in FY 2023, Webb discovered the most distant active supermassive black hole to date in the Cosmic Evolution Early Release Science (CEERS) Survey. The galaxy, CEERS 1019, existed just over 570 million years after the Big Bang, and its black hole is less massive than any other yet identified in the early universe. Webb also identified 11 galaxies that existed when the universe was 470 to 675 million years old. Webb also captured a pair of actively forming young stars, known as Herbig-Haro 46/47, in high-resolution near-infrared light. Herbig-Haro 46/47 is an important object to study because it is relatively young—only a few thousand years old. Star systems take millions of years to fully form. Targets like this give researchers insight into how much mass stars gather over time, potentially allowing them to model how our own Sun—a low-mass star—formed, along with its planetary system. Webb has also made numerous discoveries related to exoplanets

with one of the most important being a new investigation into K2-18 b, an exoplanet 8.6 times as massive as Earth, which was found to exhibit the presence of carbon-bearing molecules including methane and carbon dioxide. Webb's discovery adds to recent studies suggesting that K2-18 b could be a Hycean exoplanet, one that has the potential to possess a hydrogen-rich atmosphere and a water ocean–covered surface.

Hubble Continues Apace

Hubble keeps revealing new science about the universe, our galaxy, and even Earth's neighboring planets after decades in orbit. Astronomers using Hubble have, for the first time, directly measured the mass of a single, isolated, white dwarf—the surviving core of a burned-out Sun-like star. Researchers found that the companionless white dwarf, LAWD 38, is 56 percent the mass of our Sun. This agrees with earlier theoretical predictions of the white dwarf's mass and corroborates current theories of how white dwarfs evolve as the end product of a typical star's evolution. The unique observation yields insights into theories of the structure and composition of white dwarfs. Astronomers used the phenomenon of gravitational microlensing, whereby the light from a background star was slightly deflected by the gravitational warping of space by the foreground dwarf star. As the white dwarf passed in front of the background star, microlensing caused the star to appear temporarily offset from its actual position on the sky. Astronomers used Hubble to precisely measure how light from a distant star bent around the white dwarf.

Hubble was used to study the asteroid Dimorphos in the aftermath of NASA's DART (Double Asteroid Redirection Test) experiment. Astronomers using Hubble's extraordinary sensitivity have discovered a swarm of boulders that were possibly shaken off the asteroid when NASA deliberately slammed the half-ton DART impactor spacecraft into Dimorphos at approximately 14,000 miles per hour.[13] The 37 free-flung boulders range in size from three feet to 22 feet across, based on Hubble photometry. They are drifting away from the asteroid at little more than a half mile per hour—roughly the walking speed of a giant tortoise. The total mass in these detected boulders is about 0.1 percent the mass of Dimorphos.

Roman Space Telescope Reaches Key Development Milestone

The Nancy Grace Roman Space Telescope (Roman) will help astronomers better understand the nature of dark energy and exoplanet diversity and is expected to launch in FY 2027. In FY 2023, the 18-detector Focal Plane System, which Ball Aerospace integrated into the Wide Field Instrument, and the entire camera assembly began environmental testing in space-like conditions. The instrument carrier has been completed and delivered to NASA. Engineers

13 https://iopscience.iop.org/article/10.3847/2041-8213/ace1ec

installed the 45-mile wiring harness into the spacecraft bus,[14] and four avionics boxes have been mechanically and electrically integrated. NASA has selected a set of science teams to develop the infrastructure for science data analysis and interpretation. The Space Telescope Science Institute began the community-wide process of defining the mission's surveys in detail.[15]

Biological and Physical Sciences

The Biological and Physical Sciences Division (BPSD) leads the world in fundamental space-based research, pioneers transformational discoveries, enables sustained human space exploration, and improves life on Earth and in space. BPSD's Space Biology research is focused on animal biology; cell and molecular biology; microbiology; plant biology; and developmental, reproductive, and evolutionary biology. Physical Sciences research is focused on quantum science, biophysics, combustion science, complex fluids, fluids physics, and materials science. Below are significant highlights from FY 2023.

Decadal Survey on Biological and Physical Sciences Research

BPSD received the National Academies of Sciences, Engineering, and Medicine's (NASEM) decadal survey report titled *Thriving in Space—Ensuring the Future of Biological and Physical Sciences Research: A Decadal Survey for 2023–2032*. The report prioritizes research needed to support space exploration, advance transformative science, and benefit life on Earth. The report's recommendations and key scientific questions are organized around three key themes: adapting to space, living and traveling in space, and probing phenomena hidden by gravity or terrestrial limitations. NASA is reviewing the recommendations and will issue an initial public response in 2024.

NASA Science on Artemis I

BPSD's Space Biology Program selected four investigations to fly aboard Artemis I as a part of BioExpt-01, making these the first biological experiments to orbit the Moon as part of the Artemis Program. The experiments, which included plant seeds, fungi, yeast, and algae, were used to study the effects of space radiation on these model organisms before sending humans back to the Moon and, eventually, to Mars. During its flight, Orion passed through the Van Allen Belts—areas beyond low-Earth orbit where cosmic radiation is trapped—and provided researchers with a true deep space environment for conducting these experiments. After Orion

14 https://www.nasa.gov/missions/roman-space-telescope/nasa-begins-integrating-nervous-system-for-roman-space-telescope/

15 https://www.stsci.edu/contents/newsletters/2023-volume-40-issue-01/astronomers-begin-defining-the-science-of-romans-core-community-surveys

completed its journey around the Moon, all of the investigations were returned to their respective Principal Investigators for further study.

Pioneering Quantum Science

BPSD's Cold Atom Lab facility aboard the International Space Station has enabled researchers to produce quantum firsts–the first dual-species Bose-Einstein Condensates in space, first dual-species atom interferometers in space, and quantum bubbles. This research could contribute to the development of new quantum technologies, including ultra-sensitive quantum sensors for space applications.

Growing Crops in Space

International Space Station Plant Habitat-03 is one of many ongoing studies working toward the goal of growing plants to provide sustainable sources of fresh food for crewmembers on future space missions. The space station's facilities for this research include the Advanced Plant Habitat (APH) and the Vegetable Production System (Veggie). So far, researchers have used these facilities to grow lettuce, Chinese cabbage, mustard greens, kale, tomatoes, radishes, and chili peppers. This research builds, in part, upon BPSD-supported space- and ground-based plant investigations and capabilities. This research could provide critical insights for growing plants in the hard conditions of the Moon and Mars during future Artemis missions, as well as contribute to advancements in agriculture on Earth.

Enabling Exploration Technologies and Ensuring Crew Safety

Research aboard the International Space Station studies how microgravity affects physical phenomena, such as flame spread, thermal management, and fluid behavior. This research provides data and fundamental insights that can inform the design of safer and more efficient systems that ensure crew safety and enable astronauts to go farther and stay longer in space. In FY 2023, BPS installed two facilities that enable advancements in these areas: the Flow Boiling Condensation Experiment (FBCE) and the Solid Fuel Ignition and Extinction (SoFIE) facility.

Developing Commercial Research Capabilities

The Commercially Enabled Rapid Space Science (CERISS) initiative aims to develop transformative research capabilities with commercial space industry to dramatically increase the pace of research and facilitate the growth of the commercial space industry. Long-range goals include conducting scientist astronaut missions on the International Space Station and commercial low-Earth orbit (LEO) destinations and developing automated hardware for experiments beyond low-Earth orbit, such as to the lunar surface. In FY 2023, CERISS released two Requests for Information (RFI)—one RFI to determine the commercial industry's interest

in developing capabilities for LEO and a second RFI to determine the science community's interest in utilizing in situ analysis capabilities, sample or experiment preparation techniques, and other research hardware for crew-tended microgravity investigations. BPSD is reviewing the responses to these RFIs to guide the development of a strategic plan as NASA transitions to new commercial LEO platforms to conduct scientific research.

Exploration Science Strategy and Integration Office

The Exploration Science Strategy and Integration Office (ESSIO) was created within SMD to help develop and implement a strategy to enable robotic and human exploration of the Moon and beyond. In this capacity, ESSIO manages the Lunar Discovery and Exploration Program (LDEP) and the Commercial Lunar Payload Services (CLPS) initiative, both of which work toward strategically integrating our science and exploration goals.

Commercial Lunar Payload Services Prepare for Liftoff

NASA's Commercial Lunar Payload Services (CLPS) initiative leverages commercial capabilities and technology to deliver scientific instruments and technology demonstration payloads to the Moon, with the goal to build a sustainable lunar economy that will produce rapid, frequent, and affordable access to the lunar surface and cislunar space.[16] In FY 2023, NASA completed testing of the Mass Spectrometer Observing Lunar Operations (MSolo) instrument that will fly on the agency's first CLPS launch, the Polar Resources Ice Mining Experiment-1 (PRIME-1). Flown by Intuitive Machines, PRIME-1 will send two instruments—MSolo and The Regolith and Ice Drill for Exploring New Terrain (TRIDENT)—to the lunar South Pole region, where they will undertake the first in situ resource demonstration on the Moon and the first robotic sampling and analysis of ice from below the lunar surface.

Joint Agency Satellite Division

The Joint Agency Satellite Division, together with NOAA, manages the development and launch 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.

16 https://www.nasa.gov/commercial-lunar-payload-services/

Aeronautics Research Mission Directorate

NASA's Aeronautics Research Mission Directorate (ARMD) during FY 2023 continued to make progress on its vision of cleaner, safer, and more advanced air travel and atmospheric flight at every altitude above the United States.[17]

Alongside partners and aviation experts in government, industry, and academia, NASA researched and developed new ideas and capabilities in ARMD's wide-ranging portfolio guided by a comprehensive Strategic Implementation Plan to transform aviation for the 21st century.[18]

During FY 2023, ARMD initiated several new landmark scientific and engineering efforts contributing to the key drivers of the global aeronautics industry in five transformational areas: ultra-efficient airliners, high-speed commercial flight, advanced air mobility, future airspace and safety, and innovation.

Ultra-Efficient Airliners

NASA ARMD continued to enable greater efficiency and reduced environmental impact of aviation under the Sustainable Flight National Partnership (SFNP)—a collaboration with partners in government, industry, and academia to achieve net-zero greenhouse gas emissions in aviation by 2050 through enabling next-generation sustainable aviation technology and practices.[19] As part of SFNP, NASA worked to make aviation more environmentally friendly 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.

This past year, NASA announced its newest X-plane: the X-66. Under a Funded Space Act Agreement, NASA and Boeing began collaborating to build, test, and fly this full-scale demonstrator aircraft, which will validate new fuel-efficient designs and green technologies aimed at lowering emissions for single-aisle airliners.[20] 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. The airplane selected to be converted into the X-66 arrived at Boeing's Palmdale facility in California this year to begin its transformation into an X-plane.[21]

SFNP activities, such as the Hybrid Thermally Efficient Core (HyTEC) project, made progress in FY 2023. HyTEC made significant strides in its goal of building a more

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

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

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

20 https://www.nasa.gov/news-release/nasa-issues-award-for-greener-more-fuel-efficient-airliner-of-future/

21 https://www.nasa.gov/image-article/boeing-transports-aircraft-for-conversion-into-nasas-new-x-plane/

fuel-efficient small-core turbofan jet engine. The project performed key materials research to identify and select composite substances that can withstand the high-pressure, high-temperature environment of a small-core jet engine.[22] By reducing the size of an engine core, fuel burn is reduced while still maintaining the same thrust and power as a current jet engine.

Another SFNP activity, the Hi-Rate Composite Aircraft Manufacturing (HiCAM) project, issued $50 million in awards to 14 organizations to develop manufacturing processes and advanced composite materials for aircraft structures.[23] HiCAM seeks to reduce the cost and increase the production rate of composite structures made in the United States. By using more lightweight, composite airframes, airlines will save fuel and reduce emissions, making commercial aviation more sustainable.

High-Speed Commercial Flight

NASA made progress in its mission to enable a new market in high-speed commercial air travel.[24] The Agency's Quesst mission seeks to usher in a new era of commercial supersonic flight by demonstrating that loud sonic booms can be reduced to quieter sonic "thumps" using the uniquely shaped X-59 aircraft. Following its initial test flights to verify its acoustics, the X-59 will be flown over select communities to gauge the public's reaction to the sonic "thump." The survey data gathered can help regulators support the adoption of new rules that lift the ban on supersonic travel over land.

During FY 2023, assembly of the X-59 was completed at Lockheed Martin's Skunk Works facility in Palmdale, California, with its jet engine, tail, and lower empennage successfully installed.[25] The aircraft was towed outside the hangar to the flight line to begin testing and systems checkouts, moving closer to its official rollout and first flight.[26]

Advanced Air Mobility

NASA remained steadfast on its Advanced Air Mobility mission.[27] As interest rises for using drones and other new uncrewed aircraft in emerging aviation markets, NASA has continued to lead the vision for this transformation of our cities, towns, and rural areas by finding ways to make it sustainable, accessible, reliable, and, above all, safe.

NASA 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

22 https://www.nasa.gov/aeronautics/updates-from-nasas-hytec-engine-core-project-show-progress/

23 https://www.nasa.gov/news-release/nasa-awardees-to-develop-sustainable-aviation-composite-tech/

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

25 https://www.nasa.gov/image-article/nasas-x-59-tail-installed/

26 https://www.nasa.gov/image-article/nasas-x-59-moves-closer-to-runway/

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

revolutionary new aircraft that are only just now becoming possible. These contributions enable such aircraft to conduct missions including emergency response, civic resource management, and sustainably transporting packages and passengers.

In support of Advanced Air Mobility, NASA completed a research study this year on how wind affects Advanced Air Mobility vehicles during takeoff and landing. As part of the study, a fixed-wing drone acted as a wind sensor to fill knowledge gaps and resolve wind and weather unknowns. The data gathered inform future research activities and flights of these new types of aircraft, such as air taxis.[28]

NASA also partnered with Joby Aviation to simulate a set of flight scenarios using the company's flight simulator. A NASA research pilot flew the simulated aircraft while researchers collected key data to analyze which maneuvers are best for obstacle avoidance, route efficiency, passenger comfort, noise reduction, and more.[29]

Future Airspace and Safety

NASA furthered its research to transform the National Airspace System through several air traffic management research activities. Alongside partners and stakeholders in government, industry, and academia, NASA explored how to improve airspace and airport operations by reducing emissions, saving fuel, reducing passenger delays, and easing airport operations.

During FY 2023, NASA began the Advanced Capabilities for Emergency Response Operations (ACERO) project. Through ACERO, NASA is using drones and advanced aviation communication technologies to improve wildland fire management operations and is developing an interagency concept of operations for addressing wildland fires in collaboration with NASA's Science Mission Directorate to provide more data and situational awareness to firefighters. ACERO began collaboration with other parts of NASA, other government agencies, the scientific community, and commercial industries on developing a concept of operations that enables the safe use of drones in airspace restricted for wildland fire management.[30]

NASA also began field trials of a new Advanced Air Mobility enabling technology called the Data and Reasoning Fabric. The tool is designed to help drones and their operators have safe, efficient access to information while flying in an urban air traffic ecosystem. The agency and its partners studied the tool's responses in a simulated drone flight to deliver medical equipment and supplies from downtown Phoenix, Arizona, to the outermost areas of the greater region.[31]

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28 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-concludes-wind-study/

29 https://www.nasa.gov/centers-and-facilities/armstrong/on-the-fly-nasa-researchers-map-air-taxi-maneuvers-in-simulator-2/

30 https://www.nasa.gov/centers-and-facilities/ames/advanced-capabilities-for-emergency-response-operations-acero/

31 https://www.nasa.gov/aeronautics/nasas-autonomous-aircraft-decision-tech-gets-simulated-urban-test/

This year, NASA signed agreements with five major U.S. airlines to continue developing air traffic decision-making tools to identify opportunities for more efficient air traffic management. One of these tools saved more than 24,000 pounds (10,886 kilograms) of jet fuel in calendar year 2022 for flights departing from two major international airports. Using this machine-learning tool and others, flight coordinators were able to reduce delays and save fuel.[32]

Innovation

NASA continued working with universities in the United States to pioneer sustainable aviation technologies for a zero-emissions aviation future. Through the University Leadership Initiative (ULI) and other activities created through its innovation ecosystem, NASA pushed the frontiers of the possible with the help of our next-generation workforce.

This year, the first round of ULI awardees selected in 2017 finished their research term. Each of the five Principal Investigators from Round 1 reflected on the transformational research ULI enabled and how it furthered NASA's flight research goals.[33] ULI continued to expand during FY 2023 with a sixth round of awards to teams led by New Mexico State University, Boston University, the University of Notre Dame, and Tennessee Technological University.[34]

NASA announced the winner of the 2023 Gateways to Blue Skies Competition—Boston University's "Aluminum Powder Combustion" team. This team of students successfully presented an exciting new potential source of clean energy for aviation. Each of the eight student participants was awarded with the opportunity to intern at one of NASA's aeronautics centers.[35]

More Highlights from NASA ARMD's Programs

Advanced Air Vehicles Program

During FY 2023, NASA performed a full-scale crash test of a six-passenger, overhead-rotor electric vertical takeoff and landing concept vehicle at the Agency's Langley Research Center in Virginia. The test was conducted to best inform the Advanced Air Mobility community on simulation models for drop tests so future activities will be more realistic.[36]

NASA also conducted a series of flights to record the sound of jet engines with the goal of using those data to help predict the way future engines designed for supersonic-capable aircraft might sound at takeoff. The flights allowed researchers to make improvements and

32 https://www.nasa.gov/image-article/nasa-partners-with-airlines-to-save-fuel-reduce-flight-delays/

33 https://www.nasa.gov/aeronautics/nasa-university-leadership-initiatives-first-teams-reflect-on-5-years/

34 https://www.nasa.gov/aeronautics/university-students-test-futuristic-flight-hardware-in-nasa-facility/

35 https://www.nasa.gov/aeronautics/winners-announced-in-gateways-to-blue-skies-aeronautics-competition/

36 https://www.nasa.gov/centers-and-facilities/langley/nasa-crash-tests-evtol-concept/

adjustments to their existing dataset and create a new predictive modelling tool for supersonic jet engine noise.[37]

Airspace Operations and Safety Program

NASA completed during FY 2023 a significant research milestone toward achieving an In-Time Aviation Safety Management System—a future airspace safety system designed to prevent safety risks in the future National Airspace System. New airspace safety capabilities were developed as part of this milestone, such as machine-learning predictive modeling tools, human performance studies, data analysis tools, and more.[38]

Researchers studied how human pilots interact with flight management tools onboard aircraft to best understand how autonomous software can interface with the same software. The test was conducted with the Defense Advanced Research Projects Agency and the aircraft's manufacturer, Sikorsky. As part of the test, a NASA research pilot wore specialized goggles in flight to track pupil movements and biosensors recording vital statistics. This information on the human pilot's real-time reactions furthers the ability for these new autonomous aircraft to be integrated safely into the national airspace.[39]

Integrated Aviation Systems Program

NASA's aeronautical innovators completed load testing on a 6-foot scale model of a transonic truss-braced wing—the same type of uniquely designed, fuel-efficient wing design chosen for demonstration in flight by the X-66. The tests helped confirm how the wing handles structural loads on its trusses and opens the door to future testing with larger models.[40]

Researchers working on the Quesst mission utilized data gathered using NASA's advanced supercomputers to determine the anticipated aerodynamics and acoustics of the X-59 aircraft. The supercomputing programs, which can process enormous amounts of data, created a sort of virtual wind tunnel showing incredible detail.[41]

Transformative Aeronautics Concepts Program

NASA has demonstrated a breakthrough in 3D-printable high-temperature materials that could lead to stronger, more durable parts for airplanes and spacecraft. In partnership with The Ohio State University, NASA developed GRX-810—a new state-of-the-art alloy that,

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37 https://www.nasa.gov/centers-and-facilities/langley/nasa-creating-tool-to-predict-supersonic-jet-noise-at-takeoff/

38 https://www.nasa.gov/directorates/armd/aosp/sws/nasa-concludes-significant-technical-challenge-in-time-terminal-area-risk-management/

39 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-studies-human-pilots-to-advance-autonomous-air-taxis/

40 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-armstrong-tests-model-of-efficient-wing/

41 https://www.nasa.gov/image-article/supercomputers-aid-quesst-researchers-in-predicting-x-59s-sound/

compared to current materials, is twice as strong, more than 1,000 times more durable, and twice as resistant to oxidation.[42]

NASA also made progress toward developing an innovative solid-state battery pack that is lighter and safer and performs better than batteries commonly used in vehicles and large electronics today. During FY 2023, researchers successfully increased this battery's discharge rate beyond their initial expectations, as well as significantly reduced its weight. The activity, part of NASA's commitment to sustainable aviation, has garnered attention from partners in government, industry, and academia.[43]

STEM and Additional Workforce Development Highlights

A group of NASA interns recently made significant contributions to finding ways to apply NASA's expertise to enabling access to health care as distance to care increases. The interns contributed directly to the problems uncovered by the team, including specific challenges within emergency and non-emergency medical transport, organ transport, and physical-virtual transitions to advance in-home health care. Six interns from the group continued with NASA for another term.[44]

The NASA Aeronautics Flight Log experience, in which kids, adults, and classrooms sign up to have their name flown onboard a NASA aircraft expanded.[45] The Flight Log now includes flights that span multiple focus areas including sustainable aviation, Advanced Air Mobility, and working with our industry partners and collaborators. More than 6,000 participants had their names flown onboard NASA's Super Guppy, PC-12, and DC-8 aircraft, and on Boeing's ecoDemonstrator aircraft.

ARMD continued to strengthen its relationship with Native American communities. It supported a series of virtual STEM educator professional development workshops with the Choctaw Nation of Oklahoma. The workshops culminated in an in-person STEM event that included an ISS downlink between Choctaw Nation students and astronaut Nicole Mann. ARMD also orchestrated and supported the introduction and development of a new character in the NASA "First Woman" graphic novel series for K–12 students—a Choctaw woman pilot from Oklahoma.[46] The mission directorate is also working with the Nation to build drone programming at the high school level that will help bridge the education pipeline between K–12 schools and the Nation's robust drone industry work.

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42 https://www.nasa.gov/image-article/nasas-new-3d-printed-superalloy-can-take-the-heat/

43 https://www.nasa.gov/aeronautics/nasas-solid-state-battery-research-exceeds-initial-goals-draws-interest/

44 https://www.nasa.gov/directorates/armd/tacp/nasa-interns-help-identify-aviation-solutions-to-health-care-challenges/

45 https://www3.nasa.gov/flightlog/

46 https://www.nasa.gov/calliefirst/#graphic-novel

Significant progress was made in building and connecting aeronautics-focused STEM content from kindergarten through post-secondary education and into the workforce. ARMD developed multiple standards-based education activities at the elementary, middle, and high school levels, with several available in both English and Spanish, along with in-person upper elementary and middle school workshops for Title I students throughout California, and design challenges for middle and high school students that aligned with similar real-world opportunities at the post-secondary levels.

In addition to these developments, ARMD continued to offer its comprehensive array of educational activities and curriculum to educators year-round.

Space Technology Mission Directorate

NASA's Space Technology Mission Directorate (STMD) aims to transform future missions and ensuring American leadership in aerospace. STMD develops, demonstrates, and transfers new space technologies that benefit NASA, commercial, and other government missions.

New Partnerships

In spring and summer, STMD announced its selections under the Announcement of Collaboration Opportunity (ACO) and Announcement for Partnership Proposals (AFPP) to advance Tipping Point technologies.

- In April 2023, NASA selected 16 ACO proposals from 12 companies for unfunded Space Act Agreements, where NASA provides access to its unique facilities and technical expertise.[47] These agreements allow the agency to directly support continued development of promising technologies without the transfer of funds. The cadre of U.S. industry-led teams will test a new lunar rover tire design, develop a robotically assembled power system, build an electrically actuated device to join in-space propellant transfer lines, and more.
- In July 2023, NASA selected 11 U.S. companies to receive funded Space Act Agreements to mature space technologies. The Tipping Point technologies range from lunar surface power systems to tools for in-space 3D printing, which will expand industry capabilities for a sustained human presence on the Moon through Artemis, as well as other NASA, government, and commercial missions.[48] The projects are funded jointly by NASA and the industry partners, with a total NASA contribution of about $150 million.

Technology Demonstrations

The Technology Demonstration Missions program demonstrates cross-cutting system-level technology solutions that benefit multiple space missions by proving out those technologies in real or simulated environments.[49]

- On November 10, 2022, the Low-Earth Orbit Flight Test of an Inflatable Decelerator (LOFTID) advanced the maturity of Hypersonic Inflatable Aerodynamic Decelerator (HIAD) technology with its successful demonstration.[50] About an hour after launch, LOFTID inflated and deployed in space and began its reentry journey. It entered

47 https://www.nasa.gov/news-release/nasa-selects-12-companies-to-collaborate-on-key-technology-development/

48 https://www.nasa.gov/news-release/nasa-partners-with-american-companies-on-key-moon-exploration-tech/

49 https://www.nasa.gov/tdm/

50 https://www.nasa.gov/mission/low-earth-orbit-flight-test-of-an-inflatable-decelerator-loftid/

the atmosphere at more than 18,000 miles per hour and slowed to less than 80 miles per hour when the onboard parachutes deployed, carrying the heat shield to a gentle splashdown in the Pacific Ocean. The successful technology demonstration opens the door to landing heavier payloads at destinations with atmospheres, such as Mars, Venus, Saturn's moon Titan, and Earth. In July 2023, NASA announced that it selected the United Launch Alliance (ULA) of Centennial, Colorado for a public-private partnership award through its Tipping Point opportunity to continue to evolve LOFTID's proven HIAD design. ULA will develop a larger 10-meter HIAD that leverages a two-piece structure to enable effective load distribution for even larger inflatable decelerators.

- The Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) onboard the Perseverance rover finished operations and proved it is possible to extract oxygen from Mars's CO_2-rich atmosphere.[51] The tiny but mighty demonstration overdelivered, producing over 122 grams of oxygen—about what a small dog breathes in 10 hours—and served as the first demonstration of how we can take advantage of resources on other worlds. MOXIE proved it is possible to produce oxygen for rocket fuel and astronaut life support with in situ resource utilization.
- Engineers began component installation onto the On-Orbit Servicing, Assembly, and Manufacturing 1 (OSAM-1) servicing payload in preparation for spacecraft bus integration and space vehicle testing in simulated space environments.[52] The project was rebaselined in October 2022 due to vendor performance, in-house development technical challenges, and COVID-19 impacts. In September 2023, due to continued programmatic degradation after this rebaseline, the agency initiated an externally led independent continuation review with results due in FY 2024.OSAM-1 aims to demonstrate that servicing technologies are ready for commercial aerospace use and incorporation into other NASA science and human exploration missions. The technologies could give satellite operators new ways to manage their aging fleets.
- Deep Space Optical Communications (DSOC) prepared for launch throughout FY 2023.[53] The project reassessed the new trajectory, thermal environments, and associated funding requirements to accommodate the Psyche launch delay. The project team conducted flight preparation reviews and practiced flight operations through integrated simulations with Psyche. DSOC successfully launched onboard Psyche at the beginning of FY 2024. It will demonstrate the agency's first test of high-data-rate

51 https://www.nasa.gov/solar-system/nasas-oxygen-generating-experiment-moxie-completes-mars-mission/

52 https://www.nasa.gov/image-article/spacecraft-bus-for-satellite-servicing-mission-arrives-at-nasa-goddard/

53 https://www.nasa.gov/directorates/stmd/tech-demo-missions-program/deep-space-optical-communications-dsoc/5-things-to-know-about-nasas-deep-space-optical-communications/

laser communications beyond the Moon within the first two years of Psyche's six-year, 2.2-billion-mile journey to an asteroid of the same name.

- In January 2023, NASA and the Defense Advanced Research Projects Agency (DARPA) announced a collaboration to demonstrate a nuclear thermal rocket engine in space: the Demonstration Rocket for Agile Cislunar Operations, or DRACO, program. NASA will lead technical development of the nuclear thermal engine to be integrated with DARPA's experimental spacecraft. Over the course of the development, NASA and DARPA will collaborate on assembly of the engine before the in-space demonstration as early as 2027. The U.S. Space Force will provide the DRACO launch and launch site support.

Technology Maturation

STMD launched the Lunar Surface Innovation Initiative (LSII) in FY 2020 to spur the creation of novel technologies needed for lunar surface exploration and accelerate the technology readiness of key systems and components.[54] LSII allocated $300 million for programs to establish collaborations across industry and academia. Approximately 50 percent of the Technology Maturation portfolio comprises LSII projects.

- The Fall 2022 Lunar Surface Innovation Consortium (LSIC) meeting was held on November 2–3, 2022, at the University of Texas at El Paso with 443 people representing over 170 companies and institutions attending in person and virtually. Half of the attendees had not previously worked with NASA STMD.
- The Spring 2023 LSIC meeting was held April 24–25, 2023, at the Johns Hopkins Applied Physics Laboratory in Laurel, Maryland. There were 506 participants, 243 in-person attendees, and 263 virtual attendees, representing 209 organizations.
- As part of LSII Diversity, Equity, Inclusion and Accessibility (DEIA) efforts to recruit individuals and members from underserved communities, the LSIC team presented at three conferences targeting underrepresented communities to encourage investments from those communities in lunar surface technology development activities and participation in the LSIC consortium.

The Game Changing Development program advances space technologies that may lead to entirely new approaches for NASA's future space missions and provide solutions to significant national needs.[55]

54 https://www.nasa.gov/space-technology-mission-directorate/lunar-surface-innovation-initiative/

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

- Toward the end of 2022, teams at NASA's Kennedy Space Center completed testing and delivery of the Mass Spectrometer Observing Lunar Operations (MSolo) instrument that will fly on the agency's Polar Resources Ice Mining Experiment-1 (PRIME-1) mission.[56] PRIME-1 will be the first in situ resource demonstration on the Moon and first time NASA will robotically sample and analyze ice from below the lunar surface.
- The Distributed Spacecraft Autonomy (DSA) experiment is one of four technologies being tested on the Starling mission, which launched in summer 2023.[57] DSA demonstrates the ability of a swarm of spacecraft to collect and analyze science data onboard and cooperatively optimize data collection in response.
- As part of the Synthetic Biology (SynBio) project, two BioNutrients samples were returned to Earth on SpaceX CRS-28 in the summer of 2023 for analysis.[58] The BioNutrients project is developing innovative microbial biomanufacturing methods to produce vital products to help maintain astronaut health during extended missions. Data from both BioNutrients 1 and 2 are being used to support the BioNutrients 3 experiment, which plans to demonstrate the production of multiple nutrients in a single serving and test microbial safety techniques developed to ensure product safety.
- The Thruster for the Advancement of Low-Temperature Operations in Space (TALOS)/Frontier Aerospace Corporation Engine Testing Tipping Point (FACET-TP) project developed thrusters that reduce overall spacecraft mass and power.[59] The Frontier Aerospace Corporation delivered five axial flight thrusters to Astrobotic Technology to be integrated into its Peregrine lunar lander for its first Commercial Lunar Payload Services delivery.

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.[60] 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. This year both programs advanced a wide range of technologies,

56 https://www.nasa.gov/polar-resources-ice-mining-experiment-1/

57 https://www.nasa.gov/centers-and-facilities/nasas-starling-mission-sending-swarm-of-satellites-into-orbit/

58 https://www.nasa.gov/space-synthetic-biology-synbio/

59 https://www.nasa.gov/stmd-game-changing-development/thruster-advancement-for-low-temperature-operation-in-space-talos/

60 https://www.nasa.gov/stmd-flight-opportunities/; https://www.nasa.gov/smallspacecraft/

including capabilities for autonomous observation; human health on long-duration missions; entry, descent, and landing; autonomous navigation; and optical communications technology.

Advancing Technologies Through Suborbital Flight Tests and Orbital Capability Demonstrations

Small Spacecraft Technology

- The Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) technology demonstration mission entered lunar orbit on November 13, 2022, becoming the first CubeSat to fly to and operate at the Moon. Over the course of CAPSTONE's primary mission, the spacecraft tested a new navigation technology, called Cislunar Autonomous Position System (CAPS). CAPS could provide autonomous onboard navigation information for future lunar missions, reducing the burden on already overtaxed ground systems. The spacecraft also gathers operational data in the near-rectilinear halo orbit, the destination for NASA's Moon-orbiting outpost, Gateway, which is part of the Artemis program.[61]
- The Starling mission's four small spacecraft launched on July 17, 2023, on a Rocket Lab Electron rocket from Launch Complex 1 in Mahia, New Zealand. Upon successful deployment, mission operators achieved operational two-way communications with each spacecraft and have initiated payload commissioning. As the mission progresses into 2024, it will demonstrate autonomous maneuver planning, ad hoc communications networking, relative navigation, and autonomous coordinated science measurements, all with minimal intervention from operators on the ground.[62]
- On April 28, 2023, the TeraByte InfraRed Delivery (TBIRD) communications system achieved 200-gigabit-per-second (Gbps) throughput on a space-to-ground optical link between a satellite in orbit and Earth, the highest data rate ever achieved by optical communications technology.[63] This data rate is made possible by using laser communications, which pack information into the oscillations of light waves in lasers instead of using radio waves like most space communications systems. The TBIRD communications system launched on May 25, 2022, on Pathfinder Technology Demonstrator-3 (PTD 3), as part of the PTD series of missions that will test the operation of a variety of novel CubeSat technologies in low-Earth orbit.[64]

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

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

63 https://www.nasa.gov/directorates/somd/cubesat-set-to-demonstrate-nasas-fastest-laser-link-from-space/

64 https://www.nasa.gov/mission/pathfinder-technology-demonstrator-ptd/

- NASA's CubeSat Infrared CrossLink (CLICK) A successfully demonstrated the precision laser pointing performance of the spacecraft's fine steering mirror control system—an element of a laser communications system. The fine steering mirror control system enables the use of a lower power laser and will support the alignment of two-way communication—also called crosslink communication—between spacecraft. During the demonstration, CLICK A used the mirror control system in a single 3-unit (3U) spacecraft to precisely aim a near-infrared laser at an optical ground station and send data to the station. Following CLICK A's demonstration, CLICK B/C's two 3U spacecraft will demonstrate two-way crosslink communication in low-Earth orbit. CLICK B/C is anticipated to launch in late 2024.[65]

Flight Opportunities

- In FY 2023, the Flight Opportunities program supported 31 tests of technology payloads via 20 flights with commercial suborbital flight providers. U.S. commercial vendors that successfully flew Flight Opportunities–supported payloads in FY 2023 included Astrobotic (formerly Masten Space Systems), Near Space Corporation, Aerostar, World View, Zero Gravity Corporation, and EXOS.
- Flight tests take technologies from ground-based laboratories into relevant environments to increase technology readiness and validate feasibility while reducing the costs and technical risks of future missions. For example, in a series of flight tests in late FY 2023, University of Central Florida researchers matured an instrument designed to characterize the planetary surface disturbances caused by rocket plumes on Astrobotic's Xodiac rocket-powered lander in Mojave, California. The Ejecta Sheet Tracking, Opacity, and Regolith Maturity (STORM) technology is expected to inform model development and reduce risk for future lunar landings, ultimately enabling rover-based planetary science missions, crewed missions to the Moon and other bodies, and in situ resource utilization.
- Flight Opportunities also supported payload development for Strategic Radio and Tactical Overwatch (STRATO), a suborbital system being collaboratively developed by Aerostar, the U.S. Forest Service, the National Interagency Fire Center and NASA's Ames Research Center to help combat wildland fires by providing a continuous wireless broadband signal between firefighters out in the field and the incident command post. STRATO is designed to address challenges with line-of-sight radio communications in rugged terrain and limited coverage in remote areas. The full proof-of-concept flight test over an active wildfire is expected to take place no earlier than spring 2024.

65 https://www.nasa.gov/mission/click/

- Several Flight Opportunities–supported technologies transitioned from suborbital testing to orbital and terrestrial uses. As a single example, the dual-spinning CubeSat bus developed at the Massachusetts Institute of Technology (MIT) is now a key element in NASA's TROPICS mission, which launched on May 8 and May 26, 2023. TROPICS is a four-CubeSat constellation that is observing tropical cyclones from space. MIT researchers had matured a microwave radiometer technology—previously used only on large satellites—for small spacecraft using parabolic flights supported by Flight Opportunities.

Addressing Technology Gaps Through Technology Development and Rapid Maturation

Small Spacecraft Technology

- In August 2023, NASA's University SmallSat Technology Partnerships (USTP) initiative selected eight U.S. university teams to advance technologies for small spacecraft in the areas of navigation and timing, edge computing and machine-learning architectures, power, and thermal control. The university teams received two awards from the Small Spacecraft Technology program to mature new systems and capabilities in these areas, with support from a NASA Center of their choice. Some USTP projects may be selected for a subsequent flight demonstration through the CubeSat Launch Initiative or Flight Opportunities.

Flight Opportunities

- In January 2023, nine technologies were selected as part of the 2022 TechFlights solicitation.[66] In addition, TechFlights 2023 was released in May, seeking proposals from researchers from industry, academia, and nonprofit research institutes that have space technologies that can be advanced through flight tests. In TechFlights 2023, Flight Opportunities partnered with the Biological and Physical Sciences Division of NASA's Science Mission Directorate on the Commercially Enabled Rapid Space Science (CERISS) initiative to advance biological and physical sciences research capabilities with the commercial space industry. In addition to offering suborbital flight tests with industry providers, the solicitation also included access to commercial platforms hosting payloads in orbit in cooperation with the Small Spacecraft Technology program.
- To increase available testing options for researchers to advance their technologies and expand opportunities for a wider range of commercial companies to support suborbital

66 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-seeks-space-technologies-for-suborbital-and-orbital-flight-tests-2/

and hosted orbital flight testing for NASA, Flight Opportunities released its fourth flight and payload integration services solicitation to industry in cooperation with the Small Spacecraft Technology program on July 20, 2023.[67] The program anticipates the contracts to be in place in FY 2024.

Early Stage Innovations and Partnerships

Early Stage Innovations and Partnerships (ESIP) annually invests in more than 700 early-stage projects and activities through six programs.

The Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) program invested more than $190 million in small businesses and research institutions in FY 2023 through its various Phase I, Phase II, and post–Phase II opportunities.[68]

- Phase I and II—NASA invested $45 million in 295 Phase I proposals from 246 small businesses and 39 research institutions, including eight minority serving institutions (MSIs), to establish the scientific, technical, and commercial feasibility of each proposed innovation. About 30 percent of the awarded small businesses were first-time NASA SBIR/STTR recipients, and 25 percent were from underrepresented groups, including minority- and women-owned businesses. Additionally, four STTR awardees were part of the teams that previously received M-STTR planning grants, now part of the agency's Minority University Research and Education Project (MUREP) Partnership Annual Notification, or MPLAN, which were created to incentivize partnerships between MSIs and small businesses before Phase I submission.[69] In addition to Phase I awards, the program made 112 SBIR and 20 STTR Phase II awards—totaling $113 million—to successful Phase I awardees to expand upon their prior work and create a prototype of their technology.
- Post–Phase II—NASA invested $32 million in American small businesses via its post–Phase II opportunities to continue technology development toward a NASA mission and/or commercialization. This includes the Civilian Commercialization Readiness Pilot Program (CCRPP), Phase II-Extended (II-E), and Sequential Phase II, through which NASA awarded nearly $16 million in total to five U.S. small businesses to advance technologies to address two challenges in space exploration: orbital debris and surface dust.
- SBIR Ignite—In FY 2023, NASA invested $12 million in its first Phase I and Phase II awards for the SBIR Ignite pilot initiative, which targets U.S. early-stage, high-risk technology development to help make companies and their innovations

67 https://www.nasa.gov/directorates/stmd/nasa-seeks-proposals-for-space-technology-flight-test-services/

68 https://sbir.nasa.gov/

69 https://www.nasa.gov/general/murep-partnership-annual-notification-mplan/

more attractive to private-sector investors, customers, and partners, and has a greater emphasis on commercialization compared to the mainline SBIR/STTR solicitations.[70] In November 2022, 12 small businesses were selected to receive Phase I awards, 75 percent of whom had never received a NASA SBIR award. After successful Phase I periods, all 12 were awarded Phase II contracts. The second year of SBIR Ignite kicked off in August with the opening of the 2023 Phase I solicitation; selections are expected to be announced in mid-December 2023.

In 2023 the Space Technology Research Grants (STRG) program surpassed a milestone, having funded over 1,000 grants for space technology research since the program's inception in FY 2011.[71] The total number now stands at 1,010 grants across 129 universities in 48 states and Puerto Rico.

- In 2023, NASA made ten Early Stage Innovation awards, seven Early Career Faculty awards, and 55 NASA Space Technology Graduate Research Opportunity awards. There are currently over 300 active awards.
- Two new Space Technology Research Institutes were also selected under the STRI22 solicitation, in quantum sensing and certification of additive manufacturing, and will commence in early FY 2024.[72]
- Three new Lunar Surface Technology Research (LuSTR) awards were selected under the LuSTR23 solicitation, advancing technologies in lunar dust mitigation, extreme access, and metal extraction from lunar regolith, that may prove critical to our sustainable exploration of the Moon. These LuSTR23 awards will commence in early FY 2024.[73]

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.[74] This year, 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 2023, NIAC awarded fourteen Phase I awards, and six Phase II awards totaling $7.2 million across industry, academia, and NASA Centers. Fellows also completed twelve 2022 Phase I studies, six 2021 Phase II studies, and one 2021 Phase III study.

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70 https://sbir.nasa.gov/ignite

71 https://www.nasa.gov/space-technology-research-grants/

72 https://www.nasa.gov/directorates/stmd/space-tech-research-grants/stri-2022/

73 https://www.nasa.gov/general/lunar-surface-technology-research-lustr-2023/

74 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.[75] The program had a prolific year in FY 2023, launching 72 NASA projects, receiving more than 7,400 solutions, and awarding more than $9.2 million using procurements and prize authorities. Projects that used the PCC toolkit to solve a problem or meet a need reported a collective savings to NASA of more than $1.2 million when compared to using traditional tools.

- PCC continued the facilitation of four long-duration Centennial Challenges that are contributing to research and development related to lunar exploration and habitation, astronaut health and nutrition, and other agency priority areas.[76] Most notably, through their successes competing in the Cube Quest Challenge, three finalist teams were invited to fly their small satellites on the Artemis I rocket in November 2022 and conduct more tests as part of the challenge's final in-space competition (which will come to a close in November 2023).[77] In August 2023, the Deep Space Food Challenge opened the final phase of its competition and, by the end of FY 2024, will award up to $1.5 million to finalists who create novel food production systems that can feed a crew of four for at least three years of deep space travel.[78]
- In September 2023, in support of STMD's DEIA work and the ESIP portfolio focus on inclusive innovation, the NASA Space Tech Catalyst Prize was launched, supported by NASA's Center of Excellence for Collaborative Innovation.[79] This opportunity sets out to expand the agency's network of proposers and foster effective engagement approaches within the ESIP portfolio. Through this prize, NASA will recognize U.S. individuals and/or organizations that share effective best practices on approaches and methods for how they successfully engage underrepresented and diverse space technology innovators, researchers, technologists, and entrepreneurs. Numerous individuals and/or teams will each be awarded $25,000, and the cohort of winners will be invited to an in-person event at NASA's Goddard Space Flight Center.
- The program's annual solicitation, Crowdsourcing Contenders, has also helped to expand the use of open innovation to advance the NASA mission. This year was the fourth call, offering $830,000 to help solve NASA's pressing problems through public

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

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

77 https://www.nasa.gov/prizes-challenges-and-crowdsourcing/centennial-challenges/cube-quest-challenge/

78 https://www.nasa.gov/prizes-challenges-and-crowdsourcing/centennial-challenges/deep-space-food-challenge/

79 https://www.nasa.gov/directorates/stmd/nasa-prize-targets-inclusive-community-building-for-tech-development/; https://www.nasa.gov/coeci/

crowdsourcing projects. PCC awarded 14 projects across multiple NASA Centers and mission directorates.

- The program continues to mobilize and sustain NASA's internal crowd. The internal crowdsourcing platform was upgraded with a new interface and renamed NASA Spark in August 2023. In total, PCC hosted 27 internal challenges with more than 500 solutions received across the agency. The NASA Spark platform and its predecessor, NASA@WORK, successfully supported agency-wide initiatives including NASA's Moon to Mars efforts; the Office of Technology, Policy, and Strategy; and the agency's Office of the Chief Information Officer.

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.[80] Since its inception in 2011, CIF has funded over 1,100 innovative center projects, generating over 310 NASA New Technology Reports, 370 publications, 90 patents and patent-pending applications, over a dozen commercial licenses, and two spinoff companies. Recent CIF highlights include:

- Fiber Optic Sensing System (FOSS) was used to monitor temperatures on the back side of the LOFTID inflatable decelerator, giving engineers a thermal map of how the decelerator heats during atmospheric reentry. That map will help engineers improve future inflatable decelerator designs and represented the first use of FOSS technology in space.
- The Fluidic Telescope Experiment (FLUTE) is developing a new approach to large aperture space observatories by creating primary optics in situ via fluidic shaping and was recently awarded a 2023 NIAC Phase I award to further develop the concept.
- The CIF project THz Spectroscopy for Heliophysics ITM Remote Sensing, used to measure atomic species for space weather prediction, transitioned to a $2.5 million Early Career Initiative award to measure in situ lunar volatiles.
- The Moon Microscope Kit provides medical diagnostic capabilities for crewmembers in space or on the surface of the Moon or Mars, as well as the ability to test water, food, and surfaces for contamination; it was launched in November 2022 on the SpaceX CRS-26 mission for an FY 2023 demonstration aboard the ISS.
- The CIF project Towards Real-Time and High-Precision Trajectory Simulation for EDL Systems addresses the challenge of producing fast and high-precision predictions

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

for entry, descent, and landing systems and was recently transitioned to the STMD Game Changing Development program.

- LiDIA, the Lightweight Deployable Integrable Antenna, is developing a fully thin-film deployable antenna for small spacecraft and received $1.7 million in NOAA funds to scale LiDIA and complete Technology Readiness Level 6 environmental testing through FY 2023. LiDIA will also fly as part of the Lightweight Integrated Solar Array and anTenna (LISA-T) Pathfinder Technology Demonstration mission in FY 2024.

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. Initiated as a pilot effort in 2014, ECI has funded 30 highly innovative projects through FY 2023 and has recently selected four new projects to start in FY 2024. To date, ECI projects have published over 80 papers and 30 NASA New Technology Reports, resulting in three U.S. patents with an additional five patent applications pending. Highlights for 2023 include:

- Rotor Optimization for the Advancement of Mars eXploration (ROAMX) is developing advanced airfoils for future Mars rotorcraft. The project recently completed two-dimensional airfoil tests at Tohoku University, Japan, and its optimization framework is being used to design a Mars Sample Recovery Helicopter Blade.
- Closing Critical Technology Gaps for Continuously Rotating Detonation Cycle Engines is designing and additively manufacturing an efficient, compact lander engine for lunar and Mars applications. Initial designs have been tested for several hundred seconds, significantly exceeding prior test durations, and have demonstrated engine restart capability, a critical goal of the project.
- MERCRII, the Metallic Environmentally Resistant Coatings Rapid Innovation Initiative, is coating conventional and additively manufactured materials to improve tribological and radiation resistance for lunar and Mars surface exploration. They have completed wear, erosion, and radiation testing on multiple samples and are currently awaiting the return of coating samples flown on the ISS MISSE-17 experiment for additional analysis.
- The Lightweight Surface Manipulation System Autonomy capabilities Development for surface Operations and construction is developing a versatile and scalable robot designed for surface operations. The team is integrating and testing new autonomy software with the robotic arm and has demonstrated accurate and repeatable guidance and control in a laboratory setting. Partnering with Astrobotic, the project is building

the capability for robotic missions to emplace and build infrastructure to support a sustained lunar presence.

In FY 2023, the NASA Technology Transfer (T2) program saw a successful year of transferring technologies and software to industry and entrepreneurs:[81]

- T2 executed 155 licensing agreements, with a total of 764 active license agreements to date. The program is currently undergoing a strategic framework exercise to enhance the program's "customer-service" mindset when it comes to licensing and working with entrepreneurs and businesses.
- T2 released 5,326 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 and a Reddit "Ask Me Anything" event featuring software users at NASA.
- In January, NASA's *Spinoff* publication released the latest edition that features success stories of 43 companies using NASA technology, expertise, and research to create new products and services for consumers across the world.
- Three new inventors were inducted into the NASA Inventor Hall of Fame, which features a diverse array of 30+ NASA inventors who have 20+ patented technologies or who have made significant contributions to NASA missions.

The NASA Technology Transfer program's expansion initiative, T2X, ramped up efforts. T2X:

- hosted 56 startup/commercialization events, including webinars, participation in local pitch/ideation events, and ecosystem events;
- issued 9 startup/evaluation licenses;
- conducted 120 in-reach/outreach events, reaching 2,000 people;
- created more than 80 new informal/formal relationships;
- executed 21 contracts/formal partnerships for commercialization activities;
- added 17 new universities to Technology Transfer University, reaching 29 states and 21 MSIs; and
- engaged 18 Manufacturing Extension Partnership centers in 13 states without NASA Centers.

81 https://technology.nasa.gov/

STEM Engagement

- In July 2023, NASA awarded more than $8 million to nine MSIs and Historically Black Colleges and Universities supporting research and technology development via the MUREP Space Technology Artemis Research (M-STAR) opportunity.[82] The research topics cover small spacecraft technologies, thermal management systems, in situ resource utilization, advanced manufacturing, advanced robotics and sensors, life support systems, dust mitigation, and advanced propulsion technologies. M-STAR is funded and managed by MUREP, part of NASA's Office of STEM Engagement, in partnership with STMD.
- NASA's TechRise Student Challenge invites teams of sixth- to 12th-grade students to design, build, and launch science and technology experiments for space exploration and Earth observation on suborbital flights.[83] TechRise is sponsored and managed by STMD's Flight Opportunities program, and student payloads have been tested on commercial suborbital rocket-powered vehicles and high-altitude balloons. Summer 2023 marked a series of flight tests that successfully flew 80 student payloads on high-altitude balloons with Aerostar and World View.[84]
- In November 2022, NASA hosted the Breakthrough, Innovative, and Game-Changing (BIG) Idea Challenge Forum, in which seven university teams—awarded nearly $1.2 million in FY 2022—demonstrated their alternative modalities for extreme terrain access in the Mojave Desert.[85] Covered by National Geographic, top marks went to Northeastern University for its snake-inspired rover concept, the Crater Observing Bio-inspired Rolling Articulator (COBRA).[86] NASA's BIG Idea Challenge, now in its ninth cycle, 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 FY 2023, NASA's Next Gen STEM project created and published two new educational products based on STMD projects and missions, the First Woman Camp Experience and Lunar Surface Exploration Educator Guide, working with subject matter experts across STMD Technology Maturation and Technology Demonstrations.[87]

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82 https://www.nasa.gov/news-release/nasa-awards-14-million-to-universities-for-supportive-stem-efforts/

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

84 https://www.nasa.gov/centers-and-facilities/armstrong/nasa-techrise-student-experiments-count-down-to-flight/

85 https://www.nasa.gov/directorates/stmd/northeastern-university-slithers-to-the-top-with-big-idea-alternative-rover-concept/; https://www.nasa.gov/centers-and-facilities/langley/university-teams-take-off-the-training-wheels-to-develop-alternative-rovers/

86 https://www.nationalgeographic.com/science/article/lunar-robot-snakes-explore-the-moon-nasa

87 https://www.nasa.gov/stem-content/first-woman-graphic-novel/; https://www.nasa.gov/stem-content/lunar-surface-exploration/

- Throughout FY 2023, STMD researched, scripted, edited, compiled educational content, and relaunched a website for the second installment in NASA's interactive graphic novel series, First Woman: NASA's Promise for Humanity.[88] Through the First Woman series, NASA is inspiring the next generation of explorers—the Artemis Generation—as it works in real life to land 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 introduces new characters to expand outreach to Native American and Indigenous communities as well as International Partners. The accompanying immersive app also features six new technologies and one new extended reality environment, enabling users to be a part of the telescope mission featured in the story. In addition to connecting with new audiences and encouraging STEM literacy, First Woman reflects the diversity, equity, and inclusion that are critical to NASA's future.

88 https://www.nasa.gov/calliefirst/

Department of Defense

DOD

Aeronautics

Rotorcraft

Army

In FY 2023, 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 (ReARMM), 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. In FY 2023, Army Aviation remains deployed in support of U.S. Central Command (CENTCOM), U.S. European Command, and U.S. Indo-Pacific Command (USINDOPACOM). 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 2023, the Army continued its modernization efforts across the entire aviation fleet. Rotary-wing aircraft fielding of the AH-64E Apache, HH/UH-60M Blackhawk, CH-47F Chinook, UH-60V BlackHawk, and UH-72A/B Lakota ensured that Army aircraft will provide capability for decades to come. Unmanned Aircraft Systems (UAS) modernization included improvements to the MQ-1C Gray Eagle and the RQ-7B Shadow, supporting enhanced manned-unmanned teaming. As the Army modernizes its current fleet of rotary-wing aircraft and UAS, it looks to the future with Future Vertical Lift (FVL) initiatives. The FVL Cross-Functional Team 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 2023, the Army continued fielding the newest AH64E version 6 to active and National Guard units. The Army recently completed fielding the AH64E Version 6 to Army units at Fort Campbell, Kentucky, and the North Carolina National Guard. 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/Unmanned Teaming Extended, which allows video from 62 off-board sensors to be seen by the flight crew and allows for control of the MQ-1C Gray Eagle and RQ-7B Shadow UAS.

The UH/HH-60 BlackHawk 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 Helicopter continued to modernize the Black Hawk fleet with the UH-60V in 2023. The UH-60V updates legacy analog systems to a digital and open architecture. This architecture provides commonality with the UH-60M with a similar Pilot-Vehicle Interface.

The CH-47F Chinook is the Army's only heavy-lift cargo helicopter supporting combat and other critical operations. Fielding continued in FY 2023, and as fielding of the Block I aircraft wraps up, development of the CH-47F Block II aircraft continues to provide an option for future modernization of the cargo fleet when that decision is required.

Future Vertical Lift

The FVL Cross-Functional Team 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 Cross-Functional Team addresses aviation capability gaps against peer and near peer competitors through four signature modernization efforts: (1) Future Attack Reconnaissance Aircraft (FARA), (2) Future Long Range Assault Aircraft (FLRAA), (3) Future Tactical Unmanned Aerial Systems (FTUAS) and Launched Effects (LE), and (4) the Modular Open System Approach (MOSA).

FARA's competitive prototypes were more than 95 percent complete. The Army awarded the FLRAA contract to Bell Textron, Incorporated, in December 2022. FLRAA is a tiltrotor aircraft designed to replace a portion of the UH-60 fleet. MOSA capabilities were successfully demonstrated in FY 2023, and the 700+ member Government and Industry MOSA Acquisition Working Group set defined standards.

The Cross-Functional Team continued its campaign of learning through ongoing demonstration and experimentation. Significant 2023 events included Experimental Demonstration Gateway Event (EDGE) 23, building on EDGE 22 and Project Convergence 22 the previous year. EDGE 23 featured a partnered stakeholder approach with over 30 DOD organizations, 12 industry vendors, and 11 international military partners focused on interoperability of FVL capabilities in joint and combined operations. Other focus areas included data format standardization and conversion and digital call for fires, deep sensing in the high and low aerial tier, lethal and non-lethal launched effects, coalition interoperability, and contested logistics. In support of these efforts, EDGE 23 involved robust data collection from the Army's Test and Evaluation Command, providing feedback on the 83 FVL-related technologies to sense, penetrate, strike, move, and extend distances in support of combined arms fire and maneuver resulting in 54 first-time events.

Navy

The CH-53K Super Stallion provides the U.S. Marine Corps (USMC) with a platform with increased lift, range, survivability, and maintainability compared to the legacy CH-53E. CH-53K completed its Full Rate Production Decision in December 2022 and awarded Block Buy Contracts for Lot 7 and 8 aircraft and engines. The Marine Corps continues to make progress toward its first squadron deployment of the CH-53K.

The VH-92A Patriot Presidential Helicopter began conducting White House Military Office (WHMO) missions in November 2022. In January 2023, the Director, Operational Test and Evaluation (DOT&E) assessed the VH-92A as operationally effective and suitable for administrative lift and contingency operation missions. Four aircraft were delivered in FY 2023.

The V-22 Osprey tiltrotor aircraft remains one of the most in-demand aircraft due to its unmatched speed, range, payload, and ability to respond quickly to rapidly evolving crises. The U.S. Navy V-22 variant, the CMV-22, delivered six aircraft in FY 2023. The USMC MV-22 variant delivered five aircraft in FY 2023. The program continued progress toward redesign of the Input Quill Assembly and made progress toward the Tailored Nacelle Improvement, a cost-effective initiative to increase fleet reliability and maintainability.

In FY 2023, the Marine Corps completed Operational Testing and began fleet aircraft modification of APR-39 D(V)2 on the AH-1Z, which provides a significant increase in survivability for AH-1Z aircrew/aircraft.

In FY 2023, the U.S. Navy (USN) completed the Analysis of Alternatives for a Future Vertical Lift Maritime Strike (FVL[MS]) platform. 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 2023, the F-35 Joint Strike Fighter Program continued to deliver F-35B and F-35C aircraft for the USMC and USN. The USMC has received 157 F-35B and 23 F-35C aircraft for deployment on LHA-, LHD-, and CVN-class ships as well as shore sites. The USN has received 55 F-35C aircraft for deployment on CVNs (aircraft carriers). The Navy and Marine Corps have completed successful deployments of the F-35. During FY 2023, significant technological advancements continued to be incorporated into the F-35 fleet to increase the capabilities of the platform.

The E-2D Advanced Hawkeye (AHE) Program has delivered 59 aircraft to date. Upgrades to the platform continued in FY 2023 as the Navy built and fielded multiple Delta System/Software Configuration (DSSC) releases to pace future threats and sustain platform performance.

In FY 2023, the Navy continued its Service Life Extension Program of the E-6B Mercury National Command and Control Aircraft and delivered two Block II–configured aircraft to the fleet. The E-6B Recapitalization (E-XX) program received System Design Specification approval in April 2023 and released the Development Request for Proposal to industry in September 2023.

The P-8A Poseidon continued Increment 3 Block 2 (I3B2) upgrades in FY 2023, the largest P-8A post-production modification to date. Two test aircraft completed I3B2 modification and delivered to Patuxent River for ground and flight testing.

The F/A-18 and EA-18G program continues to sustain the Secretary of Defense's mandate of 80 percent Mission Capability for E/F/G aircraft. In FY 2023, the program focused on ways to increase reliability and time on wing. In addition, the program's Integrated Supply Chain Management success has been replicated across multiple platforms and organizations. Additionally, in FY 2023 the F/A-18E/F and EA-18G continued to pursue Service Life Modification efforts to extend these aircraft to 10,000 flight hours along with upgrading the F/A-18E/F aircraft to the Block 3 configuration capability.

Unmanned Aircraft System (UAS)

Army

In FY 2023, the Army successfully fielded the MQ-1C Extended Range aircraft to the 82nd Airborne Division. The Army has also focused on modernizing avionics and datalinks within legacy air vehicles to enable rapid payload and sensor integrations. The MQ-1C provides the warfighter with dedicated, assured, multi-mission Reconnaissance, Surveillance, and Target Acquisition (RSTA) capabilities with the extended range variation providing nearly 50 percent greater endurance.

The Army continued executing the Future Tactical Uncrewed Aircraft Systems (FTUAS) rapid prototyping competition to replace the RQ-7Bv2 Shadows in the Brigade Combat Teams and Special Operation Forces. In FY 2023 this multi-vendor effort progressed from five initial vendors to a field of two. The program completed a system requirements review and preliminary design review. FTUAS provides a runway-independent, expeditionary, on-the-move capability with lower acoustic signature, much lower equipment density, and transformational user interfaces. Currently, RQ-7Bv2 Shadows are assigned to all Brigade Combat Teams, Special Forces Groups, and Combat Aviation Brigades. The Shadow Block III will replace the RQ-7Bv2 in the Combat Aviation Brigades and Special Forces Groups. The Shadow Block III upgrade provides a new engine and propeller, reducing the acoustic signature. It also provides an improved payload, weatherization (two inches per hour), and an upgraded communications relay package.

Navy

The MQ-4C Triton (formerly Broad Area Maritime Surveillance UAS) is completing development, production, and fielding to provide a UAS meeting 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 family of systems and will provide combat information to operational and tactical users such as Expeditionary Strike Groups, Carrier Strike Groups, and Joint Forces Maritime Component Commanders. The MQ-4 Early Operational Capability assets successfully operated in the Seventh Fleet Area of Responsibility from January 2020 through October 2022. The fleet began receiving the first multiple intelligence uncrewed aircraft and commenced Unit Level Training in October 2022, and declared Initial Operational Capability (IOC) in support of the Maritime Intelligence, Surveillance, Reconnaissance, and Targeting transition plan in August 2023.

The MQ-25 program is rapidly developing an uncrewed capability to embark on CVNs to increase the strike range, capability, and lethality of the Carrier Air Wing (CVW) through organic mission and recovery tanking, and providing an Intelligence, Surveillance, and Reconnaissance (ISR) capability to the Carrier Strike Group. As the primary CVW mission and recovery tanker, MQ-25A will increase available CVW strike fighter assets, preserve F/A-18E/F Fatigue Life Expenditure, and help mitigate expected strike fighter shortfalls in the late 2020s. MQ-25 will achieve this through the use of a carrier-suitable, semi-autonomous (man in the loop, air vehicle executes preplanned missions) UAS (provided by the Air System segment) and controlled through existing C4I networks from the control systems integrated into the CVNs. MQ-25 is integral to the Air Wing of the Future and establishes the foundation for crewed-uncrewed teaming and autonomous operations from the CVN as the world's first carrier-based unmanned aircraft. MQ-25 will initially be integrated aboard Nimitz-class aircraft

carriers followed by Ford-class. As of FY 2023, seven Ground Control Station (GCS) assets have been delivered and installed, and three lab-based integrated test events have been completed between MQ-25 hardware and the GCS, including end-to-end completion of a virtual flight and command and control using real-world beyond line-of-sight (BLOS) communication paths.

The MQ-9 Marine Corps Block V (Extended Range) Marine Air Ground Task Force (MAGTF) UAS Expeditionary (MUX) Medium Altitude Long Endurance (MALE), or MUX MALE, program will provide MALE capability in the USINDOPACOM area of responsibility in support of USMC Force Design 2030 requirements and will address shortfalls in high-endurance, long-range uncrewed systems with Intelligence, Surveillance, and Reconnaissance (ISR), Electronic Warfare (EW), and lethal strike capabilities. The MQ-9 system will serve as a key enabler for USMC/Department of the Navy Expeditionary Advanced Base Operations (EABO), Distributed Maritime Operations (DMO), and Littoral Operations in a Contested Environment (LOCE) concepts. As of FY 2023, the remaining ten MQ-9As have been awarded to General Atomics-Aeronautical Systems Incorporated, bringing the USMC Program of Record to 20 total MQ-9A systems.

The RQ-21A Blackjack provides runway-independent persistent maritime and land-based tactical Reconnaissance, Surveillance, and Target Acquisition (RSTA) data collection, dissemination, and communications relay capabilities to the warfighter. The RQ-21A carries an Electro optical/Infrared (EO/IR) payload with a laser rangefinder and infrared (IR) pointer. For the Navy, the RQ-21A provides persistent RSTA support for tactical maneuver decisions and unit-level force defense/force protection for Navy ships, Marine Corps forces ashore, and Navy Special Warfare Units. Divestment of the RQ-21A Blackjack was completed in FY 2023, per direction of the Deputy Commandant, Combat Development Command, in accordance with Commandant Marine Corps Force Design Strategy 2030. Naval Special Warfare Command plans continued operation of RQ-21A with planned payload upgrades and engagement capabilities to meet deployed mission sets.

Weapons

Navy

During FY 2023, the Department of the Navy continued to mature its long-range Cruise Missile Strategy. Key developmental and sustainment tenets of this strategy include demilitarization of Tomahawk Land Attack/Block III; production of Tactical Tomahawk (TACTOM)/Block IV recertification missiles, which enable the remaining 15 years of the missile's service life as well as allow for the upgrade to Block V; continued development and test of the Advanced Anti-Radiation Guided Missile-Extended Range (AARGM-ER); continued fielding of the Long-Range Anti-Ship Missile (LRASM) as the Offensive Anti-Surface Warfare (OUSuW)/Increment 1 material solution to meet near- to mid-term anti-access ASuW threats;

and, in FY 2023, the start of the Hypersonic Air-Launched OASuW (HALO) weapon system, previously known as OASuW Inc 2.

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. The FY 2023 procurements included TACTOM missiles procured by other service partners. In FY 2023, the program made significant progress in the development and testing of the Block V Maritime Strike Tomahawk and Joint Multiple Effects Warhead System variants.

AARGM-ER provides the Department of the Navy with a fifth-generation compatible extended-range asset to project power and provide Suppression of Enemy Air Defenses, both at sea and on land. AARGM-ER combines proven AARGM sensor technology with a new rocket motor and warhead to provide a weapon with increased effective range, higher speed, and greater survivability while optimizing affordability and risk. During FY 2023, AARGM-ER continued development, testing, and Low Rate Initial Production.

LRASM is a semi-autonomous, long-range anti-ship missile that reduces dependence on external targeting platforms and GPS navigation with capability to penetrate sophisticated enemy air defense systems. Over the past few years, LRASM shifted focus from initial development and fielding to rapid incremental upgrades and obsolescence management to continue to ensure weapon effectiveness as the threat evolves; the latest capability enhancement reached IOC in FY 2023. Additional improvements in performance, range, survivability, and addition of a land attack capability are under way. Expanded aircraft platform integration efforts and execution of the LRASM foreign military sale case ensure versatility in employment.

The HALO weapon system is the second of a two-phase approach to address Anti-Surface Warfare (ASuW) shortfalls and 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. The Department of the Navy is leveraging other DOD hypersonic efforts to accelerate HALO fielding. In FY 2023, two defense contractors were awarded contracts to compete in the first phase of preliminary design.

Using multi-mode seeker and two-way datalink capabilities, the Joint Small Diameter Bomb II (SDB II) program provides an adverse weather, day-or-night standoff capability against mobile and fixed targets and enables target prosecution while minimizing collateral damage. The Navy has begun fielding SDB II for F/A-18E/F and F-35B, with IOC reached in FY 2023 for the former.

Aviation Survivability Equipment

Army

Aviation Survivability Equipment (ASE) is essential protection for aircraft against current and emerging advanced threats. The focus of Army ASE is to ensure the current fleet of aircraft

remain protected against threats while developing to integrate ASE on Future Vertical Lift 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.

APR-39C(V)1/4 is a radar warning system alerting aircrews of Radio Frequency threats. APR-39D(V)2 is an interim solution procured from the Navy's RWR Program, which is currently fielding in Korea. The first unit equipped was completed in the third quarter of FY 2023. APR-39E(V)2 is in development, and an A-Kit prototype has been installed on the AH-64E V6 Apache. Initial awarded contract was completed in the fourth quarter of FY 2023.

AVR-2B LDS provides aircrew alerts of laser energy from enemy weapon systems and is factory modified on the AH-64 and UH-60. It began fielding on CH-47 Aircraft during FY 2023.

Propulsion

Army

The Improved Turbine Engine (ITE) is the future engine for the Future Attack Reconnaissance Aircraft (FARA) and replacement engine for the UH60 and AH64 Fleets. ITE is designed to address current performance capability gaps, increasing aircraft range, endurance, and payload. The Army accepted the first T901 flight test engine on September 28, 2023.

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 Armed Services—land, sea, and air—many of the program's activities promote joint applications that advance American aeronautics and space technology.

One unique program launched and supported by DOD ManTech are the 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 2023, 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, the additive manufacturing DOD Manufacturing Innovation Institute, conducted a space propulsion workshop identifying and prioritizing strategic research and development needs with members of government, industry, and

academia from over 50 organizations. The workshop resulted in a five-year research and development strategy addressing air breathing, liquid fuel, and nuclear space propulsion applications.

- LIFT, the lightweight materials DOD Manufacturing Innovation Institute, completed a "Hypersonics Thermal Management Phase I" project in 2023. The project was designed to advance metallic materials and manufacturing processes used in high-temperature thermal applications, including those produced by powder-based additive manufacturing techniques. As a result, the project produced and validated Integrated Computational Materials Engineering material digital twins against metal alloys to drive alloy development for the hypersonic environment. The Phase II of this project will advance the prediction of hypersonic material performance to hypersonic-relevant materials that benefit from functionally graded optimization and are manufactured by Direct Current Sintering. LIFT partners on the project included Friedman Research Corporation, the University of Central Florida, the University of Arizona, and Michigan Technological University.
- NASA awarded Small Business Technology Transfer funding to the small business NLM Photonics to work with AIM Photonics, the integrated photonics DOD Manufacturing Innovation Institute. NLM Photonics previously worked with offshore integrated photonics providers. This award highlights how small U.S. businesses, supporting a variety of applications of interest to the government, are benefiting from AIM Photonics' U.S.-based access to this technology.
- AFFOA (Advanced Functional Fabrics of America), the functional fabrics and textiles DOD Manufacturing Innovation Institute, supported the prototype development and production of low-shrinkage silica fabric used in the housings of hypersonic vehicles at Auburn Manufacturing, Incorporated (AMI). AFFOA worked with AMI to establish the requirements for specialized "aerospace grade" pre-shrunk silica fabrics, determine the process required to produce silica fabric with less than 4 percent aerial shrinkage, use modeling to design the production layout, purchase and install a high-temperature furnace and ancillary equipment, and upgrade AMI's current leaching operation to meet the projected volume of pre-shrunk silica fabric DOD needs. AMI is currently under contract with the U.S. Air Force to provide at least 60,000 meters per year of low-shrinkage silica fabric for U.S. defense operations.
- NextFlex, the flexible hybrid electronic DOD Manufacturing Innovation Institute, worked with a team of engineers from GE Research and Binghamton University in collaboration with U.S. Army Combat Capabilities Development Command to develop and demonstrate processes and materials for additive manufacturing of extreme high-temperature electronics semiconductor packaging. The team proved printed electrical

conductor materials capable of service up to 1,000°C on 3D printed ceramic substrates and showed excellent performance of coplanar waveguides up to 600°C. The project defined materials, processes, and design guidelines for radio frequency die packaging. These capabilities, combined with silicon carbide semiconductor technologies the team has developed, enable new sensing and communication capabilities for applications requiring extreme environment service, such as hypersonic vehicles.

Space

Environmental Monitoring

Space Force

The Electro-Optical/Infrared (EO/IR) Weather System (EWS) program's prototyping activities have continued throughout FY 2023, with the first launch expected in December 2023 and the second launch expected in 2025. EWS will replace the Defense Meteorological Satellite Program's Operational Linescan System sensors for EO/IR capabilities, addressing DOD's two highest-priority Space Based Environmental Monitoring (SBEM) sensing needs from the family of systems' "early-morning" orbit—Cloud Characterization and Theater Weather Imagery. The collective EWS efforts will complement the SBEM Family of Systems to obtain and share weather data among civil agencies and foreign partners.

The EWS-Geostationary (EWS-G) non-materiel solution is the product of cooperation between the Department of the Air Force and the National Oceanic and Atmospheric Administration (NOAA). Using a residual NOAA Geostationary Operational Environmental Satellites (GOES) satellite, EWS-G provides persistent weather monitoring of the CENTCOM Area of Responsibility (AoR) from a dedicated U.S. geostationary SBEM satellite. A remote ground station in Western Australia became operational in late 2019, supporting tracking, telemetry, and control for EWS-G. EWS-G reached full operational capability in November of 2020, providing timely and reliable SBEM capabilities to CENTCOM. In late 2023, NOAA transferred a second GOES satellite, which became EWS-G2 and is scheduled to begin operation acceptance testing. EWS-G2 will be an eventual replacement for the first EWS-G.

Missile Warning/Attack Assessment

Space Force

The Space Based Infrared System (SBIRS) provides ballistic missile warning and defense, battlespace awareness, and technical intelligence for the United States and its allies. SBIRS satellites and ground systems provide operational capability today and will continue to deliver additional capability to the warfighter in the future.

The final SBIRS Geosynchronous Earth Orbit (GEO)-5 and GEO-6 satellites were launched and operationally accepted in FY 2022 and FY 2023, respectively, and were formally transferred to Space Operations Command on March 24, 2023.

In FY 2023, the Next Generation Overhead Persistent Infrared (Next-Gen OPIR) GEO and the Next-Gen OPIR Polar programs officially transitioned to the Major Capability Acquisition pathway as post–Milestone B ACAT-IB MDAP programs in the Engineering and Manufacturing Development phase on July 21 and October 24, 2023, respectively. The Next-Gen OPIR space and ground segments will replenish the SBIRS constellation by delivering four resilient and survivable Missile Warning Satellites (two GEO and two polar orbit), with the first GEO satellite to be delivered by 2025. In FY 2023, most of the space vehicle flight hardware is being assembled and integrated for the first Next Generation OPIR GEO satellite.

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, and technical intelligence mission areas. In FY 2023, FORGE continued to deliver increased mission data processing application framework capabilities to the Government's Tools, Application, and Processing lab. The combined mission data processing effort is foundational to ensuring a ground solution that supports the first GEO satellite launch in 2025. In May 2023, the SAE determined the Enterprise Ground Services (EGS) would not be a viable host for the Command and Control (C2) function and directed a change in C2 strategy. As a result, the FORGE program office awarded a FORGE C2 prototyping contract to determine a viable future command and control solution.

In collaboration with key stakeholders, and considering emerging threat assessments, analysis, and wargaming, a more resilient Missile Warning/Missile Tracking architecture was defined. That analysis and wargaming drove a mission area architecture pivot from a geosynchronous and highly elliptical force presentation to a proliferated low- and medium-Earth orbit (LEO and MEO) force design. Resilient Missile Warning/Missile Tracking is on an accelerated path to fielding a resilient and enhanced capability that allows for detection of new and emerging threats, such as hypersonics. This new architecture is fielded by the U.S. Space Force's (USSF) Space Systems Command and the Space Development Agency (SDA). The first LEO satellite capability demonstration was launched in FY 2023. Also in FY 2023, the MEO Epoch 1 program and the Tranche 2 Tracking program were approved for the Middle Tier of Acquisition Rapid Prototyping acquisition pathway.

Positioning, Navigation, and Timing

Space Force

The Global Positioning System (GPS) program entered its 28th year of providing uninterrupted Positioning, Navigation, and Timing (PNT) data, free of charge, to users worldwide. GPS has been operational since July 1995. The success of the GPS program can be reflected in the total number of GPS receivers produced to date, estimated at more than four billion worldwide. The first six GPS III satellite launches occurred in December 2018, August 2019, June 2020, November 2020, June 2021, and January 2023, ushering in the next generation of GPS technology with significant enhancements to the current constellation, including higher-power military signal and a new civilian signal. GPS III space vehicles (SVs) 7–10 have been delivered to the Government and are available for launch (AFL).

In FY 2023, the GPS III Follow-on (GPS IIIF) continued with the Production and Deployment phase, with a planned production of 22 satellites adding increased regional anti-jam performance to the military signal 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 AFL in FY 2026.

The GPS Next-Generational Operational Control System (OCX) is a modernized control system that will enable the effective use of the latest military and civilian GPS signals while providing significantly improved cyber resiliency and signal monitoring. OCX Block 0 successfully performed the launch and on-orbit checkout of the first six GPS III satellites, with checkout of SV 06 occurring in FY 2023. The OCX Block 1/2 development phase is projected for completion in FY 2025, signaling the program's transition into integration, testing, and operations. OCX 3F is primarily a software modification to OCX that enables launch, command and control, and enhanced capabilities of the GPS IIIF SVs.

The Military GPS User Equipment program's first ground systems card achieved Program Executive Officer (PEO) Certification in FY 2021, signifying its readiness for operational testing and integration into Department of Defense platforms. These Military GPS receiver cards will provide users with access to higher-power military signals and are more jam-resistant than previous generations. The aviation/maritime variant of the card completed Technical Requirements Verification in FY 2023 and is scheduled to achieve PEO certification and complete operational testing in FY 2025 on both Air Force and Navy lead platforms.

Satellite Communications (SATCOM)

Space Force

The Evolved Strategic SATCOM (ESS) program is the disaggregated strategic communications follow-on to the Advanced Extremely High Frequency (AEHF) program. ESS will provide survivable, secure, and jam-resistant communication for strategic users and provide nuclear

command, control, and communications. In FY 2023 the Space Service Acquisition Executive approved the Software Acquisition Pathway for the ground segment, and it was placed on contract with two vendors, with plans to downselect to one in the first quarter of FY 2025.

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 (UFO) constellation and a Wideband Code Division Multiple Access (WCDMA) payload that enables 3G-like voice and data services. In FY 2023, the Space Force continued planning a Service Life Extension (SLE) that will extend the WCDMA capability to 2034 by developing and launching two replenishment satellites. As of FY 2023, the SLE satellite contract award will occur no earlier than FY 2025 with planned launches in FY 2030 and FY 2031. The design contract is planned to be awarded in FY 2024. The Narrowband Communications Service Analysis of Alternatives study started in June 2023 with the Space Force's Space Warfighter Analytics Center (SWAC) as the study lead.

PTES develops the ground infrastructure providing near-term and enduring operational benefits while laying the foundation for future Protected Tactical SATCOM (PTS) space and terminal segments. PTES will deliver a software-intensive ground system to provide worldwide, protected communications to tactical and expeditionary warfighters operating in anti-access/area denial environments who are currently unable to operate through interference. PTES is frequency agnostic and will use the Protected Tactical Waveform (PTW) to enable anti-jam capability over the existing WGS system, commercial SATCOM systems, and the future PTS system. In June 2023 PTES transitioned from being a Middle Tier of Acquisition (MTA), Rapid Prototyping Activity to the Software Acquisition Pathway. In FY 2023, PTES continued development to operationalize the PTW over WGS in medium and geosynchronous Earth orbit and integrate commercial capabilities into the architecture.

The Family of Advanced Beyond-Line-of-Sight Terminals (FAB-T) program will field nuclear-event-survivable terminals capable of communicating with the Milstar and AEHF satellite constellations using jam-resistant extremely high-frequency SATCOM capabilities for ground-fixed, ground-transportable, and E-4B/E-6B airborne platforms. On February 7, 2019, the Milestone Decision Authority approved the procurement of all FAB-T Command Post Terminals (CPTs) during Low-Rate Initial Production. All 84 planned terminals are now on contract. As of FY 2023, 78 terminals have been delivered, 58 terminals have been installed, and 52 terminals are available for operational use.

Space Access

Space Force

National Security Space Launch

The National Security Space Launch (NSSL) program continues to successfully place satellites into orbit. As of September 30, 2023, there were five launches during FY 2023:

November 1, 2022	Falcon 9	USSF-44
January 15, 2023	Falcon Heavy	USSF-67
January 18, 2023	Falcon 9	GPS III-6
June 22, 2023	Delta IV Heavy	NROL-68
September 10, 2023	Atlas V 551	SILENTBARKER

In FY 2023, the NSSL program took on the major effort of developing the acquisition strategy for the Phase 3 launch service procurement contract with expected release in October 2023. NSSL Phase 3 is a dual lane strategy with separate contract types. Lane 1 will utilize an IDIQ contract to award multiple Firm Fixed Price (FFP) contracts open to all qualified bidders. Lane 2 will consist of three competitively awarded FFP IDR contracts to the best value, next best value, and third best value launch service providers who meet all NSSL orbits and unique mission capabilities. Awards for Lane 1 base IDIQ are planned in spring 2024, and awards for the Lane 2 IDR contracts are targeted for fall 2024. The NSSL Phase 3 strategy will be the follow-on to the NSSL Phase 2's ordering period that ends in FY 2024.

In 2023, Space Systems Command, in partnership with the National Reconnaissance Office's (NRO) Office of Space Launch, conducted two Mission Assignment Board meetings for Phase 2 NSSL missions: FY 2023 Order Year 4 (OY4) and FY 2024 Order Year 5 (OY5). On May 19, 2023, the OY4 Mission Assignment Board assigned 12 missions with Initial Launch Capability (ILC) beginning in FY 2024. ULA was assigned NROL-64, GPS III-8, SDA T1TR-B, SDA T1TR-D, NROL-83, and USSF-114 (using the Vulcan Centaur launch vehicle). SpaceX was assigned SDA T1TL-B, SDA T1TL-C, SDA T1TL-D, SDA T1TL-E, SDA T1TR-C, and USSF-31 using the Falcon 9 and Falcon Heavy launch vehicles.

On September 29, 2023, the OY5 Mission Assignment Board assigned 21 missions with ILC scheduled ranging from FY 2025–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. Space-X 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, SDA T2TL-C.

Rocket Systems Launch Program

The Space Force's Rocket Systems Launch Program (RSLP) continues 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. RSLP provided the launch service using the Firefly Alpha launch vehicle to successfully launch the VICTUS NOX spacecraft on September 14, 2023, responding to a 24-hour Notice-to-Launch, including mating the spacecraft, fueling the vehicles, calculating the orbital insertion parameters, and obtaining final range approvals. In FY 2023, RSLP also awarded launch service contracts to Astra Space for its Rocket 4 to launch the Space Test Program-S29B and to Northrop Grumman for its Minotaur IV to launch the Electro-Optical Infrared Weather System Operational Demonstration-1. RSLP continues its record of success with one space launch in FY 2023:

September 14, 2023 Alpha VICTUS NOX

Launch Ranges

Range modernization efforts continue to implement the Chief of Space Operations' 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 2023, the Range Services Hosting Platform earned operational acceptance for the first three 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 IP network, additional capacity, plug-and-play for range users, and modernized information assurance. These efforts enhance compatibility with commercial systems and increase launch throughput on both Ranges, continuing progress to meet the SOTF vision. The program entered the planning phase of the Software Acquisition Pathway in 2023. 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.

Space Command and Control

In FY 2023 the Space C2 program continued to successfully develop an open architecture technology stack for the Space Domain Awareness (SDA) and Battle Management Command and Control (BMC2) missions. The program delivered four important operational C2 software applications to operations centers in FY 2023. The program conducted its first four quarterly SDA Capability Integrated Test (SCIT) events, a new construct for developing, testing, and deploying operational capability. These SCITs are focused on the Advanced Tracking and Launch Analysis System, a significant operational SDA capability that will allow for the

decommissioning of legacy systems and provide greater capability to track objects in space. In FY 2023 the program also received a three-year Authorization to Operate for a government cloud instance of Space C2's organically managed Kobayashi Maru Platform, paving the path to transition on-premises hosting of Space C2 applications to a high-availability and scalable cloud service. Finally, in April 2023, the program delivered its fourth annual report to Congress, continuing to provide Congress with transparency in program progress.

In FY 2023, the Satellite Control Network (SCN) continued development of the Advanced Scheduling Tool system to automate scheduling and connectivity of the network with a minimum viable product planned for 2024. The Federal Augmentation service effort to use NOAA antennas to augment the SCN continued installations in Alaska and Virginia in FY 2023. In May, typhoon Mawar caused extensive damage to the Guam Tracking Station, estimated to be $54 million at a minimum. One of the three antennas needs a complete replacement, and radome replacement is necessary for the other two antennas. These recovery efforts continue.

Space Domain Awareness

Space Force

SILENTBARKER is a collaborative program between the USSF and NRO to satisfy common DOD and Intelligence Community (IC) requirements, which include maintaining custody of threats in geosynchronous Earth orbit (GEO) and providing indications and warning. SILENTBARKER initial baseline launch occurred on September 10, 2023.

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 power, thermal, communications, and attitude control. The payload on-orbit checkouts were completed successfully, verifying the signal capture and processing is 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.

U.S. Army astronaut COL Frank Rubio broke the record for the longest single spaceflight by a U.S. astronaut on September 11, 2023, and returned to Earth on September 27, 2023, with a new record of 371 days in space. The previous record was set by NASA astronaut retired COL Mark Vande Hei with 355 days in space.

Defensive Cyber Operations–Space

In FY 2023, prototype Defensive Cyber monitoring and protection capabilities continued deployment at multiple locations to protect space operations centers. A total of 15 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 Defensive Cyber Operations–Space (DCO-S) program entered the planning phase of the Software Acquisition Pathway to advance from prototyping to a formal acquisition program.

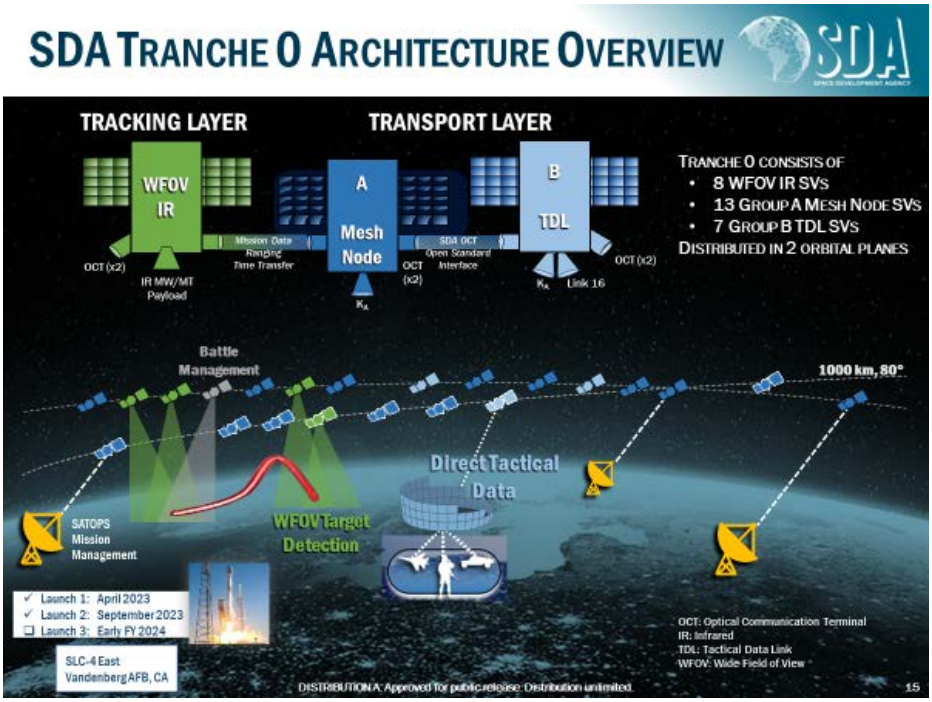
Space Development Agency

Recognized as DOD's constructive disruptor for space acquisition, the Space Development Agency (SDA) will quickly deliver 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/.

Tranche 0 (T0)

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 beyond line of sight (BLOS) targeting and advanced missile detection and tracking. T0 consists of 28 space vehicles (SV) in LEO at an altitude of approximately 1,000 km.

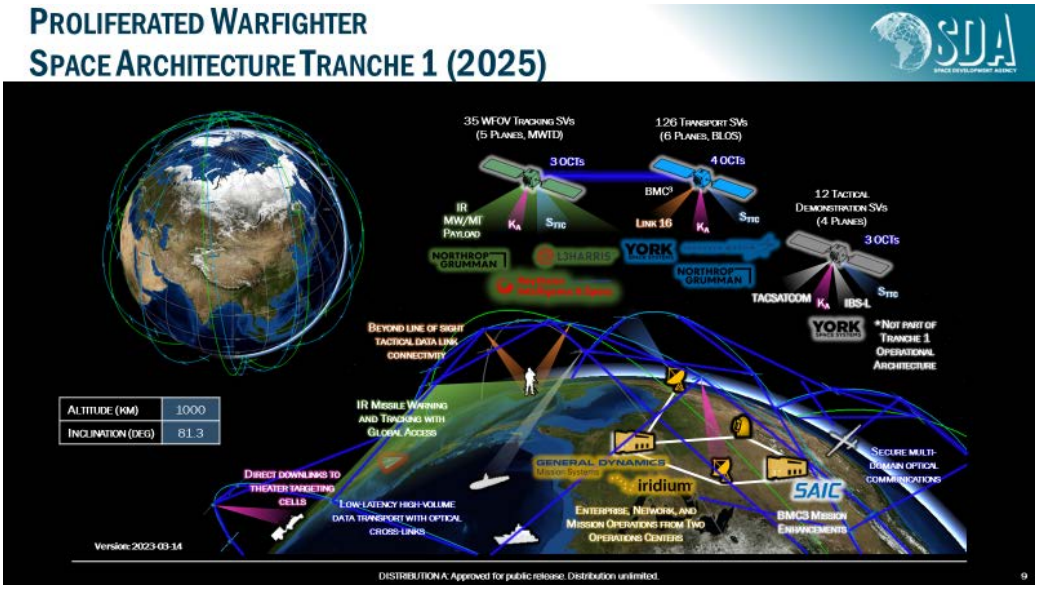
T0 Transport Layer (T0TL). The T0TL demonstrates the ability to provide warfighters with periodic regional access to low-latency data connectivity via space-based extensions of existing tactical data links. York Space Systems and Lockheed Martin are on contract to each deliver ten SVs, for a total of 20 SVs, for T0TL. Six 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 BLOSLink 16 transmit/receive capability from space. In FY 2023, both vendors successfully completed assembly, integration, and test (AI&T) of the SVs and completed delivery of the SVs to the launch site, Vandenberg Space Force Base (VSFB). Nineteen T0TL SVs were successfully launched and delivered to orbit by the launch vendor, SpaceX, in two separate launches that occurred on April 2, 2023, and September 2, 2023. One York T0TL SV remains at the vendor to serve as a software testbed.



Overview illustration of SDA Tranche 0 architecture.

T0 Tracking Layer (T0TK). The T0TK demonstrates the ability to provide periodic regional access and to detect and track hypersonic vehicles. T0TK SVs are configured with a wide field of view (WFOV) infrared payload. SpaceX and L3 Harris are each on contract to deliver four SVs for the T0TK architecture. In FY 2023, SpaceX completed AI&T of their T0TK SVs and completed delivery of the SVs to the VSFB launch site. Two SpaceX SVs were launched by SpaceX on two separate launches that occurred on April 2 and September 2, 2023. Since launch, first light imagery has since been successfully collected via the T0TK SVs.

T0 Support. Tranche 0 ground support is provided by the U.S. Naval Research Laboratory. Tranche 0 has basing locations at Blossom Point Tracking Facility and the University of Alaska-Fairbanks' Alaska Satellite Facility. The Operational Readiness Review and Flight Readiness Review were successfully held in mid-FY 2023, ahead of both T0 launches. Launch and Early Operations activities, such as orbit raising, payload checkout, and calibration, have progressed very well since launch for all vehicles. Ground systems successfully collected first light imagery from the launched T0TK SVs, as well as successfully deployed and verified the functionality of the Link 16 antenna of the T0TL SVs.



Overview illustration of SDA Tranche 1 architecture for 2025.

Tranche 1 (T1)

Tranche 1 (T1) forms the PWSA Initial Warfighting Capability and is planned to provide regional persistence for Link 16, advanced missile detection, and beyond line of sight targeting. T1 consists of 161 space vehicles, in LEO at an altitude of approximately 1,000 km, across 11 orbital planes.

T1 Transport Layer (T1TL). The PWSA T1TL aims to provide global communications access and persistent regional encrypted connectivity in support of warfighter missions around the globe. T1 is planned to serve as the backbone for Joint All-Domain Command and Control (JADC2) built on low-latency data transport, sensor-to-shooter, and direct-to-weapon connectivity. T1TL will consist of 126 SVs across six near-polar orbital planes linked together to form a global space mesh network. The T1TL SVs will be similar in capability to the T0TL SVs, with targeted technology enhancements, mission-focused payload configurations, increased integration, and greater production efficiencies. Each T1TL SV will carry a Link 16 payload, enabling global access to the tactical data network for the warfighter. In addition, each SV will also carry a second GPS receiver so that beginning with T1, SDA will provide continuous GPS situational awareness data from a global perspective. In FY 2023, each of the T1TL SV vendors (Lockheed Martin, York Space Systems, and Northrop Grumman) successfully completed their Critical Design Reviews. All T1TL space vehicle vendors are now 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 General Dynamic Mission Systems (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 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 SDA OCs via globally dispersed RF and optical GEPs: Redstone Arsenal, AL (SDA-South), and Grand Forks Air Force Base, ND (SDA-North). In FY 2023, GDMS successfully completed Critical Design Review (CDR). Ground entry point (GEP) build and site acceptance are progressing on schedule as a number of GEP site surveys and approvals were completed in FY 2023. The build-out of SDA-North and SDA-South continues on schedule.

T1 Tracking Layer (T1TK). The primary mission objective of the T1TK 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 T1 Tracking Layer is planned to consist of four planes of seven SVs configured with a WFOV 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 SWAC force design representing an integrated approach to advanced missile detection, tracking, and defeat. In FY 2023, T1TK space vehicle vendors Northrop Grumman and L3 Harris each completed CDR and are now in AI&T. Also, Raytheon was awarded $250 million to provide an additional plane of seven SVs for T1TK. This additional T1TK contract award is in response to a congressional plus-up to accelerate the PWSA Tracking layer and expands T1TK from 28 WFOV SVs across four planes to 35 WFOV SVs across five planes. This enabled Raytheon to complete their System Requirements Review (SRR) during FY 2023.

Tranche 2 (T2)—Enhanced Warfighter Capability

Tranche 2 (T2) is the PWSA Enhanced Warfighting Capability tranche and is planned to provide global persistence for all Tranche 1 capabilities plus demonstration of advanced tactical data link(s) and future proliferated missions. In FY 2023, SDA completed planning of the Tranche 2 framework.

T2 Transport Layer (T2TL). The T2TL is planned to complete the global pLEO mesh communications data transport capability required by the warfighter for worldwide operations and

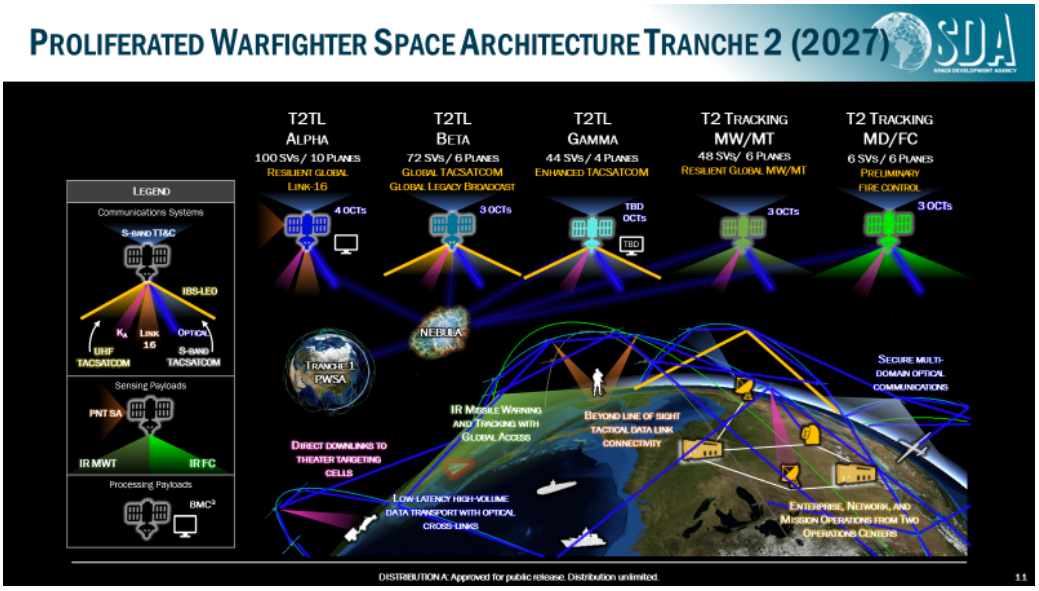


Illustration of Proliferated Warfighter Space Architecture Tranche 2 (2027).

would begin to proliferate needed warfighting capability. It will provide global persistence and is sized to support at least two adversarial campaigns plus future proliferation of prototypes demonstrated in T1 and additional advanced tactical data links and/or waveforms. In FY 2023, SDA received concurrence on the T2TL Minimum Viable Capability (MVC) from the PWSA Warfighter Council (WFC). This formed the basis for finalization of requirements used to develop solicitations for T2TL. Funding was secured using the MTA pathway to acquire the T2 Transport prototype constellation. T2TL is planned to include 216 Transport SVs, which break out into three SV variants: Tranche 2 Transport Alpha, Beta, and Gamma. FY 2023 activity occurred for the Alpha and Beta variants, which are described below. The Gamma variant will not have any significant activity until FY 2024.

- Tranche 2 Transport Alpha (T2TL-α): The T2TL-α prototype constellation will be made up of 100 SVs distributed between four low-inclination and six high-inclination planes. The T2TL-α SVs are designed to be very similar in capability to the T1TL SVs with targeted technological enhancements, increased integration, and greater production efficiencies. SDA released an Other Transaction Program Solicitation for T2TL-α in July 2023.
- Tranche 2 Transport Beta (T2TL-β): The T2TL-β prototype constellation will be made up of 72 SVs distributed among six high-inclination planes. The T2TL-β SVs are designed to be similar to Tranche 1 Demonstration and Experimentation SVs while also 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 the Tranche 1 Development and Experimentation System (T1DES). SDA released an Other Transaction Program Solicitation for T2TL-β in July 2023. Two companies, Lockheed Martin and Northrop Grumman, were awarded agreements totaling $1.5 billion to build and operate 36 SVs.

T2 Tracking Layer (T2TK). The T2TK is planned to proliferate missile warning and missile tracking (MW/MT) WFOV sensors on 54 SVs, for near-global continuous stereoscopic coverage providing MW/MT mission capabilities, and incorporate fire control (FC)/missile defense (MD) infrared sensors on six SVs capable of generating FC quality tracks to provide access to MD mission capabilities. The T2TK SVs would be distributed across six high-inclination orbital planes. In FY 2023, SDA received concurrence on the T2TK MVC from the PWSA WFC. This formed the basis for the finalization of requirements used to develop an Other Transaction (OT) Program Solicitation for T2TK. Funding was secured using the MTA pathway to acquire the T2 Tracking prototype constellation. SDA released an OT Solicitation for T2TK in September 2023.

PWSA Futures Programs (PFP)

In FY 2023, SDA established the PFP Office to consolidate select demonstration activities across the agency.

Tranche 1 Demonstration and Experimentation System (T1DES). In FY 2023, T1DES joined the PFP Office and will eventually field 12 demonstration SVs that, although not connected to the T1 operational architecture, leverage the BLOS command and control infrastructure established by T1. T1DES SVs will leverage interoperable optical communication terminals and will host mission payloads serving Integrated Broadcast Service–LEO and TACSATCOM missions. York Space Systems is on contract to deliver 12 T1DES SVs and support launch integration, ground systems, and operations and sustainment services. In FY 2023, York completed their Preliminary Design Review for T1DES.

NExT SDA 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. is on contract for the development, manufacture, deployment, and operations of ten NExT SVs and mission-enabling ground systems. The NExT program kickoff occurred at the start of FY 2023, followed by SRR in December 2022. Agreements have been formed with mission partners to provide payloads for NExT. These payloads will demonstrate a range of capability to include tactical electronic support; alternative positioning, navigation, and timing (APNT); and telemetry monitoring for advanced

systems testing over broad ocean areas. In addition to mission partner–provided payloads, SDA is also procuring a payload system for NExT called Sabre. Sabre will deliver three intendant functional capabilities to include collection and relay of telemetry from Vehicles Under Test on U.S. missile test ranges; alternative pointing, navigation, and timing; and tactical electronic support. The Sabre solicitation was released in April of 2023.

Additional Noteworthy Progress

Battle Management Command, Control, and Communications (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. In FY 2023, SDA awarded a $64 million Other Transaction Agreement to Science Applications International Corporation (SAIC) to establish the BMC3 software development and hosting environment for the PWSA, the BMC3 AppFac. SAIC will be responsible for the implementation of an AppFac and secure interoperable-middleware layer (SIL) to allow the PWSA BMC3 ecosystem to execute mission applications in support of warfighter needs. As the first BMC3 application, the SIL provides future mission applications with the ability to leverage the T1TL vendors' BMC3 payloads, plus additional compute capabilities integrated into each SV for the purpose of enabling orbital data management, fusion, and analysis with the goal of lowering the overall data latency inherent in beyond line of sight operations.

Small Business Innovative Research/Small Business Technology Transfer Research (SBIR/STTR). SDA continued and expanded partnerships with small businesses via these programs in FY 2023 by adopting Phase 2 development efforts based on successful Phase 1 studies from other DOD development mission partners as well as taking advantage of proposals to others deemed selectable for which the mission partner had insufficient funding to award the contract. SDA awarded a total of 24 SBIR/STTR awards in FY 2023. Awards topics included Free-Space Optical Communication Technology for Optical Intersatellite Links; high-bandwidth sensor processing applications; Advanced Space Mesh Networking and Routing systems; antenna development for Ubiquitous Communication Systems; Improved Ground System Control and Monitoring; Digital Intermediate Frequency SATCOM modem development; Space System Digital Twin development and integration; satellite data compaction; and novel linear voltage regulator architecture. In each case, SDA is encouraging small business partners to focus on key technology developments suitable for deployment on orbit with the goal of increasing warfighter capability.

In addition, as SDA transitioned from the Office of the Secretary of Defense in FY 2022 to the USSF in FY 2023, SDA began the process of fully integrating into, and taking advantage

of, the U.S. Air Force and USSF AFWERX and SpaceWERX programs, submitting recommendations into Open and Specific Topic calls, interacting with small businesses via Collider events, and aligning SDA small business needs and interests with those of the greater Space Force enterprise. Through small business partnerships, SDA remains committed to the development of optical, RF, data, cybersecurity, space and ground operations, and battle management capabilities of warfighting value throughout the PWSA and greater Space Force Programs of Record.

Defense Innovation Unit

The Defense Innovation Unit's (DIU) mission to harness cutting-edge space systems and technologies from commercial industry. As commercial sector markedly outpaces government expenditure in research and development, DIU actively seeks to leverage commercial efforts, fostering collaboration and prototyping capabilities with industry trailblazers. This engagement is designed to accelerate integration of innovative space solutions into the national security domain, and secure commercial advancements for national defense imperatives. Through these partnerships, DIU hopes to cultivate a new era of space-centric military capabilities, tailored to meet the exigencies of any combat operation.

As an example of the DIU's work in Space Domain Awareness, the Global Space Innovation Project aims to offer DOD and space operators simplified access to commercially developed space domain awareness data visualization and analysis tools to augment existing government tools. In FY 2022, two companies, ExoAnalytic and Tibco, were awarded agreements to prototype their unique solutions and in FY 2023 demonstrated their prototypes alongside operators in real-world and simulated events. With transition paths identified, these tools will be available not only for U.S. DOD space operators, but to our partners and allies. As commercially developed software, ally and partner nations could independently license the same tools as U.S. operators, effectively creating a common operating reference for unclassified visualization and analysis of commercial and/or government space domain awareness data.

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 NextGen,[1] the U.S. National Airspace System (NAS) is shifting from tactical and reactive air traffic control to more strategic and integrated air traffic management using advanced automation and information-sharing. As air traffic continues its rebound past pre-pandemic levels, the FAA is balancing the sustainment of current operations with NextGen investments and moving closer to regular use of Trajectory Based Operations (TBO).[2]

NextGen delivered more than $9.5 billion worth of total benefits between calendar years 2010 and 2022, with future benefits expected to substantially grow.[3] In FY 2023, the FAA enabled the first increment of full Data Communications services at 12 en route facilities, allowing pilots on select transcontinental routes to digitally accept certain clearances from air traffic controllers. More than 400 air routes and nearly 9,500 departure, arrival, and approach procedures use Performance-Based Navigation, reducing travel distance and time with more direct trajectories and enhancing safety with fewer converging points. The FAA added arrivals with an optimized profile descent for 11 airports, bringing the total locations with fuel-saving

1 NextGen, or the Next Generation Air Transportation System, is an FAA initiative to transform the U.S. National Airspace System (NAS). Digital communications supplement voice communications; navigation and surveillance have transitioned from mainly ground-based to primarily satellite-enabled; and segmented information exchange has turned into enterprise-level information sharing through a single connection. Controllers and pilots are better aware of traffic, making flying safer. Improved efficiency and capacity reduce delays, cancellations, fuel consumption, and engine exhaust emissions. For more information, see https://www.faa.gov/nextgen.

2 TBO is an air traffic management concept that provides all stakeholders with a common understanding of planned aircraft flight paths in 4D. The sharing of a four-dimensional flight trajectory among systems and stakeholders is the core tenet of TBO. Expected benefits are improved flight efficiency, increased airspace and airport throughput, and improved operational predictability and flexibility. For more information, see https://www.faa.gov/go/tbo.

3 NextGen improvements in communication, navigation, and surveillance are the sources for nearly $5.3 billion in benefits, automation accounts for about $2.3 billion, and separation takes credit for an estimated $1.9 billion. For more information, see https://www.faa.gov/nextgen/reporting-benefits.

procedures to 64. The FAA published 30 new and 24 amended T-Routes as part of the Alaska Aviation Safety Initiative and made 169 new Q-Routes available along the East Coast, optimizing air traffic flow. Six facilities joined 11 other en route centers in using Automatic Dependent Surveillance–Broadcast technology to enable a three-nautical-mile (NM) separation standard instead of five NM in certain airspace below 23,000 feet.

Enhancements to the En Route Automation Modernization system expanded the automated coordination of flight data and aircraft control with Canada, and upgrades to the Advanced Technologies and Oceanic Procedures system optimized flight trajectories and improved system safety. The FAA also implemented additional Terminal Flight Data Manager decision support systems, enabling a total of five locations to use this technology to improve efficiency on the ground and in the terminal airspace.

The FAA participated in expert panels considered necessary for international harmonization of efforts to help direct global air traffic modernization and mitigate operational risks. In June 2023, the FAA joined Aeronautical Radio of Thailand, the Civil Aviation Authority of Singapore, the Japan Civil Aviation Bureau, and Boeing to sign a declaration of intent on Multi-Regional TBO, signaling a commitment to make TBO a global reality. The FAA and its Multi-Regional TBO partners completed a six-day live flight demonstration that month showcasing how sharing and coordinating trajectory information across multiple countries could reduce fuel burn and carbon dioxide emissions by up to 10 percent, minimize delays and disruptions, and cut travel costs and time.

Part of NextGen is accommodating the growth of non-traditional forms of aviation, including advanced air mobility (AAM) operating at various altitudes.[4] The FAA is engaged in robust partnerships with academia and works with other government agencies, industry, international aviation stakeholders, and standards bodies to understand and navigate the evolving range of technologies. The FAA demonstrated traffic management concepts to safely incorporate unmanned aircraft systems (UAS) or "drones," spacecraft, and other emerging technologies into the NAS without disrupting existing traffic. In FY 2023, the FAA released version 2 of the Urban Air Mobility Concept of Operations (which provides the technical roadmap and defines the levels of maturity for AAM) and the AAM Implementation Plan (which guides initial AAM implementation in the near term). The FAA also participates in the AAM Interagency Working Group led by the Department of Transportation. The group comprises more than 15 federal agencies collaborating to develop and deliver the AAM national strategy in FY 2024.

4 AAM, as defined by the AAM Coordination and Leadership Act, is a transportation system that moves people and property by air using aircraft with advanced technologies, including electric aircraft, or electric vertical take-off and landing aircraft, in both controlled and uncontrolled airspace. Urban Air Mobility is a subset of AAM that focuses on operations in a metropolitan area. For more information, see: https://www.faa.gov/air-taxis.

As NextGen progresses, the FAA is developing the next iteration of airspace modernization focused on information-sharing. The Info-Centric NAS (ICN)[5] charts aviation's future and builds upon NextGen and TBO.

Aviation Workforce Development Grants

When commercial aviation passenger levels rebounded in 2022, 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 more inclusive talent pool of pilots and aviation maintenance technicians.

In FY 2022 and FY 2023, the FAA awarded two rounds totaling $20 million in Aviation Workforce Development Grants to more than 50 educational institutions across the country. The FAA published the Notice of Funding Opportunity (NOFO) for a third round of grants in July 2023, with another $13.5 million available, and received applications in August. The FAA anticipates publishing the NOFO for a fourth round of grants in summer 2024, pending authorization and appropriation.

Veterans Pilot Training Pilot Program

In addition to the above grant programs, the FAA 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 a four-year cooperative agreement to the University of North Dakota to begin this program. The FAA is committed to creating bridges to the civilian

5 The ICN is the FAA's vision for a future airspace system that will be interconnected on communication networks, will be flexible to accommodate changes in operations, and will include all stakeholders. ICN will take advantage of the ongoing information revolution with increased telecommunication, computational power, and storage, along with new technologies that secure and learn from accumulated data. For more information, see https://www.faa.gov/icn.

workforce for veterans returning from service and assisting their transition into new career paths that provide long-term stability through ladders of opportunity at home.

Sustainability in Aviation

The FAA is committed to making aviation cleaner, quieter, and more sustainable. At the United Nations Framework Convention on Climate Change Conference of Parties in November 2021, U.S. Secretary of Transportation Pete Buttigieg released the 2021 U.S. Aviation Climate Action Plan. This plan aims to achieve net-zero greenhouse gas emissions from U.S. aviation by 2050.

The FAA has several programs committed to realizing net-zero greenhouse emissions by 2050. Key among these programs is the support to develop and deploy Sustainable Aviation Fuel (SAF), which is in use today, and, once blended with conventional jet fuel, is a drop-in fuel that can be used without modifying existing aircraft, fueling infrastructure, or handling systems. SAF is made from a range of raw materials, including biomass, residues, and waste products. SAF has the potential to significantly reduce greenhouse gas emissions on a lifecycle basis and will play a critical role in a broader set of actions by the U.S. Government and the private sector to meet the aviation industry's net-zero emissions goal by 2050.

In September 2021, the Departments of Transportation, Energy, and Agriculture signed an MOU to co-lead a government-wide effort—the SAF Grand Challenge—to align Federal actions to support rapid industry scale-up of SAF production to three billion gallons per year by 2030 and meet roughly 100 percent of estimated domestic aviation fuel needs by 2050. The FAA is a proud participant in the SAF Grand Challenge, which intends to reduce costs, enhance sustainability, and expand production and use of SAF that achieve a minimum of 50 percent reduction in lifecycle greenhouse gas emissions compared to conventional jet fuel. Released in September 2022, the SAF Grand Challenge Roadmap lays out six action areas spanning all activities that have the potential to impact the SAF Grand Challenge objectives.

In FY 2023, the FAA published a NOFO to launch the new Fueling Aviation's Sustainable Transition (FAST) competitive grant program. The FAST program will make investments to accelerate the production and use of SAF and the development of low-emission aviation technologies. This new program, provided by the Inflation Reduction Act of 2022 (IRA), will carry out projects located in the United States that produce, transport, blend, or store SAF and develop, demonstrate, and apply low-emission aviation technologies. The FAST grant program, together with the tax incentive provisions of the Inflation Reduction Act, supports the goals of the SAF Grand Challenge and U.S. Aviation Climate Action Plan to achieve net-zero greenhouse gas emissions from the aviation sector by 2050.

In addition, the FAA also supports research for piston aircraft to operate safely without leaded gasoline and encourages actions that minimize exposure to aircraft lead emissions. In

FY 2022, the FAA approved supplemental type certificates that allow every general aviation spark-ignition engine and every airframe powered by those engines to use General Aviation Modification, Inc.'s 100-octane unleaded fuel. It marked an important step toward eliminating the use of leaded fuel in aviation.

The Continuous Lower Energy, Emissions, and Noise (CLEEN) Program is the FAA's principal effort to accelerate the development of new aircraft and engine technologies that reduce noise, emissions, and fuel burn. Through the CLEEN Program, the FAA partners with the aviation industry via a cost-sharing approach to enable the industry to expedite integration of these environmentally beneficial technologies into current and future aircraft. Through the first two phases of this cost-share partnership, industry contributed $388 million to the CLEEN Program, far exceeding the FAA contribution of $225 million. The FAA initiated CLEEN Phase III in 2021, and will spend more than $125 million through 2026, matched by industry, on the development of additional aircraft technologies that reduce the effects of aviation on the environment. In FY 2023, the FAA completed the second year of technology development under CLEEN Phase III, completing design activities in preparation for full-scale ground and flight testing in future years of the program.

Internationally, the FAA provides leadership in developing and establishing the International Civil Aviation Organization (ICAO) Committee on Aviation Environmental Protection (CAEP)'s technology-based standards to reduce aircraft carbon dioxide (CO_2) emissions, noise, and local air quality–related aircraft engine emissions such as nitrogen oxides (NOx). For the first time, CAEP is developing more stringent standards for airplane CO_2 emissions and noise simultaneously, through an integrated analysis that considers the interdependencies between noise and CO_2 emissions. CAEP's current plans are to complete the development of these more stringent standards by February 2025. The FAA also leads CAEP technical efforts to develop sustainability criteria and methodologies for SAF and lower carbon aviation fuels that are eligible under the Carbon Offsetting and Reduction Scheme for International Aviation Domestically, the FAA collaborates with the Environmental Protection Agency (EPA) to promulgate ICAO emissions standards into U.S. regulations. On June 15, 2022, the FAA released for public comment a notice of proposed rulemaking to establish certification requirements for our Nation's first fuel efficiency standard for civil airplanes. This rulemaking activity is based on ICAO's airplane CO_2 emissions standard from 2017 and will mandate U.S. airplane manufacturers to incorporate fuel-efficient technologies in newly built airplanes. The FAA finalized the airplane fuel efficiency certification rule on December 13, 2023, and it was published in the Federal Register on February 16, 2024.[6] The FAA also collaborates with the Departments of Agriculture and Energy, alongside the EPA, in supporting

6 See https://www.federalregister.gov/documents/2024/02/16/2024-02330/airplane-fuel-efficiency-certification.

the development of SAF lifecycle methodologies for domestic SAF tax credits established under the IRA.

The FAA is reducing its own emissions by installing renewable energy at its facilities and purchasing carbon-free electricity. In FY 2023, the FAA installed solar farms at facilities in Guam and Hawaii. These projects increased the production of renewable electricity to over 6,200 megawatt-hours. Other renewable installations are being planned and designed, including a large-scale solar farm planned at the FAA Mike Monroney Aeronautical Center.

Aircraft Certification Reform

The FAA understands and embraces the need to promote and sustain the primacy of safety, as well as continuous and proactive risk management throughout its workforce, across industry, and with other aviation authorities. We continue to improve and refine our certification and safety oversight processes using a comprehensive approach to implementing the provisions of the Aircraft Certification, Safety, and Accountability Act (ACSAA).

We have identified the following general themes:

- Treat aircraft as complex systems, with full consideration of 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.

Among the FAA's many notable accomplishments in FY 2023 are:

- Bolstering the FAA's organization designation authorization (ODA) program through various efforts, including publishing policy to prevent interference with ODA unit members and to facilitate open communication between unit members and the FAA. These efforts are part of the agency's work to fortify the FAA's ODA program to drive consistency and transparency in how the FAA appoints, manages, and oversees designees. The FAA also completed a special qualification review of ODA unit members at ODA holders who manufacture transport airplanes to ensure that unit members performing authorized functions on behalf of the FAA are appropriately qualified.
- Issuing a flightpath management advisory circular, which provides guidance and recommended practices to operators on developing operational policies, procedures, and

training to support effective flightpath management to help pilots avoid becoming overly reliant on automation. The advisory provides a unifying framework for operations and training programs. The FAA developed the advisory circular in response to Section 119(d) of ACSAA based on recommendations received from the Air Carrier Training Aviation Rulemaking Committee and includes recommended practices for flightpath management that can be incorporated into training programs and operational procedures.

- Publishing an FAA Order that defines an issues resolution and appeals process for decisions made during certification programs. The order provides a structured process to resolve issues that are identified by either the applicant or FAA team members, and a structured appeals process to elevate appeals of certification decisions within the FAA's Aviation Safety Organization (AVS). This process has already been successfully used several times, and summaries of such appeals are provided to Congress annually.
- Completing an inaugural assessment of the safety culture within the FAA's AVS organization via a comprehensive safety culture survey and focus groups. The output of this assessment will inform AVS leadership priorities and actions for FY 2024 and beyond. AVS will conduct annual checks of the safety culture within AVS moving forward.
- Conducted a comprehensive survey targeting Safety Assurance System (SAS) users to pinpoint root causes. The survey analysis, combined with previous research, affirmed assumptions within Flight Standards, such as resource shortages, insufficient SAS training effectiveness, lack of data quality awareness, and heavy workloads, especially in General Aviation Safety Assurance offices. Results from this survey proposed several recommendations to encompass intuitive SAS automation interface improvements, comprehensive and recurring training, agile learning solutions, organizational risk assessments, policy revisions, workload evaluations, and specialized workgroups for pilot deviations and air carrier certification.
- Chartered and continuing to lead the Changed Product Rule International Authority Working Group (CPR IAWG) to revise and improve the policy and standards related to the amended type certificate (TC) process associated with Aircraft Certification, Safety, and Accountability Act requirements, as well as consider recommendations from expert panel reviews and the MITRE report titled *Study of Type Certification Reform and Section 136 of the Aircraft Certification Safety and Accountability Act.* Participating authorities in the working group include the FAA, European Union Aviation Safety Agency, Transport Canada Civil Aviation, National Civil Aviation Agency of Brazil (Agência Nacional de Aviação Civil), Civil Aviation Administration of China, and Japan Civil Aviation Bureau. The FAA and other authorities' leadership received recommendations from the CPR IAWG in September 2022. Their

recommendations included proposed rulemaking actions to amend both parts 21.19 and 21.101 of title 14, Code of Federal Regulations. The FAA initiated rulemaking in December 2022.

- Published the Notice of Proposed Rulemaking (NPRM) for System Safety Assessments (SSA) on December 8, 2022, in response to Section 115 of the Aircraft Certification, Safety, and Accountability Act. The FAA proposes to amend 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 risk associated with airplane accidents and incidents that have occurred in service, and reduce risk associated with new technology in flight control systems. The intended effect of this proposed action is to improve aviation safety by making SSA certification requirements more comprehensive and consistent.
- Published the NPRM for Safety Management Systems (SMS) on January 11, 2023, in response to Section 102 of the Aircraft Certification, Safety, and Accountability Act. This proposed rule would extend 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 (PC) holders that are holders or licensees of a TC for the same product, and holders of a TC who license out that TC for production. This proposed rule is intended to improve aviation safety by requiring organizations to implement a proactive approach to managing safety.
- Issued the Policy Statement *Submission of Outline of New and Changed Systems at the Beginning of the Type Certificate Amendment Process for Transport Category Aircraft* on May 25, 2023, in response to Section 105 of the Aircraft Certification, Safety, and Accountability Act. Section 105(c) required the FAA to revise its procedures in order to require applicants for amendments to TCs for transport category aircraft to disclose, in a single document at the beginning of the certification process, all new systems and intended changes to existing systems known to the applicant.

As part of the ACSAA, the FAA implemented the Voluntary Safety Reporting Program (VSRP) to enable confidential reporting of identified safety concerns by all 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. Similar to 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 of 2021 and has received more than 560 reports, of which 80 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 as operators explore new and innovative applications for these technologies.

Beginning in 2015, the FAA revisited and continued rulemaking efforts to regulate small drones with the Registration and Marking Requirements for Small Unmanned Aircraft interim final rule. Shortly thereafter, the FAA published requirements for small UAS operations and the certification of remote pilots in the "Small UAS rule" in 2016 (Title 14 Code of Federal Regulations (14 CFR) part 107). Subsequent rulemakings, including the Operation of Small Unmanned Aircraft Systems Over People (amendment to 14 CFR part 107) and Remote Identification of Unmanned Aircraft, which established 14 CFR Part 89, have provided safety and security requirements to further small UAS integration. In 2014, the FAA issued the first TCs to the Insitu ScanEagle and Aerovironment Puma drones/UAS in the restricted category based on the collective knowledge and experience of the FAA team gained from the previous SAC-EC projects.

By granting waivers, the FAA collected adequate data to formulate standardized, data-driven operating requirements for safe night operations that were subsequently incorporated into the Part 107 amendment. Furthermore, the amendment to Part 107 revised training prerequisites and established criteria allowing operations over people under specific conditions.

Publishing the Remote Identification (RID) of Unmanned Aircraft Final Rule was the next incremental step toward further integration of unmanned aircraft in the NAS. RID is a digital "license plate" for an unmanned aircraft. With RID, law enforcement and national security partners can discern compliant airspace users from those potentially posing a safety or security risk and respond appropriately. The operator's UAS RID serial number and location information are available to anyone within range with RID broadcast receiver technology on their personal wireless device, such as a smartphone. For privacy reasons, only authorized government agencies and law enforcement can request more detailed registration information from the FAA. The compliance date for meeting these requirements was September 16, 2023. However, the FAA exercised enforcement discretion through March 16, 2024, due the limited availability of the broadcast modules and approved FAA-Recognized Identification Areas where unmanned aircraft may be flown without Remote ID. These issues have been remedied and the FAA is expecting full compliance with the Remote ID for all UAS operations.

Enabling routine and scalable BVLOS operations safely and securely, while also being economically feasible, marks the next significant stage in drone integration. The FAA's strategic plan involves transitioning from case-by-case approvals via waivers and exemptions to the development of rules and policies particularly 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 processes, and the recommendations outlined in the final report of the UAS BVLOS Aviation Rulemaking Committee.

The FAA has been using existing 14 CFR 11 processes to permit more complex drone operations. The FAA issued four exemptions to permit more complex BVLOS operations, including infrastructure inspection and package delivery, in August and September 2023. In granting these petitions, the FAA is enabling increased operations. Unmanned Aircraft to Unmanned Aircraft (UA-UA) collision risk can be mitigated in several ways. One mitigation is through airspace awareness by checking Notice to Air Missions (NOTAMs) for areas where another BVLOS drone may be flying or through the use of UAS Traffic Management (UTM) strategic deconfliction services. Data gathered by operations conducted under these exemptions will inform efforts for repeatable and scalable operations. The FAA has 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 "full operational capability" of the UTM ecosystem. Over the past several years, collaboration between industry, NASA, FAA's Centers of Excellence (COEs), academia and the FAA has been ongoing to test and enhance capabilities for managing UA-UA risk across different airspace environments. Furthermore, industry stakeholders have consistently emphasized the necessity to implement UTM services to facilitate safe drone deliveries, thereby enabling increased compensations and hire operations. Under existing regulations, the FAA does not have a regulatory mechanism for independently recognizing third-party UTM services. This has hindered the industry from developing and marketing services. To address this gap, in the second half of 2023, the FAA developed the UTM Near-Term Approval Process (NTAP) program, which utilizes existing FAA approval processes to facilitate the review, testing, and evaluation of UTM third-party services. The NTAP provides a pathway for evaluating UTM services supporting BVLOS operations of multiple operators and is foundational to informing the evolving regulatory framework and future service qualification, as well as to provide data to support

future rulemaking. In August 2023, the FAA announced the UTM Operational Evaluation. This initiative will permit industry and government to gather data from coordinated, real-life UAS operations in the North Dallas, Texas, area, which will be instrumental in validating the effectiveness of strategic deconfliction services for managing UA-UA risk.

To support the FAA's work to safely and efficiently integrate drones into the NAS, the Agency is conducting research related to risk assessment, operational assessment, and human factors studies, FAA established the UAS COE, Alliance for System Safety of UAS through Research Excellence (ASSURE). This alliance features expertise across a broad spectrum of research areas including air traffic control interoperability, UAS airport ground operations, command, control and communications, detect and avoid, human factors, UAS noise reduction, UAS wake signatures, unmanned aircraft pilot training and certification, mid-air collision risk assessment, low altitude operations safety, spectrum management and UAS traffic management. The mission of the COE is to provide the FAA the research needed to integrate unmanned aircraft systems quickly, safely, and efficiently into the NAS with minimal changes to our current operations. From its inception in 2015, ASSURE has completed numerous detailed, UAS-related research projects, and there many ongoing research efforts that will enrich the FAA's efforts of safe and secure UAS integration when completed.

The FAA remains committed to finding new and innovative pathways to reach the next level of safety, efficiency, and operations so the United States may continue to be a global leader in innovation, safety, and international air transportation systems.

Commercial Space

FAA's Office of Commercial Space Transportation (AST) achieved new records in FY 2023 with 113 licensed operations (106 launches and 7 reentries) from multiple operators, 39 more than in FY 2022. The FAA continued 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 2023, the FAA licensed eight launches and four reentries for human space flight launches and reentries. Virgin Galactic and SpaceX operated private astronaut and space operations. Additionally, SpaceX continued to provide spaceflight capability to NASA astronauts and the International Space Station (ISS) by conducting three launches and three reentries carrying ISS crewmembers in addition to three cargo resupply missions. This capability eliminates

the United States' 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 2023, commercial space transportation activities expanded as follows. The FAA:

- issued five vehicle license determinations.
- issued a record number of 40 license modifications and nine renewals.
- conducted a record number of safety inspections—over 750—exceeding the FY 2022 record of 539.
- granted a license to ABL Space Systems in November 2022 under part 450 for launches at Kodiak Pacific Spaceport Complex in Alaska. It had an inaugural launch on January 10, 2023.
- granted a license to Relativity Space in February 2023 under part 450 for its Terran 1 launch vehicle from Cape Canaveral Space Force Station (CCSFS) and had an inaugural launch on March 22, 2023. Relativity's Terran 1 is the world's first 3D printed rocket.
- licensed the SpaceX reusable super-heavy-lift launch system, known as the Starship. SpaceX designed this system to be the world's most powerful rocket, and it was launched for the first time on April 20, 2023, from Boca Chica, Texas.
- granted a license to United Launch Alliance Vulcan in July 2023 under 14 CFR part 415 (legacy regulations), for launches from CCSFS.

As more rocket launch operators seek to share the Nation's airspace, the FAA has deployed 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 FAA telemetry information which is used by ATO Space Operations to enhance mission awareness and facilitate the accelerated release of launch airspace, or aircraft hazard areas, back to the National Aerospace System. SpaceX voluntarily provides FAA certain operational information to implement dynamic launch and reentry windows that the FAA uses at launch sites in Vandenberg, California and Cape Canaveral, Florida. 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 2023 specifically, AST had many accomplishments, including:

- Updating its human spaceflight recommended practices to *cover* space vehicle occupants from the time they are exposed to hazards before flight until after landing, when

hazards are no longer present.[7] The updated practices incorporate lessons learned from the NASA Commercial Crew program and recent private human spaceflight missions. This is the first update since the recommended practices were first issued in 2014.

- Proposing a rule to reduce the growth of orbital debris from commercial space vehicles.[8] This rule would promote a sustainable space environment by limiting the amount of new orbital debris and reducing the potential for collisions with spacecraft and satellites. The primary focus would require FAA-licensed commercial space operators to choose from among five disposal options for the upper stages of launch vehicles. The public comment period closed on December 26, 2023.[9]
- Proposing a rule to incorporate changes required by the Commercial Space Launch Competitiveness Act of 2015 into FAA regulations.[10] It would update definitions for commercial space launch and reentry vehicles and occupants, expand the applicability of permitted operations to include certain reusable vehicles, and clarify financial responsibility requirements. It would also provide clarity to applicants seeking licenses for operations involving government astronauts. The public comment period closed on October 17, 2023.[11]
- Delivering a report to Congress on the risk of debris from reentering satellites. This report evaluates the risk to people on the ground and in aircraft due to debris from random and controlled reentries of satellites from low-Earth orbit and how the FAA's commercial space licensing process might address this risk.[12]
- The Secretary of Transportation chartered an Aerospace Rulemaking Committee (commonly referred to as a SpARC) known as the 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.
- The Secretary of Transportation also chartered a SpARC to gain industry advice and recommendations on improvements to 14 CFR part 440, Financial Responsibility,

7 https://www.faa.gov/media/71481

8 https://www.federalregister.gov/documents/2023/09/26/2023-20531/mitigation-methods-for-launch-vehicle-upper-stages-on-the-creation-of-orbital-debris

9 https://www.regulations.gov/document/FAA-2023-1858-0001

10 https://www.federalregister.gov/documents/2023/08/18/2023-16858/us-commercial-space-launch-competitiveness-act-incorporation

11 https://www.regulations.gov/document/FAA-2023-1656-0001/comment

12 https://www.faa.gov/sites/faa.gov/files/PL_116-260_Risks_Associated_w_Reentry_Disposal_of_Satellites_from_Large_Constellations.pdf

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.

Department of Commerce

DOC

The Department of Commerce's (DOC) mission is to create the conditions for economic growth and opportunity for all communities. Through its 13 bureaus, the Department works to drive U.S. economic competitiveness, strengthen domestic industry, and spur the growth of quality jobs in all communities across the country. During FY 2023 the DOC continued its efforts to promote responsible U.S. innovation, investment, and space operations, and engage commercial efforts in support of U.S. government missions and the U.S. economy in alignment with Secretary Gina Raimondo's Strategic Goal 1, "Drive U.S. innovation and global competitiveness" and Strategic Objective 1.7, "Advance U.S. leadership in the global commercial space industry."

The Department has employed its multifaceted tools to strengthen the competitiveness of U.S. businesses, communities, and workers, while also engaging allies and partners to promote innovation, sustainability, and global security for the U.S. space economy.

The Department's wide-ranging contributions include the development of products, services, technologies, and standards in coordination with the National Space Council, under the leadership of Vice President Harris, and in accordance with the U.S. Space Priorities Framework to bolster the health and vitality of the U.S. space sectors—civil, commercial, and national security—for the benefit of the American people.

National Oceanic and Atmospheric Administration

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

and forecasting. Below is a summary of major accomplishments regarding new NOAA and partner satellite assets in FY 2023.

Office of Space Commerce

The Office of Space Commerce (OSC) is the principal unit for space commerce policy activities within the DOC. Its mission is to foster the conditions necessary for the economic growth and technological advancement of the U.S. commercial space industry. The Office is leading efforts for the U.S. Government for developing the U.S. civil space situational awareness and space traffic coordination system, growing U.S. commercial space solutions, championing space safety and sustainability, and ensuring sound U.S. Government space policy development and implementation.

Developing Space Situational Awareness and Space Traffic Coordination Services

Supporting basic Space Situational Awareness (SSA) data and basic Space Traffic Coordination (STC) services. In partnership with industry, government, and academia, the OSC is implementing an operational public SSA and STC services system called the Traffic Coordination System for Space (TraCSS). TraCSS will provide satellite tracking data and associated products and services to support all private and civil space satellite owners/operators. The OSC is pursuing a phased development approach for TraCSS to build up capabilities and ensure a smooth offloading of SSA and STC responsibilities from the Department of Defense (DOD). TraCSS will ingest unclassified data from DOD and integrate commercial SSA data and services to promote spaceflight safety, space sustainability, and international coordination. This public-private collaboration continues to evolve through ongoing research, integration, and testing to advance capabilities for civil SSA and STC. These combined efforts will improve SSA data interoperability and increase SSA data sharing.

Collaborating and coordinating with the Department of Defense. DOD and OSC engaged in several continuing weekly working groups and semiannual in-person workshops on collaboration and coordination related to SSA and development of TraCSS. As part of a pilot project to assess spaceflight safety mission assurance to select spacecraft in the medium-Earth orbit and geostationary Earth orbit, the OSC partnered with DOD through 2023 to award seven contracts to U.S. commercial space firms for space situational awareness data analysis. The pilot project demonstrated that the U.S. Government needs to clearly define program goals, metrics, and contractual deliverables to assess commercial performance and to take full advantage of commercial capabilities. It also helped identify clear areas for government-funded "commercial pathfinder" programs with the private sector to mature industry capability tailored specifically for OSC TraCSS service needs.

Defining the scope of basic Space Traffic Coordination services. On January 26, 2023, the OSC issued a "Basic SSA Services" Request for Information (RFI) seeking input and feedback on the planned scope of basic safety services that the TraCSS program will provide. This input informed OSC's development of capabilities to share SSA data, information, and services to space operators and the public.

Progressing toward deployment of TraCSS Phase 1.0 initial capabilities: The OSC, working closely with its partners at DOD and NASA, continued to make good progress on the implementation of the TraCSS program. OSC continued to progress in the architecture and procurement strategy to deploy Phase 1.0 initial capabilities in the fourth quarter of 2024. The OSC developed a procurement strategy that has three distinct components: TraCSS-OASIS—a data lake repository for storing, sharing, and disseminating government, international, and commercial SSA data; TraCSS-SKYLINE—the SSA application layer providing collision alerts, warnings, and other safety services; and TraCSS-HORIZON—a development and testing environment and modeling, simulation, and research environment to advance the state of the art in SSA. In 2023, OSC awarded a cloud utility contract for TraCSS and is progressing on major procurements.

Engaging commercial providers on Space Traffic Coordination services. The OSC hosted two workshops—a virtual workshop on July 12, 2023, and an in-person workshop on July 19, 2023—for commercial Space Situational Awareness data/products and service providers to discuss TraCSS. The OSC hosted these workshops as part of a series of continuing engagements with the user community to discuss the future of TraCSS. On April 12, 2023, the OSC hosted a live video presentation about TraCSS, where the OSC shared its findings from the Basic SSA Services RFI. On July 28, 2023, the OSC released a second video presentation updating the progress of TraCSS, discussing related interagency cooperation between DOC, DOD, and NASA; the primary objectives for TraCSS; the three components of TraCSS (OASIS, SKYLINE, and HORIZON), what they handle, and how they work together; the roll-out of capabilities across Phase 1 of TraCSS; the engagement approach for integration of commercial SSA data and services in Phase 1; and expectations for future phases.

Developing SSA and STC standards and practices. The OSC and the National Institute of Standards and Technology (NIST) have continued to coordinate and engage to share input from the U.S. Government and commercial industry to develop internationally accepted common standards, best practices, and guidelines for space situational awareness and space traffic coordination.

Promoting space cybersecurity. On March 29, 2023, Deputy Secretary of Commerce Don Graves joined other top leaders from the government and the U.S. space industry at the White House for a forum discussing cybersecurity in the space systems ecosystem and driving action for critical cybersecurity investments across the space systems ecosystem. Department of Commerce officials and representatives from other government agencies emphasized the need to partner closely with the private sector to ensure the resiliency and defense of the U.S. space ecosystem against cyber threats.

Championing Space Safety and Sustainability

Supporting in-space servicing, assembly, and manufacturing. The OSC supported the White House Office of Science and Technology Policy Interagency Working Group on the development of the In-space Servicing, Assembly, and Manufacturing (ISAM) National Strategy issued in April 2022. The document lays out a national strategy to ensure U.S. leadership in ISAM and ensures applications are maintained and expanded for future use. The Office also contributed to the development of the national ISAM implementation plan released in December 2022. It outlines ways to build capabilities and technologies in space, consistent with the U.S. National Space Priorities Framework, with DOC contributing to engagement with the private sector, industry partners, domestic and international bodies, and academia for universal standards development for ISAM technologies through the engagement in standard developing organizations and workshops and industry forums. OSC contributed to the development of the International Organization for Standardization standard 24330:2022 "Rendezvous and Proximity Operations for On Orbit Servicing Programmatic Principles and Practices," released in July 2022. In addition, OSC participated in NASA's ISAM Workshop "Envisioning Our Future in Space" and the Consortium for Execution of Rendezvous and Servicing Operations Global Satellite Servicing Forum in October 2022 to hear about upcoming ISAM missions, opportunities to collaborate on ISAM technologies and capabilities development, and standards developments. Engagements through these events led to OSC's introduction to companies working on active global satellite servicing with whom OSC was able to meet later at space conferences such as the Space Symposium in April 2023.

Mitigating the impact of orbital debris. The OSC participated regularly in the Orbital Debris Research and Development Interagency Working Group led by the White House Office of Science and Technology Policy. The Office supported the development of the July 2022 National Orbital Debris Mitigation Plan, a national effort to meet the United States' space sustainability priorities to mitigate, track, and remediate debris, and continued participation in the Interagency Working Group to deliver implementation updates. The implementation plan accomplishes objectives outlined in the U.S. Space Priorities Framework and builds upon the

National Orbital Debris Research and Development Plan published in 2021 that OSC worked on as well. In addition, the OSC kicked off a technical working group with NASA centered on the R&D component of the Traffic Coordination System for Space (TraCSS-HORIZON) to address issues around advancing the state of the art in SSA, including basic R&D, to address scientific questions on how the space environment impacts SSA, space weather, and orbital debris.

Ensuring Sound U.S. Government Space Policy Development and Implementation

Eliminating restrictive operating conditions from commercial remote sensing satellite licenses. Executing streamlined regulations on private remote sensing systems implemented in 2020, NOAA's Commercial Remote Sensing Regulatory Affairs (CRSRA) office, a division of the OSC, modified the operating licenses of multiple commercial satellite systems. These modifications removed restrictive conditions that prevented these systems from offering their full remote sensing capabilities to the public. This action cuts out significant red tape in private remote sensing systems' regulation and keeps with the Department's commitment to accelerate U.S. leadership in the fast-growing commercial space industry. On July 19, 2023, CRSRA removed 39 individual temporary license conditions. Other changes included a reduction of global imaging restrictions for certain imaging modes to permit imaging and distribution for all but less than 1 percent of Earth's surface; removal of some Non-Earth Imaging and Rapid Revisit conditions; and removal of all of current X-Band Synthetic Aperture Radar (SAR) temporary conditions.

Advancing export control for U.S. businesses. The OSC provided subject matter experts to assist the DOC Bureau of Industry and Security in numerous export control reform working groups. OSC helped advocate for, with adequate technical justification, the transfer of certain U.S. space-related technology from the International Trafficking in Arms Regulations (ITAR) to the DOC Export Administration Regulations, with the goal of maximizing U.S. industry competitiveness in overseas markets.

Engaging with the international space program community and leadership. The OSC collaborated with the European Space Surveillance and Tracking Consortium on assessing the risk of in-orbit collisions and uncontrolled reentry of space debris into Earth's atmosphere, as well as detecting and characterizing in-orbit fragmentation with Consortium EU member states represented through their national designated entities: France (CNES), Germany (German Space Agency at DLR), Italy (ASI), Poland (POLSA), Portugal (PT MoD), Romania (ROSA), and Spain (CDTI) and presented results from a joint study during the Advanced Maui Optical and Space Surveillance Technologies Conference in September 2023.

The OSC Director and team provided remarks on the current state of the field for SSA, international SSA policy, and the DOC's efforts in TraCSS at the 2023 Advanced Maui Optical and Space Surveillance Technologies Conference, Maui, Hawaii, in September 2023. The Director and staff also participated in executive meetings with businesses, government agencies, and foreign governments to share information on the DOC's role with industry, government, and academia on publicly available SSA and space traffic coordination services.

The OSC actively participated in multilateral organizations such as the U.S. Committee on the Peaceful Uses of Outer Space and in bilateral working groups and ad hoc engagements to support expert exchanges in collaboration with interagency partners, led by the U.S. Department of State. In addition, the Office participated in the Space Five meetings with Canada, New Zealand, Australia, and the United Kingdom. Topics discussed included SSA, space cybersecurity, on-orbit authorization, space resource use, and policies and regulations for future U.S. orbital operations in key orbits for maneuver-based missions such as orbital servicing, survey, and assembly.

Geostationary Satellites

NOAA's current generation of Geostationary Operational Environmental Satellites, known as the GOES-R Series, is providing 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 provide 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 of more than half the globe—from the west coast of Africa to New Zealand and from near the Arctic Circle to the Antarctic Circle. They also monitor the Sun and detect approaching space weather hazards that can disrupt communications, navigation systems, and power grids on Earth.

NOAA's newest geostationary satellite, GOES-18, entered operational service as GOES West in January 2023, replacing GOES-17. GOES-17 is now the primary on-orbit standby.

GOES-U, the final satellite in the GOES-R Series, completed environmental testing in FY 2023 and is on track for a planned April 2024 launch.

GOES satellites provided imagery and critical information about destructive hurricanes, wildfires, flooding, and severe weather worldwide.

NOAA's Geostationary Extended Observations (GeoXO) mission was formally approved in December 2022. GeoXO will continue and expand NOAA's Earth observations from geostationary orbit. The information GeoXO supplies will address emerging environmental issues and challenges regarding weather, the ocean, and the climate that threaten the security and well-being of everyone in the Western Hemisphere. NOAA plans for GeoXO to begin

operating in the early 2030s as the GOES-R Series nears the end of its operational lifetime. The GeoXO team collaborated with industry partners to complete definition-phase studies to design the instrument and spacecraft concepts; mature necessary technologies; and define potential performance, risks, costs, and development schedules. The Congressional Readiness Report for the GeoXO program was delivered to Congress on February 9, 2023. In March 2023, NASA awarded the first development contract on behalf of NOAA when it selected L3Harris Technologies Inc. to build the primary instrument—the GeoXO Imager. NASA announced the selection of Ball Aerospace & Technologies Corporation on September 11, 2023, to develop NOAA's GeoXO Sounder instrument. The remaining development contracts will be awarded by mid-2024.

Following is a list of NOAA geostationary satellites on orbit with date launched:

GOES West (GOES-T/GOES-18)	March 1, 2022
GOES East (GOES-R/GOES-16)	November 19, 2016
GOES-17 (GOES-S/on-orbit primary backup)	March 1, 2018
GOES-14 (GOES-O/on-orbit backup)	June 27, 2009

Low Earth Orbiting Satellites

NOAA's current generation of low Earth orbiting operational environmental satellites, the Joint Polar Satellite System (JPSS), represents significant technological and scientific advancements in observations used for severe weather prediction and environmental monitoring. JPSS satellites circle Earth from pole to pole and cross the equator 14 times daily in the afternoon orbit—providing 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. All major numerical weather prediction centers around the world use this information as the basis of nearly every medium-term (three to seven days in advance) weather forecast. NOAA-20 and Suomi National Polar-orbiting Partnership (Suomi NPP) are the primary low Earth orbiting operational environmental satellites, and NOAA's National Weather Service (NWS) uses these data as critical input for numerical forecast models. These forecasts enable emergency managers to make timely decisions to protect American lives and property, including early warnings and evacuations. Polar satellites are considered the backbone of the global observing system.

NOAA-21, which is the third in the JPSS series, was launched in November 2022 from Vandenberg Space Force Base in California and ensures continuity of the JPSS measurements into the future. NOAA-21 provides continuity of observations from NOAA-20 and Suomi NPP. NOAA plans to place NOAA-21 in a quarter orbit ahead of Suomi NPP, and NOAA-20 will be a quarter orbit behind Suomi NPP. Upon validation of its data products, NOAA-21

will become the primary operational satellite, NOAA-20 will become the primary on-orbit standby satellite, and Suomi NPP will become the secondary on-orbit standby satellite in low Earth orbit.

JPSS-3 successfully passed its Key Decision Point-D in June 2023 and is now in satellite-level environmental testing. Once environmental testing is complete, JPSS-3 will hold a pre-storage review, currently scheduled in late 2024. It will then be placed in storage with periodic testing until preparations for launch begin in late 2031. It is scheduled to launch in FY 2033.

The instruments for JPSS-4 are in or have completed their final stages of development. The instruments will be shipped to the Northrop Grumman facility in Gilbert, Arizona, to be integrated with the satellite bus. The JPSS-4 satellite-level Pre-Environmental Review is scheduled for late 2024. The Launch Commitment Date is FY 2028.

The launch sequence for JPSS-4 and JPSS-3 was switched to minimize the risk to the satellites as the Libera instrument is integrated. Libera is a NASA instrument designed to measure the radiation budget of Earth. It is the replacement for the CERES instrument on S-NPP and NOAA-20. By using JPSS-4 to accommodate the Libera instrument, Libera can be included in the satellite-level environmental testing. This will minimize technical and financial risk to the JPSS satellites as it will eliminate the need to remove JPSS-3 from storage to integrate the Libera and test the fully integrated satellite.

The Near-Earth Orbit Network (NEON) was approved at its Key Decision Point-0 in September 2023. The NEON Program was created by NOAA to satisfy the mission need for global measurements to provide continuity to current LEO measurements, as well as new and enhanced future measurements. The NEON Program will field the next-generation LEO observational capabilities to support the DOC's Primary Mission Essential Functions and NOAA strategic objectives associated with terrestrial weather prediction and warning, climate adaptation and mitigation, healthy oceans, and resilient coastal communities and economies. NEON is the follow-on to the JPSS and other National Environmental Satellite, Data, and Information Service (NESDIS) LEO observation endeavors. The program will continue, improve, and extend NESDIS global observations for weather forecasting and climate monitoring. NEON intends to hold its DOC Milestone 1 review by early 2024.

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) follow-on COSMIC-2/FORMOSAT-7 constellation provides precision radio occultation soundings from equatorial orbit to support improved numerical weather prediction model forecasts. The program is being conducted under an agreement between the American Institute in Taiwan (AIT) and the Taipei Economic and Cultural Representative Office (TECRO) in the United States, for which NOAA is AIT's designated representative and the Taiwan Space Agency (TASA) is TECRO's designated representative. The mission consists of six satellites designed to improve weather forecasts and space weather monitoring

via state-of-the-art instruments that measure Global Navigation Satellite System (GNSS) signal refraction in the atmosphere. By having five times the number of measurement capabilities, the instruments provide improved precision and performance as well as near-real-time information about Earth's atmosphere to support numerical weather prediction. By measuring the bending due to refraction of GNSS signals through Earth's atmosphere, the COSMIC-2 satellites provide meteorologists with information such as temperature, pressure, density, and water vapor that help them better observe, study, and forecast severe storms. Temperature measurements derived from radio occultation are very accurate and are well suited to help scientists understand long-term climate changes. Additionally, the COSMIC-2 GNSS receivers are sensitive to space weather effects on the ionosphere that can cause regional and local disruption of radio communications and affect accuracy of GNSS readings.

The six COSMIC-2/FORMOSAT-7 satellites launched on June 25, 2019, have proved to be a valuable resource during the Atlantic hurricane season. NOAA will continue partnering with TASA using COSMIC-2 observations.

The Argos Data Collection and location System (DCS) is a satellite- and terrestrial-based system that collects, processes, and disseminates environmental data from fixed and mobile platforms located around the world, supporting a wide variety of applications including environmental monitoring, marine fisheries applications, and maritime security applications. The Argos system consists of DCS instruments that are hosted on polar-orbiting satellites operated by EUMETSAT, the Indian Space Research Organisation, and NOAA in three Sun-synchronous orbits that ensure timely reporting at all latitudes. To provide continuity of service, NOAA, under an international agreement with the French space agency CNES, is providing accommodation for the next Argos DCS payload (Argos-4) on a commercial spacecraft using a U.S. Space Force Hosted Payload Solutions contract. The launch took place on October 7, 2022, from Mahia Peninsula, New Zealand.

Metop is a series of three polar-orbiting meteorological satellites that form the space segment component of the overall European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) Polar System. The Metop series satellites are part of a joint commitment between NOAA and EUMETSAT to fly complementary polar-orbiting satellites. EUMETSAT covers the morning orbit, and NOAA covers the afternoon orbit. The third in the Metop series, Metop-C, which launched on November 7, 2018, is a state-of-the-art polar-orbiting satellite that helps improve complex weather forecasts and models as well as long-term climate assessments. This satellite works together with its predecessor (Metop-B), as well as Suomi NPP, NOAA-20, and NOAA legacy satellites, to collect more precise weather data as we continue to improve forecast errors from combined satellite observations incorporated into models. NOAA supplied four of the 13 instruments onboard the satellite, including two microwave sensors that measure global atmospheric temperature, humidity, and sea ice, as

well as a visible/infrared radiometer that delivers imagery of clouds, oceans, ice, and land surfaces. The last instrument is the Space Environment Monitor, which monitors space plasma and radiation around the spacecraft. Additionally, the satellite's instruments provide new and improved observations to the National Weather Service on atmospheric aerosols, soil moisture, greenhouse gasses such as carbon dioxide and methane, and radio occultation soundings that deliver enhanced vertical temperature and humidity profiles of the atmosphere. The launch was a collaborative effort involving NOAA, NASA, and international partners at EUMETSAT and the European Space Agency.

The next generation of Metop, Metop Second Generation (Metop-SG) satellites, following on from the EUMETSAT Polar System program, will secure the continuation of meteorological observations from the polar orbit in the 2024–2043 timeframe.[1] It will bring observations to a new standard through the suite of innovative European instruments flown on the Metop-SG spacecraft. The mission (known as the EUMETSAT Polar System-Second Generation or EPS-SG) is composed of two series of spacecraft, Metop-SG A and B, flying on the same mid-morning orbit, like the current Metop satellites. The orbit height is in the range of 823–848 km (dependent on latitudes). There will be three satellites each of Metop-SG A and Metop-SG B. Under the Joint Polar Satellite agreement between NOAA and EUMETSAT, both organizations will establish and operate a Joint Polar System composed of EUMETSAT's Metop-Second Generation (Metop-SG) satellites, NOAA's JPSS satellites, and shared ground systems and services. Joint operations will include cross support for data acquisition and spacecraft monitoring through European and U.S. ground stations located in Svalbard, Spitsbergen, and McMurdo, Antarctica.

The Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission (GCOM) consists of two satellite series, GCOM-W and GCOM-C. The GCOM-W project is a 13-year mission with a series of two satellites that aims to measure global-scale water-cycle changes over a long period of time. GCOM-W1, launched in May 2012, carries the Advanced Microwave Scanning Radiometer 2 (AMSR2), an instrument to observe water-related targets such as precipitation, water vapor, sea surface wind speed, sea surface temperature, soil moisture, and snow depth. GCOM-C1, launched in December 2017, carries the SGLI (Second Generation Global Imager), an instrument for surface and atmospheric measurements of phenomena involved in the carbon cycle and radiation budget, such as clouds, aerosol, ocean color, vegetation, and snow and ice. The current cooperative activity will be extended into the future with the new-generation Global Observing SATellite for Greenhouse gases and Water cycle (GOSAT-GW) (scheduled to be launched in 2025. 2024). JAXA will continue to transmit the

1 https://www.eumetsat.int/metop

Advanced Microwave Scanning Radiometer 3 (AMSR3) data from the GOSAT-GW satellite to NOAA's ground receiving sites in the Arctic Circle and the United States.

The following is a list of NOAA low Earth orbiting satellites in use with date launched:

NOAA-20 (Joint Polar Satellite System [JPSS]-1):	November 18, 2017
Suomi NPP	October 28, 2011
NOAA-19	February 6, 2009

Following are the satellites with which NOAA partnered for launch and/or operations, with launch date:

Currently in use

Jason-CS/Sentinel 6	November 21, 2020
COSMIC-2	June 25, 2019
Metop-C	November 6, 2018
GCOM-C	December 23, 2017
Jason-3	January 17, 2016
Metop-B	September 19, 2012
GCOM-W	May 18, 2012

Planned

GOSAT-GW	2024
Metop-SG A1	December 2024
Metop-SG B1	2025
Metop-SG A2	2031
Metop-SG B2	2032
Metop-SG A3	2038
Metop-SG B3	2039

In 2021, NOAA proposed the NEON satellite portfolio to complement the current, ongoing program of record (i.e., Polar Weather Satellites) and to fund gap mitigation and risk reduction activities along with supporting continuity of observations from LEO. Nearly every product category and subcategory across the thematic areas described in the NESDIS Level Requirements relies on observational measurements from LEO. These measurements help fulfill NESDIS' commitment to United States statutes, Executive Branch policies and plans, DOC primary mission essential functions and strategic plans, and NOAA Mission Service Areas. The NEON Program was charged to develop fast, responsive missions that can take advantage of the emerging commercial small spacecraft capabilities and commercial satellite operations marketplace and evaluate whether these types of lower-oversight, higher-risk

acquisition approaches can be effectively integrated into the Program of Record data product generation and distribution capabilities. With a primary objective of testing new ways of doing business and new technologies, a secondary benefit, if successful, would be to address the potential disruption of sounding data in the late afternoon/early morning caused by the retirement of the existing Polar Operational Environmental Satellites assets expected in late calendar year 2024. To serve as a pathfinder for NEON program acquisitions and to address the coverage gap, NESDIS authorized the QuickSounder mission to fly an existing Advanced Technology Microwave Sounder (ATMS) engineering development unit on a NASA Rapid Spacecraft Development Office–procured spacecraft operating in the late afternoon/early morning polar Sun-synchronous orbit. In December 2023 the QuickSounder mission reached DOC Milestone 2, and a contract was awarded for the ATMS engineering development unit refurbishment. Additionally, the NEON program started holding several user engagement workshops to solicit feedback from users and practitioners of LEO data, to better understand how the current data are used and the needs for future enhanced observations of oceans, land, and the atmosphere to improve NOAA's products and services.

Space Weather Observations

Geomagnetic storms are major disturbances of Earth's magnetosphere caused by shock waves in the solar wind. Geomagnetic storms are the costliest type of space weather events as they can cause widespread damage to power grids, satellites, and communication and navigation systems. The Deep Space Climate Observatory (DSCOVR) mission, launched in 2015, is NOAA's first operational deep space mission operating at Lagrange Point 1 (L1). The satellite has become America's primary warning system for solar magnetic storms and solar wind data while giving Earth scientists a unique vantage point for studies of the planet's atmosphere and climate.

NOAA's Space Weather Follow On (SWFO) Program will maintain observational continuity of real-time solar imagery and solar-wind measurements and replace the two legacy missions: DSCOVR and SOHO. The SWFO-L1 observatory will be placed at the first Sun-Earth Lagrange point (L1) with the goal of providing images and data critical for the operations of the National Weather Service's Space Weather Prediction Center (SWPC) alerts and forecasting. As part of the SWFO Program, NOAA is partnering with the Naval Research Laboratory (NRL) to build three Compact Coronagraph (CCOR) instruments for future space weather observations. The first CCOR has been integrated onto the GOES-U spacecraft, which is planned for launch in April 2024. NOAA is developing the SWFO-L1 mission, which will include CCOR-2 and a suite of in situ instrumentation to monitor the solar wind. SWFO-L1 is planned for launch in 2025 as a rideshare with NASA's Interstellar Mapping and Acceleration Probe for positioning at the LL1 point. In FY 2023, NOAA's SWFO Program completed the

Mission Operations Review, as well as several Pre-Environmental and Pre-Ship reviews for the various instruments and sensors.

The Space Weather Next (SW Next) Program is a loosely coupled program implemented under the joint NOAA-NASA Space Weather Observations Programs Division. SW Next will provide NOAA space weather observations through a comprehensive architecture and coordinated multi-mission program to ensure space weather products are available to meet user requirements. The program is responsive to the Promoting Research and Observations of Space Weather to Improve the Forecasting of Tomorrow Act (2020), which specified NOAA as providing space weather observational data continuity and enhanced space weather capability. SW Next completed program formulation in FY 2023 with a successful DOC Milestone 1 review on October 25, 2022, a System Definition Review on February 28, 2023, and approval by the joint NOAA-NASA Agency Program Management Council at Key Decision Point 1 on June 21, 2023.

To maintain data continuity and provide enhancements for high-priority space weather products, SW Next must collect observations in multiple locations such as LEO, GEO, L1 orbit, and off the Sun-Earth line (off-SEL) such as Lagrange point 5 (L5). The first SW Next projects address two of these.

The program is now in the Implementation phase and initiated formulation of the first two projects.

L1 Series. The L1 Series Project includes development and deployment of two dedicated space weather observatories to meet continuity of observations at L1 beyond the SWFO-L1 mission. Each observatory includes capabilities similar to SWFO-L1, plus the high-priority observation of x-ray irradiance measurements, as well as accommodations for an instrument of opportunity. Under the NOAA–European Space Agency (ESA) Agreement on Cooperation on Space-based Space Weather Observations, signed in February 2022, ESA is providing an X-ray Flux Monitor instrument that collects the x-ray irradiance measurements on the first L1 Series observatory.

L5 Compact Coronagraph. The L5 Project, in partnership with NRL, is working to build and deliver the third Compact Coronagraph to ESA as part of the NOAA-ESA Agreement, to be flown on ESA's Vigil mission to L5. The ESA agreement includes the provision for exchange of data from the Vigil and future missions, which can fulfill NOAA requirements for off-SEL observations.

In 2023, NESDIS's Office of Space Weather Observations worked with the NWS SWPC and other stakeholders on outreach and user engagement activities that involve users of space weather data products and those impacted by space weather events to foster an exchange of

information that better informs them of forecast and modeling capabilities and that helps guide SW Next long-range planning and product improvements.

Commercial Data Program

On September 18, 2023, NOAA's Commercial Data Program (CDP) awarded a Commercial Weather Data (CWD) Ocean Surface Winds (OSW) Pilot contract to Spire Global. NOAA's CDP supports Commercial Weather Data Pilot (CWDP) studies to demonstrate the quality and impact of commercial data on NOAA's weather forecast models. This contract award constitutes the next round of NOAA's CWDP studies with a particular focus on ocean surface wind (OSW) data. For this Pilot Study, NOAA will assess the quality and impact of available commercial global navigation satellite system reflectometry observations for the measurement of OSW and other characteristics. NOAA will use Pilot Study data to improve upon its derived wind speed products and investigate the utility of derived wind speed products developed by commercial vendors.

In FY 2023, NOAA's CDP also continued purchasing space-based commercial radio occultation data for use in NOAA's operational weather forecasts. On March 27, 2023, NOAA announced the awards of two Radio Occultation Data Buy II (RODB-2) Delivery Order 1-Test contracts to Space Sciences and Engineering LLC (PlanetiQ) and Spire Global Subsidiary Inc. These "test" data will be used to validate that the vendor formats, latency, quality, and coverage of the data will be sufficient for longer-term operational use in numerical weather prediction models and other systems. On April 12, 2023, NOAA awarded a six-month Delivery Order-2 contract to PlanetiQ under the Radio Occultation Data Buy II Indefinite Delivery, Indefinite Quantity contract. Subsequent Delivery Orders off this contract will be released throughout the five-year contract period at NOAA's discretion.

Promoting space cybersecurity. On March 29, 2023, Deputy Secretary of Commerce Don Graves joined other top leaders from the government and the U.S. space industry at the White House for a forum discussing cybersecurity in the space systems ecosystem and driving action for critical cybersecurity investments across the space systems ecosystem. DOC officials and representatives from other government agencies emphasized the need to partner closely with the private sector to ensure the resiliency and defense of the U.S. space ecosystem against cyber threats.

National Institute of Standards and Technology

In FY 2023, the National Institute of Standards and Technology (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, supplies, calibrations and sensor development for satellites, standards and guidance for reliable and secure space commerce, and extraterrestrial research. In these areas, NIST provides calibrations, technology development, technical guidance, and standards.

Advanced Manufacturing for Aerospace Applications

NIST regularly uses measurement expertise in mass, force, networking, and other areas to provide calibration support to multiple industrial aerospace corporations. In addition to providing calibration support, 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 is currently working to deliver measurement science that will establish the foundation for qualification and certification of machines, processes, and parts used in (AM at reduced cost. Machines and processes used to produce critical components for defense, aerospace, and medical applications must first be formally qualified and certified to demonstrate that a machine or process will function as expected. Currently, qualification and certification of AM machines and processes for critical defense or aerospace applications are very expensive and time-consuming, and the ever-increasing pace of technological change compounds the difficulty. NIST's excellence in measurement science and its standing as a neutral third party with a broad public forum make it the ideal place to develop test methods and protocols, provide reference data, and establish minimum requirements needed to achieve lower costs and more rapid qualification.

NIST founded and leads the Additive Manufacturing Benchmark Series (AM Bench) that partners with DOD, DOE, NASA, academia, and industry to produce rigorous measurement data that industry uses to validate AM simulation codes. In FY 2022, eight sets of measurement data were released along with simulation challenge problems that garnered 138 submissions from the international AM modeling community. In February 2023, NIST AM Bench 2022 Follow-up Challenge Problem Participant Workshops were held.

NIST research addresses safety standards for robotic manipulators and automated guided vehicles (i.e., mobile platforms), as well as measurement science to enable new capabilities for collaborative robotics of interest to aerospace manufacturers.

The NIST Manufacturing Extension Partnership (MEP) continues to expand its services to the aerospace manufacturing sector via the establishment of collaborations with strategic

stakeholders from the private and public sectors as they relate to MEP's three strategic goals: (1) narrowing the workforce gap, (2) minimizing supply chain vulnerabilities, and (3) leveraging innovation and technology.

NIST MEP is currently engaged with the aerospace original equipment manufacturer (OEM) and part of interagency space councils, and MEP contributed to the NASA-led Space Manufacturing Technology Report pursuant to the National Space Council task issued in September 2022. In addition, MEP is contributing to the STEM and Workforce Sub-Interagency Space Policy Committee to strengthen the space workforce pipeline.

In FY 2023, the NIST MEP organized several forums with the Airbus company's senior leaders and eight MEP Centers focusing on the aerospace sector's supply chain gaps, needed digital transformation of tier 2+ suppliers, and future technological advances (e.g., hydrogen-driven airplanes).

NIST MEP is also aligned with NASA's efforts in smart manufacturing for small- and medium-sized manufacturers (SMMs), including aerospace and transportation firms, to integrate physical and digital processes to optimize both current and future supply chain requirements. In this regard, in December 2022, MEP and NASA signed a Memorandum of Understanding to implement a pilot project with 18 MEP Centers to maximize technology transfer to SMMs in the areas of additive manufacturing, automation, robotics, and cybersecurity. Key activities for the MEP-NASA phase 1 pilot include establishing NASA collaboration with MEP Centers' manufacturing clients and workforce partners.

Aerospace Systems and Supplies

NIST's contributions to the manufacturing sector are complemented with support for the design, development, and calibration of aerospace systems and supplies. Contributions include collaborative robotics, material development for advanced applications, fuel development, weapons calibrations, and thrust calibrations. NIST provides 30–40 laser power and energy meter calibrations to aerospace industry and DOD customers each year, supporting both laser weapons systems and target designation systems.

Newly developed NIST Standard Reference Materials (SRMs) include several metal SRMs supporting the manufacturing of aerospace alloys, especially the nonferrous ones in SRM categories 102.1, Aluminum Base Alloys, and 102.16, Titanium Base Alloys. In addition, NIST SRM 1617b–Sulfur in Kerosene (High Level) is used by the aviation industry in the United States because it is classified as "Jet A" aviation fuel by ASTM D1655 (and other standards). Sulfur is the only certified value in this material related to regulatory compliance, but there has been much interest in the industry, both in the civil and military aviation sectors, to blend traditional and renewable feedstock blends. Also, the NIST Glass SRM 610 is aboard the Mars

Perseverance Rover and is being used to calibrate measurements of the elemental chemistry in Martian rock samples.

The recently launched NIST MEP Supply Chain Optimization and Intelligence Network expansion program incorporates the mapping of the various OEM supply chains, including those in the aerospace sector. All 51 MEP Centers were awarded about $400,000 each for two years to build and expand their capabilities in supply chain optimization services across the manufacturing ecosystem.

Calibrations and Sensor Development for Satellites

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

A microfabricated photonic accelerometer recently developed at NIST provides exceptional precision and accuracy in a small package and without external calibration—critically important advantages for navigational guidance in satellites and spacecraft. That work resulted in an associated optical readout in a photonic integrated circuit, implementing the tabletop system on a chip and substantially reducing the size, weight, and power consumption of the system. This will enable a new class of inertial sensors for aerospace applications and for resilient positioning and navigation when GPS service fails or is unavailable.

NIST continues its collaboration with NASA to improve remote-sensing calibration standards, leading to significant accuracy and congruence improvements in satellite data. Small satellites have shown significant promise at a fraction of current cost and size, as their performance is comparable to, if not better than, that of conventional large satellites. In FY 2023, NIST collaborated with NASA to leverage NIST's long-standing expertise in microwave radiometer calibration to develop new technology standards that will enhance instrument evaluation, increase data repeatability among instruments, and enable constellations of CubeSats to provide microwave-sounding data more reliably. In addition to representing a major step forward for the microwave community, the work will enable effective calibration and traceability between microwave instruments on satellites in space.

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 2023, the company sent batches of solar cells for irradiation by an electron beam from the NIST Van de Graaff accelerator, where the equivalent electron fluence experienced by a satellite over several decades in Earth orbit may be delivered in less than one hour. Characterizing the degradation in performance of the solar cells caused by irradiation is an important part of the qualification process, validating 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 their technology in terms of product reliability and functionality.

A joint NIST–NASA Jet Propulsion Laboratory (JPL) project seeks to assess the survivability of microbes in ultra-cold environments and embedded within ice cores in a radiation environment. The NIST Medical-Industrial Radiation Facility electron accelerator facility is used to expose samples of bacterial spores, mounted in a cryogenic chamber and placed at various depths within ice core samples, to high-energy electrons. This high-radiation environment is similar to what might be encountered near the surface of planetary icy bodies, and by determining the surviving fraction of microbes after irradiation, this study can help shed light on whether Jupiter's moons and other planetary bodies might be able to support life.

NIST is collaborating with the Laboratory for Atmospheric and Space Physics (LASP), NASA's Earth Science Technology Office, and NASA's Langley Research Center to extend the Earth Radiation Budget data record. NIST is designing and fabricating detectors for the Libera mission, which will provide data continuity for this essential climate variable. NIST scientists are working to extend these detectors' capabilities by developing arrays that will provide additional information about the impact of clouds on these measurements. In FY 2023, the Libera program completed Critical Design Review.

NIST is collaborating with JPL on the development of superconducting nanowire single-photon detectors (SNSPDs). SNSPDs are a type of single-photon detector 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. In FY 2023, NIST and JPL, with funding from NASA and the Defense Advanced Research Projects Agency Invisible Headlights program, demonstrated a 400,000-pixel SNSPD array, a factor of 400 improvement over the previous state of the art.

In support of satellite and related missions, NIST provided calibration services and research to enable the aerospace industry and Government agencies to obtain optical properties of materials, temperature, pressure, vacuum, humidity, and thermodynamic measurements of leaks traceable to international standards. Calibrations provided traceability to maintain quality systems, to maintain process control, and to qualify instrumentation for flight and space travel. Industries that rely on this unique calibration capability include U.S. aerospace manufacturers, who need to know if their plane materials and designs will be able to withstand the massive forces that occur on takeoff and during flight.

In FY 2023, NIST contributed to several of NASA's projects, including designing and fabricating the cryogenic readout circuitry for the Athena x-ray satellite mission. NIST's time-domain multiplexer readout circuitry for Athena achieved Technology Readiness Level 5 after a NASA review. NIST is also developing a variety of future-looking technologies, including sensors for the cosmic microwave background, advancements in sensor cooling, readout circuits that will enable larger arrays of faster-responding sensors, and more sensitive far-infrared

detectors. These technologies are relevant to several early-stage or potential space missions including LiteBIRD, LEM, and far-infrared probe concepts.

In FY 2023, NIST continued to provide calibration support to NASA Langley Research Center and their industry contractor, L3Harris Corporation, for the Cross-track Infrared Sounder (CrIS) that is part of the NASA/NOAA JPSS. NIST completed the analysis and delivered a report for on-site operation of a NIST-developed cryogenic thermal-infrared transfer radiometer at L3Harris for calibration of the radiometric standard used by the CrIS instrument team.

NIST continued to provide calibration support to NASA 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.

To address the complexities of integrating greenhouse gas concentration data with that observed from low Earth orbiting and geosynchronous Earth orbiting satellites, the NIST Urban Dome Test Bed System, which allows NIST and other researchers to test various emissions measurement methods in cities with different characteristics, can be used as a tool to link surface emissions measurements to satellite observations.

Standards and Guidance for Reliable and Secure Space Commerce

NIST contributes extensively to two important technical standards that are heavily used by the aerospace industry: Managed model-based 3D engineering (ISO 10303-242) and the Object Management Group's Systems Modeling Language.[2]

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); commercial satellite operations (Introduction to Cybersecurity for Commercial Satellite Operations); satellite ground segments (Satellite Ground Segment: Applying the Cybersecurity Framework to Assure Satellite Command and Control); and hybrid networks (Cybersecurity Framework Profile for Hybrid Satellite Networks Annotated Outline).[3] NIST is also collaborating with the public to develop strategies and approaches for algorithms for post-quantum cryptography that ensure

2 https://www.iso.org/standard/66654.html, https://www.omgsysml.org/

3 https://csrc.nist.gov/publications/detail/nistir/8323/rev-1/draft, https://www.federalregister.gov/documents/2020/02/18/2020-03337/strengthening-national-resilience-through-responsible-use-of-positioning-navigation-and-timing, https://csrc.nist.gov/publications/detail/nistir/8401/draft, https://csrc.nist.gov/publications/detail/nistir/8270/draft, and https://csrc.nist.gov/publications/detail/white-paper/2022/07/12/cybersecurity-profile-for-hsn-draft-annotated-outline/draft

confidentiality and integrity of digital communications for all industries, including aerospace. In FY 2023, NIST released drafts of three Federal Information Processing Standards for public comment.

Support for Extraterrestrial Research

NIST's support for extraterrestrial research included providing data and measurements for extraterrestrial bodies and support for the equipment used to observe them.

NIST researchers made significant progress on two related projects to measure the spectral irradiance of the Moon, allowing the Moon to be used as an on-orbit absolute calibration source for Earth-viewing satellites. This will lead to more effective and accurate monitoring of Earth's climate and weather changes and better data integration from different satellite sources. In one project in FY 2023, analysis was performed for data collected from the Airborne Lunar Spectral Irradiance (air-LUSI) system that flew a campaign in FY 2022 for four successful nights of data collection from the NASA ER-2 high-altitude aircraft. In the other project, analysis was performed for the lunar spectral irradiance (LUSI) measurement system on a site managed by NOAA on Mauna Loa (MLO) in Hawaii. The system is remote controlled, allowing data collection on any good-weather nights. This new MLO-LUSI system will augment the Air-LUSI dataset by providing much more frequent measurements. In FY 2023, significant progress was made by NIST in developing an automated data analysis pipeline for these instruments as well as a similar instrument designed to calibrate the flux from the standard stars used by astronomers for flux calibration.

In FY 2023, NIST researchers began to design an artificial starlight source in collaboration with NASA and various universities in a project called Calibration using an Artificial star with NIST-traceable Distribution of Luminous Energy (CANDLE), which will provide an entirely new method of providing improved flux calibration of astronomical telescopes.

International Trade Administration

The Commerce Department's International Trade Administration (ITA) Office of Transportation and Machinery (OTM) participates in multiple fora, providing industry's perspective regarding the operations and industry development of UAS. OTM participates in the interagency UAS Executive Committee, which addresses UAS policy issues, and the UAS Security Senior Steering Group (SSG), which implements policy initiatives derived from the Executive Committee. OTM provides industry perspective through the SSG and participates in a working group to address testing and evaluation of counter-UAS systems to be operated by the U.S. Government. OTM supports the development of standards and conformity assessment programs through participation in the UAS Standards Collaborative (UASSC) hosted by

the American National Standards Institute. OTM also supports rulemaking through participation in the Beyond Visual Line of Sight Aviation Rulemaking Committee.

OTM continues to support the National Security Council–led effort to create and implement the Domestic Counter-UAS National Action Plan. OTM continues to collaborate with the Department of Defense on facilitating exports of Blue sUAS and other proven commercial capabilities, as appropriate.

Throughout FY 2023, OTM organized and led two meetings of the Industry Trade Advisory Committee on Aerospace Equipment. This group provides advice to the Secretary of Commerce and the U.S. Trade Representative on aerospace-related trade policy issues. The Committee provided advisory opinions to the Secretary of Commerce and the U.S. Trade Representative concerning the Brazil WTO Civil Aircraft Agreement, the Indo-Pacific Economic Framework, critical materials trade agreements, the U.S.-Taiwan Trade Initiative for the 21st Century, current priorities vis-à-vis China, the U.S.–EU Trade and Technology Council, per- and polyfluoroalkyl substances issues affecting access to the EU market, EU defense policies that impact U.S. aerospace trade with Europe, supply chain issues, and aerospace industry initiatives that have a positive impact on the environment.

ITA continues to support the Office of the U.S. Trade Representative (USTR) on issues relating to the enforcement of U.S. rights under the World Trade Organization Agreement on Trade in Civil Aircraft. Following the resolution of the case between Boeing and Airbus, ITA has supported USTR in working group meetings with EU and United Kingdom counterparts to ensure that the agreement is not newly violated.

ITA's Office of Finance and Insurance Industries 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 (OECD). The governments of almost all countries with major aircraft manufacturers are signatories to the ASU, an annex to the OECD Arrangement on Officially Supported Export Credits, which establishes rules for export credit agencies. The OECD rules aim to ensure that government-provided export financing is not a competitive factor in civil-aircraft sales competitions.

ASU signatories also discussed necessary technical adjustments, most notably the need to replace references to the discontinued London Interbank Offered Rate (LIBOR) in the ASU text with appropriate replacement benchmark interest rates. This issue remained under discussion as countries continued to develop various LIBOR alternatives.

As a member of the U.S. delegation, ITA helped ensure that the interests of the industry were represented during the ASU discussions, continued to monitor implementation, and participated in negotiations of potential ASU adjustments. ITA also worked closely with interagency partners to monitor conditions in the aircraft finance market and supported EXIM

Bank's ongoing COVID-19 initiatives to provide enhanced financing support to the U.S. aerospace industry and its supply chain.

ITA continued their active participation in the implementation of the National Space Council's policies, which include industrial base, supply chain risk, and competitiveness issues. To ensure that commercial interests continue to be adequately addressed, ITA and NOAA continued to ensure that the policies' implementation actions will 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. ITA participated in and organized trade events and provided advocacy to support U.S. companies in international aerospace competitions, including commercial sales for aircraft and helicopters, airport construction, communications, remote sensing satellites, commercial projects, and air traffic management projects. At the close of FY 2023, ITA's Advocacy Center had 29 active space-related cases with a total project value of $9.6 billion and U.S. export content of $8.4 billion. At the same time, the Advocacy Center had 504 active cases in the aerospace and defense sectors valued at $567.7 billion with $464.4 billion of U.S. export content.

Industry and Trade Promotion

ITA's Global Aerospace and Defense Team (Global Team) recorded approximately 267 Written Impact Narratives (WIN) in FY 2022 and is on track to submit more in FY 2023 with 210 WINs submitted by the third quarter of FY 2023. A WIN is an organizational metric that showcases ITA's contribution to a company's success. These include ITA, and particularly Commercial Service personnel-impacted deals, with small- and medium-sized companies, as well as with larger corporations.

The Global Team held approximately 3,163 counseling sessions with over 825 U.S. aerospace, defense, and space companies in FY 2022 and held approximately 2,676 counseling sessions with over 1,348 U.S. companies by the third quarter of FY 2023, helping them to resolve international trade issues, identify new export markets, and develop strategies for entering those markets.

Global Team members provided one-on-one counseling sessions, individualized business-to-business meetings with international business partners, and export counseling services to U.S. exhibitors at 36 shows worldwide in FY 2023. ITA trade show support generated trade leads for participating companies, allowing them to enter or expand their exports to international markets. Virtually, the Global Team conducted 17 webinars for U.S. businesses, covering topics such as export controls, advocacy, defense sales, and regional market entry strategies. Approximately 3,511 companies registered for these virtual events. The team also organized two in-person defense trade missions to the Middle East (Israel and Bahrain) and Indonesia for 22 companies.

Bureau of Economic Analysis

The Bureau of Economic Analysis (BEA) produces some of the world's most closely watched economic statistics, including U.S. gross domestic product, better known as GDP. In FY 2023, BEA published revised and new statistics quantifying the U.S. space economy for 2012–2021.[4] The new statistics included more detail than previous estimates and reduced the publication lag by one year. Additionally, BEA consulted with the European Space Agency to begin development of a European Space Economy Satellite Account modeled after BEA's space economy statistics.

United States Patent and Trademark Office

The United States Patent and Trademark Office's (USPTO) commercial space work focuses on supporting the transformative needs of the aerospace industry by advancing the USPTO mission to drive U.S. innovation, inclusive capitalism, and global competitiveness, and to bring U.S. innovation to impact for the public good. In 2023, the USPTO convened a multidisciplinary working group to explore and develop policies and initiatives to accelerate innovation in commercial space. To better understand the technological advancements in the space sector, the Office of the Chief Economist began tracking space-related patents filed and issued by the USPTO. Additionally, the USPTO held intellectual property (IP) seminars at the USA Pavilion of the 2023 Paris Air Show in Paris-Le Bourget, France, for U.S. businesses engaged domestically and abroad in commercial space innovation. Finally, the USPTO used ongoing strategies directed toward small-to-medium-sized enterprises, first-time filers, inclusivity initiatives, and pro bono programs to reduce barriers to the IP landscape faced by underrepresented innovators, including those in the commercial space sectors.

4 https://www.bea.gov/data/special-topics/space-economy

Department of the Interior

DOI

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

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 light detection and ranging (lidar). The BLM also utilizes passive and active imaging system information collected by uncrewed aircraft systems (UAS). Remote sensing data and products are being 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. By integrating remote sensing into the BLM's Assessment, Inventory, and Monitoring strategy, field-based data are used to generate information and maps that would otherwise be too expensive to produce. The BLM is leveraging 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.*

CDEDT: A New Tool Supporting Resource Monitoring and Management

The BLM's National Operations Center developed the Change and Disturbance Event Detection Tool (CDEDT). This web-based application allows the user to visualize and identify surface cover changes and disturbances between two dates captured with remotely sensed imagery. CDEDT leverages a cloud computing laser platform with an extensive multitemporal imagery archive to support multiple resource management objectives. Examples include monitoring energy development, wildfire impacts, inundation events, and restoration planning.

CDEDT computes a suite of differenced spectral indices on the fly from bitemporal imagery, predominantly from the Sentinel-2 satellite mission. These indices are mathematical equations that use spectral reflectance from multiple wavelengths to detect features or cover of interest. Spectral indices can be used to identify the presence of, and changes in, vegetation and water cover. The application also allows the user to develop vector end-products for use within a Geographic Information System environment.

CDEDT allows the user to efficiently perform analysis and to develop products without locally downloading or processing large imagery datasets. This reduces labor, computation, and storage costs. The tool does not require a license and is open to all users.[2]

UAS Imagery Employed for Riparian Mitigation Efforts in Western Wyoming

Riparian areas in the Wyoming Range foothills exhibit substantial channel incision, sediment erosion, and degraded habitat from more than a century of intensive resource use. Sediment contributions from intermittent and perennial streams in this area impact downstream water quality, which affects both wildlife and human settlements. The BLM's Pinedale Field Office is using Bipartisan Infrastructure Law funding to install erosion control measures in the next year, including beaver dam analogs and small hand-built structures, to help stabilize riparian areas, reconnect the channel to the floodplain to affect improved wildlife habitat, and capture sediment washing downstream to enhance water quality and aquatic habitat.

In July 2023, an uncrewed aircraft system (UAS) collected stereo imagery over 575 acres of riparian corridor to collect pre-treatment baseline data before future erosion controls take effect. Scientists processed stereo imagery photogrammetrically to create 5-centimeter ground sample distance digital surface models and 1-centimeter orthomosaics of the planned treatment areas. The resolution of these products allows fine-scale monitoring of further erosion or deposition in these systems, giving land managers precise quantitative data to use in further mitigation efforts and to adjust existing plans. UAS data collection is cost-effective, nimble, and quickly deployable in difficult terrain for effective targeted monitoring of these riparian systems.

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2 https://cjcole.users.earthengine.app/

Bureau of Ocean Energy Management

The Bureau of Ocean Energy Management's (BOEM) Environmental Studies Program (ESP) develops, funds, and manages rigorous scientific research specifically to inform policy decisions on the development of energy and mineral resources on the U.S. Outer Continental Shelf. BOEM uses remote sensing to inform its research covering physical oceanography, atmospheric sciences, biology, protected species, social sciences and economics, submerged cultural resources, and environmental fates and effects. Mandated by Section 20 of the Outer Continental Shelf Lands Act, the ESP is an indispensable requirement informing BOEM's decisions on offshore oil and gas, offshore renewable energy, and the marine minerals program for coastal restoration. Through its ESP, BOEM has provided over $1 billion for research to this end since its inception in 1973.

Automating the Detection and Classification of Wildlife in Aerial Imagery

Monitoring marine wildlife in remote locations is a challenge, and incorporating remote sensing and automation tools can improve the quality of monitoring data while reducing risk and cost.

BOEM is involved with permitting and monitoring of offshore wind energy projects and needs accurate wildlife observations to evaluate project impacts.

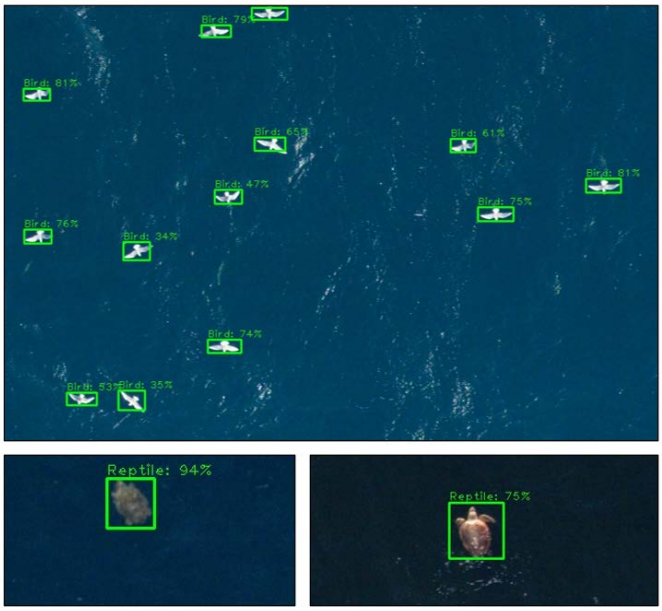
This project (1) collected and annotated an archive of aerial imagery to train deep learning algorithms, (2) developed deep learning algorithms for detection and taxonomic classification, (3) enumerated target species found in aerial imagery, and (4) evaluated image and environmental characteristics that influence algorithm performance.

BOEM and the U.S. Fish and Wildlife Service (FWS) collected terabytes of imagery data from flights over the Atlantic Outer Continental Shelf and the Great Lakes. The U.S. Geological Survey (USGS) Upper Midwest Environmental Sciences Center developed and hosts the Wildlife Annotation Tool, a customized annotation tool based on the open-source Computer Vision Annotation Tool.[3] This tool creates annotation datasets that train models using machine learning. Imagery provided by BOEM and FWS is manually processed to draw polygons around each wildlife object in an image. Wildlife objects are then classified to the lowest taxonomic level possible by experts from the USGS, FWS, and external partners. The dataset currently includes more than 70,000 annotations for 205 unique taxonomic classifications of birds, turtles, marine mammals, and fish.

Scientists are training machine learning models for object detection on an initial benchmark dataset and evaluating model performance compared to other model options. Detection

3 https://www.usgs.gov/centers/upper-midwest-environmental-sciences-center/science/deep-learning-automated-detection-and

models are trained to draw bounding boxes around wildlife objects and assign a primary identification, such as bird or reptile. Work in this area is being supported by the University of Michigan.[4]



A collage of oceanic wildlife detected by machine learning algorithms and classified at a high level (bird and reptile with "confidence" values) from aerial imagery.

Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS), in concert with its international, Federal, Tribal, state, local, and nongovernmental 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 FWS utilizes acoustic 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, thermal imagery, radar, sonar, and lidar imagery. This time and geospatial system of imagery and location is used 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.

Enhancing Migratory Bird Surveys with Thermal Imagery and Deep Learning

The FWS Division of Migratory Bird Management is improving on migratory bird surveys by combining aerial remote sensing with deep learning (a form of artificial intelligence) analyses to automate survey counts. The goal is to provide accurate wildlife counts while simultaneously reducing risk to pilots by conducting aerial surveys at higher altitudes. In partnership with the College of William and Mary, FWS 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 spring of 2023, the project collected more than 75,000 nighttime thermal

4 For more information regarding this classification work, see https://doi.org/10.1002/rse2.318.

images while the birds were roosting on or near the Platte and North Platte Rivers. In addition, researchers obtained thermal imagery in places where ducks and geese were congregating. The result will be the first complete survey of roosting sandhill cranes on the Platte River and will show that these innovative surveys can be accomplished at a broad spatial scale. The FWS has also begun collaborating with the USGS Northern Prairie Wildlife Research Center, the Crane Trust, and the International Crane Foundation to advance these thermal imagery surveys.

Mapping Eastern Red Cedar at Valentine National Wildlife Refuge

Eastern red cedar (cedar) expansion across the Nebraska Sandhills poses great ecological risks to this largely intact (and massive) grassland ecosystem. Centered on Valentine National Wildlife Refuge (72,350 acres, plus 2-mile buffer), this project used lidar data and WorldView-2 winter color-infrared imagery to map cedars quickly and effectively, including smaller-stature trees.[5]

Within the project area, the project team mapped 567 acres of cedars in 12,478 patches. Patch size ranged from single trees to 84 acres. Within the refuge, the team mapped 174 acres of cedars in 5,592 patches, with the largest patch just under 10 acres. They further characterized each patch as potential "seed trees" or "seedlings" using height metrics derived from lidar as a proxy for tree maturity. Patches containing at least one pixel with a height of more than 1.5 meters (about 5 feet) were classified as containing seed trees; otherwise, patches were classified as seedlings. Across the project area, most patches (more than 98 percent) contained potential seed trees.

Although 174 acres of cedars may seem inconsequential (less than 0.25 percent of the 72,350-acre refuge), the potential vulnerability to intact grasslands is high due to the sheer number and distribution of patches with potential seed-producing trees. Areas within 180 meters of seed-bearing trees are at highest risk of seed contamination and eventual seedling recruitment. On the refuge, 3,578 single tree patches exist, with each tree affecting a 28-acre area. Over 26 percent (13,726 acres) of all upland habitat on the refuge is in a dispersal zone.

Mapping Tree Species Alpha-diversity in a Dry Tropical Forest

Rapid rates of seasonally dry tropical forest (SDTF) loss, fragmentation, and degradation underscore the need to map forest diversity, both prospectively and retrospectively. SDTF diversity is notable in southern Ecuador and northern Peru because of high turnover in species composition at relatively short geographic distances and sub-regional endemic flora. Using remote sensing machine learning model ensembles (MLME), this project predicted SDTF diversity for permanent forest plots in southwestern Ecuador.[6] Tree census data taken over a 9-hectare SDTF served as a basis for the analyses. The project team spatially referenced all

5 Visit https://ecos.fws.gov/ServCat/Reference/Profile/158669 for more information.

6 Visit https://doi.org/10.3390/rs15030583 for more information on this project.

trees at least 5 centimeters in diameter at breast height (DBH, at least 1.3 meters above base) with a total station (optical survey instrument) and used them to simulate randomly located 0.10-hectare plots for measuring and predicting six local-scale diversity indices. The team used tree coordinates and height measurements to develop 1-meter tree canopy height and elevation models, at a scale conventionally obtained from lidar. They also used pectral bands, vegetation indices, and biophysical variables (for example, leaf area index, chlorophyll content, fraction of vegetation cover) taken from multidate, multispectral RapidEye (5-meter pixels) and Sentinel-2 (10-meter and 20-meter pixels) satellite imagery as predictors for comparing single and multi-sensor MLMEs. Combined sensor MLME for multiple measures of tree species richness and diversity typically showed lower root mean squared error and increased goodness of fit, while a measure of evenness (that is, the commonness or rarity of a species), was poorly predicted with all approaches. Combined sensor models and mapped tree species richness and diversity showed the most favorable agreement with field validation observations (n = 25). The inclusion of predictors such as multidate red-edge vegetation indices and fine-scale topography, related to phenology and the biophysical environment, was important to predicting SDTF tree diversity. Small-scale model experiments revealed essential relationships between tree diversity and data from multiple satellite sensors with repeated global coverage that can help guide larger-scale biodiversity mapping efforts.

Orphan Gas and Oil Well Detection in Southwest National Wildlife Refuges

Abandoned gas and oil wells are a serious source of pollution emissions in the United States. There are an estimated 2.3 million onshore abandoned wells in the United States, according to the U.S. Environmental Protection Agency (EPA). Orphan wells are a type of abandoned oil and gas well that have no known owner and must be assessed by state and Federal agencies such as the U.S. Fish and Wildlife Service for remediation. The Bipartisan Infrastructure Law provides aid for remediating orphan wells on Federal lands, including the National Wildlife Refuge System (NWRS). Many well locations are unknown in the NWRS because of their drilling history prior to state regulation or poor record keeping, and recorded locations for wells prior to the 2000s can be inaccurate due to positional error from GPS equipment.

This project aimed to improve methods for locating previously unknown orphan gas and oil wells within the NWRS Southwest Region (Texas, Oklahoma, New Mexico, Arizona) to aid orphaned well remediation. The team created digital elevation models of refuges using lidar data obtained through the USGS 3D Elevation Program (3DEP) at quality level 2 (at least 4.0 ground returns per square meter). Researchers identified sites with terrain features characteristic of well activity—such as well platforms, berms, or storage tanks—using the models and aerial imagery from the National Agriculture Imagery Program; they then used these features as predictor variables to develop automated well detection algorithms. Model outputs consisted

of well detection polygons and confidence levels to indicate the location of potential orphan wells, often in unknown and remote locations overgrown by vegetation.

Currently, researchers have detected 1,518 potential wells in the 22 National Wildlife Refuges in Texas and Oklahoma. The refuges with the most orphan oil and gas wells detected were Deep Fork, Neches River, and Anahuac, with 354, 105, and 91 possible orphan detections, respectively.

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 have been 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 because of its remote and vast expanses of public land and the fact that the Arctic is warming rapidly in response to climate change. 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.[7]

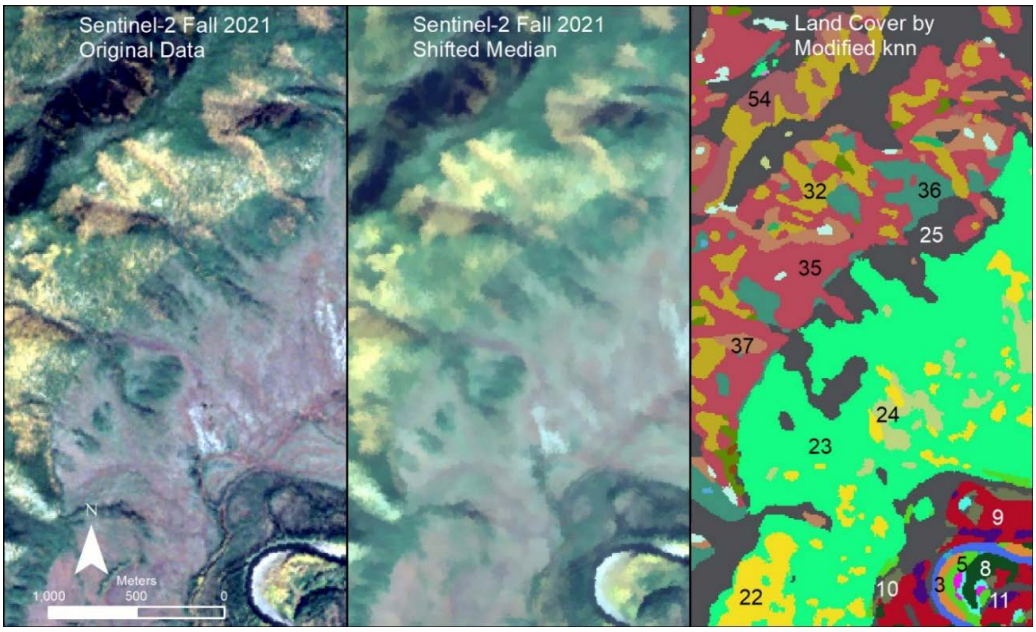
Land Cover Mapping of Yukon-Charley Rivers National Preserve, Alaska

In 2023 the NPS made a land cover map of Yukon-Charley Rivers National Preserve to replace an outdated map from 1991. The new map covers 16,300 square kilometers in east-central Alaska, with resolution of 10 meters.[8] It is based on summer and fall Sentinel-2 satellite image data (10-meter resolution), plus topography and vegetation height data from the Alaska Statewide interferometric synthetic aperture radar digital elevation model (5-meter resolution, resampled to 10 meters).

Researchers smoothed image data using an edge-preserving filter and located training data points by examining the Sentinel-2 and higher-resolution image data while referencing field plot data from multiple previous projects, especially the U.S. Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) soil survey sample plots and the NPS

7 Visit the Monitoring Trends in Burn Severity website at https://mtbs.gov/.

8 New map and report are available at https://irma.nps.gov/DataStore/Reference/Profile/2297197.



Basic steps in the land cover mapping process. On the left, the original fall 2021 Sentinel-2 satellite image. In the center, the Sentinel-2 image after processing with an edge-preserving smoother. On the right, the smoothed image classified by the modified k-nearest neighbor method. Numbers refer to land cover types, described in the report. The scene is centered near longitude 142.35° W, latitude 65.44° N, approximately 140 miles northeast of Fairbanks, Alaska.

Central Alaska Inventory and Monitoring Network vegetation monitoring plots. The training points were used to extract training data from the smoothed images, which were then used to classify the smoothed data from the whole study area. To do this classification, NPS scientists used and compared a modified k-nearest neighbor method and a Random Forest method. The two methods produced similar results; the modified k-nearest neighbor method appeared to be slightly better and was chosen for the final product. The final map contains 38 land cover types, including 31 vegetated types, water, and 6 unvegetated or sparsely vegetated types. The map was made with minimal cost, thanks to extensive preexisting vegetation data and free imagery.

Detecting Icing Events in the Arctic

Rain-on-snow (ROS) events occur across many regions of the terrestrial Arctic in midwinter months. In extreme cases, ice layers form, which can affect wildlife, vegetation, and soils beyond the duration of the event. Researchers can use satellite microwave observations to evaluate the severity of ROS events, since active as well as passive microwave sensors can detect their characteristic wet snow. Ku-band radar (scatterometer) has been applied across the entire Arctic, but data availability at this frequency is limited. In this study, researchers

investigated the potential for other radar systems to support ROS studies.[9] C-band radar is of special interest due to its data availability, which includes a range of nominal spatial resolutions (10 meters–12.5 kilometers). The temperature dependence of C-band backscatter at VV (V–vertical) polarization observable down to –40°C is identified as a major issue for ROS retrieval but can be addressed by combining data with a passive microwave wet snow indicator, as demonstrated for data from satellites Metop ASCAT (Advanced Scatterometer) and SMOS (Soil Moisture and Ocean Salinity).[10] The project team compared results to in situ observations (snowpit records, caribou migration data) and Ku-band products. Results showed that ice crusts were found in the snowpack after detected events with an overall accuracy of 82 percent. The more crusts (events) there are, the higher the winter season backscatter increase at C-band. ROS events captured on the Yamal and Seward peninsulas have had severe impacts on reindeer and caribou, respectively, due to ice crust formation. Retrieval is most robust in the tundra biome, where results are comparable between sensors. Records can be used to identify extremes and to apply the results for impact studies at regional scales.

U.S. Geological Survey

The U.S. Geological Survey (USGS) is both a provider and a user of remotely sensed data. The USGS manages the Landsat satellite program 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.[11] 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.

Assessing 35 Years of Lake Trophic Status Change in 56,000 Lakes Across the Conterminous United States

Lake trophic status is a key water quality property that integrates a lake's physical, chemical, and biological processes. Trophic status is related to a lake's color: oligotrophic (blue) lakes

9 Article available at https://doi.org/10.5194/tc-17-889-2023.

10 For more information on ASCAT and SMOS, visit https://www.ospo.noaa.gov/Products/atmosphere/ascat/ and https://earth.esa.int/eogateway/missions/smos respectively.

11 Access the National Map at https://www.usgs.gov/programs/national-geospatial-program/national-map.

have low amounts of nutrients, algae, and zooplankton, while eutrophic (green) lakes have high amounts of nutrients, algae, and zooplankton; dystrophic (brown) lakes have high amounts of organic matter but low nutrients, algae, and zooplankton, while mixotrophic (murky) lakes have high amounts of nutrients, algae, zooplankton, and organic matter. To enhance understanding of broad spatial and temporal patterns in lake water quality, scientists created the Lake Trophic State–US (LTS-US) dataset by combining remotely sensed Landsat optical reflectance values with in situ true-color and phosphorus data from the EPA's National Lake Assessment.[12] The project team used this dataset to train classification models of trophic status from satellite imagery. Model accuracy was estimated to be about 76 percent. Misclassification of lakes occurred most frequently when a lake's constituents were located along a boundary between two trophic state groupings, where models may have a harder time distinguishing the boundaries between categories. Validation routines suggested that models performed exceptionally well and were able to recreate spatial and temporal patterns documented in the EPA's National Lake Assessment, even though models were only given a lake's annual median red, green, blue, and near-infrared reflectances.

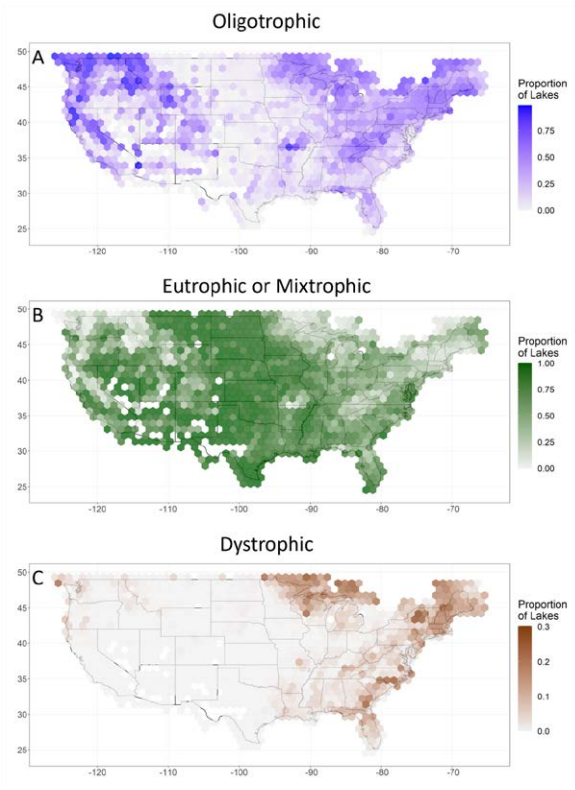
Researchers applied the validated models to 56,000 lakes to conduct a comprehensive nutrient-color assessment of lake trophic status across the conterminous United States from 1984 to 2020. Over the 35-year study period, they found that the majority (about 55 percent) of lakes greater than 10 hectares in the United States were consistently mixotrophic/eutrophic. While the proportion of eutrophic/mixotrophic lakes has remained relatively constant, the proportions of dystrophic (brown) and oligotrophic (blue) lakes have substantially increased and decreased, respectively, over the last 35 years. This "brownification" pattern is concentrated in the Upper Midwest and Northern Appalachian regions, where interactions among forest cover, lake morphometry, and acid rain legacy impacts may drive lake dystrophication. Together, these results support previous findings, suggesting that while eutrophication is a pervasive water-quality concern, dystrophication is another pathway for lake trophic status change across macroscales.[13]

Contemporary (1984–2020) Fire History Metrics for the Conterminous United States

Fire management across the United States benefits from comprehensive burned area data, delivered in a format that facilitates use by diverse stakeholders. Scientists from the Tall Timbers Research Station and the USGS Geoscience and Environmental Change Science Center calculated a suite of fire history metrics from the Landsat burned area product (1984–2020) across

12 Access the Lake Trophic State–US Dataset at https://www.usgs.gov/special-topics/year-of-open-science/news/lake-trophic-state-us-dataset.

13 The dataset can be accessed at https://portal.edirepository.org/nis/mapbrowse?packageid=edi.1395.1 and https://data.usgs.gov/datacatalog/data/USGS:26bee400-ee8b-4283-8cf9-050baa61f81d. An associated publication is available online at https://eartharxiv.org/repository/view/5366/.



Hexbins of the United States, colored by the proportion of lakes within a given area that are classified as (A) oligotrophic, (B) eutrophic or mixtrophic, or (C) dystrophic. (A) oligotrophic (blue water) lakes tend to be located in the Pacific Northwest, Upper Midwest, and Northeast within the conterminous United States; (B) eutrophic and mixtrophic (green or murky water) lakes tend to be located in the Great Plains, Southern Plains, and Southeast; and (C) dystrophic (brown water) lakes tend to be located in the Northeast but are also concentrated in the Upper Midwest and Coastal Plains.

the conterminous United States: (1) fire frequency, (2) time since last burn, (3) year of last burn, (4) longest fire-free interval, (5) average fire interval length, and (6) contemporary fire return interval. The research team summarized metrics by ecoregion and land ownership, then related them to historical and cheatgrass datasets to demonstrate example applications of the products.

Fire regimes varied widely across the United States, with the proportion burned ranging from 0.7 percent in the Northeast Mixed Woods to 74.1 percent in the Kansas Flint Hills over the 37-year period. The appropriate or useful fire metric(s) may therefore depend on the local or regional amount and frequency of burning. Land ownership differences were also observed in fire regimes. Compared to private lands, public lands had greater burned area (19 of 31 ecoregions) and shorter contemporary fire return interval (25 of 31 ecoregions), highlighting the importance of accurately tracking fire activity across both public and private land. The fire history metrics are being updated annually and are currently available for 1984–2022; a related web-based viewer for fire patterns across the Southeast is accessible online.[14] The suite of fire history metrics may help manage future fire risk, meet national fire-related goals, and prioritize areas to focus increased engagement with private landowners. Continued progress toward accurate and complete mapping of burned area and the consolidation of burned area products into useful and relevant fire history metrics support attempts to manage ecosystem condition under

14 https://www.landscapepartnership.org/key-issues/wildland-fire/fire-mapping/regional-fire-mapping/se-firemap

climate change and control the growing economic costs of wildfire damage and suppression. The associated manuscript and associated data are available online.[15]

Exotic Annual Grass Abundance and Weather Scenarios

Invasion of Exotic Annual Grass (EAG), such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*), can cause irreversible change to dry and semi-dry rangeland ecosystems in the western United States. The abundance of these EAG species is influenced by weather variables such as temperature and precipitation, yet published, spatially explicit EAG distribution and abundance maps driven by multiple precipitation scenarios do not exist. Scientists from the USGS Earth Resources Observation and Science (EROS) Center used Harmonized Landsat and Sentinel (HLS) remotely sensed data to develop a machine-learning modeling approach to predict how changes in annual and immediate past precipitation regimes impact the abundance of EAG. The predictive model used HLS-derived Normalized Difference Vegetation Index data as a proxy for vegetation greenness, with weather variables, elevation, and estimated EAG percent cover from previous years as a proxy for seed source. The model achieved excellent training accuracy (r = 0.94; median absolute error [MdAE] = 2.83 percent cover) and test accuracy (r = 0.80; MdAE = 6.05 percent cover). Scientists used the model to predict five versions of EAG abundance for 2022 based on five different precipitation scenarios: a 9-year average, half the average, three-fourths the average, one and one-half the average, and double the average. The approach can be replicated to new study domains, and it is relatively easy to implement the model algorithms with different sets of precipitation and temperature scenarios. Spatially explicit datasets of these five versions of EAG abundance can be important resources to local and regional land managers trying to understand what EAG abundance might be based on variable precipitation scenarios. The datasets are available for download via the USGS Rangeland Exotic Plant Monitoring System, and the associated manuscript is available online.[16]

Global Operational Actual Evapotranspiration

Actual evapotranspiration (ETa) is a key landscape response variable that connects the soil-plant-atmosphere system and the hydrologic cycle through the transfer of mass and energy. ETa quantification and mapping over large areas has become an active applied research activity in recent years with the use of satellite-derived inputs and global weather datasets. In addition to contributing to an improved understanding of the water budget, ETa is an important indicator of crop water use and crop production. As a landscape response variable, it provides crucial

15 See https://www.publish.csiro.au/wf/pdf/WF22044 and https://www.sciencebase.gov/catalog/item/6244bbeed34e21f8276030bf.

16 See https://doi.org/10.5066/P9X84TAN and https://doi.org/10.1016/j.rama.2023.04.011.

information for monitoring and assessing the extent and severity of drought in both rain-fed and irrigated systems at fine spatial resolution.

One of the models widely used for operational global ETa research and application is the Operational Simplified Surface Energy Balance (SSEBop) model, which integrates parametric and surface energy balance modeling techniques for estimating actual ET based on the principles of satellite psychrometry.[17] The global implementation of the SSEBop model used thermal data from multiple satellite sensors (Landsat, the Moderate Resolution Imaging Spectroradiometer, and the Visible Infrared Imaging Radiometer Suite [VIIRS]) in combination with gridded global weather datasets.

In April 2023, scientists at the USGS EROS Center released the most up-to-date global SSEBop ETa model (version 6), which uses the VIIRS data to produce decadal, monthly, and seasonal ETa and ETa anomaly products.[18] The 1-kilometer spatial resolution data are available from February 2012 to the present and can be accessed through data portals online.[19] USGS scientists parameterized SSEBop v6 using a novel algorithm to establish the wet-bulb boundary condition, allowing for robust modeling of the spatiotemporal dynamics of ETa in all landscapes and all seasons regardless of vegetation cover density. In addition, they created ETa anomaly products as a ratio (in percent) of "current" to median year ETa (2013–2022), which are useful for region-specific drought monitoring applications.

The USGS EROS Center developed these operational global ET products for the Famine Early Warning Systems Network for project activities supporting food security mapping, drought monitoring, and water resource assessments.[20] SSEBop v6 data are also freely available for access at the ClimateEngine.org web mapping application.[21]

LANDFIRE Is Now Current for Previous Year Disturbances

For the first time in the Landscape Fire and Resource Management Planning Tools' (LANDFIRE) history, prior year disturbances will be represented in current year mapped products. This accomplishment is a milestone in LANDFIRE's overall plan for moving to annual updates to provide users with the best and most current information for strategic fire and resource management planning.

As part of the move to annual updates, LANDFIRE now incorporates disturbance events within each fiscal year (October through September) to coincide with reporting by Federal

17 For more about the SSEBop model, visit https://doi.org/10.13031/aea.12614.

18 https://doi.org/10.3390/rs15010260

19 See https://earlywarning.usgs.gov/fews and https://earlywarning.usgs.gov/fews/product/461.

20 https://fews.net/

21 https://app.climateengine.org/

agencies.[22] The LANDFIRE team pushes events collected or received by September through the update process and releases them sequentially by region or "GeoArea," which provides current fuels products to the western United States the following spring at the beginning of the typical fire season.

Several major advancements have made it possible to update the maps more frequently and with less latency. An automated process removes overlap in the hundreds of polygons compiled in the Events Geodatabase that capture disturbances and land management activities contributed by agencies and obtained from public websites, which shortens the turnaround time for incorporating them into the disturbance products.

The team's methods for satellite change detection are better than ever. New algorithms for identifying disturbances in conjunction with smoother and cleaner percentile-based satellite image composites using HLS data have resulted in far fewer false positives and substantially reduced the time needed for manual review.

The annual disturbance product is used to update vegetation and fuels map products in addition to updates for agriculture and development. New fuel model assignments were developed to accurately portray burnability in the first growing season post-disturbance, or Time Since Disturbance 1 (TSD1) in fuel model products. All products are now available on a new and improved web-based viewer.[23]

Landsat Collection 2 Provisional Science Products

In 2022, two Landsat Collection 2 (C2) science products—Provisional Aquatic Reflectance and Provisional Actual Evapotranspiration—became available on demand from the USGS.[24] While these products are provisional, they are proving to be useful in the advancement of water-quality studies and the effects of evaporation/transpiration in cropland areas.

Aquatic Reflectance (AR) is the spectral distribution of reflected visible solar radiation upwelling from beneath water surfaces and is the primary input for characterizing optically active constituents within upper water columns.

USGS scientists derived Global Landsat C2 Provisional AR products from the Sea-WiFS Data Analysis System using the Landsat 8–9 Operational Land Imager (OLI) Level-1 reflective bands at 30-meter resolution. Landsat C2 Provisional AR shows potential to greatly contribute to aquatic science and environmental mapping capabilities for aquatic ecosystems. Water resource managers and remote sensing scientists can use this product to systematically monitor

22 https://landfire.gov/about.php

23 https://www.landfire.gov/viewer/

24 https://www.usgs.gov/landsat-missions/landsat-collection-2-provisional-aquatic-reflectance-science-product and https://www.usgs.gov/landsat-missions/landsat-collection-2-provisional-actual-evapotranspiration-science-product

the changes in water quality of lakes, rivers, and near-shore coastal zones that are otherwise difficult to access by conventional field sampling methods.

ETa is the quantity of water removed from a surface due to evaporation and transpiration and is measured in millimeters. USGS scientists generated Global Landsat C2 Provisional ETa 30-meter products using an SSEBop model for Landsat 4–5 Thematic Mapper, Landsat 7 Enhanced Thematic Mapper Plus, and Landsat 8–9 OLI/Thermal Infrared Sensor acquisitions that successfully process to a Level-2 Surface Temperature product.

ETa is fundamental in the understanding of spatiotemporal dynamics of water use around the world, providing useful information for a range of applications such as calculating a basin's water budget and assessing water consumption and crop yield and drought monitoring.[25]

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

Irregularly flooded wetlands supply important ecosystem services, such as providing 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 at 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 Mexico coast, from Texas to Florida. Additionally, the data release produced through this effort includes a map from Lake Pontchartrain, Louisiana, to the Florida Big Bend delineating the coverage of irregularly flooded wetlands dominated by *Juncus roemerianus* (black needlerush); a supplemental map with a second high marsh class in Texas dominated by succulents and *Distichlis spicata* (saltgrass); a project-specific field reference dataset; and spatial metadata showing the elevation data used to create these products. These products are the first regional maps of elevation-based irregularly flooded wetland probability and high marsh and salt panne/flat along the northern Gulf of Mexico coast and provide a baseline condition from which future changes can be compared.

25 Landsat C2 AR and ETa products are considered provisional and are subject to revision. The data have not received final approval by the USGS and are provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the data.

This effort is the result of research funded by the National Oceanic and Atmospheric Administration's RESTORE Science Program to Mississippi State University and the USGS.[26] Many other agencies assisted with the development of these products, including the U.S. Fish and Wildlife Service, 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 and can be viewed via ArcGIS Online.[27] The elevation-based irregularly flooded wetland probability map produced via this study was published online.[28]

National Land Cover Database

The National Land Cover Database (NLCD) is produced by the USGS in collaboration with the Multi-Resolution Land Characteristics (MRLC) consortium.[29] The MRLC, a consortium of Federal agencies that coordinate and generate consistent and relevant land-cover information at the national scale for a wide variety of environmental, land management, and modeling applications, has provided the scientific community with detailed land-cover products for more than 30 years. Over that time, NLCD has been one of the most widely used geospatial datasets in the U.S., serving as a basis for understanding the Nation's landscapes in thousands of studies and applications and trusted by scientists, land managers, students, city planners, and many more as a definitive source of U.S. land cover.

NLCD released the latest version of this collaboration for the conterminous United States, NLCD 2021. This release includes map products characterizing land cover, land-cover change, developed impervious surface estimations, and impervious surface descriptors across nine epochs from 2001 to 2021 (2001, 2004, 2006, 2008, 2011, 2013, 2016, 2019, and 2021). The 2021 suite of NLCD products follows the same protocols and procedures of the previously released NLCD epochs (2001–2019), is directly comparable to the 2019 release across the full time series, and is suitable for multitemporal analysis. Other collaborative work released this year under the NLCD umbrella includes percent forest canopy produced with the U.S. Forest Service spanning 2008 to 2021, and the 2020 North American Land Change Monitoring System, which is produced through the Commission for Environmental Collaboration by the Canadian, Mexican, and United States Governments and their respective mapping agencies. All data are available online.

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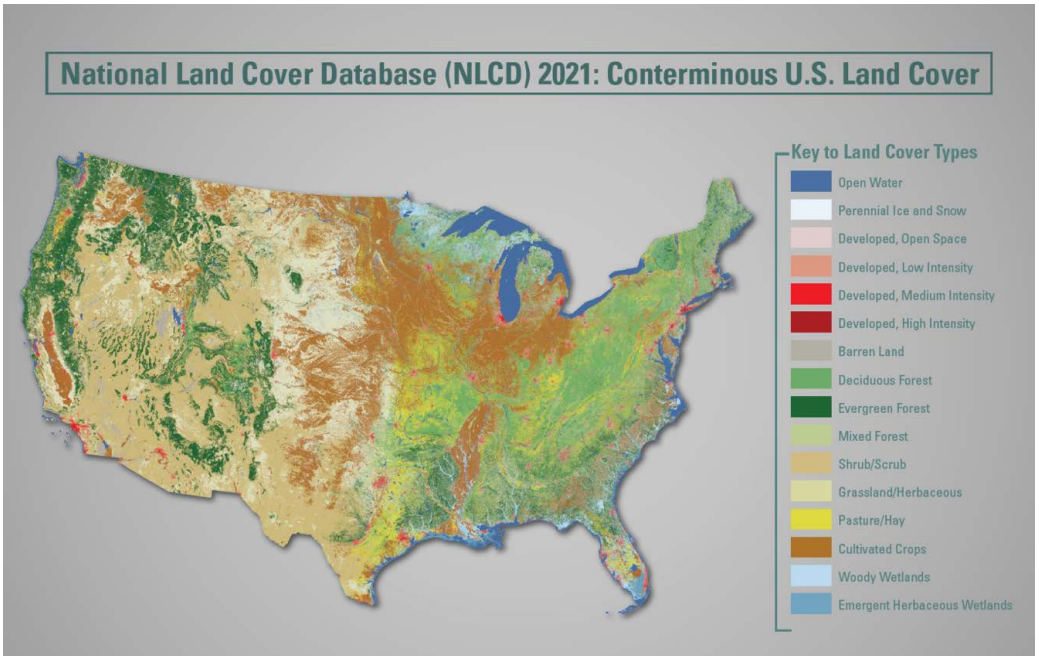
26 https://www.usgs.gov/centers/wetland-and-aquatic-research-center/science/mapping-high-marsh-along-northern-gulf-mexico

27 https://www.sciencebase.gov/catalog/item/628cf979d34ef70cdba3c03b and https://usgs.maps.arcgis.com/home/item.html?id=98d03a92d84940b9ac67e5c339c6eb2b

28 https://doi.org/10.1016/j.rse.2023.113451

29 Visit https://www.usgs.gov/centers/eros/science/national-land-cover-database for more information on the NLCD and https://www.mrlc.gov/ to learn more about the MRLC consortium.



The land cover layer from the 2021 National Land Cover Database.

Rangeland Condition Monitoring Assessment and Projection

Rangeland ecosystems in the western United States are vulnerable to climate change, fire, and anthropogenic disturbances. Scientists from the USGS 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 2021 in the current generation. The RCMAP product suite includes nine fractional components (annual herbaceous, bare ground, herbaceous, litter, non-sagebrush shrub, perennial herbaceous, sagebrush, shrub, and tree) and the temporal trends of each. The latest generation of RCMAP data has been enhanced with additional training data, improved imagery composites, the inclusion of a Neural Network modelling framework, the expansion of study area to the Pacific Northwest, and the addition of a tree-canopy cover component designed specifically for applications in stands of pinyon-juniper. These changes resulted in a 5–7 percent reduction in error measured at independent validation sites.

Results showed the net cover of shrub, sagebrush, and litter significantly ($p < 0.05$) decreased across the range, while bare ground and herbaceous cover had no significant change and annual herbaceous cover significantly ($p < 0.05$) increased. Change was ubiquitous, with a mean of 92 percent of pixels with some change and 38 percent of pixels with significant change ($p < 0.05$). However, most change was gradual; well over half of pixels had a range of less than 10 percent, and most change occurred outside of known disturbances such as fires

and vegetation treatments. Data depict the effects of disturbance such as fire, the interannual variation related to yearly weather cycles, and long-term patterns of response to climate change.

RCMAP fractional component time-series data spanning 1985–2021 and trends analysis products are now available for download at https://www.mrlc.gov and on the rangelands viewer application.[30] 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 climate change and interannual variation, and appraise landscape health and fragmentation.

Remote Aquatic Chlorophyll Tracker: A Public Web Application for Remote Sensing of Water Quality

The Remote Aquatic Chlorophyll Tracker web tool was published by the USGS in 2022 as a public-facing application to map aquatic chlorophyll in near-real time from 10-meter multispectral satellite imagery. This webtool assists public-health officials and waterbody managers in allocating scarce monitoring resources for timely identification and mapping of potentially harmful algal blooms. The application is based on a 2022 USGS-authored journal article that successfully used an ensemble approach to classify aquatic chlorophyll concentrations.[31] The same publication demonstrated an approach to address the very common data limitation issue that arises in evaluating remote sensing of water quality methods. Classification models developed from a supervised point classification routine were shown to perform almost as well as models developed on in situ sample collection alone while an assimilation of in situ and image-derived datasets produced the best performing model, which was capable of accurately classifying chlorophyll concentrations more than 80 percent of the time.

This trained aquatic chlorophyll ensemble model is now operationally applied to new imagery to produce weekly maps of aquatic chlorophyll in two dozen waterbodies in Idaho. To facilitate further adoption, relative chlorophyll and turbidity products are also provided at the global scale for imagery from 2019 to the present. Data summary and extraction tools are provided to place a given image in context.

Thermal Hyperspectral Imagery and Spectrometry for Geologic Mapping

Thermal imagery can be helpful for distinguishing geologic features because thermal infrared spectra are indicative of specific material composition, alteration, and soil compositions. Thermal properties of rocks depend on composition, porosity, and structures such as surface

30 For the rangelands viewer application, visit https://www.mrlc.gov/rangeland-viewer/.

31 Article available at https://doi.org/10.1117/1.JRS.16.044522.

roughness or folds, while the thermal properties of sedimentary deposits depend on compositions of clasts and matrix (for example, derived from basalt or granite), as well as grain sizes, amounts, and 3D arrangement of clasts and matrix.

The southwestern Cima volcanic field in California contains many basaltic scoria cones and lava flows that are intermingled with alluvial fan deposits. Researchers showed good qualitative comparisons between an existing map of these geologic features and two sources of remote sensing imagery: aerial photographs from Google Earth and two images from NASA's Hyperspectral Thermal Emission Spectrometer.[32]

UAS Remote Sensing for Carbon Sequestration Research on Public Lands

USGS Southwest Biological Science Center researchers are studying ways to quantify and manage carbon sequestration across drylands. UAS, also known as drones, provide a high-spatial-resolution (2- to 4-centimeter) perspective that can help connect field measurements to airborne and satellite observations. In May 2023, the USGS National Uncrewed Systems Office (NUSO) coordinated with the BLM and the National Ecological Observatory Network (NEON) to collect field, UAS, and airborne data at a NEON long-term monitoring site located on high-desert BLM land 40 kilometers south of Moab, Utah. NEON collected airborne data at a flight altitude of 1,000 meters on April 28. During the following week, USGS NUSO collected UAS natural color, multispectral, hyperspectral, and lidar data at flight altitudes of 15 to 31 meters over two BLM Assessment, Inventory, and Monitoring (AIM) plots that were imaged by the NEON's airborne platform. BLM AIM teams also collected field-based measurements of vegetation and soil at these two sites. USGS researchers will link these datasets to inform carbon storage questions on public lands.[33]

Understanding Patterns of Habitat Creation and Loss for Coastal Species

Although coastal storms have negative consequences for human lives and infrastructure, they are also important natural disturbances that create early successional habitats critical for many species. Early successional coastal habitats are typically flat with minimal to no vegetation—conditions that are created as waves push sand landward and scour existing vegetation in a process known as overwash. Ground-nesting shorebirds like piping plovers (*Charadrius melodus*) rely on these open overwash features for nesting throughout the species' Atlantic coast breeding range. In periods between storms, as coastal dunes redevelop and vegetation regrows, early successional habitats used by piping plovers slowly disappear until the next storm. It is

32 Visit https://doi.org/10.3133/ofr02272 for the map of geologic features, https://earth.google.com/web/ for Google Earth, https://hytes.jpl.nasa.gov/ to learn more about HyTES and https://pubs.usgs.gov/publication/70236544 to read a publication about this project.

33 Read more about this project at https://uas.usgs.gov/nupo/missions-2023.shtml#MoabC.

important for conservation management to understand these cycles of habitat creation and loss so that natural resource managers can estimate how much habitat might be available in any given year, plan for changes in these cycles as storm frequency and intensity alter with climate change, and protect areas that reliably contain habitat each year.

Scientists from the USGS St. Petersburg and Woods Hole Coastal and Marine Science Centers worked with managers from the National Park Service at Cape Lookout National Seashore to learn more about these cycles of habitat creation and loss. The team used high-resolution aerial imagery and lidar-derived digital elevation models (DEMs) to produce a time series of habitat maps for the Seashore's three barrier islands (Shackleford Banks, South Core Banks, and North Core Banks). The team employed machine learning image classification and other remote sensing tools, along with manual digitization techniques, to produce raster-based maps (5×5-meter resolution) of land cover, geomorphic setting, substrate type, vegetation type and density, distance from every raster cell to the (mean high water) ocean shoreline and to low-energy foraging areas (such as inlet shorelines), and elevation. They processed the maps using a Bayesian network that assigns a probability to every raster cell that that location would support piping plover habitat given the aforementioned landscape characteristics in that cell. This analysis was repeated for aerial imagery and DEMs captured in 2014, 2017, 2018, 2019, and 2022 to produce habitat maps for each year. Comparison of the location and amount of habitat predicted across years will improve understanding of these storm-induced cycles of habitat creation and loss.[34]

Using Landsat to Detect Sudden Onset of Iron Mineralization in Alaska's Arctic Rivers

In arctic Alaska, a growing number of independent field observations describe the sudden transformation of historically clear streams and rivers into opaque, rust-colored waterways. Concern by local communities, land managers, and outdoor user groups prompted a collaborative investigation including the USGS, NPS, University of California, Davis, University of Alaska Anchorage, and Alaska Pacific University.[35] Research activities were focused on understanding the mechanism behind these changes, quantifying the impacts to aquatic ecosystems, and verifying where and when these changes developed and whether there are instances of historical occurrence. The Landsat campaign met the need for a broad, consistent archive of remotely sensed imagery for investigating and quantifying water quality across northern Alaska.

Project researchers produced a time series of historical water conditions for select study sites from Landsat Collection 2, Tier 1 Surface Reflectance products accessed within a cloud-computing environment. They manually delimited areas of interest (AOIs) within study

34 Read more about this project at https://www.usgs.gov/centers/whcmsc/science/beach-dependent-shorebirds.

35 Learn more about this collaborative investigation at https://www.usgs.gov/centers/alaska-science-center/science/rusting-arctic-rivers-freshwater-ecosystems-respond-rapidly.

rivers to correspond with Landsat pixel geometry and iron-oxide precipitate/staining. The researchers retained only Landsat scenes between 1985 and 2022 that were acquired over the AOI in July or August, with scene-wide cloud cover less than 30 percent. They masked clouds and cloud shadows and calculated an "iron index" for each scene based on the ratio of surface reflectance in the red band and blue band. After removing outlier values, they calculated a mean iron index value from all pixels intersected by the AOI for each Landsat scene and generated a mean annual iron index value for each year. For the overall study area, mean annual iron index values ranged from 0 to 2.5. Assuming the area of interest corresponds with a consistent water surface, values of 0–0.5 can be interpreted as deep clear water, 0.5–1.5 as clear shallow water, and greater than 1.5 as iron oxide–stained water.[36]

An aerial image showing an example of a sudden and dramatic shift in water quality at the confluence of the iron-impacted Kutuk River (orange) and the Alatna River in Gates of the Arctic National Park in Alaska on July 26, 2016. (Photo credit: National Park Service/Kenneth Hill)

36 The data associated with the project can be accessed at https://doi.org/10.5066/P9TP9TZH.

Federal Communications Commission

FCC

On April 11, 2023, Federal Communications Commission (FCC) Chairwoman Jessica Rosenworcel launched the Space Bureau of the FCC. The FCC, through its Space Bureau, plays a key role in advancing the Commission's Space Innovation Agenda to meet the needs of the next-generation Space Age. The Bureau promotes a competitive and innovative global communications marketplace by leading policy and licensing matters related to satellite and space-based communications and activities. Among its responsibilities, the Bureau leads complex policy analysis and rulemakings; authorizes satellite and earth station systems used for space-based services; streamlines regulatory processes to provide maximum flexibility for operators to meet customer needs; and fosters the efficient use of scarce spectrum and orbital resources. The Space Bureau also serves as the FCC's focal point for coordination with other U.S. Government agencies on matters of space policy and governance and collaborates with the Office of International Affairs for consultations with other countries, international and multilateral organizations, and foreign government officials that involve satellite and space policy matters.

The Bureau strives to achieve its mission of promoting a competitive and innovative space-based global telecommunications marketplace by

1. authorizing eligible satellite systems for the purpose of facilitating the deployment of satellite services,
2. aligning regulatory processes to better meet the needs of the next-generation Space Age,
3. maximizing flexibility for operators to meet consumer needs,
4. fostering efficient use of the radio frequency spectrum and orbital resources,
5. serving as the FCC's focal point for coordination with other U.S. Government agencies on matters of space policy and governance, and
6. supporting the FCC's Office of International Affairs for dialogues with international organizations and foreign governments on space policy matters.

In FY 2023, the Space Bureau has also undertaken a Transparency Initiative, as directed by the Commission (IB Docket Nos. 22-411 and 22-271). The goal is to provide interested parties with user-friendly information and guidance regarding the Commission's space station and earth station application and authorization procedures. The initiative covers a variety of topics, including application completeness, orbital debris requirements, and inter-bureau and inter-agency coordination. Additionally, the Space Bureau plans to release an updated version of its electronic filing database (the International Communications Filing System, or ICFS) that will include multiple forms of guidance for users, including training videos for the ICFS application process and a helpful links page.

The FCC also took a number of significant actions in administrative and rulemaking proceedings in FY 2023, including the following:

- On December 22, 2022, the FCC established timeframes for placing space and earth station applications on notice for public comment, permitted applicants to apply for authority to operate in frequency bands where there is not already an international allocation for the satellite services to be provided, provided flexibility for non-geostationary orbit licensees to have more than one unbuilt system without facing potential dismissal of their applications, and streamlined processing of earth station operators' requests to add space stations as points of communication.
- On September 21, 2023, the FCC proposed additional ways to further improve its processing of space and earth station applications. The proposals include elimination of the procedural burden of printing and maintaining a paper copy of a license, changing the default status of space and earth station proceedings to permit-but-disclose, and a question of whether a process can be implemented for operators of non-U.S. licensed space stations that is similar to special temporary authority (STA). The FCC also sought comment on other updates to its processes for STA applications, whether to consider a "Permitted List" type of process for non-geostationary-satellite orbit (NGSO) operators, and whether to expand the window for operators to file renewal applications for existing licenses. The FCC also sought further comment about establishing timeframes or shot clocks for action on the merits of applications, updating processes to avoid potentially duplicative coordination procedures, and whether the FCC can expand the new auto-granted process for adding satellite points of communication to earth station licenses.
- On March 16, 2023, the FCC proposed a new regulatory framework to add mobile-satellite service allocation on some terrestrial flexible-use bands and leverage the growth of space-based services to connect smartphone users in remote, unserved, and underserved areas. Specifically, satellite operators in collaboration with terrestrial service providers would be able to obtain FCC authorization to operate space stations

on certain currently licensed, flexible-use spectrum allocated to terrestrial services. The FCC also sought comment on how this framework might best support access to emergency response systems like 911 and Wireless Emergency Alerts when a consumer is connected via supplemental coverage from space. The new proceeding also seeks to build a record on whether the framework can be extended to other bands, locations, and applications that might be supported by such collaborations.

- On April 20, 2023, the FCC adopted revisions to its rules concerning the interference protection obligations among non-geostationary-orbit, fixed-satellite service systems. The revisions address coordination of earlier-authorized systems with later-authorized systems and the methods for ensuring protection of systems from radio frequency interference. The FCC also sought further comment on the appropriate values and assumptions for the technical analysis related to interference protection.
- On May 19, 2023, the FCC authorized the merger of Viasat, Inc., and Connect Topco Limited with Inmarsat and its various holdings, finding after extensive review that the transaction served the public interest, convenience, and necessity.
- On September 21, 2023, the FCC adopted a new part 26 to its rules, establishing a spectrum allocation and licensing framework that will provide regulatory certainty and improved efficiency for commercial space launch operations, helping to ensure they will have the spectrum resources they need for reliable communications. The rules establish a non-exclusive, nationwide licensing framework and technical rules to give operators the predictability needed to conduct commercial space launch operations. The FCC also sought additional comment on ways to further optimize spectrum use, including the potential for additional spectrum bands to support commercial space launch operations and the possibility of extending the licensing framework to payload activities and suborbital operations.

During FY 2023, the FCC issued rulings facilitating the deployment and operations of several non-geostationary systems, including for systems designed to provide and support high-speed broadband, the "Internet of Things," and connectivity for cellular devices. These rulings include the following:

- On December 1, 2022, the FCC granted in part and deferred in part, with conditions, the request of Space Exploration Holdings, LLC (SpaceX), to construct, deploy, and operate a "next-generation" (Gen2) constellation of low-Earth orbit, non-geostationary satellite orbit satellites operating at altitudes of 525, 530, and 535 kilometers and inclinations of 53, 43, and 33 degrees, respectively, using frequencies in the Ku- and Ka-band, for the provision of broadband in the fixed-satellite service. To address concerns about orbital debris and space safety, the FCC authorized 7,500 of the 29,988

satellites requested, deferring action on the remainder. The FCC also adopted reporting requirements on mitigation actions taken to avoid collisions in space and required SpaceX to coordinate and collaborate with NASA to ensure continued availability of launch windows and on other matters, and pause deployment of new satellites if satellite disposal failures exceed a certain threshold. To address issues related to spectrum rights, interference concerns, and competition in low-Earth orbit, the FCC required SpaceX to coordinate with NGSO fixed-satellite service systems licensed in certain prior processing rounds and report whether the International Telecommunication Union's (ITU) finding on compliance with equivalent power flux-density limits takes into account all of the relevant ITU filings for its Gen2 Starlink system combined; and for operations in certain frequency bands, use no more than one satellite beam from any of its authorized Gen2 Starlink satellites in the same frequency in the same or overlapping areas at a time. Finally, to address concerns about protection of science missions, the FCC adopted conditions requiring SpaceX to continue to coordinate and collaborate with NASA to minimize impacts to NASA's science missions, requiring SpaceX to coordinate with the National Science Foundation, and requiring SpaceX to coordinate with specific observatories to protect radioastronomy operations.

- On April 10, 2023, the FCC granted Spire Global, Inc., access to the U.S. market to operate four low-Earth, non-geostationary satellites. The satellites would operate at altitudes between 385 and 650 kilometers, utilizing frequencies in the UHF band.
- On April 26, 2023, the FCC authorized Turion Space Corp. to deploy and operate one low-Earth, non-geostationary orbit satellite, DROID.001, which is intended to serve as a demonstrator for the company's fleet of satellites that are planned to provide space situational awareness data, service satellites, and remove orbital debris. The DROID.001 will operate at an altitude of approximately 550 kilometers, utilizing frequencies in the S- and X-bands to provide space research and space operation service.
- On April 27, 2023, the FCC authorized Outpost Technologies Corporation to deploy and operate one low-Earth, non-geostationary satellite orbit satellite, Outpost Mission 0, deployed to an approximate altitude of 525 kilometers and utilizing frequencies in the UHF band to provide space operations service for the purposes of testing flight software, avionics, power system, radiofrequency links, and gas generators that could support future reusable satellites. Later, on August 31, 2023, the FCC authorized Outpost Technologies Corporation to deploy and operate one low-Earth orbit, non-geostationary satellite orbit satellite, Outpost Mission 2, for additional testing. These applications were granted under the Commission's streamlined small satellite process.

- On August 31, 2023, the FCC authorized Odyssey SpaceWorks to deploy and operate one low-Earth, non-geostationary orbit satellite, to be known as the OSW Cazorla, deployed to an altitude of approximately 525 kilometers and utilizing frequencies in the S-band to test Odyssey SpaceWorks' programmable, laboratory modules for in-space research. This application was granted under the Commission's streamlined small satellite process.

The FCC also granted authority for the operations of non-geostationary satellites, including small satellites, in low-Earth orbit for remote sensing and other activities. Specifically:

- On October 20, 2022, the FCC granted the request of HawkEye 360, Inc., as amended, to deploy and operate a low-Earth, non-geostationary orbit satellite system consisting of up to 174 satellites, limited to 60 operational at any one time, operating at altitudes between 500 and 615 kilometers and utilizing frequencies in the X-, S-, UHF, and L-bands to provide Earth exploration service. HawkEye 360, Inc., had previously been authorized to operate up to 80 satellites, with 15 operational at any one time.
- On November 15, 2022, the FCC authorized Loft Orbital Solutions, Inc., to deploy and operate a low-Earth, non-geostationary satellite, YAM-5, deployed to an altitude of approximately 525 kilometers and utilizing frequencies in the X-, S-, and L- bands to provide Earth exploration satellite service, mobile-satellite service, and space operations service to transport customer devices and equipment into space and provide them with power, data, and on-board data processing, among other services.
- On December 7, 2022, the FCC authorized Orbital Sidekick, Inc., to deploy and operate a low-Earth, non-geostationary orbit satellite system consisting of six satellites, the Global Hyperspectral Observation Satellite system, deployed to an approximate altitude of 525 kilometers, utilizing frequencies in the K-, L-, S-, and UHF bands to provide Earth-exploration satellite service for hyperspectral imaging.
- On February 27, 2023, the FCC authorized Momentus Space LLC to deploy and operate one low-Earth, non-geostationary satellite orbit spacecraft, the Vigroride-6 (VR-6), deployed to an altitude between 480 and 520 kilometers, for a period of up to 250 days, utilizing frequencies in the X-, S-, and UHF bands to conduct a number of maneuvers in LEO and to deploy customer spacecraft into low-Earth orbit.
- On March 6, 2023, the FCC authorized ICEYE US, Inc., to deploy and operate two low-Earth, non-geostationary satellite orbit space stations, deployed to an altitude of approximately 550 kilometers as part of its Earth exploration satellite service system utilizing frequencies in the X- and S-bands to conduct Synthetic Aperture Radar imaging. Later, on August 31, 2023, the FCC authorized ICEYE US, Inc., to deploy and operate an additional eight low-Earth, non-geostationary satellite orbit

space stations. These applications were granted under the Commission's streamlined small satellite process.

- On April 26, 2023, the FCC authorized Launcher Inc. to deploy and operate, for a period of less than two years, one low-Earth, non-geostationary orbit spacecraft, Orbiter SN3, deployed to an approximate altitude of 525 kilometers and utilizing frequencies in the S-band to deploy four customer spacecraft.
- On June 23, 2023, the FCC authorized Capella Space Corp. to deploy and operate two low-Earth orbit, non-geostationary satellites, Acadia-1 and Acadia-2, deployed to an altitude between 585 and 640 kilometers and utilizing frequencies in the X-, S-, and L-bands to enable the Earth-exploration satellite service to conduct synthetic aperture radar imaging. This application was granted under the Commission's streamlined small satellite process.

In FY 2023, the FCC also authorized commercial geostationary communication satellite operations. These authorizations include the following:

- On December 6, 2022, the FCC authorized Astranis Projects USA LLC to deploy and operate a geostationary orbit satellite, known as Arcturus or Aurora 4A, at the 168.0° west orbit location to provide fixed-satellite service.
- On March 31, 2023, the FCC authorized Intelsat License LLC to deploy and operate a geostationary orbit satellite, known as Intelsat 40e, at the 91.0° west orbit location to provide fixed-satellite service.

In addition to these commercial operations, the FCC continued to grant applications for experimental operations by non-Federal satellites. Many of the experimental grants were to universities and institutions conducting research and developing new spacecraft technologies. The satellites' missions include activities ranging from remote sensing missions to missions testing the performance of certain technologies in space, such as hyperspectral imaging, satellite deployers, and propulsion systems.

In FY 2023, the FCC granted several license modifications and special temporary authority authorizations for satellite networks. Many involved routine testing or redeployment of satellites with a multi-satellite system. Several of these actions warrant particular mention:

- On November 9, 2022, the FCC granted a license modification to Spire Global, Inc., to reflect operations of inter-satellite links in the 2,025–2,026 MHz frequency band with some of its non-geostationary orbit satellites operating at altitudes of up to 525 kilometers.
- On January 10, 2023, the FCC modified the license of BlackSky Global LLC for its non-geostationary satellite orbit system to update the technical parameters for three

satellites. Specifically, the modification reflects operations planned for orbits ranging between 385 km and 500 km, the inclusion of a water-based propulsion system, and certain other technical changes.

- On February 17, 2023, the FCC granted special temporary authority to Space Exploration Holdings, LLC, to operate radio frequency beacons on up to 56 SpaceX second-generation non-geostationary-orbit Starlink satellites on each launch, up to a maximum of 300 simultaneously operating satellites, in order to track and maintain satellite positional information during satellite orbit-raising and for emergency operations once at operational orbit, for a period of up to 60 days. This grant was subsequently extended on May 4, 2023, for an additional 60-day period.
- On February 23, 2023, the FCC granted the request of Space Norway AS for modification of its grant of U.S. market access for a two-satellite, non-geostationary satellite orbit system, operating under the authority of Luxembourg, and approved Space Norway's updated orbital and technical parameters and orbital debris mitigation plan.
- On March 3, 2023, the FCC granted the request of Hawkeye360, Inc., for modification of its license for a non-geostationary satellite orbit constellation. The FCC modified the license to specify, for three satellites identified as Cluster 7, additional antennas capable of receiving signals in certain UHF frequencies; a change in the authorized satellite operational altitude range from 500–615 kilometers to 475–615 kilometers; and the use of a water-based propulsion system.

The FCC also added a non-U.S.-licensed space station to its permitted list to allow the space station to provide satellite service to U.S. earth stations that have routine technical parameters.

- On October 6, 2022, the FCC added Embratel TVSAT Telecomunicacoes S.A.'s Star One D2 satellite to the permitted list, operating under the authority of Brazil and using the Ku-band at the 70° west orbit location.

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, nutrition, and related issues based on public policy, the best available science, and effective management. In doing so, USDA seeks the best strategies to induce growth and progress in all the areas that it oversees, including advancing racial equity across the food system, building a climate-resilient future, investing in healthy communities, and leveling the playing field for small and mid-sized farms. USDA aims to promote agricultural production that better nourishes Americans while helping feed others throughout the world and to preserve our Nation's natural resources through conservation, restored forests, improved watersheds, and healthy 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.

The USDA Geospatial Strategic Plan (GSP) contains a strategy for advancing geospatial information and related technology and activities; it also requires formalizing a framework to guide strategic implementation.[1] The USDA GSP that outlines critical steps to implement the requirements of the Geospatial Data Act of 2018, strengthen the value of geospatial information and technology across the enterprise, implement collaborative partnerships to create cost efficiencies, and empower the USDA geospatial community to provide effective mission support.[2] By bringing geospatial data to the forefront, USDA is working to further this vision, strengthen USDA mission delivery, and become a Federal leader in the use of geospatial information and technology.

1 USDA, Geospatial Strategic Plan, 2020.

2 43 U.S.C. Ch. 46, *Geospatial Data Act of 2018*, as amended.

Monitoring agriculture, rangelands, and forests with remote sensing allows USDA to meet many of its mission-critical objectives. A wide variety of remote sensing products and technologies are used for daily operations, research, and compliance efforts, including forest and wildland fire management, conservation, resilience, precision agriculture, rural development, emergency response, food safety, and food security. The platforms and products used include polar and geosynchronous satellites, aerial imagery, and ground-based collections.

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 NISAR mission, set to launch in 2024. 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 Soil Moisture Active Passive (SMAP), NASA-ISRO Synthetic Aperture Radar (NISAR), the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station, 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. Carbon monitoring is also a 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. The basis of this monitoring is a combination of remote sensing observations, models, and ground-based monitoring throughout the United States.

To improve these collaborations, a Memorandum of Understanding was executed between USDA and NASA in 2020, and was renewed in 2023, with annual meetings being held each spring to update the various agencies on the collaborations that are happening, as well as providing a forum for new partnerships to develop. ARS has served as the organizational leader for this endeavor. 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.

National Agricultural Statistics Service

As the statistical agency for USDA, the National Agricultural Statistics Service (NASS) data are used to support research, education, and advocacy for the future of agriculture throughout the country.

The NASS used remote sensing data to construct and sample area frames for agricultural statistical surveys; estimate crop area and yield; monitor crop condition, area, and soil moisture via data visualizations; impute for survey non-response; and provide geospatial data products and disaster assessments for hurricanes, wildfires, and disaster events. NASS used Landsat imagery, digital NAIP imagery, and other remotely sensed inputs for the conterminous United States (CONUS) to select the yearly area-based samples for the 2023 June Area Survey.

The remote sensing acreage estimation program used satellite imagery from the Landsat 8 and 9 and Sentinel-2 A and B missions to produce crop acreage estimates for crops at state and county levels. Remote sensing–based acreage indications for all states were derived from the Cropland Data Layer (CDL) for all market-sensitive crops. The NASS Agricultural Statistics Board (ASB) utilized the remote sensing acreage indications as independent input for setting official estimates for monthly crop production reports. In addition, NASS distributed the CDL for 48 states to stakeholders for the 2023 crop seasons via the USDA Geospatial Data Gateway and CroplandCROS.[3]

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, and crop-frequency data-layer products. NASS released a new geospatial data product called Crop Sequence Boundaries developed cooperatively with USDA's Economic Research

3 https://croplandcros.scinet.usda.gov

Service, which produces estimates of field boundaries, crop acreage, and crop rotations across the contiguous United States. These web applications offer advanced tools such as interactive visualization, web-based data dissemination, and geospatial queries. They deliver crop-specific land-cover data and visualization tools directly to the agricultural community via a web browser without needing specialized expertise or GIS software.

NASS continued development on the 30-meter crop-type prediction layers and corresponding entropy (uncertainty) layers derived from historic CDLs using machine learning techniques. These geospatial products are called Predictive CDLs (PCDLs). In 2023, the PCDLs were added to a tool used by NASS statisticians for manual imputation and editing of farmer reports during the June Area Survey, NASS's largest annual survey. The PCDLs were produced for the 48 conterminous states and made available for internal use for the June Area Survey.

In FY 2023, geospatial decision-support data products were delivered for disaster inundation and wildfire assessments to assess impacts on agriculture from Hurricane Nicole (November 2022), the midwestern derecho (June 2023), Hawaii wildfires (August 2023), and Hurricane Idalia (September 2023). The products included crop and pastureland inundation assessments, estimated precipitation totals, impacted crop acreage maps and tables, and wind swaths or surface winds overlaid onto crop areas over impacted areas.[4] This information was used to assess real-time storm inundation or wildfire impact over croplands and pasturelands and shared with both USDA and the Federal Emergency Management Agency.

NASS utilized NASA Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) and the NASA Global Inventory Modeling and Mapping Studies Global Agricultural Monitoring application for modeling corn and soybean yield estimates covering the 16 largest corn producing and 11 largest soybean producing states. Updated yield estimates were delivered operationally 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.[5] VegScape showed crop condition, vegetation greenness, and drought anomaly assessments. Additionally, NASS continued monitoring the ongoing California drought, providing monthly growing-season CDL-based fallowed-land estimates for California water resource stakeholders.

Crop Condition and Soil Moisture Analytics (CropCASMA) continued to provide both volumetric and categorical topsoil and subsoil moisture from the NASA SMAP mission.[6]

4 https://www.nass.usda.gov/Research_and_Science/Disaster-Analysis/

5 https://nassgeodata.gmu.edu/VegScape

6 https://nassgeo.csiss.gmu.edu/CropCASMA/

CropCASMA was customized to deliver 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 purpose of this project is to develop a digital twin infrastructure by integrating land/hydrology process models, agricultural models, and remote sensing 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 has developed and tested a software module that loosely coupled NASA Land Information System (LIS) with crop process models DISSAT and APEX. Iowa model simulation has demonstrated notable geospatial improvement of crop yield prediction by introducing LIS soil moisture data.

Research efforts started 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" during FY 2023. This project aims to produce weekly in-season crop yield predictions over CONUS at the county level by utilizing publicly available satellite remote sensing datasets and state-of-the-art deep learning technologies.

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.[7] Geospatial systems and data, including space-based remote sensing systems, have played a fundamental role in RMA's program delivery, particularly in the compliance and oversight program areas.

Through crop insurance, RMA aided farmers and ranchers impacted by natural disasters, including hurricanes and fires.[8] In FY 2023, RMA used remote sensing data from Landsat, Sentinel-2, MODIS, and others, as well as high-resolution aerial and satellite imagery. Many of these imagery products were collected because of the USDA's interagency coordination. RMA

7 https://www.rma.usda.gov/Federal-Crop-Insurance-Corporation

8 Emergency Relief Program and Natural Disaster Resources: https://www.rma.usda.gov/en/News-Room/Continuing-Interest/Emergency-Relief-Program-and-Natural-Disaster-Resources

incorporated many different geospatial decision-support products that have been provided to the USDA and RMA leadership for situational awareness. These products help mitigate many natural disasters that have significant impacts to agricultural areas that use crop insurance. The products included impacted program estimates; estimated precipitation; and natural-disaster extents for flood events, hurricanes, and wildfires.

Orthoimagery elevation data and GPS information were essential geospatial data integrated into RMA program applications. RMA offices used geospatial data daily to support crop insurance. Orthoimagery data are typically high-resolution aerial images that combine the visual attributes of an aerial photograph with the spatial accuracy and reliability of a planimetric map.

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 in developing applications that benefit crop insurance delivery and oversight, as well as benefiting farmers and ranchers across America.

In addition, RMA often partnered with scientists and researchers to develop products to meet agency business needs on integrating satellite imagery for enhancing program integrity models.

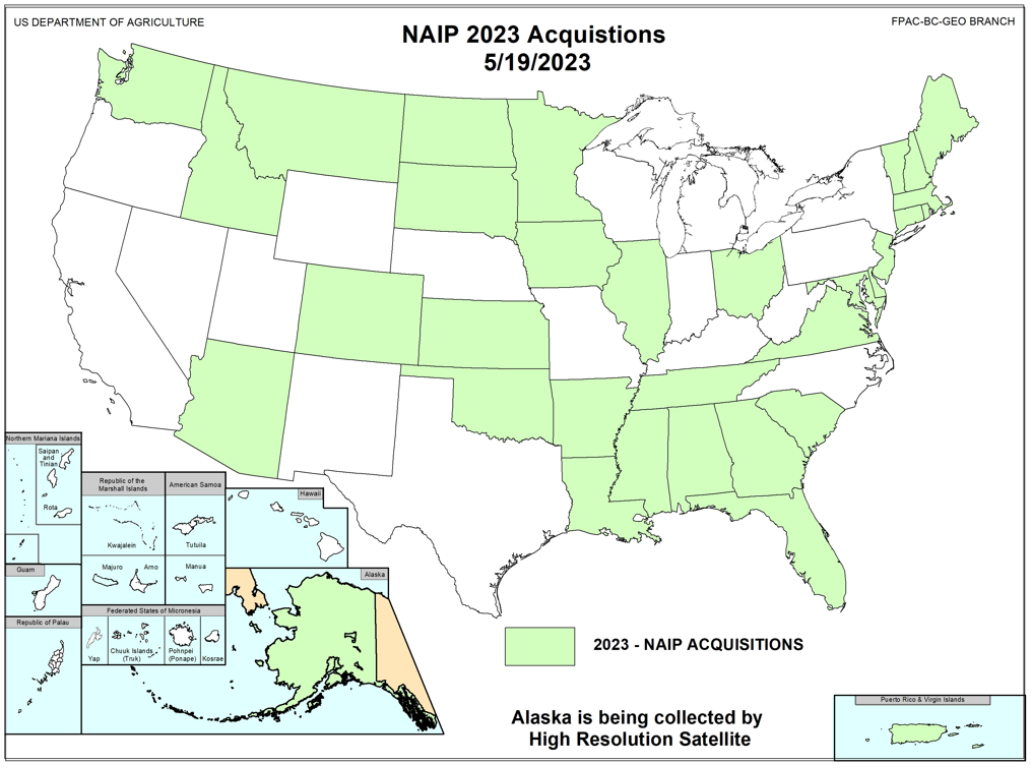
Farm Service Agency

The Farm Service Agency (FSA) administers several safety-net, price support, conservation, disaster assistance, and loan programs as 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 2023 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 National Agriculture Imagery Program (NAIP).[9] NAIP is a multi-department-funded program led by FSA that provides current high-resolution imagery of the contiguous United States, Hawaii, Puerto Rico, and the U.S. Virgin Islands to the public. Imagery is acquired as a leaf-on product during peak agricultural growing seasons. NAIP imagery is collected every two years for CONUS and every four years for Hawaii, Puerto Rico, and the U.S. Virgin Islands. This dataset is the primary base map used for the creation of

9 National Agriculture Imagery Program (NAIP) GeoHub: https://naip-usdaonline.hub.arcgis.com/

Example of National Agriculture Imagery Program (NAIP) 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 National Agriculture Imagery Program (NAIP) in 2023, as of May 19, 2023.

geospatial data used in USDA field offices. NAIP is used by nearly all civilian Federal agencies as a base layer in their geographic information system (GIS) to support a wide variety of activities, such as conservation and land management, and is also used by commercial platforms like Google and Apple. 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.

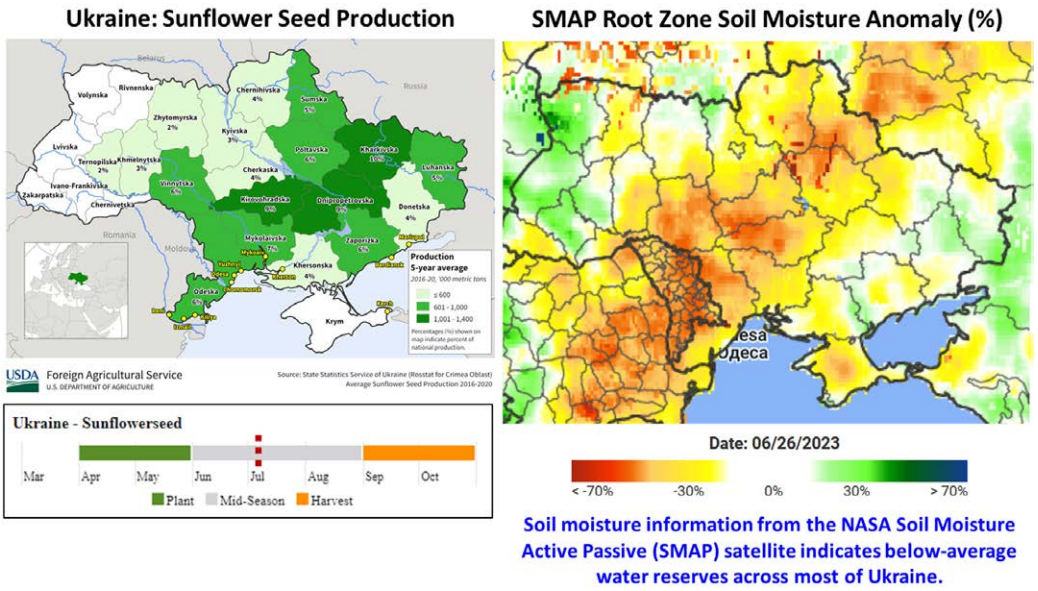
In 2023, FSA used high-resolution aerial and satellite imagery as well as satellite data to support disaster recovery programs, including Emergency Farm Loans and the Emergency Conservation Programs, on an ad hoc basis. In addition to the civilian-managed space-based systems, FSA incorporated high-resolution Maxar satellite imagery for Alaska, acquired by the Natural Resources Conservation Service (NRCS) and 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.

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 the USDA's monthly World Agricultural Supply and Demand Estimates (WASDE) report, the primary source of the 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. FAS/GMA authors the World Agricultural Production (WAP) circular, and both WASDE and WAP publications are Principal Federal Economic Indicators. FAS/GMA uses satellite imagery at regional, national, and subnational scales to operationally monitor and analyze monthly changes in global crop production. FAS archives and displays global monthly crop production, supply, and distribution (PSD) data from the USDA's WASDE report on the FAS PSD Online website.[10]

During FY 2023, the International Production Assessment Division (IPAD) operated the remote sensing program at FAS/GMA. FAS/IPAD is an operational user of remotely sensed imagery for estimating seasonal crop yield and area, and global imagery output products are displayed with five-day and eight-day time steps on several web application sites. Global crop

10 https://apps.fas.usda.gov/psdonline/app/index.html#/app/home



In Ukraine's primary sunflower-producing region (shown on the left), Root-Zone Soil Moisture Anomaly (right) indicated below-average water reserves during the critical midseason for this crop. The anomaly product was calculated from NASA's Soil Moisture Active Passive (SMAP) satellite, using the latest data in comparison with the eight-year average (April 2015–March 2023) available from SMAP. Soil moisture status products are used by FAS to support crop condition analysis and foreign crop production estimates.

conditions and relative crop yields were primarily monitored and measured by NASA's MODIS sensor onboard the Aqua and Terra satellites. Crop type and crop area were primarily mapped and estimated from 30-meter-resolution Landsat 8 and 9, as well as 10-meter-resolution Sentinel 2A and 2B imagery available on Google Earth Engine (GEE). NASA's L4 Root Zone Soil Moisture product derived from Soil Moisture Active and Passive (SMAP) satellite (with nine-kilometer spatial resolution) was also released on GEE in late 2022, and below is a Root Zone Soil Moisture Anomaly image example over Ukraine published in FAS/IPAD's monthly WAP circular in July 2023.[11]

FAS/GMA also hosts Crop Explorer, 12 Commodity Explorers, and the Global Agricultural and Disaster Assessment System (GADAS) web application systems.[12] Crop Explorer allowed public users to monitor and analyze seasonal rainfall and extreme temperatures over global croplands, which may cause crop damage. The 12 online Commodity Explorers are crop-specific and support monitoring NDVI and cumulative precipitation over global croplands for corn, wheat, rice, cotton, soybean, barley, palm oil, rapeseed, sorghum, sunflower seed, peanuts, and millet. GADAS is a state-of-the-art geographic information system that displayed

11 https://www.fas.usda.gov/data/world-agricultural-production

12 Crop Explorer: https://ipad.fas.usda.gov/cropexplorer/; Commodity Explorer: https://ipad.fas.usda.gov/cropexplorer/cropview/; Global Agricultural and Disaster Assessment System: https://geo.fas.usda.gov/GADAS/index.html

numerous Earth observation data streams from NASA, NOAA, and other agencies, with GIS tools and cropland datasets to support agricultural and disaster assessment analysis.

FAS/GMA also maintained several public global agricultural datasets that processed, archived, and displayed a variety of satellite imagery products from NASA's Goddard Space Flight Center. The USDA-NASA Global Agricultural Monitoring (GLAM) web applications is hosted and operated by NASA's GIMMS, and displayed time series NDVI satellite data and products over global croplands and major inland water bodies.[13] The GLAM-NDVI-MODIS web interface system compared current vegetation conditions with past years' by utilizing NDVI satellite imagery from NASA's MODIS-Terra and MODIS-Aqua satellite systems. In addition, the Global Reservoir and Lake Monitor displayed reservoir and lake water heights by utilizing satellite radar altimeter data from NASA's Ocean Topography Experiment/Poseidon, Jason-1, Jason-2, and Jason-3 satellites.[14]

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); and 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.

In FY 2023, the USFS collaborated with NASA, NOAA, the USGS, other agencies, and other external agency 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: "Addressing Land and Water Monitoring Needs Using Remote Sensing Data," in April 2023.[15] The workshop, hosted in Salt Lake City, focused on increasing awareness at NASA of the operational needs of the Forest Service and other agencies as well as increasing awareness among USFS resource managers of NASA data products that can inform their decisions.

13 http://glam1.gsfc.nasa.gov/

14 Global Reservoirs and Lakes Monitor (G-REALM): https://ipad.fas.usda.gov/cropexplorer/global_reservoir/

15 https://www.aeoip.com/2023-usfs-nasa-workshop

- USFS partnered with NASA to provide comprehensive, low-latency remote sensing products to support strategic wildland fire management needs for the Forest Service and other agencies in the United States and Canada.[16] 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.
- USFS collaborated with the NASA Terrestrial Information Systems Laboratory, NASA Land-Atmosphere Near Real-Time Capabilities for EOS, NASA Direct Readout Laboratory, NASA Applied Sciences Program, NASA Global Imagery Browse Services, NOAA, USGS, and university partners to complete development of a NASA-hosted computing platform to serve Forest Service 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 download on this site is the full archive of global active fire detections from MODIS and VIIRS.
- The USFS utilized MODIS, Sentinel-2, and Landsat imagery to conduct coarse- and moderate-scale forest damage assessments for large geographic areas of the continental United States in the immediate aftermath of significant forest disturbance events (e.g., hurricanes, tornadoes). This strategic information supported the agency in targeting areas for fuels management activities and/or areas where higher-resolution forest damage assessments are required.
- USFS continued coordination with NASA Ames Research Center to overhaul and upgrade the Automated Modular Sensor (AMS) electronics and sensor components and further develop the AMS firmware and software for use on USFS aircraft. This included efforts to renew a multiyear interagency agreement between the Forest Service and NASA to provide financial support to address this work.

16 https://firms.modaps.eosdis.nasa.gov/usfs/

- Landsat 7 Enhanced Thematic Mapper (ETM), Landsat 8 and 9 OLI, and Sentinel 2 imagery was operationally applied to provide 100 burn severity mapping emergency assessment products for 79 wildland fire events covering approximately 611,000 acres. These rapid-response products support post-fire emergency stabilization/hazard mitigation activities conducted by Forest Service Burned Area Emergency Response teams.
- In FY 2023, Landsat 7 ETM, Landsat 8 and 9 OLI, and Sentinel 2 imagery was operationally applied to map and estimate post-fire basal area loss and canopy cover loss for 92 large wildfires occurring in 2022 and 2023 and affecting more than 1.9 million acres. These products support forest restoration planning management activities and efficient use of resources to support those activities. The USFS also conducted similar remote sensing estimates for an additional 60 large wildfires occurring in 2009 or earlier in support of Repairing Existing Public Land by Adding Necessary Trees Act requirements.
- In FY 2023, USFS also continued to operationally apply Landsat 4 and 5 Thematic Mapper (TM), Landsat 7 ETM, Landsat 8 and 9 OLI, and Sentinel 2 imagery to inventory and map the location, extent, and severity of 888 current and historical large fires affecting nearly 6.9 million acres across multiple land ownerships in the United States. The purpose for this effort is to characterize large fires to assess the effectiveness of national fire management policies as part of the Monitoring Trends in Burn Severity (MTBS) program. MTBS mapping activities during FY 2023 included the completion of more than 1,082 new and/or revised fire mappings, increasing the extent of the historical MTBS data record to include 30,418 fires covering more than 213 million acres of burned lands.
- 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 USGS to provide 30-meter 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, Forest Service, 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 NAIP 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 three National Forests encompassing approximately 17 million acres. Additionally, three CONUS-level products are currently being produced using national inventory data.

- The Forest Service used Landsat 7, Landsat 8, and Landsat 9 OLI data to create annual updates of 30-meter tree canopy cover data from 2008 to 2021 for CONUS, interior 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 2023, the 1985–2021 CONUS change product was extended to include 2022. This effort is being conducted in collaboration with several Federal and academic partners.
- 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).
- USFS continued to expand its engagement in the USGS 3D Elevation Program as it transitions to the USGS 3D Hydrography Program to ensure consistent acquisition specifications and to minimize redundant collections by partnering with other state and Federal entities on data acquisitions.
- USFS continued to provide operational web mapping and data services for NAIP and other high-resolution aerial and satellite imagery data. Additionally, it provided resource management guidance based on airborne imagery and selected moderate-resolution imagery from NASA satellite assets for consumption/use by USDA and Bureau of Land Management staff. The approximately one-petabyte data archive provided spatially and temporally comprehensive coverage for the United States and is essential for daily USDA and partner operational business information needs.
- USDA continued ongoing work with NASA scientists to use NASA Goddard's LiDAR, Hyperspectral and Thermal (G-LiHT) imager to collect data that augment

the forest inventory of interior Alaska, which includes investigations for improving carbon monitoring. This work is anticipated to last for an additional seven years.

- Forest Inventory and Analysis (FIA) and Forest Health Protection staff continue to utilize Landsat 5, Landsat 8, and Landsat 9 OLI, Terra and Aqua MODIS, NAIP imagery, 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.
- USFS initiated coordination with NASA to develop a four-band imager and lidar data acquisition pod for use to support Forest Service programmatic needs (e.g., forest health, forest inventory, landscape mapping and characterization).
- NASA and USDA continued a 50-year legacy of collaboration regarding public engagement and STEM education around "Moon Trees" by again partnering to send tree seeds to space on Artemis I, launched on November 16, 2022. This collaboration continues the legacy of "Moon Trees" grown from seeds that orbited the Moon on Apollo 14 in 1971. The collaboration connects Artemis I programming to Earth science, conservation education, data literacy, and citizen science, serving both educators and youth nationwide via such programming as the Forest Service's Natural Inquirer Moon Tree Lesson Plans and Learning Modules and NASA's Office of STEM Education.[17]
- USFS supports NASA's Carbon Monitoring System (CMS) program with two USFS scientists serving as team members in Phase 3 CMS through 2023 and three scientists serving as Biomass Working Group Team Lead and participating members. A Forest Service scientist serves as coinvestigator for "Preparing the global CMS Flux system for application to carbon flux inventories via regional-scale, observation-based evaluations."
- Under the 2020 Resources Planning Act, the Forest Inventory Analysis team is undertaking national reporting of carbon using FIA and NRCS data together with Landsat.

17 https://www.naturalinquirer.org/Artemis-Moon-Trees-v-397.html and https://www.nasa.gov/stem/about.html

- The Forest Inventory and Analysis program has an agreement to share Forest Service data with NASA's Jet Propulsion Laboratory and Goddard Space Flight Center. This agreement allows the Forest Inventory Assessment Program to monitor all of Alaska's forests using a subset of field plots. Remote sensing scientists often rely on Forest Inventory and Analysis data to calibrate or validate observations or to support observational data for scientific studies.

Natural Resources Conservation Service

Aerial Imagery

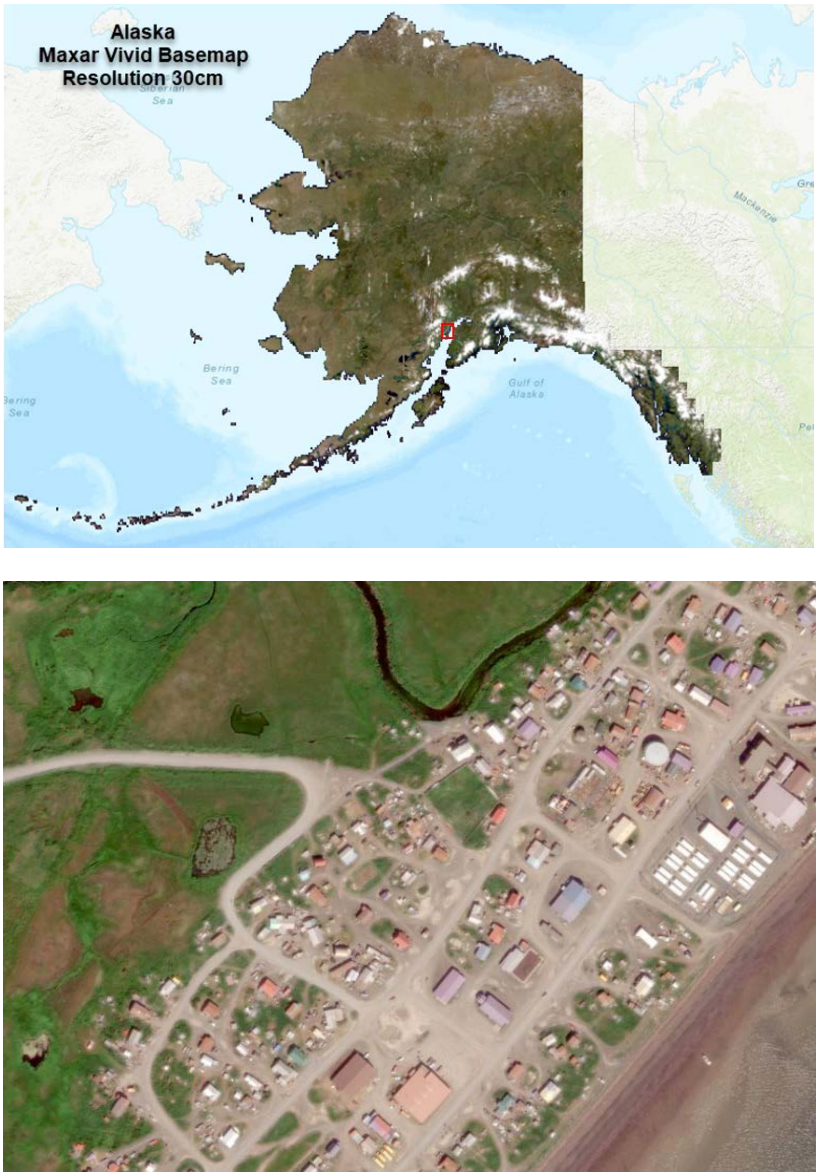
The Natural Resources Conservation Service (NRCS) helps America's farmers, ranchers, and forest landowners conserve the Nation's soil, water, air, and other natural resources. To fulfill this mission, NRCS acquires, develops, interprets, analyzes, and delivers natural-resource information to enable knowledge-based 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 Systems are essential geospatial data integrated into NRCS program applications, service centers, state offices, and national centers. Today, NRCS offices use geospatial data daily to support conservation programs. NRCS coordinates acquisitions of aerial imagery and digital elevation data with other Federal and state agencies through interagency committees like the National Digital Ortho imagery Program and the USGS 3D Elevation Program (3DEP). 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-cm or higher resolution imagery for most agency programs. Acquisition of imagery in non-CONUS areas is challenging because of their remoteness and weather. NRCS uses commercial high-resolution satellite imagery from Maxar for areas such as these and lands with restricted airspace. In FY 2023, NRCS acquired state-wide high-resolution imagery for all of Alaska, working with DOI-USGS on this acquisition project.

NAIP

The National Agriculture Imagery Program (NAIP) is a high-resolution imagery program that usually collects data during leaf-on time periods during the summer



Example of high-resolution satellite Imagery for Alaska (top), and Togiak, Alaska, depicted in close-up image (bottom).

months. This dataset is the primary base map used for the creation of geospatial data used in USDA field offices, and the same base map is provided for their use. NRCS, USFS, USGS-DOI, and FSA (the NAIP leader) have successfully funded and supported NAIP since the program's inception in 2003. NAIP imagery is used extensively within NRCS mission delivery and is available for most NRCS offices in the continental United States.[18]

18 Please visit https://naip-usdaonline.hub.arcgis.com/ and the NAIP program section marked FSA-NAIP for more information on NAIP.

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. It is mandated by the Rural Development Act of 1972 (P.L. 92-419) 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, 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 70,000 NRI sites in the contiguous United States, Puerto Rico, the U.S. Virgin Islands, 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.

Stewardship Lands

NRCS offers easement programs (Stewardship Lands) to landowners who want to maintain or enhance their land in a way beneficial to agriculture and/or the environment. All NRCS easement programs are voluntary. For FY 2023, NRCS surpassed 5.7 million acres on approximately 24,290 conservation easements enrolled in NRCS agricultural conservation easement programs. Use of high-resolution aerial photography is 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 has a national strategy to acquire, integrate, and deliver these data to meet its geospatial needs. High-quality digital elevation data and derivatives help NRCS employees work more effectively and efficiently to help customers. NRCS participates in the USGS 3DEP to acquire high-quality 3D elevation data through remote sensing.[19]

By the end of FY 2023, 3DEP and its partners had increased lidar coverage to more than 90 percent of the continental United States and Hawaii. Interferometric Synthetic Aperture Radar coverage for Alaska is 100 percent complete. NRCS contracted $28.6 million of the $102.2 million total 3DEP investments for FY 2023 awards. Based on the approved national

19 https://www.usgs.gov/3d-elevation-program

strategy, NRCS obligated $69.1 million in FY 2023 on an Interagency Agreement with USGS for acquisitions in FY 2024 and FY 2025.

Use of Positioning, Navigation, and Timing Signals from Space

Space-based Positioning, Navigation, and Timing (PNT) signals from space are core to all NRCS geospatial activities. The U.S. GPS constellation of satellites is the primary source of space-based PNT. The NRCS utilizes GPS signals from space as well as the FAA Wide Area Augmentation Service signals and ground-based cellular Real Time Kinematic corrections to space-based PNT to enhance conservation practices on the ground daily in every state of the United States as well as in the Caribbean and Pacific basins. The use of PNT services continues to support the NRCS mission of "Helping People Help the Land." NRCS vendors and partners for aerial imagery, UAS, 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 NRCS will continue to depend on the availability and reliability of the GPS signals from space well into the future.[20]

20 See https://www.nrcs.usda.gov/conservation-basics/natural-resource-concerns.

National Science Foundation

NSF

The National Science Foundation (NSF) is an independent Federal agency that supports science and engineering in all U.S. states and territories. NSF was established in 1950 by Congress to promote the progress of science; advance the national health, prosperity, and welfare; and secure the national defense. NSF fulfills its mission chiefly by making grant awards; investments account for approximately 25 percent of Federal support to U.S. colleges and universities for basic research: research driven by curiosity and discovery, supporting solutions-oriented research with the potential to produce advancements for the U.S. people.

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. 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, and the formulation and design of new space mission concepts. NSF funded a highly active translational research and development space tech portfolio, investing in hundreds of entrepreneurs over the past year with ties to many of the key technologies relevant to U.S. space leadership. Investments advanced foundational research for aerospace, communications, electronics, manufacturing, robotics, and vehicle technologies. Starting in FY 2023, NSF placed increased focus on developing a diverse space-related STEM workforce through research and education that increase awareness of and preparation for space-related careers.

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 2023. Additionally, AGS funding supported several hundred faculty members and students at U.S. universities, research institutes, and small companies and helped diversify the current and future space workforce. The Geospace Section (GS) within 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. In FY 2023, GS revised and reissued the solicitation as "Faculty Development in GeoSpace Science" and received proposals to expand these tenure-track positions, including in minority-serving institutions and emerging research institutions.

The GS continued to support research infrastructure and facilities that are the foundation of NSF-supported geospace research. These include advanced radar systems to study the ionosphere and magnetosphere, including Incoherent Scattering Radars (ISRs) and the Super Dual Auroral Radar Network, ground-based optical and radio instruments to study the upper atmosphere as well as aurora and airglow phenomena, and partial support to 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, provides global and continuous measurements of the Birkeland currents using magnetic field data from the commercial satellites of the Iridium constellation. The GS also funds the Subauroral Geophysical Observatory near Gakona, Alaska, anchored by the High-Altitude Auroral Research Program facility, an ionospheric heating array that is being 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.

The GS 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. These projects played a crucial role in space research and are also great opportunities to train our future experimentalists. In addition, the GS supported the SuperMAG collaboration in collecting and disseminating vital magnetic measurements to researchers and space weather operators across the country.

The GS also issued a revised solicitation titled "Distributed Array of Small Instruments (DASI)" that supports 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 DASI program emphasizes both strong scientific merit and a well-developed plan for student training and involvement of a diverse workforce.

The GS continued its support of CubeSat missions. 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 measures 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 GS funded a portfolio of basic and use-inspired research in space physics through the Space Weather Research, Solar-Terrestrial Research, Aeronomy, and Magnetospheric Physics programs. GS continued to support the 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," or ANSWERS. There are 7 ANSWERS projects at 17 U.S. universities, research institutes, and women-led private companies, and GS is investing $11.8 million in the program between FY 2022 and FY 2026, pending availability of appropriations in future years.

The National Center for Atmospheric Research (NCAR) continued to be funded by the AGS. The High-Altitude Observatory (HAO) at NCAR supports its mission to "understand and quantify the impact of solar variability on Earth's atmosphere across temporal scales" by observing and modeling the Sun-Earth system and potentially devastating effects on Earth, people, and technology. HAO continued to support Mauna Loa Solar Observatory's instrumentation and its related data-sharing website. HAO also made progress on closing the science gap focused on the coronal magnetic field 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. This instrumentation was deployed to measure atmospheric conditions critical to the operation of coronagraph telescopes, such as aerosol content, sky brightness, cloud cover, and atmospheric stability.

The AGS's Atmosphere Section 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 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 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 USAF, and TASA. Currently the COSMIC team is working on ROMEX, the Radio Occultation Modeling Experiment, 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 and the NSF-DOE plasma partnership. NSF, NASA, NOAA, and the Department of the Air Force signed a Memorandum of Agreement for Space Weather Research-to-Operations-to-Research Collaboration to encourage and support collaboration among the agencies to advance the Nation's space weather research and operations capabilities. AGS and AST staff continued to represent NSF on the Space Weather Operations, Research, and Mitigation (SWORM) Subcommittee within the Committee on Homeland and National Security of NSTC. AGS continued to implement the goals and objectives identified in the National Space Weather Strategy and Action Plan (NSW-SAP). NSF focuses on the NSW-SAP objective to "improve observations and modeling for characterization and forecasting" of space weather.

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 (AST), within the Directorate for Mathematical and Physical Sciences, supports research in all areas of astronomy and astrophysics as well as related multidisciplinary studies. Because of the scale of modern astronomical research, the Division engages in numerous interagency and international collaborations. Areas of emphasis and the priorities of specific programs are guided by community recommendations, which have been developed and transmitted by National Research Council decadal surveys and by Federal advisory committees.

AST supports forefront merit-reviewed research in observational, theoretical, and laboratory astronomy to help ensure the scientific excellence of the U.S. astronomical community. The Division encourages broad understanding of the astronomical sciences by a diverse 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, outreach, and spectrum management.

AST seeks participation from all segments of the population and has contributed to funding opportunities that help broaden participation and develop the future generation of science leaders, including the Partnerships in Astronomy & Astrophysics Research and Education, Education and Special Programs, Research Experiences for Undergraduates, the Graduate Research Fellowship Program, Alliances for Graduate Education and the Professoriate, Astronomy and Astrophysics Postdoctoral Fellowships, Ascending Postdoctoral Research Fellowships, Launching Early-Career Academic Pathways, the Faculty Early Career Development Program, and Growing Research Access for Nationally Transformative Equity and Diversity.

An important component of the Astronomy Division's effort is supporting technology development and instrumentation. Solicitations request proposals for research projects with a range of scope, including Advanced Technologies and Instrumentation, the Major Research Instrumentation Program, and Mid-scale Research Infrastructure, providing direct benefit to both ground-based and space-based detector development. AST supported awards covering technologies and techniques for application in astronomy across the electromagnetic spectrum.

Many of the funded proposals will improve the interaction between U.S. industry and academic U.S. researchers so as to make feasible needed scientific measurements. An example of such a project includes establishing a U.S.-based design, foundry fabrication, and testing capability to advanced charge quantizing sensor chips that are needed in various astronomy, laboratory spectroscopy, and satellite applications, and advancing techniques for fabricating photonics devices to enable miniaturizing spectrographs and for coupling light from large optics into such instruments as is needed for the next generation of Extremely Large Telescopes. This project utilizes an emerging U.S.-based foundry for photonics fabrication and will expand

those capabilities. Another awarded program is developing significantly improved adaptive optics techniques to correct for atmospheric turbulence using post-processing combined with instrument telemetry and neural networks that will enable the Keck and Magellan Telescopes to produce their ultimate imaging performance. Another award supported new efforts of the Collaboration for Astronomy Signal Processing and Electronics Research that develops and maintains a collection of open-source hardware, software, libraries, and instrument designs that are used in, for example, the Event Horizon Telescope, but also drive instrument advances in brain research, genomics, radar applications, and neutron and magnetic field imaging.

Through merit review, AST provides access to world-class, ground-based research facilities. The NSF's national astronomical facilities include the National Radio Astronomy Observatory (NRAO), the Green Bank Observatory (GBO), NSF's National Optical-Infrared Astronomy Research Laboratory (NOIRLab), and the National Solar Observatory (NSO). This network of telescopes delivers data that directly test and challenge 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 (DKIST) carried out its second observing cycle in FY 2023 as part of its operations commissioning phase (OCP). An extended OCP is under way, including preparation for integration of the final instrumentation. One of DKIST's main objectives is to study solar magnetic fields at the smallest scales to better explain their behavior. This has helped scientists not only understand what makes our Sun and other stars "tick," but also be better prepared for Earth-impacting space weather events. Preliminary science results emerged at meetings over the last year. DKIST is the result of a collaboration of scientists from more than 20 institutions representing a broad segment of the U.S. solar physics community, and DKIST is now the world's flagship ground-based solar telescope designed specifically for the study of our Sun and its magnetic fields.

Staff from AST and from the Directorate for Geosciences' Division of AGS participated in the National Science and Technology Council's (NSTC) SWORM Working Group under the Space Weather, Security, and Hazards subcommittee. SWORM has continued to implement its program plan. 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. Concerns 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 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 received a record number of observing proposals (approximately 1,800) and 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 topics such as planets and planet formation, proto-stellar and debris disks, low- and high-mass star formation, stellar evolution, normal galaxies, galactic centers, and galaxy formation and evolution. Science highlights included the discovery of chemical signals of planet formation in circumstellar nebulae, the first detection of water in a protoplanetary disk, the most distant galaxy ever observed, and early-universe observations of supermassive black holes and galaxies in conjunction 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 twenty-eight 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, including radio galaxies, quasars, pulsars, supernova remnants, gamma-ray bursts, stars, the Sun and planets, astrophysical masers, black holes, and hydrogen gas in the Milky Way galaxy and other galaxies. The ongoing VLA Sky Survey is expected to discover ten million new radio sources and provide useful support to future observations by the Rubin Observatory and other multi-messenger astronomy projects. Highlights included the discovery of ammonia gas distribution in rare mega-storms on Saturn, challenging our understanding of how such storms form; observations that indicate cosmic rays drive winds and rob galaxies of gas to form stars; and evidence for the most powerful pulsar discovered, in a distant galaxy.

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 provide 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 and point to climate change.

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 reveals an asteroid's spin rate and direction and allows prediction of changes in its orbit. With the VLBA's timing accuracy, astronomers can keep an eye on

potentially devastating "killer" asteroids and monitor asteroids targeted for possible future human exploration.

NSF's 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 GHz to 116 GHz. The GBT's large sky coverage, very high sensitivity, wide wavelength coverage, and extensive suite of instruments enable work in nearly all areas of astrophysics, from pulsars and long wavelength gravitational waves to interstellar chemistry and physics. The GBT played a major role in the recent discovery of the long wavelength gravitational wave background. The GBT is complementary and synergistic with interferometric arrays. It is a highly sensitive and thus a critical element in very-long-baseline interferometry. It also 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 2023. The project has been re-baselined because of COVID-induced delays totaling nearly three years, with completion now projected late in 2025, and NSF has authorized additional funding to cover the full costs of COVID impacts. 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 open up the time domain and revolutionize the study of transient events. Rubin will also support planetary defense. Assuming other existing near-Earth object (NEO) efforts continue, by the end of Rubin Observatory's 10-year prime mission, the catalogue for objects larger than 140 meters across should be about 75 percent complete for NEOs (about 80 percent for potentially hazardous asteroids [PHAs]). Without Rubin Observatory, the completeness would be about 60 percent for NEOs (about 65 percent for PHAs).

Construction of the Rubin dome passed the milestone of closure, and the interior is thus protected from weather while the last details of the dome are completed. The telescope mount assembly is complete, and the project moved into commissioning of the optical and mechanical systems. Development of the data management system has continued apace. NSF's Federal partner, the Department of Energy (DOE), is funding the camera and maintenance of the U.S. data facility in a project led by the SLAC National Accelerator Laboratory. The camera construction is now complete, and SLAC is conducting electro-optical testing. 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. Federally funded pre-operations ramp-up activity continued through FY 2023.

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 continue to broaden and deepen our understanding of space environments. For example, in FY 2023, a team using the Dark Energy Camera on the Blanco 4-meter Telescope in Chile discovered three new NEOs hiding in the inner solar system, the region interior to the orbits of Earth and Venus. Only a few dozen asteroids with orbits completely within Earth's orbit have been discovered to date. This is a notoriously challenging region for observations because asteroid hunters must observe at twilight and must therefore contend with the glare of the Sun. One of the newly discovered NEOs is a 1.5-kilometer-wide asteroid called 2022 AP7, which has an orbit that may someday place it in Earth's path. With a surface that gets hot enough to melt lead, 2021 PH27 is the closest known asteroid to the Sun and displays the largest general-relativity effects of any object in our solar system.

AST continues 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 ESM 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 SWIFT program (Spectrum and Wireless Innovation enabled by Future Technologies), 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 fourth 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 (NRDZ) 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 and diverse workforce through education and training programs and has during the past year made significant investments in these areas.

NSF ESMU is also engaged in efforts in the optical domain, primarily due to coexistence issues between ground-based optical/infrared astronomy and satellite constellations. As an example of this engagement, NSF NOIRLab co-hosts the Centre for the Protection of the Dark and Quiet Sky from Satellite Constellation Interference of the International Astronomical Union. The Centre aims to mitigate the impact of satellite constellations on ground-based astronomical observations, including those by amateur astronomers and the general public.

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. This run includes approximately half of the planned instrument upgrade that will lead to an increase in detection sensitivity of about 70 percent. In the three months since the start of the run, LIGO had detected 33 events, or a third of 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 a large number of pulsars for timing deviations caused by gravitational waves. In June 2023, NANOGrav presented analysis pointing to the existence of 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.

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 Station McMurdo, 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. A total of 58 LDB science payloads have been successfully launched from McMurdo since the first interagency Memorandum of Understanding was signed in August 1988. Post COVID-19 pandemic, the LDB support program was restored during the

2022/2023 austral summer season with a successful launch and 16-day flight operation of the CMB payload instrument called SPIDER.

Other primary activities of the Office of Polar Programs included observations 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 constraints that SPT and BICEP telescopes have produced on primordial gravitational waves continued 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 consider gravitational lensing and foregrounds to unprecedented precision. One of the most important BICEP results published in 2023 addressed cosmological constraints. After many orders of magnitude improvement in the precision of measurements, primordial CMB fluctuations remain statistically isotropic. SPT astronomers discovered the most distant "relaxed" galaxy cluster to date—the farthest cluster ever spotted that is not being disrupted by violent collisions with other clusters; astronomers estimated the cluster has a mass some 700 trillion times that of our Sun. This galaxy cluster, named SPT2215, is 8.4 billion light-years from Earth and shows the universe when it was only 5.3 billion years old, compared to its current age of 13.8 billion years. This implies that the cluster got a head start in its formation and has been "coasting" for the last billion years, allowing it to relax. This finding has paved the way to learning how and when some of these gigantic structures form and why the universe looks like it does in the present day.

The IceCube Neutrino Observatory (ICNO), jointly operated at the South Pole by NSF's Office of Polar Programs and Division of Physics) has observed cosmogenic neutrinos—tiny, ghostlike astronomical messengers—with energies ranging from 100 gigaelectronvolts to tens of petaelectronvolts. The IceCube detector provided us an entirely new view of our own galaxy. The IceCube Collaboration, an international group of over 350 scientists, presented the first evidence of high-energy neutrino emission from the Milky Way. In FY 2023, for the first time, ICNO produced an image of the Milky Way in "neutrino light," a galaxy-wide picture of background neutrinos. 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

Through the longstanding NSF Small Business Innovation Research/Small Business Technology Transfer (SBIR/STTR) programs, NSF's Directorate for Technology, Innovation, and Partnerships (TIP) invested in technologies to be deployed outside Earth's atmosphere to

enhance the commercial use of space. The NSF SBIR/STTR programs funded startups and small businesses advancing technologies that are critical to U.S. leadership in space, including artificial intelligence and machine learning, edge computing, advanced energy, robotics and advanced manufacturing, communications technology, biotechnology, and digital health. Indeed, the NSF SBIR/STTR 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. For example:

Satellites, Internet, position navigation and timing, and weather data: NSF-funded companies are working toward position navigation and timing systems with expected advantages over GPS. Strategies employed focus on using small satellite radar to provide lower-cost and hourly coverage of wind data around the globe and using reusable stratospheric balloons to provide a lower-cost alternative to satellite data. These companies are advancing communications and wireless, disaster risk and resilience, and artificial intelligence.

Driving down rocket and launch costs; increasing space access: NSF-funded companies are developing a fully reusable rocket, innovative heat shielding, and 3D-printed affordable engines for small satellite launches. These companies are advancing advanced manufacturing and advanced materials.

In-space manufacturing: In-space manufacturing brings a wide range of advantages to advanced manufacturing back on Earth. The microgravity environment enables physics and chemistry that are not restricted by the force of gravity. Layer-by-layer deposition and self-assembly bring advantages for a range of fields from biology to semiconductors. One NSF-funded company has developed the first protein-based artificial retina and won two ISS National Lab Research Announcements to support its biomanufacturing in low Earth orbit. These companies are advancing biotechnology, cyberinfrastructure and advanced computing, semiconductors and microelectronics, artificial intelligence, and quantum information science.

In situ resource utilization and construction: NSF-funded off-planet research developed synthesized terrestrial materials (regolith simulants) on Earth to aid in the development of regolith processes and utilization, including lunar water extraction and geotechnical studies on altered regolith. One NSF-funded company demonstrated how regolith may be used for a wide range of applications from landing pad pavers to rover parts to habitat bricks. These companies are advancing Advanced manufacturing, advanced materials, and energy technologies.

Carbon utilization, food, and fuels: Carbon utilization is critical on Earth and in space. NSF invested in dozens of startups and small businesses engaged in the transformation of carbon dioxide to various fuels and materials. One of these companies announced a strategic partnership to accelerate the development of sustainable aviation fuel and won a $65 million Department of Defense contract with the U.S. Air Force to develop sustainable fuel. Other NSF-funded small businesses engaged in chemical transformations from carbon dioxide to fuels, polymers, and a range of materials and chemicals. These companies are advancing advanced manufacturing, biotechnology, and energy technologies.

Advanced energy and recycling with space applications: Several NSF-funded startups advanced energy technologies and energy storage for both terrestrial and in-space applications. In 2023, one such company announced that it will open a new lithium-ion battery recycling facility, while another opened the first domestic nickel and cobalt production refining facility. The TIP directorate has also funded a number of advanced propulsion, electromagnetic, nuclear and fusion technologies. These companies are advancing energy technologies, advanced manufacturing, and advanced materials.

Leveraging the broader NSF biology and digital health portfolios for space: As the United States sends more astronauts (both government and commercial) into space, there will be increased need for both advanced biological technologies and telehealth. NSF invested in digital health companies that provide a wide range of telehealth and remote treatment options for various health conditions and health monitoring needs. Several of these health- and biologically focused companies demonstrated interest in providing services in space. Other NSF awardees enhanced the cost-effectiveness of food production with new processes and advances. These companies are advancing biotechnology, cybersecurity, and cyberinfrastructure and advanced computing, and artificial intelligence.

NSF Regional Innovation Engines (NSF Engines): In May 2022, the TIP directorate launched the NSF Engines program, which aims to catalyze regional innovation ecosystems throughout the United States, and particularly in regions that have not participated in the technology boom of the past few decades. By fostering partnerships across industry, academia, government, nonprofits, civil society and communities of practice, the program seeks to catalyze and foster innovation ecosystems across the United States to: advance critical technologies like semiconductors, artificial intelligence, advanced wireless and biotechnology; address pressing national, societal, and geostrategic challenges; promote and stimulate economic growth and job creation; and spur regional innovation and talent. The inaugural portfolio of NSF Engines awards, announced by NSF and The White House on January 29, 2024, includes

the development of space technology. For example, the Paso del Norte Defense and Aerospace Innovation Engine and Piedmont Triad Regenerative Medicine Engine focus on in-space bio-manufacturing. These NSF Engines bring together a wide range of participants, including space ports, industry organizations, research institutions and universities (including Minority Serving Institutions) to advance their research objectives. In addition, these NSF Engines also focus on workforce development and education in space technology, seeking to harness the full geography and demography of innovation throughout the United States.

Co-chairing LEO commercialization and manufacturing: The TIP directorate also co-chairs the interagency working groups for the National Strategy in LEO, including in advanced manufacturing. A key subgroup is focused on expansion and increase in accessibility of capital formation for Space-Based Finance.

Catalyzing Higher Throughput In-Space R&D: The TIP directorate has worked closely with interagency colleagues to experiment with a wide range of initiatives to expand in-space access and output for translational R&D. This includes working closely with NASA's In-Space Manufacturing and the ISS to develop a "More Shots on Goal" approach for translational research to achieve competitive advantages for U.S. industries and societal benefits on an accelerated timeline. While this approach has initially focused on LEO where R&D infrastructure faces capacity constraints to date, the directorate has also received feedback that the move toward enhancing the level of R&D that may be accomplished with limited space and facilities is also highly relevant to future capacity constrained environments (including Mars initiatives). This joint high-throughput, in-space manufacturing initiative across leading agency and private sector participants has funded a growing number of researchers and companies. The funded work is increasing access to in-space R&D and amplifying the throughput of high-priority research for national advantage in several of the key technology focus areas enumerated in the CHIPS and Science Act (including in-depth focus in areas such as biotechnology, advanced materials, semiconductors, and AI and cybersecurity). This has included TIP funding a decentralized autonomous organization (DAO) with broad industry and interagency participation with working groups focused on in-space cybersecurity as well as high-throughput, advanced, in-space manufacturing. The DAO has benefitted from a wide range of participants across the government including NASA, the ISS, and U.S. Space Force, among others. These initiatives have also included engagement with a broad range of stakeholders to inform the needs for in-space capabilities and investment to support translational research and expansion of U.S. industry leadership in space.

Department of State

DOS

In FY 2023, 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 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, Verification and Compliance (AVC/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 AVC/ESC work in FY 2023 included the public release of the Department's first-ever Strategic Framework for Space Diplomacy; conclusion of ten years of negotiation on a bilateral space framework agreement with Japan; deeper collaboration between the United States and India on space; advancements in Global Navigation Satellite Systems (GNSS) interoperability, capability, and transparency regimes; and heightened U.S. advocacy and leadership in promoting responsible behavior in space, space security, and space STEM education and outreach.

Strategic Framework on Space Diplomacy

In May 2023, Secretary of State Antony Blinken released the Department's first-ever Strategic Framework on Space Diplomacy. This groundbreaking document outlines how diplomatic

efforts will promote continued U.S. leadership and expand international cooperation on mutually beneficial activities in space. The Strategic Framework also provides detailed guidance on how U.S. diplomacy will promote responsible behavior from all space actors; strengthen the understanding of and support for U.S. national space policies and programs; and promote global use of U.S. space capabilities, systems, and services. This Strategic Framework outlines actions for the Department across three pillars: (1) Diplomacy for Space: Advancing space policy for the benefit of future generations, (2) Space for Diplomacy: Leveraging U.S. space activities for wider diplomatic goals, and (3) Empowering the Department Workforce on Space Diplomacy.[1]

UN Committee on the Peaceful Uses of Outer Space

In FY 2023, 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 (UNCOPUOS) and its Scientific and Technical Subcommittee (STSC) and Legal Subcommittee (LSC). Across all sessions, OES/SA utilized negotiations to promote shared global norms and responsible behavior in space, as well as Long-Term Sustainability (LTS) goals. At the 60th STSC session in February 2023, U.S. Ambassador Laura Holgate highlighted the visual and scientific achievements of NASA's James Webb Space Telescope, noted the first major step toward effective planetary defense with NASA's Double Asteroid Redirection Test mission, and celebrated the United States' journey back to the Moon and onward to Mars with the launch and recovery of NASA's Artemis I test flight.

At the 62nd session of the LSC in March 2023, Department experts led negotiations to shape global governance of space activities, including the legal and regulatory environment for space, and to uphold and strengthen a rules-based international order for space. Through the LSC's Working Group on Legal Aspects of Space Resource Activities, OES/SA and other U.S. experts promoted practical and effective policies and practices for space resource utilization, helping address diverging opinions at the international level on issues such as what constitutes a space resource, what is considered "national appropriation," and how space resources can be utilized safely and responsibly.

OES/SA also led the U.S. delegation to the 66th UNCOPUOS Plenary in June 2023, where Ambassador Holgate highlighted recent space strategies, such as the National Preparedness Strategy and Action Plan for Near Earth Objects and Planetary Defense, National Cislunar Science and Technology Strategy, National LEO Research and Development Strategy, and Strategic Framework for Space Diplomacy. The U.S. delegation highlighted the

1 The Strategic Framework is publicly available at https://www.state.gov/united-states-leads-in-space-with-diplomacy/.

close connection between multilateral bodies like UNCOPUOS and U.S. strategies related to outer space, demonstrating the United States' commitment to work closely with international partners and to operate responsibly, safely, and cooperatively in outer space. UNCOPUOS adopted several proposals in June 2023, including plans for an STSC 2024 LTS Working Group and the Space Resources Working Group, which reached consensus on the modalities for an expert meeting and international conference in 2024. A U.S.-led effort to build consensus around agenda and modalities reform at UNCOPUOS bore fruit, promising more time for substantive discussions in future meetings.

Space Security

During the 77th sessions of the UN General Assembly (UNGA) in fall 2022, AVC/ESC advanced U.S. policy principles and goals regarding space security and sustainability in UNGA's First and Fourth Committees. These engagements, which included a joint panel discussion of the two committees, highlighted U.S. commitment to international cooperation to preserve the safety, stability, security, and long-term sustainability of outer space activities. U.S. delegations also reiterated long-standing commitments to consideration of proposals and concepts for arms control measures that are equitable and effectively verifiable and that enhance the national security of the United States and its allies.

At the 77th session of UNGA, the United States urged all nations to join the United States in making a commitment to refrain from conducting destructive, direct-ascent anti-satellite (DA-ASAT) testing as outlined in UNGA Resolution 77/41, which was adopted by UNGA on December 7, 2022. In parallel, AVC led bilateral security discussions to encourage other countries to make national commitments to refrain from DA-ASAT testing. By September 30, 2023, 35 other nations had made such commitments.

The United States also participated in two meetings of a UN Open-Ended Working Group (OEWG) on Reducing Space Threats through Norms, Rules, and Principles of Responsible Behavior on January 30 to February 3 and August 28 to September 1, 2023. The United States submitted proposals for seven voluntary, non–legally binding norms, rules, and principles of responsible State behavior. In its submission, the United States noted these proposals could serve as a starting point for developing specific measures that are consistent with the criteria recommended by the 2013 Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities. Although the OEWG was regrettably unable to adopt a report, the United States and nearly all other participants noted that the discussions were valuable and should continue. Such multilateral discussions can also build upon the more positive outcome of UN Disarmament Commission discussions on space transparency and confidence-building measures in April 2023.

Global Navigation Satellite Systems (GNSS)

International Committee on Global Navigation Satellite Systems: In October 2022, OES/SA led the U.S. delegation to the 16th meeting of the International Committee on GNSS (ICG), hosted by the United Arab Emirates in Abu Dhabi. OES/SA also cochaired the ICG Working Group on Systems, Signals, and Services, where a recommendation on GNSS resilience was adopted by the Committee. Under the ICG, NASA led a subgroup focused on space service use and made significant progress in their efforts to promote GNSS usage in space. The ICG continues to provide a platform for multilateral discussions on important GNSS topics, focused on system compatibility, interoperability, and transparency in service provision. The United States also organized an ICG workshop on GNSS interference detection and mitigation in December 2022 and a workshop on commercial aspects of LEO positioning, navigation, and timing systems in June 2023.

GNSS Technical Working Groups with Japan and the Republic of Korea: The United States and the Republic of Korea (ROK) established a GNSS Technical Working Group (TWG) in March 2023, during a meeting in Seoul, that will focus on technical compatibility issues related to GPS and the Korean Positioning System. A Joint Statement was signed between the two countries on the margin of the meeting, outlining the establishment of the TWG. The United States also hosted a group of technical GNSS experts from the ROK in Colorado in September 2023, providing them with a tour of the GPS Operations Center in Colorado Springs and facilitating a meeting and tour of the National Institute for Standards and Technology (NIST) Time and Frequency Center in Boulder, Colorado. The United States also held a GNSS TWG meeting with Japan in Tokyo in March, focused on discussing compatibility issues related to GPS and QZSS, the Japanese government's GNSS.

U.S.-EU GPS-Galileo Agreement Extension: In December 2022, the United States and European Union (EU) completed a five-year extension to the 2004 GPS-Galileo Cooperation Agreement. This Agreement provides the mechanism for enhanced cooperation between the United States and EU on issues related to GPS and Galileo, including the establishment of four working groups. Three of the working groups remain active, including the Working Group on Next Generation GNSS Services, which met twice during FY 2023. The Working Group on Compatibility and Interoperability held a cochairs meeting in June 2023, focused on planning and preparation for a full working group meeting.

Europe: 12th U.S.-EU Space Dialogue: AVC Assistant Secretary Mallory Stewart and OES Acting Assistant Secretary Jennifer R. Littlejohn co-led the U.S. delegation to the 12th U.S.-EU Space Dialogue in Brussels. Discussions included important cooperation on GNSS, Earth Observation and its applications, Space Situational Awareness, the safety of spaceflight, and LTS. The agenda also included a dedicated focus on space security, this year in the context of the March 2023 Joint Communication on and EU Space Strategy for Security and Defence, including space cybersecurity and multilateral engagement. The U.S. delegation also included representatives from the UGS, NOAA, NASA, the FAA, and the Departments of Homeland Security, Commerce, Defense, and State. The EU delegation was led by Timo Pesonen, Director-General of the European Commission's Directorate-General for Defense Industry and Space (DG DEFIS), and Benedikta von Seherr-Thoss, Managing Director for Common Security and Defense Policy and Crisis Response at the European External Action Service (EEAS). Experts from DG DEFIS, EEAS, the European Space Agency, the European Space Programme Agency, and the European Organisation for the Exploitation of Meteorological Satellites also participated.

Eighth U.S.-India Civil Space Joint Working Group: OES/SA and NASA's Office of International and Interagency Relations organized the Eighth U.S.-India Civil Space Joint Working Group (CSJWG) in Washington on January 30 and 31, 2023. Noteworthy this year was the high level of representation from both governments, including NASA Administrator Bill Nelson, ISRO Chairman S. Somanath, U.S. Assistant Secretary of State for South and Central Asia Don Lu, Executive Secretary of the U.S. National Space Council Chirag Parikh, and Indian Ambassador to the United States Taranjit Singh. The U.S. delegation was cochaired by OES Principal Deputy Assistant Secretary Jennifer R. Littlejohn and NASA Associate Administrator for International and Interagency Relations Karen Feldstein. The Indian delegation was led by Shantanu Bhatawdekar, Scientific Secretary for ISRO. The work of the CSJWG covers all areas of bilateral civil space cooperation and has four working groups (Earth Science, Planetary Science, Heliophysics, and Human Spaceflight Program) that meet regularly. New working groups were proposed, including one for space commerce.

U.S.-India Space STEM Workshop: In facilitating the CSJWG's space STEM outreach goals and those of the Biden-Harris space STEM workforce and other STEM-related strategies and initiatives, OES/SA and The George Washington University's Space Policy Institute cohosted a workshop in June 2023 on "U.S.-India Space STEM for Women and Girls: Challenges and Solutions." The four-hour roundtable included prominent guest speakers such as astronaut

Sirisha Bandla and Indian American female space scientists from NASA. The event also included an acclaimed Indian American author and space policy experts from governments, the private sector, and civil society.

France: First Meeting of the U.S.-France Comprehensive Dialogue: OES/SA and AVC/ESC supported the organization of the first meeting of the U.S.-France Comprehensive Dialogue on Space in Paris on November 10, 2022. This meeting was cochaired by representatives from the National Space Council and National Security Council for the United States and by representatives from the Secretariat-General for Defense and National Security and the Ministry of Europe and Foreign Affairs of France. Other U.S. participants included the Departments of Defense, Commerce, Homeland Security, and Transportation; NASA; and the Office of the Director of National Intelligence.

The convening of this first Comprehensive Dialogue on Space began an initiative announced by Vice President Kamala Harris and French President Emmanuel Macron in November 2021 to ensure a whole-of-government approach to bilateral space cooperation. This Dialogue underscored the importance of more than 60 years of U.S.-French collaboration in space and recognized the growing nexus of civil, commercial, and national security space activities and the increasingly interconnected nature of all three sectors. At the inaugural meeting, U.S. and French officials exchanged information on respective space policies, including the U.S. Space Priorities Framework and U.S. National Security Strategy and France's national-level space policies and strategies. Both sides reiterated their determination to expand robust bilateral cooperation on topics like addressing the climate crisis; developing and implementing guidelines and norms, rules, and principles of responsible behavior to promote LTS of the outer space environment, as well as the security and stability of space activities; advancing national security space cooperation; and enabling a sustainable space economy that preserves the benefits of space for future generations.

Participants recognized the important contributions of the private sector in expanding our capabilities in outer space and welcomed efforts to strengthen industry cooperation. Both sides acknowledged a shared desire to create a safe and transparent environment for commercial activities in outer space, including evolving and emerging space activities, by clarifying government and private-sector roles and responsibilities and supporting a timely and responsive regulatory environment. To create a free and fair market competition internationally, both sides noted the need to update and harmonize space policies, regulations, and other measures that govern commercial activities worldwide.

Japan: Eighth Meeting of the U.S.-Japan Space Comprehensive Dialogue: AVC/ESC and OES/SA also supported the organization of the Eighth Meeting of the U.S.-Japan

Comprehensive Dialogue on Space in Tokyo on March 24, 2023. This meeting was cochaired by representatives of the Ministry of Foreign Affairs and National Space Policy Secretariat in the Cabinet Office for Japan and by representatives from the Executive Office of the President's National Space Council and National Security Council for the United States. Additional U.S. participants included the Departments of Defense, Transportation, and Commerce; NASA; the Office of the Director of National Intelligence; and the Office of the National Cyber Director.

At this meeting, U.S. and Japanese experts shared updates on national space policies and strategies, including the U.S. Space Priorities Framework as well as Japan's upcoming revision of the Basic Plan on Space Policy. The U.S. delegation also shared views on threats to space and the use of space by strategic competitors. In this regard, both sides recalled the recognition that attacks to, from, or within space, in certain circumstances, could lead to the invocation of Article V of the Japan-U.S. Security Treaty. In discussions on the new U.S. National Cybersecurity Strategy, both sides affirmed the importance of cybersecurity for enabling future space cooperation. In civil space, the U.S. delegation emphasized the necessity of embracing open-source science to advance mutual science and innovation goals; meet economic, industrial, and foreign policy objectives; and advance solutions that meet climate objectives and improve life on Earth for citizens of Japan, the United States, and nations around the world.

Prior to this meeting, OES/SA and the Department of State's Office of the Legal Advisor concluded over 10 years of negotiations on a new U.S.-Japan Framework Agreement for Cooperation in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, for Peaceful Purposes. This Framework was signed in January 2023 by Japanese Prime Minister Kishida Fumio, Foreign Minister Hayashi Yoshimasa, and NASA Administrator Bill Nelson. The agreement will facilitate deeper collaboration on a wide range of space activities, including lunar science; Earth science; space operations and exploration, including lunar operations and exploration; aeronautical science and technology; space technology; space transportation; safety and mission assurance; and related topics.

Multilateral Diplomacy

Artemis Accords: OES/SA led the Department's collaboration with NASA to promote international participation in the Artemis Accords. The Artemis Accords are a non-binding political commitment to the safe, sustainable, and responsible exploration and use of outer space, as the United States and its partners and allies return to the Moon and journey beyond. In FY 2023, after concerted diplomatic efforts, OES/SA was pleased that seven new countries decided to join the Artemis Accords, including the first two African nations (Rwanda and Nigeria) and major spacefaring nations like India and Germany. This fiscal year also saw the formation of the first signatory working groups to advance the implementation of the Artemis Accords,

as well as the convening of two meetings of Heads of Space Agencies on the margins of the International Astronautical Congress in Paris in October 2022 and Baku in October 2023.

International Lunar Year: In support of the Office of Science and Technology Policy's (OSTP) 2022 National Cislunar Science & Technology Strategy, the Department of State worked together with NASA, NOAA, the NSF, and OSTP to kick off targeted outreach to the wider space science community on the concept of an International Lunar Year (ILY). For example, OES/SA delivered a presentation to UN Member States at UNCOPUOS, as well as in-person briefings to leading scientific institutions and academic and technical conferences. Building on historical precedents from astronomy, polar research, and geophysics, an ILY will promote collaboration between like-minded countries and experts to raise awareness of and coordinate lunar science in the coming decade.

Luxembourg: OES/SA and the U.S. Embassy in Luxembourg organized a one-day space workshop in conjunction with the EU's Governmental Satellite Communications Conference, hosted by the Government of Luxembourg, focused primarily on the European space industry. Approximately 25 U.S. experts attended this workshop from U.S. Embassies in the EU region, as well as the Department of Defense, NASA, and the FAA. U.S. Ambassador to Luxembourg Thomas Barrett opened the workshop and hosted a reception for local officials, industry, and workshop participants.

Western Hemisphere: OES/SA participated in the U.S. delegation to the AmeriGEO Week held in Costa Rica on August 7–10, 2023, to enhance collaboration among national experts under the Group on Earth Observations. OES/SA participants helped promote inclusive, comprehensive, and sustained Earth observations to address biodiversity conservation, disaster risk reduction, public health, water management, and climate change adaptation. U.S. experts also highlighted the importance of the Artemis Accords in promoting the peaceful and sustainable exploration of space. The Central American Climate Change Network session marked a significant milestone, aiming to unite climate and social scientists from the region. In September 2023, OES/SA also spoke on a panel on "Space and Scientific Diplomacy" at the first-ever Central American Space Congress in San Jose, Costa Rica.

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 use of national investments in science and technology. DOE directly supports research and operations of facilities at our 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.[1] Finally, DOE's laboratories conduct research selected and supported by their Laboratory Directed Research and Development programs that aligns with NASA missions. Overall, this portfolio of work within the DOE is aligned to four major goals:

- power the exploration of space,
- support the secure and peaceful use of space,
- solve the mysteries of space, and
- enable the development of space.

Each of these areas has aspects that support NASA's overall mission.

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

1 See https://science.osti.gov/lp/Strategic-Partnership-Projects and https://www.energy.gov/nnsa/strategic-partnership-projects-spp for further information. SPP was previously known as Work for Others prior to December 2016.

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 2023, DOE through NE did the following:

- Implemented documented safety analysis for lightweight Radioisotope Heater Units and General Purpose Heat Source (GPHS) modules.
- Developed a preliminary Safety Design Strategy, which will be used to prepare the Safety Analysis Report for the Dragonfly mission.
- Progressed toward fabrication of an electrically heated Multi-mission Radioisotope Thermoelectric Generator (MMRTG) flight unit with mission-unique features for Dragonfly.
- Supported MMRTG compatibility assessments for the lunar environment.

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; optimizing processes; and maintaining, modernizing, and replacing equipment and infrastructure. DOE supported CRP activities in FY 2023, including the following, to meet CRP goals of 1.5 kg/year average annual production rate of heat source plutonium oxide and average annual production of 10–15 fueled clads/year:

- Approximately 0.5 kilograms of heat source plutonium oxide was shipped from Oak Ridge National Laboratory (ORNL) to Los Alamos National Laboratory (LANL).
- Np-237 targets were irradiated in the High Flux Isotope Reactor (HFIR) at ORNL and the Advanced Test Reactor at Idaho National Laboratory (INL).
- Flight-quality fuel clads were manufactured and packaged at LANL and shipped to INL in support of the Dragonfly mission.
- Process optimization was performed by reducing the chemical processing and separations steps needed in the production of heat source material and by developing sustainable waste removal processes.
- The production of specialized components, including Carbon-bonded Carbon Fiber, iridium alloy blanks/foils, Clad Vent Sets, and Lightweight Radioisotope Heater Units clad components, was maintained at ORNL.

- A comprehensive assessment of the equipment at LANL was performed to reduce manufacturing risks and risks from aging systems and equipment, such as replacing the Radiography Cabinet, Astro Furnaces, and Limited Volume Chilled Circulating Water Systems, and installing the Hot Press Furnace Line.
- Equipment replacement and refurbishment activities were conducted at INL to reduce risks, including the Space Security and Power Systems Facility (SSPSF) roof refurbishment and SSPSF vibration system power amplifier upgrade.

RPS Technology Development Activities

In FY 2023, DOE through NE continued to provide technical expertise, procurement coordination, and planning and support to NASA in conducting basic and applied energy conversion research and development to advance state-of-the-art performance in heat-to-electrical-energy conversion. Static energy conversion projects are under way with the goal of providing higher conversion efficiency and improving mission performance over design lifetime. DOE continued to work with NASA on the delivery of a next-generation radioisotope thermoelectric generator (NGRTG).

DOE continued the development of concepts and identification of risks for NGRTGs. A legacy GPHS-RTG unit will be refurbished for use as Mod-0 as a risk mitigation for development of the new NGRTG design. In FY 2023, DOE completed two system checkpoints for Mod-0: an electric heat source health check and reverse heat pump check.

In FY 2023, DOE completed the Enhancement Assessment for NGRTG Mod-1 and held the System Requirements/System Definition Review at INL with Aerojet Rocketdyne and designated peer review members. All action items from the review were recorded in Request for Action.

Surface Fission System Development

DOE through NE provides 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-kW electric nuclear reactor on the Moon by the end of the decade. In September 2022, DOE awarded 12-month design contracts to three teams for their design proposals.[2] In FY 2023, each of the three contract teams successfully delivered on an intermediate milestone, culminating in a successful closeout review in August 2023. The deliverables included detailing each team's conceptual design along with a cost and schedule estimate to provide both a ground demonstration qualification unit and a flight unit.

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2 Press release available at https://inl.gov/article/battelle-energy-alliance-nasa-select-industry-partners-to-design-nuclear-power-system-for-lunar-applications/.

In FY 2023, DOE successfully completed all milestones for the first year of development as outlined in the Technology Maturation Plan, which provides technical direction for government-funded technology development efforts that support FSP. These milestones included the fabrication and thermal testing of a notional Yttrium-Hydride (YH) moderator element along with the delivery of key technical reports: an assessment of technology gaps for FSP instrumentation and control components, an evaluation of potential design solutions to reduce the mass of FSP radiation shielding, and, lastly, test plans for YH moderator elements including both thermal and criticality testing.

Nuclear Thermal Propulsion System Development

Through NE, DOE provides technical support for Nuclear Thermal Propulsion (NTP) system development. In FY 2023, DOE focused on experimental activities and contract design.

Experimental Activities. DOE completed irradiation testing of the Sirius-2c fuel samples in the Transient Reactor Test (TREAT) facility at INL. The irradiation experiments are intended to simulate NTP operational conditions to determine the limits of fuel performance. The Sirius fuel samples, made at INL, were the first ceramic-ceramic (cercer) fuel compacts for the NTP irradiation testing program. DOE continued to work with unirradiated cercer material to refine fabrication methods and to characterize thermal properties of the material and the coatings used on cercer fuel particles. Additionally, DOE started the construction of a gaseous hydrogen supply system at TREAT to allow hydrogen exposure during future irradiation experiments. Construction is expected to be completed in FY 2024.

Contract Design. DOE worked with NASA on the RFP development and contract procurement for NTP reactor design activities. Industry teams led by BWX Technologies, Inc.; General Atomics, Inc.; and Ultrasafe Nuclear Technologies, Inc., successfully completed design contracts issued by INL in FY 2022. Each contractor developed a reactor design and supporting information used to evaluate the potential for future development. In FY 2023, DOE supported $5 million award extensions to two of the teams, one led by General Atomics and the other by Ultrasafe, for an additional 12 months of design work on their respective designs.

Support the Secure and Peaceful Use of Space

In FY 2023, 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, DOD, and the Department of Homeland Security 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 NEO impacts. The NEO plan has five 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 2023, 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.

In addition, DOE continued to support NASA's Double Asteroid Redirection Test (DART) by providing essential numerical methods and multi-dimensional simulation results. The details of DOE's technical support to DART impact modeling were documented through peer-reviewed papers. On September 26, 2022, the DART spacecraft successfully impacted asteroid Dimorphos. DOE expertise is being leveraged to simulate the impact in 3D, with high-fidelity representations of the DART spacecraft and the rubble pile asteroid target. These simulations provide improved understanding to NASA of the geodynamics of impact mitigation procedures and improve the validation basis and international credibility of DOE/NNSA's multi-physics codes through accurate pre-impact predictions and high-fidelity post-impact analysis.

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 2023, 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 2023, 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 Memorandum of Understanding (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 NSF, and the OSTP. In FY 2023, the IWG completed, and OSTP released, the "National Low Earth Orbit Research and Development Strategy,"[3] which provides an interagency strategy and action plan to enable Federal agencies across the U.S. Government to collaborate on the continued development and sustainment of LEO as an R&D destination through the end of the International Space Station's life and transition to commercial LEO destinations.

Plasma Science

DOE, through its Fusion Energy Science program, supports frontier plasma science research that contributes to DOE-NASA mutual interests in the knowledge of heliospheric and astrophysical systems. In FY 2023, 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

3 https://www.whitehouse.gov/wp-content/uploads/2023/03/NATIONAL-LEO-RD-STRATEGY-033123.pdf

of Wisconsin–Madison (high-fidelity measurements of magnetic reconnection, dynamo, turbulence, and particle-energization processes); and the Magnetorotational Instability (MRI) experiment (accretion processes involving star and planet formation) device at the Princeton Plasma Physics Laboratory (PPPL). Recently, PPPL researchers, through computer simulations and validation using MRI data, discovered an instability mechanism believed to be behind astrophysical disk accretion rates. Approximately two years ago, NASA made a few multi-year awards to PPPL to support research focusing on predicting the potentially damaging effects of blasts of subatomic particles from the Sun. These awards have extended PPPL's extensive history in space and astrophysical plasma research. PPPL, which has been collaborating with NASA's Magnetospheric Multiscale mission since it was launched in 2015, is now installing 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 and Astrophysics

In FY 2023, DOE through its High Energy Physics (HEP) program continued to support fundamental physics 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.

The AMS science goals include a search for evidence of dark matter and cosmic domains of antimatter, as well as 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, for example, 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 have been collected. During FY 2023, DOE continued to work with NASA and the AMS Collaboration to ensure the AMS scientific data are 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 at least 2030. Following DOE and NASA discussions, NASA approved this upgrade, which requires an additional EVA orbital crew for installation. NASA is conducting a series of technical reviews to ensure the upgrade can be installed safely and efficiently, with minimum impact on other ISS science payloads. A DOE review is planned for early FY 2024 and will assess the status of AMS, including the upgrade.

The Large Area Telescope (LAT), the primary instrument on FGST in orbit approximately 565 km above Earth, entered its 16th year of successful operations and data analysis on such topics as searches for dark matter and high-energy particle acceleration mechanisms. In FY 2023, the collaboration published results on searches for candidate dark matter particles. The team analyzed the spectra of three radio quasars that were flaring in the gamma-ray spectrum to search for axions. No evidence was found, though increased exclusion limits were placed on axion mass and couplings. The collaboration also published a study of Milky Way dwarf spheroidal galaxy systematic errors that were not previously considered, impacting the current indirect dark matter limits from these galaxies. Following NASA's senior review in early 2022, FGST was approved for an extension of operations through at least 2026. DOE will continue to support critical science operations for the LAT at the SLAC National Accelerator Laboratory.

DOE continued its role building and operating ground-based observatories (in partnership with the National Science Foundation) to carry out microwave, optical, and near-infrared imaging, as well as spectroscopic surveys. 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 to work 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 Rubin Observatory (survey to start in mid- to late 2025).[4] Rubin Observatory's ten-year survey, along with existing searches of objects larger than 140 meters in diameter, will discover and catalog approximately 75 percent of near-Earth objects and 80 percent of potentially hazardous asteroids with orbits having a high probability of crossing Earth's path someday.

4 NASA was directed in 2005 to catalog 90 percent of potentially hazardous asteroids.

In FY 2023, DOE and NASA continued development of the LuSEE-Nightmission, a partnership with the Space Sciences Laboratory (SSL) in Berkeley, California. LuSEE-Night will deliver a new instrument package, developed through a partnership of two DOE laboratories, 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-cm 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). A final design review was held at the end of FY 2023, with instrumentation delivery to SSL planned for mid-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 radiation 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, through the Advanced Scientific Computing Research and High Energy Physics programs, continued to support 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 Lawrence Berkeley National Laboratory (LBNL) made significant contributions to science funded by NASA, conducted by NASA researchers, and of direct relevance to NASA projects and missions. In FY 2023, NERSC hosted 25 researchers from NASA research centers, 19 projects that received NASA funding, and an additional 11 with direct relevance to NASA programs. Among the projects were GEOS on GPUs, Neutron Star Mergers: Nucleosynthesis and Multimessenger Emissions, development of analysis and calibration capabilities for the Nancy Grace Roman Space Telescope, more than six studies on magnetic reconnection in various space environments, and a project to support the EUSO Super Pressure Balloon telescopes.

Since 2020, more than 300 refereed scientific publications have referenced both NERSC and NASA.

The Advanced Scientific Computing Research (ASCR) Leadership Computing Facilities, as part of DOE's Exascale Computing Project, made significant contributions to space science projects. Fourteen projects at the Argonne Leadership Computing Facility and the Oak Ridge Leadership Computing Facility cited funding support from NASA in FY 2023. These projects spanned a wide range of topics from computational fluid dynamics research in the search for fuel-efficient jet engines, to creating a digital twin of Earth to simulate weather and climate at ultra-high resolutions, to modeling the fluid flow in small modular reactors. Computer allocations for this work were made through the ASCR Leadership Computing Challenge and Innovative and Novel Computational Impact on Theory and Experiment programs.

Atmospheric Science and Terrestrial Ecology

DOE, through the Biological and Environmental Research program, engaged in many collaborative research efforts with NASA in the areas of atmospheric science and terrestrial ecology. During FY 2023, DOE's 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 carbon dioxide concentrations. ARM provided support for ground-based measurements of carbon dioxide 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 (formerly Barrow), 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. In FY 2023, ARM supported the deployment of a G-band radar from the NASA Jet Propulsion Laboratory during the Eastern Pacific Cloud Aerosol Precipitation Experiment in La Jolla, California. The deployment helped to quantify the capabilities and limitations of the emerging technology of G-band radars for constraining stratocumulus cloud microphysics. 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 renewed Memorandum of Agreement) with the NASA Arctic-Boreal Vulnerability Experiment to couple real-time ground-based and airborne-based measurements of soil moisture, temperature, carbon dioxide, and methane flux 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 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

DOE, through the Nuclear Physics (NP) program, supported fundamental research on nuclear reactions of astrophysical interest, contributing knowledge to DOE and NASA interests in stellar evolution, neutron star mergers, gamma-ray bursts, and the composition of interstellar space. Neutron stars are extremely condensed stellar objects at supranuclear densities. The nucleon density is so high in supranuclear matter that the mean internucleon separation becomes less than the range of internucleon forces, suggesting more exotic forms of matter within neutron stars. Researchers supported by the NP program leveraged electromagnetic radiation data from NASA's Neutron Star Interior Composition Explorer to study the properties of such supranuclear systems.[5]

Through outreach, DOE and NASA staff have worked together in the Nuclear Data InterAgency Working Group, a Federal-level working group led by DOE's NP program in the Office of Science, to coordinate and prioritize nuclear data needs for Federal programs. In FY 2023, DOE continued discussions on addressing nuclear data needs for human spaceflight safety, planetary exploration, and electronics protection from radiation, including from cosmic-ray interactions with spacecraft. Those discussions included the use of the Relativistic Heavy Ion Collider at Brookhaven National Laboratory to collect nuclear data for elements important for human safety in space and electronics resiliency. An outcome of the FY 2023 Nuclear Data InterAgency Working Group funding opportunity announcement was an award to a project on neutron-induced reactions for elements found in the solar system. Data from this project will help inform the NASA Dragonfly mission to Saturn's moon Titan. Nuclear data needs

5 A recent paper highlighting this research at https://doi.org/10.1103/PhysRevD.107.123017 describes a successful effort to increase the range of nuclear phenomenology efficiently available to astrophysical model simulations.

for space applications were included in the interim report from the Nuclear Science Advisory Committee charge on nuclear data needs, published in September 2022.

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 at DOE's Brookhaven National Laboratory (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.[6] The work advances the understanding of the link between ionizing radiation and cell damage. NASA continued to provide funding in FY 2023 to support the operation of DOE's 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 2023. Representative techniques and their applications used in FY 2023 included scanning transmission x-ray microscopy and x-ray absorption near edge structure spectroscopy at the Advanced Light Source to map the composition and diversity of macromolecular organic matter with spatial resolution below 30 nm, scanning transmission electron microscopy at the Molecular Foundry to determine elemental composition and iron redox states at the surface and in the bulk of samples returned from the asteroid Ryugu by JAXA's Hayabusa2 spacecraft, and performing neutron radiography and computed tomography imaging with the Multimodal Advanced Radiography Station at the High Flux Isotope Reactor to study the distribution of minerals in lunar samples returned during the original Apollo missions.[7]

Isotope R&D and Production

DOE, through the Office of Isotope R&D and Production (DOE IP), supplied critical isotopes for NASA space-related R&D and applications in FY 2023. The DOE IP also supplied helium-3 to NASA for use in detectors and cryogenics; mercury-199 and mercury-202

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6 A recent paper highlighting research available at https://doi.org/10.1016/j.lssr.2022.09.001 describes the development of a galactic cosmic-ray simulator for modeling space missions.

7 Investigators found a surprising level of diversity in the composition of organic matter within the samples. The data suggest Ryugu's organic matter formed in the interstellar medium or solar system's protoplanetary disk nearly 4.6 billion years ago and was incorporated into Ryugu's parent body, where it reacted to varying degrees with liquid water. See https://als.lbl.gov/vestiges-of-the-early-solar-system-in-ryugu-asteroid/. An international team of investigators, utilizing a range of electron microscopy and x-ray synchrotron techniques, characterized the effect of space weathering on Ryugu grains, finding evidence of surface dehydration rather than bulk volatile loss. See https://www.nature.com/articles/s41550-022-01841-6#Sec2. Characterization of the lunar samples with neutrons provided researchers with a 3D model of the distribution of hydrogen. Understanding how hydrogen is stored and transported in lunar materials provides both a clearer picture of the Moon's history to the present day and insight into how lunar material can be used for future space missions. See https://www.ornl.gov/news/50-years-after-nasas-apollo-mission-moon-rocks-still-have-secrets-reveal.

for atomic clock research; rubidium-87 for navigation satellite systems; and aluminum-26, holmium-163, and curium-244 for astrophysics research.

Enable the Development of Space

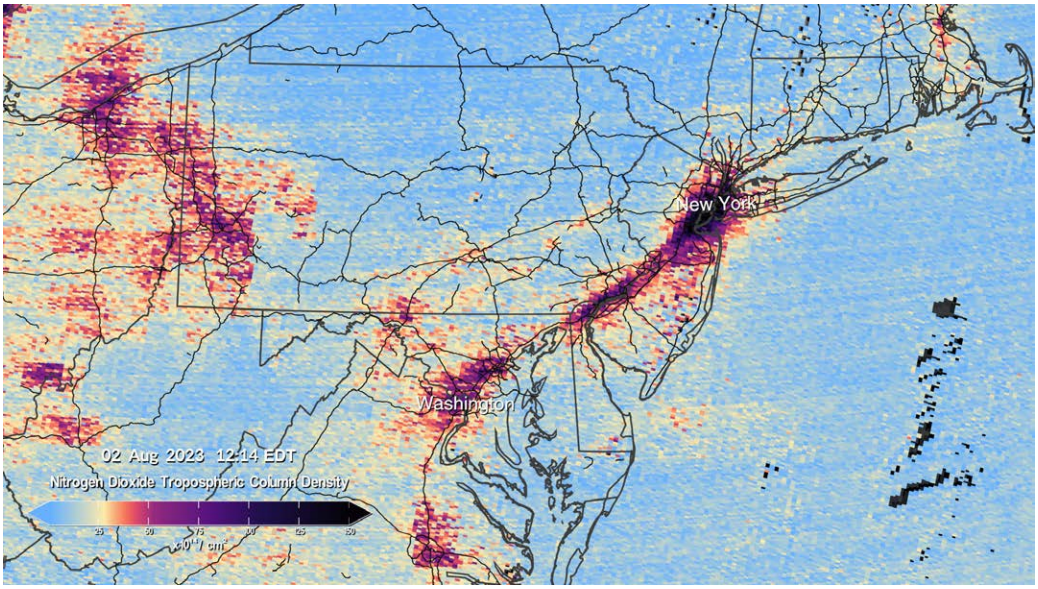
In FY 2023, DOE through the Solar Energy Technologies Office (SETO) worked on reducing the cost and increasing the efficiency of III-V photovoltaic cells, as well as improving the efficiency and stability of perovskite solar cells, including perovskite cells on lightweight and flexible substrates. In FY 2023, the National Renewable Energy Laboratory (NREL) focused on supporting substrate reuse research, lowering cell costs, and optimizing III-V multijunction cell efficiency for terrestrial applications. Additionally, continued to provide cell calibrations and measurements, including those under the AM0 (extraterrestrial) solar spectrum. In FY 2023, 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.

Smithsonian Institution

The Smithsonian Institution continued to make internationally recognized contributions to national aerospace programs, discoveries, and public education in FY 2023. The Smithsonian Units contributing to this effort include the Smithsonian Astrophysical Observatory, the National Museum of Natural History, and the National Air and Space Museum. These efforts demonstrate the long-standing commitment of the Smithsonian to supporting world-leading space technology, record-breaking discoveries, and impactful education and public engagement about space.

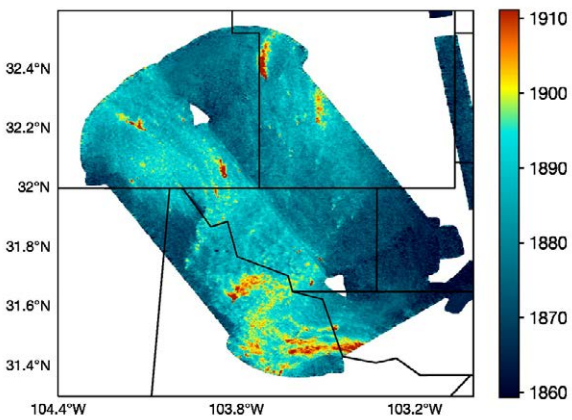
The Smithsonian Astrophysical Observatory (SAO) is a partner of the Center for Astrophysics | Harvard & Smithsonian in Cambridge, Massachusetts, and represents the largest component of the Smithsonian's space contributors. The organization has more than 400 scientists, engineers, and telescope staff engaged in a broad program of research in astronomy, astrophysics, Earth and space sciences, and science education.

After ten years of work by SAO as the Principal Investigator (PI) institution, the NASA-Smithsonian Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument launched in April 2023. As shown below, TEMPO is the first space-based instrument to measure air quality over North America hourly during the daytime and at spatial regions of several square miles—far better than existing limits of about 100 square miles in the United States. TEMPO has initiated a new era of exquisite air-quality monitoring over North America, enabling studies of rush hour pollution, the effects of lightning on ozone, the movement of pollution from forest fires and volcanoes, and even the effects of fertilizer application. The impact of TEMPO on public health will be considerable, with its data leading to more effective air-quality warnings, helping individuals with preexisting respiratory conditions, and informing larger policy decisions on air quality. TEMPO has already had strong public engagement as one of the Smithsonian's most popular Instagram stories and the top-performing press release on nasa.gov in 2023.



TEMPO measured six hourly scans of atmospheric pollution over North America for the first time on August 2, 2023. The image shows nitrogen dioxide levels over the DC/Philadelphia/New York region and the I-95 corridor in the U.S. northeast at 12:14 ET.

SAO also plays a leading role in MethaneSAT, an Environmental Defense Fund mission funded by philanthropic donors to address climate change. MethaneSAT has been completely built and is under final testing before the scheduled launch into a low-Earth orbit in early 2024. MethaneSAT will determine global methane concentrations and leakage rates from 80 percent of global oil and gas fields (see figure below), enabling methane emissions reductions from the oil and gas industry by 70 percent by 2030. SAO has been involved in the MethaneSAT project since its inception in 2015 and led the building of its airborne precursor instrument, MethaneAIR. MethaneAIR has been flying on a dedicated Learjet for 40–60 hours each month since May 2023 to augment MethaneSAT data collection, mapping and quantifying methane from basins encompassing roughly 80 percent of U.S. onshore productions.



Observations of methane concentrations over the oil and gas infrastructure of the Permian Basin by MethaneAIR. The northern edge shows a methane plume extending for 20 km over an oil- and gas-gathering pipeline, with an estimated methane leakage rate of ~5,000 kg/h. The leakage was a result of pipeline rupture by high line pressure, and it was reported 15 days later by the operator.

In FY 2023, SAO scientists continued leading a series of experiments to study the Sun. In October 2023, the Extreme ultraviolet Coronal Mass Ejection and Coronal Connectivity Observatory (ECCCO) was selected for a Phase A study in NASA's Heliophysics Small Explorers competition, with SAO as the PI institution. ECCCO will contribute to understanding the middle corona, the dynamics of eruptive events leaving the Sun, and the conditions that produce the outward streaming solar wind. In FY 2023, the Solar Dynamics Observatory spacecraft photographed the Sun in ten different wavelength bands once every 12 seconds, producing the most spectacular images ever recorded of the active surface of the Sun. SAO contributes to the operations, calibration, and science of NASA's Interface Region Imaging Spectrograph satellite, which provides information on energy transfer in the Sun's lower atmosphere and a better understanding of the physical processes powering solar flares. Finally, the SAO-built X-ray Telescope on the joint U.S./Japan/Europe mission Hinode is the only currently operating imager of the Sun in the x-ray region of the spectrum, and its data provide important constraints on the temperatures of structures in the solar corona.

SAO also 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 completed the sixth of seven planned encounters with Venus and four successful plunges into the solar atmosphere this year. Along the way, the SWEAP team made the closest-ever measurements of the million-degree plasma that surrounds and emanates from the Sun. In FY 2023, SAO scientists presented evidence that the Sun's atmosphere and the solar winds are energized by magnetic jets, operating like waves of very small solar flares that sweep across the Sun. Among other firsts, the team also studied a major coronal mass ejection—an eruption of the sort that would produce strong aurorae and technological disruptions if directed at Earth—by flying through it during the eruption. They were able to identify the magnetic structures and the origins of energetic particle radiation in these types of eruptions, which are key for forecasting hazards in space.

SAO operates the Minor Planet Center (MPC), which is the single worldwide location for receipt and distribution of positional measurements of minor planets, comets, and outer irregular natural satellites of the major planets. The MPC received and processed over 6 million observations from the NEOWISE and Transiting Exoplanet Survey Satellite (TESS) spacecraft missions respectively during FY 2023, allowing the MPC to improve the calculated orbits for 29,647 comets, near-Earth objects, and main belt asteroids.

SAO is also responsible for orchestrating the follow-up observations needed to confirm and characterize the planet candidates identified by NASA's TESS mission, now in its sixth year of operation. SAO's telescopes at the Whipple Observatory on Mount Hopkins in Arizona play a major role in this work. As of September 1, 2023, TESS data had been used in 1,475

peer-reviewed publications, of which 41 percent were for exoplanet studies and 59 percent for other astrophysics.

SAO scientists are members of NASA's SPHEREx science team, which progressed in Phase C of its mission development during FY 2023. SAO SPHEREx scientists and their collaborators supported two successful external reviews of spectral reduction software they designed, and they analyzed James Webb Space Telescope's (JWST) Near-Infrared Spectrograph spectra to establish the absolute photometric calibration of this observatory. They also published two refereed papers describing the roughly nine million galactic targets that SPHEREx will observe during its four all-sky infrared spectral surveys.

The Chandra X-ray Observatory continues to deliver critical discoveries about a wide range of questions across astrophysics. While conceived and developed before the discovery of exoplanets (that is, planets outside our solar system), Chandra is making important headway in our understanding of these distant worlds and the stars they orbit. For example, a result published in FY 2023 showed, through Chandra's x-ray data, that some exoplanets are slowing down the aging process of their host star.

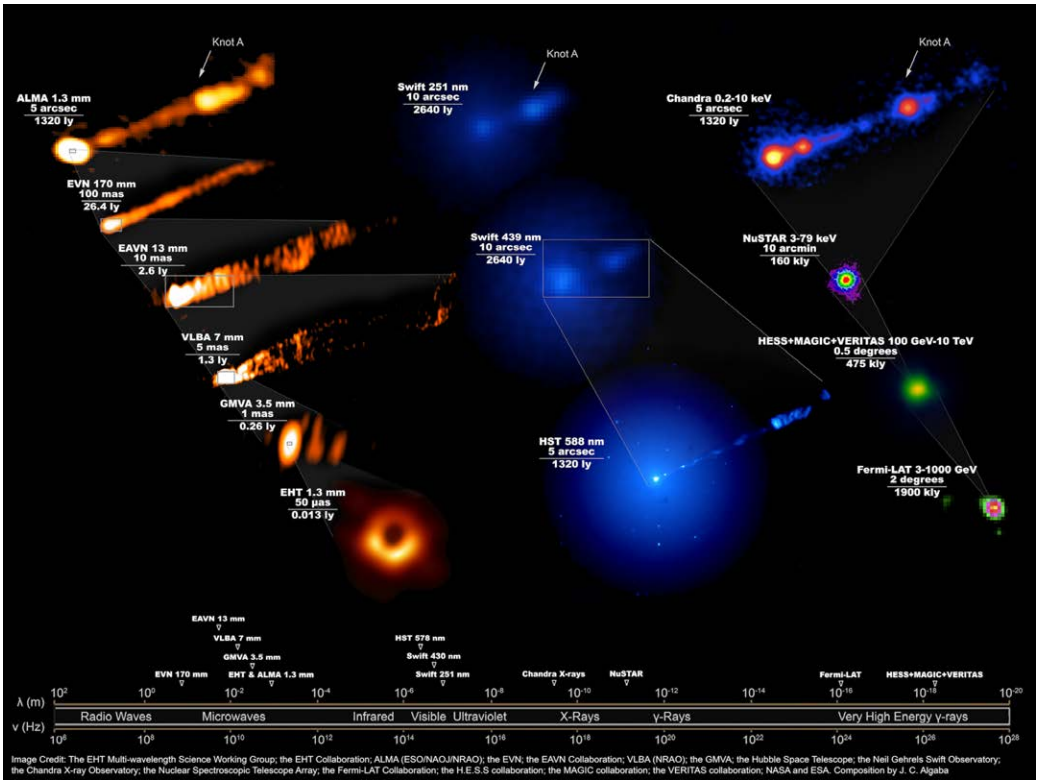
For its nearly quarter century of operations, Chandra has been known for its exploration of black holes, and FY 2023 was no exception. One of the most notable results involved study of a "tidal disruption event" where a black hole tore apart a star that wandered too close. Researchers used Chandra data to identify elements in the debris of the destroyed star, showing that the star was unusually massive.

Another significant finding from Chandra probed the evolution of some of the largest known objects over all of cosmic time. A team discovered that a very distant galaxy cluster—some 8.4 billion light-years from Earth—shows no evidence for violent collisions in an era when such events should have been common. This result provides insight into how these cosmic megastructures grow and evolve from the earliest epochs of the universe through today.

The Chandra Communications and Public Engagement group had a string of successful and well-received programs during FY 2023. These included the sonification project, which Chandra has led on behalf of NASA, which translates astronomical data into sounds and musical notes.[1] Chandra's sonification work was part of a panel discussion at the South by Southwest festival in March 2023, featured on the Apple Music and Spotify platforms, as well as being the topics on numerous podcasts throughout the year.

SAO astronomers also play leading roles across the Event Horizon Telescope (EHT), the global array of radio telescopes that captured the first images of black holes. In FY 2023, the EHT jointly observed with the newly launched JWST and the Imaging X-ray Polarimetry Explorer for the first time. This observing campaign also included observations with additional

1 https://chandra.si.edu/sound/



Composite image showing the M87 galaxy across the entire electromagnetic spectrum. The EHT provides the highest angular resolution in astronomy, revealing the supermassive black hole at the heart of the galaxy. The full view of this galaxy requires 19 different facilities across Earth and in space.

NASA observatories including Swift, Chandra, and NuSTAR. As shown in the figure below, coordinated observations of this type are crucial for studies of flaring emission from supermassive black holes, which extends across the entire electromagnetic spectrum, from radio wavelengths to gamma rays.

The Smithsonian National Museum of Natural History (NMNH) continued, through the Department of Mineral Sciences and the Offices of Education and Exhibits, its mission of education, research, and curation related to space exploration. In a regular year, approximately one million people visit the Moon, Meteorites and Solar System Gallery of the Geology, Gems and Meteorites Hall. At this gallery, they can see one of the finest displays of meteorites anywhere in the world, ranging from presolar diamonds separated from the Allende meteorite to the carbonate-bearing Allan Hills 84001 meteorite, which spurred the debate about past microbial life on Mars, to impactites including a square-meter section of the Cretaceous-Tertiary (K–T) boundary.

The collections of the Division of Meteorites continue to grow. Notably, the Smithsonian's partnership with the NSF and NASA in the U.S. Antarctic Meteorite Program surpassed

23,400 individual meteorites collected in Antarctica, including samples from Mars, the Moon, and numerous poorly known asteroids. Provided free of charge to qualified scientists, these samples have addressed fundamental questions about the origin and evolution of our solar system. After cancellations of the previous three field seasons due to the COVID pandemic, preparations in FY 2023 led to the selection of the U.S. Antarctic Meteorite Program for a return to collecting in the 2023–2024 Antarctic summer.

Scientists in the Department of Mineral Sciences remain engaged in the study of meteorites and asteroids to unravel their origin in the early solar nebula, their evolution on asteroids, the differentiation of asteroids in the early history of the solar system, and the geologic evolution of Mars. Glenn MacPherson continues his work on understanding processes in the solar nebula and linking observations made in the laboratory with those made from astronomical observations. His research is focused on a possible periodicity in the formation of the solar system's first components related to episodic T Tauri activity observed in forming stars. Catherine Corrigan continues her studies of fragments of meteorites formed during melting caused by collisions. Age-dating these samples is key to understanding the extent and duration of the intense impact history of the early solar system. She is a Co-Investigator in the Apollo Next Generation Sample Analysis Program, studying drill cores collected by Apollo 17 but not opened for 50 years. These cores promise to reveal the stratigraphy of the near-surface, including regolith movement, impact gardening, and interactions with the solar wind. NMNH scientists remain actively engaged in spacecraft missions, with Tim McCoy serving as Co-Investigator on the OSIRIS-REx and Psyche missions. The OSIRIS-REx Sample Return Capsule, bearing samples of the asteroid Bennu, returned to the Utah Test and Training Range on September 24, 2023. By the end of that month, a team at Johnson Space Center analyzed the first samples from that mission (see image below). NMNH is preparing a public exhibit of the first sample of Bennu, scheduled to open in November 2023.

The OSIRIS-REx sample return canister after opening at Johnson Space Center.

FY 2023 also saw final preparations for the launch of the Psyche mission in October 2023. The Psyche spacecraft will visit the asteroid of the same name, which is a 200-kilometer-diameter asteroid thought to be composed of metallic iron, similar to Earth's metallic core. McCoy is leading the efforts to constrain the oxidation-reduction conditions of the asteroid, which is a major control on its mineralogy and constrains its formation in time and space.

The National Air and Space Museum (NASM) selected Perkins & Will as the architect for the Bezos Learning Center, which will be built on the east end of the NASM National Mall Building (NMB). NASM launched the first Center program, a design challenge for student and young professional architects. The individuals who created the selected design will receive a paid, term position on the design team.

At the NMB, the American Institute of Graphic Arts (AIGA) selected the Kenneth C. Griffin Exploring the Planets exhibition as a winner of the 365: AIGA Year in Design competition. The exhibition also received a Special Achievement Award for Design as part of the Smithsonian Excellence in Exhibitions Awards program.

Planetary science at NASM's Center for Earth and Planetary Studies (CEPS) spanned much of the solar system. Dr. Jennifer Whitten is the Associate Deputy Principal Investigator of the Venus Emissivity, Radio Science, InSAR, Topography and Spectroscopy (VERITAS) mission to Venus now in development, as well as a member of the European Space Agency's EnVision VenSAR instrument team. Dr. Bruce Campbell is an instrument team member on the upcoming VERITAS and DaVinci missions to Venus, including the radar system co-lead on VERITAS. His recent work highlights the importance of the rugged highlands of Venus to understanding the planet's geologic history, and how Magellan and VERITAS mission data will enable a search for ongoing volcanic activity. Dr. Ellen Stofan, Under Secretary for Science and Research at the Smithsonian, is also a member of the VERITAS Science Team. She is also a Co-Investigator on the Dragonfly mission, a dual quadcopter that will explore the largest moon of Saturn, Titan, sampling materials in different geologic settings and determining its surface composition.

Dr. Tom Watters used Lunar Reconnaissance Orbiter and Apollo Passive Seismic Experiment data to evaluate possible seismic hazards in and around the proposed south polar landing sites on the Moon for the Artemis III astronauts.

CEPS has long-standing depth in studies of Mars. Dr. John Grant served on the science teams for the Curiosity rover, InSight lander, and HiRISE camera on the Mars Reconnaissance Orbiter (MRO). As a participating scientist on Curiosity, Dr. Sharon Purdy helped to guide the rover's investigation of young deposits that may have formed by late-occurring water in Gale crater. Drs. Purdy and Grant also targeted the orbiting HiRISE high-resolution camera. The Geological Society of America elected Dr. Purdy as a Fellow to recognize her sustained, distinguished contributions to geosciences and the Society. Sounding radar studies of Martian ice

and sediment included the Mars Advanced Radar for Subsurface and Ionospheric Sounding on the European Mars Express spacecraft and the Shallow Radar instrument on MRO. Dr. Bob Craddock's comparison of Martian valley network drainage basins to rivers on Earth showed that the climate of early Mars was probably semi-arid.

Dr. Erica Jawin participated on the OSIRIS-REx mission to the asteroid Bennu and the new extended mission to asteroid Apophis, OSIRIS-APEX. She analyzed boulders on Bennu and made predictions for the Bennu sample returned to Earth.

On some icy moons in the outer solar system, subsurface water over bedrock may create present-day habitable environments. Dr. Emily Martin is a co-investigator on a $2 million grant from the Precursor Science Investigations for Europa program. She was appointed to the National Academies of Sciences' Committee on Astrobiology and Planetary Science. Dr. Bruce Campbell serves as a science team member on the active Jupiter Icy Moons Explorer and upcoming Europa Clipper missions to Jupiter's moons.

Following the successful reopening of the NMB west end in October 2022, the NASM Aeronautics Department continued work on aviation-related galleries in the central core and east end of the building. The reimagined and reinterpreted Boeing Milestones of Flight Hall and Barron Hilton Pioneers of Flight gallery are scheduled to open in 2024. The completely

The We All Fly gallery in the National Air and Space Museum's west end examines the importance of general aviation in modern life.

new World War I, World War II, and Modern Military Aviation galleries will follow, along with the How Things Fly interactive gallery, developed by the NASM Education Department in close cooperation with the Aeronautics Department. A series of new exhibitions in the Flight in the Arts gallery will complement these efforts.

Aeronautics curator and internationally noted professor of aerodynamics Dr. John Anderson published the seventh edition of his landmark text *Fundamentals of Aerodynamics* with coauthor Christopher Cadou.

Significant collections continued while the NMB was under construction. Dr. Roger Connor acquired the Reagan National Airport crash truck "Foam 331" that responded to the attack on the Pentagon on 9/11. It was restored by the donor and is now exhibited at NASM's Udvar-Hazy Center. As part of the efforts to create the new Modern Military gallery, Dr. Michael Hankins collected a late-model North American F-86F. Dr. Jeremy Kinney coordinated the acquisition and delivery of the Boeing B-17G "Shoo Shoo Shoo Baby," a World War II heavy bomber and combat veteran of the Eighth Air Force. Dr. Hankins and Dr. Alex Spencer collected additional flight clothing and memorabilia of Colonel Kim Campbell, who was one of the first U.S. Air Force female pilots to see combat and a veteran of the 2003 Iraq War. Dr. Spencer also collected the memorabilia of World War II German Luftwaffe Junkers Ju 88 bomber pilot Ernst Staib.

The Aeronautics Department provided content for the Aviation Adventures Lecture Series, which featured prominent authors and participants. They spoke on civil rights leader Representative Charles C. Diggs and his efforts to desegregate the airline industry in the 1950s, the innovative Orbis Flying Eye Hospital, Colonel Merryl Tengesdal's career as the first Black woman to fly the legendary Lockheed U-2 reconnaissance airplane, and the remarkable career of the aerobatic pilot Sean Tucker.

The American Institute of Aeronautics and Astronautics selected Department of Space History curator Dr. Cathleen Lewis's book *Cosmonaut: A Cultural History* as the winner of the AIAA History Manuscript Award. The department published two more scholarly books this year: Dr. Margaret Weitekamp's *Space Craze: America's Enduring Fascination with Real and Imagined Spaceflight* and Dr. Matthew Shindell's *For the Love of Mars: A Human History of the Red Planet*. Drs. Shindell and Weitekamp coauthored a revised and expanded second edition of the book *Spaceships: An Illustrated History of the Real and the Imagined* with original author Ron Miller. Curator emeritus Dr. Paul Ceruzzi's *Computer Driven World: A New History of Modern Computer Development* was translated into Chinese by Liu Taoying.

Dr. Emily Margolis joined Space History as the first curator of contemporary spaceflight. Curator Dr. Samantha Thompson was elected to the American Astronomical Society Working Group for the Preservation of Astronomical Heritage. Dr. Mathew Shindell was elected secretary of the History of Science Society. The National World War II Museum published an oral

history interview of retired Senior Curator Michael Neufeld's that highlighted his career as a curator and historian.

NASM educators continued to spark audience curiosity and empower learners to imagine the possibilities of the future. Throughout 2023, the Education team went fully hybrid, connecting with learners both online and onsite.

A corps of paid youth, the Explainers, facilitated drop-in, hands-on learning experiences for over 500,000 visitors at the NMB and Udvar-Hazy Center combined. Facilitated activities range from understanding life and work in space to exploring the principles of flight through a paper airplane flying contest. In 2023, the team introduced a new node to the Explainers Program: Remote Explainers are located across the country and facilitate online experiences for youth and student audiences, like Virtual Planetarium Shows and Virtual Science Demonstrations.

The closure of the Phoebe Waterman Haas Observatory at the NMB provided the Astronomy Education team with an opportunity to "pop up" and engage learners in new ways and places. In 2023, Astronomy Educators and Volunteers facilitated Sun observation at the Eisenhower Memorial routinely on Fridays and Saturdays; engaged lecture attendees in stargazing, post-lecture, as they departed the Museum; and presented Second Saturday Sungazing outside the entrance to the Udvar-Hazy Center. In all, Astronomy Education at the National Air and Space Museum helped more than 18,000 individuals to look up and observe the sky.

The Museum's Education team continued to focus energy on intentionally engaging audiences who did not cross our physical thresholds. A new Learning Resources hub featured on the Museum's website, launched at the end of 2022, was utilized by audiences in all 50 states and 62 countries. Airspace, a podcast for young professionals, had more than 230,000 downloads.

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
TOTAL	**2,115**	**177**	**127**	**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.

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				

(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
1991	20	62			2	1			9	1					
1992	31	55			2	3			7	2					
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
TOTAL	**1,866**	**3,181**	**10**	**8**	**119**	**543**	**1**	**1**	**304**	**84**	**10**	**7**	**3**	**4**	**35**

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.

Appendix B-1

Successful Launches to Orbit or Beyond on U.S. Vehicles

October 1, 2022–September 30, 2023 (FY 2023)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
October 1, 2022 Serenity TechEdSat-15 FOSSASAT-1B GENESIS-G and -J QUBIK-3 and -4 2022-122 *Firefly Alpha*	Education Technology Demonstration Technology Demonstration Amateur Radio Technology Demonstration	Partially successful due to lower-than-planned orbit. Satellites were deployed but reentered before reaching their intended design life.
October 4, 2022 SES-20 and SES-21 2022-123 *Atlas V 531*	Communications	Final flight of the Atlas V 531 configuration.
October 5, 2022 Crew Dragon 5 2022-124 *Falcon 9 v1.2 Block 5*	International Space Station Crew Rotation	Fifth operational Crew Dragon mission (see Appendix C).
October 5, 2022 Starlink v1.5 G 4-29-1 to -52 2022-125 *Falcon 9 v1.2 Block 5*	Communications	The 34th launch of 52 Starlink Block v1.5 satellites.
October 7, 2022 GAzelle (Argos-4) 2022-127 *Electron KS*	Communications	Small satellite carrying multiple payloads including Argos-4.
October 8, 2022 Galaxy 33 and 34 2022-128 *Falcon 9 v1.2 Block 5*	Communications	Part of the Galaxy series of communications satellites operated by Intelsat.
October 15, 2022 Hotbird 13F 2022-134 *Falcon 9 v1.2 Block 5*	Communications	Direct broadcasting satellite.
October 20, 2022 Starlink v1.5 G 4-36-1 to -54 2022-136 *Falcon 9 v1.2 Block 5*	Communications	The 35th launch of 54 Starlink Block v1.5 satellites.
October 28, 2022 Starlink v1.5 G 4-31-1 to -53 2022-141 *Falcon 9 v1.2 Block 5*	Communications	The 36th launch of 53 Starlink Block v1.5 satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Remarks
November 1, 2022 LDPE-2 Shepherd Demonstration TETRA11 Alpine LINUSS 1 and 2 USA 344 2022-144 *Falcon Heavy Block 5*	 Space Tug Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration	U.S. Space Force 44 mission carrying several CubeSats to geosynchronous orbit.
November 3, 2022 Hotbird 13G 2022-146 *Falcon 9 v1.2 Block 5*	Communications	Part of the Hotbird communications constellation operated by Eutelsat.
November 4, 2022 MATS 2022-147 *Electron*	Science and Technology	Swedish National Space Agency payload for gravity wave observation launched from Mahia, New Zealand.
November 7, 2022 Cygnus NG-18 PearlAfricaSat-1 SpaceTuna1 TAKA ZIMSAT-1 2022-149 *Antares 230+*	 ISS Logistics Earth Observation Technology Demonstration Earth Observation Earth Observation	Cargo resupply docked with ISS for 163 days. Payload included four CubeSats.
November 10, 2022 JPSS 2 LOFTID 2022-150 *Atlas V 401*	 Meteorology Technology Demonstration	Final Atlas V launch from Vandenberg and final flight of the 401 configuration.
November 12, 2022 Galaxy 31 and 32 2022-153 *Falcon 9 v1.2 Block 5*	Communications	Part of the Galaxy series of communications satellites operated by Intelsat.
November 16, 2022 Artemis I BioSentinel CuSP LunaH-Map Lunar-IceCube NEA-Scout LnIR EQUULEUS OMOTENASHI ArgoMoon Team Miles 2022-156 *SLS Block 1*	 Technology Demonstration Astrobiology Space Weather Lunar Orbiter Lunar Orbiter Technology Demonstration Technology Demonstration Technology Demonstration Lunar Lander Technology Demonstration Technology Demonstration	Maiden flight of the SLS rocket with the Orion spacecraft. 10 CubeSats were deployed, of which CuSP, Lunar IceCube, NEA-Scout and OMOTENASHI experienced spacecraft failures.
November 23, 2022 Eutelsat 10B 2022-157 *Falcon 9 v1.2 Block 5*	Communications	Geosynchronous communications satellite operated by Eutelsat.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
November 26, 2022 Dragon CRS-26 PetitSat SPORT MARIO TJREVERB LORIS ORCASat DanteSat NUTSat HSKSAT OPTIMAL-1 SS-1 2022-159 *Falcon 9 v1.2 Block 5*	 ISS Logistics Technology Demonstration Ionospheric Research Technology Demonstration Technology Demonstration Education Education Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Education	Cargo resupply docked with ISS for 43 days. Payload included 11 CubeSats.
December 8, 2022 OneWeb L15-1 to -40 2022-166 *Falcon 9 v1.2 Block 5*	Communications	Launch of 40 satellites in the OneWeb constellation.
December 11, 2022 Hakuto-R Mission 1 Rashid SORA-Q Lunar Flashlight 2022-168 *Falcon 9 v1.2 Block 5*	 Lunar Lander Lunar Rover Lunar Rover Lunar Orbiter	Hakuto-R Mission 1 was a private Japanese lunar lander carrying the United Arab Emirates' Rashid and Tomy and JAXA's SORA-Q payloads. Crashed on lunar surface on April 25, 2023. NASA's Lunar Flashlight CubeSat failed to enter lunar orbit.
December 16, 2022 SWOT 2022-173 *Falcon 9 v1.2 Block 5*	Earth Observation	Satellite altimeter providing global measurements of water bodies.
December 17, 2022 Starlink v1.5 G 4-37-1 to -54 2022-175 *Falcon 9 v1.2 Block 5*	Communications	The 37th launch of 54 Starlink Block v1.5 satellites.
December 28, 2022 Starlink v1.5 G 5-1-1 to -54 2022-177 *Falcon 9 v1.2 Block 5*	Communications	First launch for Shell 5 of the Starlink constellation, and the 38th launch of 54 Starlink Block v1.5 satellite.
December 30, 2022 EROS C3-1 2022-179 *Falcon 9 v1.2 Block 5*	Earth Observation	Israeli commercial satellite in a retrograde orbit.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
January 3, 2023		Dedicated SmallSat Rideshare mission. Three CubeSats and two PocketQubes (MDQSAT-1A and 1B and Unicorn-2G and 2H) failed to deploy from the Falcon 9 second stage.
YAM 5	Payload Hosting	
Lynk Tower 03 and 04	Communications	
Umbra-SAR 04 and 05	Earth Observation	
EOS-SAT 1	Earth Observation	
ICEYE X21, X22, and X27	Earth Observation	
NuSat 32 to 35	Earth Observation	
Skykraft 1	CubeSat Deployer	
Skykraft 1A to 1D	Air Traffic Management	
Chimera LEO-1	Space Tug	
ION-SCV 007 and 008	CubeSat Deployers	
Astrocast 0401 to 0404	Internet of Things	
Futura SM1 and SM3	Technology Demonstration	
Kelpie 1	Internet of Things	
Sharjah-Sat 1	Technology Demonstration	
TAU-SAT 2	Technology Demonstration	
Orbiter SN1	Space Tug	
MDQSAT 1A and 1B	Internet of Things	
PROVES-Yearling	Technology Demonstration	
Sapling 1	Technology Demonstration	
Unicorn 2G and 2H	Earth Observation	
Vigoride 5	Space Tug	
ZEUS 1	Technology Demonstration	
KSF 3A to 3D	Navigation	
Flock-4y 1 to 36	Earth Observation	
Lemur-2 157 to 162	Earth Observation	
SpaceBEE 156 to 167	Communications	
EWS-RROCI	Earth Observation	
BRO 8	Signals Intelligence	
Gama Alpha	Technology Demonstration	
Menut	Earth Observation	
MilSpace2 1 and 2	Technology Demonstration	
NSLSat 2	Communications	
Platform 2 (SharedSat 2211)	Payload Hosting	
STAR-VIBE	Earth Observation	
Sternula 1	AIS Ship Tracking	
EYE 1 (Star Sphere 1)	Earth Observation	
Connecta T1.2	Internet of Things	
Guardian Alpha	Technology Demonstration	
PolyITAN-HP-30 (QBUA01)	Technology Demonstration	
KuwaitSat 1	Technology Demonstration	
BDSAT 2	Amateur Radio	
Pushan Alpha	Space Weather	
2023-001		
Falcon 9 v1.2 Block 5		
January 10, 2023		Launch of 40 satellites in the OneWeb constellation.
OneWeb L16-1 to -40	Communications	
2023-004		
Falcon 9 v1.2 Block 5		
January 15, 2023		U.S. Space Force mission.
CBAS 2	Military Communications	
LDPE 3A	Technology Demonstration	
2023-008		
Falcon Heavy Block 5		

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Remarks
January 18, 2023 GPS 3-06 2023-009 *Falcon 9 v1.2 Block 5*	Navigation	Launch of the sixth of the third-generation GPS satellites.
January 19, 2023 Starlink v1.5 G2-4-1 to -51 2023-010 *Falcon 9 v1.2 Block 5*	Communications	The 39th launch of 51 Starlink Block v1.5 satellites.
January 24, 2023 Hawk 6A, 6B, and 6C 2023-011 *Electron KS*	Signals Intelligence	Launch of three small satellites in the Hawk constellation.
January 26, 2023 Starlink v1.5 G5-2-1 to -56 2023-013 *Falcon 9 v1.2 Block 5*	Communications	The 40th launch of 56 Starlink Block v1.5 satellites.
January 31, 2023 Starlink v1.5 G2-6-1 to -49 ION-SCR 009 2023-014 *Falcon 9 v1.2 Block 5*	Communications	The 41st launch of 49 Starlink Block v1.5 satellites.
February 2, 2023 Starlink v1.5 G5-3-1 to -53 2023-015 *Falcon 9 v1.2 Block 5*	Communications	The 42nd launch of 53 Starlink Block v1.5 satellites.
February 7, 2023 Amazonas Nexus 2023-017 *Falcon 9 v1.2 Block 5*	Communications	Launch of geostationary communications satellite operated by Hispasat.
February 12, 2023 Starlink v1.5 G5-4-1 to -55 2023-020 *Falcon 9 v1.2 Block 5*	Communications	Launch of 55 Starlink Block v1.5 satellites.
February 17, 2023 Starlink v1.5 G2-5-1 to -51 2023-021 *Falcon 9 v1.2 Block 5*	Communications	Launch of 51 Starlink Block v1.5 satellites.
February 18, 2023 Inmarsat-6 F2 2023-022 *Falcon 9 v1.2 Block 5*	Communications	British satellite in geosynchronous orbit.
February 27, 2023 Starlink v2-Mini G6-1-1 to -21 2023-026 *Falcon 9 v1.2 Block 5*	Communications	First launch of 21 Starlink V2-Mini satellites.
March 2, 2023 Crew Dragon 6 2023-027 *Falcon 9 v1.2 Block 5*	International Space Station Crew Rotation	Sixth operational Crew Dragon mission (see Appendix C).

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
March 3, 2023 Starlink v1.5 G2-7-1 to -51 2023-028 *Falcon 9 v1.2 Block 5*	Communications	Launch of 51 Starlink Block v1.5 satellites.
March 9, 2023 OneWeb L17-1 to -40 2023-029 *Falcon 9 v1.2 Block 5*	Communications	Launch of 40 satellites in the OneWeb constellation.
March 15, 2023 Dragon CRS-27 STP-H9 ARKSAT 1 LightCube Ex-Alta 2 AuroraSat YukonSat NEUDOSE 2023-033 *Falcon 9 v1.2 Block 5*	ISS Logistics Technology Demonstration	Cargo resupply docked with ISS for 30 days. Payload included the STP-H9 technology demonstration mission and six CubeSats.
March 16, 2023 Capella 9 and 10 2023-035 *Electron KS*	Earth Observation	Launch of two Synthetic Aperture Radar (SAR) satellites in the Capella constellation.
March 17, 2023 Starlink v1.5 G2-8-1 to -52 2023-037 *Falcon 9 v1.2 Block 5*	Communications	Launch of 52 Starlink Block v1.5 satellites.
March 17, 2023 SES 18 and 19 2023-038 *Falcon 9 v1.2 Block 5*	Communications	Launch of two C-band only communications satellites into geosynchronous orbit.
March 24, 2023 BlackSky 18 and 19 2023-041 *Electron KS*	Earth Observation	Launched from Mahia, New Zealand.
March 24, 2023 Starlink v1.5 G5-5-1 to -56 2023-042 *Falcon 9 v1.2 Block 5*	Communications	Launch of 56 Starlink Block v1.5 satellites.
March 29, 2023 Starlink v1.5 G5-10-1 to -56 2023-046 *Falcon 9 v1.2 Block 5*	Communications	Launch of 56 Starlink Block v1.5 satellites.
April 4, 2023 Transport Layer Tranche 0 ×8 Tracking Layer Tranche 0 ×2 2023-050 *Falcon 9 v1.2 Block 5*	Military Communications Military Tracking	First launch for DOD's Space Development Agency's Tranche 0 Transport and Tracking Layer.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
April 7, 2023 Intelsat 40e with TEMPO 2023-052 *Falcon 9 v1.2 Block 5*	Communications and Earth Observation	TEMPO, the first payload under NASA's Earth Venture Instrument program, is hosted on Intelsat 40e.
April 15, 2023 İmece Umbra-SAR 06 ŃuSat 36 to 39 GHOSt 1 and 2 Tomorrow R1 GHGSat C6, C7, and C8 Hawk 7A, 7B, and 7C NORSAT TD ION-SCV 010 Kepler 20 and 21 ELO 3 EPICHyper 1 VCUB1 Vigoride 6 LLITED 1 and 2 REVELA DISCO 1 VIREO IRIS C BRO 9 Brokkr 1 (OrbAstro AF-1) CIRBE DEWA-Sat 2 It's About Time KILIÇSAT SSS 2B Sapling 2 (Sapling Giganteum) PROVES-Yearling 2 Platform 3 (Sateliot 0) FACSAT 2 (Chibiriquete) Connecta T2.1 LacunaSat 2f (LS2f) ADLER 2 (Lemur-2 163) Lemur-2 164 and 165 INSPIREsat 7 Taifa 1 RoseyCubesat 1 2023-054 *Falcon 9 v1.2 Block 5*	 Earth Observation Earth Observation Earth Observation Earth Observation Technology Demonstration Earth Observation Signals Intelligence Technology Demonstration CubeSat Deployer Communications Internet of Things Earth Observation Earth Observation Space Tug Earth Observation Technology Demonstration Technology Demonstration Technology Demonstration Technology Demonstration Signals Intelligence Technology Demonstration Space Weather Technology Demonstration Navigation Technology Demonstration Education Technology Demonstration Technology Demonstration Internet of Things Earth Observation Internet of Things Internet of Things Earth Observation Earth Observation Earth Observation Earth Observation Education	Dedicated SmallSat Rideshare mission.
April 19, 2023 Starlink v2-Mini G6-2-1 to -21 2023-056 *Falcon 9 v1.2 Block 5*	Communications	Second launch of 21 Starlink V2-Mini satellites.
April 27, 2023 Starlink v1.5 G3-5-1 to -46 2023-058 *Falcon 9 v1.2 Block 5*	Communications	Launch of 46 Starlink Block v1.5 satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Remarks
April 28, 2023 O3b mPower 3 and 4 2023-059 *Falcon 9 v1.2 Block 5*	Communications	Second launch of two second-generation O3b satellites.
May 1, 2023 ViaSat 3.1 Arcturus G-Space 1 2023-060 *Falcon Heavy Block 5*	Communications Communications Communications	Launch of three satellites on a fully expended Falcon Heavy vehicle.
May 4, 2023 Starlink v1.5 G5-6-1 to -56 2023-061 *Falcon 9 v1.2 Block 5*	Communications	Launch of 56 Starlink Block v1.5 satellites.
May 8, 2023 TROPICS 05 and 06 2023-062 *Electron KS*	Communications	Launch of two of the four satellites for NASA's TROPICS constellation from Mahia, New Zealand.
May 10, 2023 Starlink v1.5 G2-9-1 to -51 2023-064 *Falcon 9 v1.2 Block 5*	Communications	Launch of 51 Starlink Block v1.5 satellites.
May 14, 2023 Starlink v1.5 G5-9-1 to -56 2023-065 *Falcon 9 v1.2 Block 5*	Communications	Launch of 56 Starlink Block v1.5 satellites.
May 19, 2023 Starlink v2 Mini G6-3-1 to -22 2023-067 *Falcon 9 v1.2 Block 5*	Communications	Third launch of 22 Starlink V2-Mini satellites.
May 20, 2023 Iridium NEXT x5 OneWeb L19-1 to -15 OneWeb L19-16 (JoeySat) 2023-068 *Falcon 9 v1.2 Block 5*	Communications Communications Technology Demonstration	Launch of five Iridium NEXT Satellites, and 15 OneWeb first-generation and one second-generation satellites.
May 21, 2023 Crew Dragon Axiom 2 2023-070 *Falcon 9 v1.2 Block 5*	Space Tourism	Private crewed mission carrying four astronauts to the International Space Station. (See Appendix C.)
May 26, 2023 TROPICS 03 and 07 2023-073 *Electron KS*	Earth Observation	Launch of final two of the four satellites for NASA's TROPICS constellation from Mahia, New Zealand.
May 27, 2023 Arabsat 7B 2023-075 *Falcon 9 v1.2 Block 5*	Communications	Saudi Arabian communications satellite in geostationary orbit.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
May 31, 2023 Starlink v1.5 G2-10-1 to -52 2023-078 *Falcon 9 v1.2 Block 5*	Communications	Launch of 52 Starlink Block v1.5 satellites.
June 4, 2023 Starlink v2-Mini G6-4-1 to -22 2023-079 *Falcon 9 v1.2 Block 5*	Communications	Fourth launch of 22 Starlink V2-Mini satellites.
June 5, 2023 Dragon CRS-28 ESSENCE Iris Maya-5 and -6 Moonlighter RADSAT-SK SC-ODIN UKpik-1 2023-080 *Falcon 9 v1.2 Block 5*	ISS Logistics	Cargo resupply docked with ISS for 23 days. Payload included eight CubeSats that were deployed from the ISS in July 2023.
June 12, 2023 Starlink v1.5 G5-11-1 to -52 2023-083 *Falcon 9 v1.2 Block 5*	Communications	Launch of 52 Starlink Block v1.5 satellites.
June 12, 2023 W-Series 1 (Winnebago 1) Skykraft Deployer 3 Skykraft 3A, 3B, 3C, 3D ICEYE X23, X25, X26, X30 GHOSt 3 Grégoire Runner 1 Tomorrow R2 QPS-SAR 6 (Amateru 3) NuSat 40 to 43 Blackjack Aces 1 to 4 HOTSAT 1 (MWIR Pathfinder) AFR (ABA First Runner) DROID.001 MuSat 1 ION-SCV 011 Outpost Mission 1 EPICHyper 2 (Drgonette 002) Kelpie 2 (AAC-AIS-SAT 2) Spei Satelles (SpeiSat) ELO 4 MRC-100 Unicorn 2I SATLLA 2I URESAT 1 Istanbul ROM 2 (Space Sparrow)	 Technology Demonstration Satellite Deployer Air Traffic Management Earth Observation Earth Observation Technology Demonstration Earth Observation Technology Demonstration Earth Observation Earth Observation Reconnaissance Earth Observation Earth Observation Space Debris Monitoring Technology Demonstration CubeSat Deployer Technology Demonstration Earth Observation Internet of Things Religious Broadcasting Internet of Things Earth Observation Earth Observation Communications Amateur Radio Technology Demonstration Technology Demonstration	Dedicated SmallSat Rideshare mission. (continued on next page)

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
Orbiter SN3 Otter Pup MDQSAT 1C and 1D Pleiades-Squared GEI-SAT Precursor XVI (Link-16) AII-Delta Ayris 1 and 2 EIVE Lemur-2 166 to 168 MISR-A 1 and -B 2 Tiger 4 (Layan-23) FOSSASat FEROX 1 to 4 SpaceBEE 168 to 179 2023-084 *Falcon 9 v1.2 Block 5*	Space Tug Satellite Docking Internet of Things Technology Demonstration Earth Observation Technology Demonstration Technology Demonstration ? Communications Earth Observation Technology Demonstration Internet of Things Internet of Things Communications	
June 18, 2023 Satria 2023-086 *Falcon 9 v1.2 Block 5*	Communications	Indonesian geostationary communications satellite.
June 22, 2023 Starlink v1.5 G5-7-1 to -47 2023-088 *Falcon 9 v1.2 Block 5*	Communications	Launch of 47 Starlink Block v1.5 satellites.
June 22, 2023 Orion 11 2023-089 *Delta IV Heavy*	Signals Intelligence	NRO mission.
June 23, 2023 Starlink v1.5 G5-12-1 to -56 2023-090 *Falcon 9 v1.2 Block 5*	Communications	Launch of 56 Starlink Block v1.5 satellites.
July 1, 2023 Euclid 2023-092 *Falcon 9 v1.2 Block 5*	Astronomy	ESA space telescope launched to Sun–Earth second Lagrange point L2.
July 7, 2023 Starlink v1.5 G5-13 to -48 2023-094 *Falcon 9 v1.2 Block 5*	Communications	Launch of 48 Starlink Block v1.5 satellites.
July 10, 2023 Starlink v2-Mini G6-5-1 to -22 2023-096 *Falcon 9 v1.2 Block 5*	Communications	Fourth launch of 22 Starlink V2-Mini satellites.
July 16, 2023 Starlink v1.5 G5-15-1 to -54 2023-099 *Falcon 9 v1.2 Block 5*	Communications	Launch of 54 Starlink Block v1.5 satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
July 18, 2023 Telesat LEO 3 Lemur-2 169 and 170 Starling 1 to 4 2023-100 *Electron KS*	Technology Demonstration Earth Observation Technology Demonstration	Launched from Mahia, New Zealand.
July 20, 2023 Starlink v2-Mini G6-15-1 to -15 2023-102 *Falcon 9 v1.2 Block 5*	Communications	Fifth launch of 22 Starlink V2-Mini satellites.
July 24, 2023 Starlink v2-Mini G6-6-1 to -22 2023-105 *Falcon 9 v1.2 Block 5*	Communications	Sixth launch of 22 Starlink V2-Mini satellites.
July 28, 2023 Starlink v2-Mini G6-7-1 to -22 2023-107 *Falcon 9 v1.2 Block 5*	Communications	Seventh launch of 22 Starlink V2-Mini satellites.
July 29, 2023 Jupiter-3 2023-108 *Falcon Heavy*	Communications	Launch of EchoStar's Jupiter-3, the heaviest geostationary communications satellite.
August 2, 2023 Cygnus CRS-19 2023-110 *Antares 230+*	ISS Logistics	Cargo resupply docked with ISS for 61 days.
August 3, 2023 Galaxy 37/Horizons 4 2023-112 *Falcon 9 v1.2 Block 5*	Communications	Part of the Galaxy series of communications satellites operated by Intelsat.
August 7, 2023 Starlink v2-Mini G6-8-1 to -22 2023-113 *Falcon 9 v1.2 Block 5*	Communications	Eighth launch of 22 Starlink V2-Mini satellites.
August 8, 2023 Starlink v1.5 G6-20-1 to -15 2023-115 *Falcon 9 v1.2 Block 5*	Communications	Ninth launch of 15 Starlink V2-Mini satellites.
August 11, 2023 Starlink v2-Mini G6-9-1 to -22 2023-119 *Falcon 9 v1.2 Block 5*	Communications	Tenth launch of 22 Starlink V2-Mini satellites.
August 17, 2023 Starlink v2-Mini G6-10-1 to -22 2023-122 *Falcon 9 v1.2 Block 5*	Communications	11th launch of 22 Starlink V2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date **Spacecraft Name** **COSPAR* Designation** **Launch Vehicle**	**Mission Objectives**	**Remarks**
August 22, 2023 Starlink v2-Mini G7-1-1 to -21 2023-124 *Falcon 9 v1.2 Block 5*	Communications	12th launch of 21 Starlink V2-Mini satellites.
August 23, 2023 Capella 11 (Capella Acadia 1) 2023-126 *Electron KS*	Earth Observation	Launched from Mahia, New Zealand.
August 26, 2023 Crew Dragon 7 2023-128 *Falcon 9 v1.2 Block 5*	International Space Station Crew Rotation	Seventh operational Crew Dragon mission (see Appendix C).
August 27, 2023 Starlink v2-Mini G6-11-1 to -22 2023-129 *Falcon 9 v1.2 Block 5*	Communications	13th launch of 22 Starlink V2-Mini satellites.
September 1, 2023 Starlink v2-Mini G6-13-1 to -22 2023-131 *Falcon 9 v1.2 Block 5*	Communications	14th launch of 22 Starlink V2-Mini satellites.
September 2, 2023 Transport Layer Trache 0 x 11 Tracking Layer Tranche 0 x 2 2023-133 *Falcon 9 v1.2 Block 5*	Military Communications Missile Tracking	Second of two launches for the DOD's Space Development Agency's Tranche 0 Transport and Tracking Layer.
September 4, 2023 Starlink v2-Mini G6-12-1 to -21 2023-134 *Falcon 9 v1.2 Block 5*	Communications	15th launch of 21 Starlink V2-Mini satellites.
September 9, 2023 Starlink v2-Mini G6-14-1 to -22 2023-138 *Falcon 9 v1.2 Block 5*	Communications	16th launch of 22 Starlink V2-Mini satellites.
September 10, 2023 Silentbarker 1, 2, and 3 2023-140 *Atlas V*	Space Domain Awareness	Geosynchronous orbit.
September 12, 2023 Starlink v2-Mini G7-2 2023-141 *Falcon 9 v1.2 Block 5*	Communications	17th launch of 21 Starlink V2-Mini satellites.
September 15, 2023 Victus Nox (TacRS 3) 2023-142 *Firefly Alpha*	Space Domain Awareness	Space Systems Command Tactically Responsive Space-3 mission.
September 16, 2023 Starlink v2-Mini G6-16-1 to -22 2023-144 *Falcon 9 v1.2 Block 5*	Communications	18th launch of 22 Starlink V2-Mini satellites.

(continued)

Appendix B-1: Successful Launches to Orbit or Beyond on U.S. Vehicles, October 1, 2022–September 30, 2023 (FY 2023) (continued)

Launch Date Spacecraft Name COSPAR* Designation Launch Vehicle	Mission Objectives	Remarks
September 20, 2023 Starlink v2-Mini G6-17-1 to -22 2023-146 *Falcon 9 v1.2 Block 5*	Communications	19th launch of 22 Starlink V2-Mini satellites.
September 24, 2023 Starlink v2-Mini G6-18-1 to -22 2023-147 *Falcon 9 v1.2 Block 5*	Communications	20th launch of 22 Starlink V2-Mini satellites.
September 25, 2023 Starlink v2-Mini G7-3-1 to -21 2022-148 *Falcon 9 v1.2 Block 5*	Communications	21st launch of 21 Starlink V2-Mini satellites.
September 30, 2023 Starlink v2-Mini G6-19-1 to -22 2023-151 *Falcon 9 v1.2 Block 5*	Communications	22nd launch of 22 Starlink V2-Mini satellites.

Appendix C-1

Human Spaceflights

October 1, 2022–September 30, 2023 (FY 2023)

Spacecraft/ Mission	Launch Date	Crew	Flight Time (d:h:min)	Highlights
SpaceX Crew-5, "Endurance" Expedition 68	October 5, 2022	Nicole Aunapu Mann Josh A. Cassada Koichi Wakata Anna Kikina	157:10:01	First flight on a Crew Dragon spacecraft made by a Russian cosmonaut. First spaceflight for three of the four crewmembers.
Shenzhou 15	November 29, 2022	Fei Junlong Deng Qingming Zhang Lu	186:07:25	Fourth crewed flight to the Tiangong space station.
Soyuz MS-23 Expeditions 67, 68, 69	February 24, 2023	Sergey Prokopyev Dmitry Petelin Francisco Rubio	215:10:53	The uncrewed Soyuz MS-23 was launched to the ISS to replace the damaged Soyuz MS-22 spacecraft. Francisco Rubio set a new U.S. space duration record of 370.6 days upon his return on September 27, 2023.
SpaceX Crew-6, "Endeavour" Expedition 68, 69	March 2, 2023	Stephen G. Bowen Warren Hoburg Sultan Al Neyadi Andrey Fedyaev	185:22:43	Sixth crewed flight of a Crew Dragon spacecraft to the International Space Station.
Axiom Mission 2, "Freedom"	May 21, 2023	Peggy Whitson John Shoffner Ali AlQarni Rayyanah Barnawi	9:05:27	Private crewed spaceflight to the International Space Station. It included the first female Saudi astronaut to go to space.
Shenzhou 16	May 30, 2023	Jing Haipeng Zhu Yangzhu Gui Haichao	153:22:41	Fifth crewed flight to the Tiangong space station.
SpaceX Crew-7 "Endurance" Expedition 69, 70	August 26, 2023	Jasmin Moghbeli Andreas Mogensen Satoshi Furukawa Konstantin Borisov	199:2:20	Seventh crewed flight of a Crew Dragon spacecraft to the International Space Station.
Soyuz MS-24 Expedition 69, 70, 71	September 15, 2023	Oleg Kononenko Loral O'Hara Nikolai Chub	203:15:33	Kononenko and Chub are slated to return on the MS-25 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	DODa	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

(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	DODa	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1996	13,884	12,569	11,514	828	46	472	36	37	231	6	24,911
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	24,488	22,800	2,592	229	1,657	92	35	531	48	49,880

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 CECR 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 2023 dollars)

FY	NASA Total	NASA Space	DODa	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1959	2,670	2,105	3,952	274	274						6,331
1960	4,170	3,677	4,465	342	342						8,484
1961	7,567	7,269	6,390	534	534						14,192
1962	14,182	13,965	10,087	1,546	1,150	396					25,598
1963	28,211	27,850	11,905	1,974	1,644	330					41,729
1964	38,676	38,039	12,126	1,615	1,593	23					51,781
1965	39,139	38,304	11,734	1,797	1,707	89					51,835
1966	37,770	36,967	12,327	1,562	1,365	197					50,856
1967	35,175	34,212	11,786	1,509	1,303	205					47,507
1968	31,396	30,321	13,155	1,192	992	192	1	7			44,668
1969	26,125	25,018	13,177	1,115	772	131	1	7	204		39,310
1970	23,275	22,038	10,426	876	640	50	6	6	174		33,340
1971	19,577	18,335	8,940	957	562	160	12	6	218		28,233
1972	18,667	17,335	7,942	753	310	175	34	11	222		26,030
1973	18,430	16,736	8,782	797	292	216	54	11	224		26,316
1974	15,340	13,935	8,920	798	212	303	45	15	223		23,654
1975	14,782	13,345	8,662	722	137	293	37	9	246		22,729
1976	15,193	13,802	8,487	720	98	308	43	17	254		23,009
TQ*	3,873	3,528	1,912	179	21	91	12	4	50		5,619
1977	15,239	13,730	9,627	772	88	363	40	24	257		24,129
1978	15,181	13,547	10,238	845	127	385	37	30	265		24,630
1979	15,902	13,943	10,504	858	204	339	35	28	253		25,306
1980	16,675	14,893	12,245	735	127	296	38	45	229		27,873
1981	15,991	14,467	13,991	679	119	252	35	46	227		29,137
1982	16,379	14,981	18,100	847	165	393	33	41	216		33,928
1983	17,851	16,430	23,417	849	101	462	13	52	221		40,697
1984	18,695	17,191	25,556	990	85	592	8	48	258		43,737
1985	18,370	16,798	30,971	1,416	82	1,026	5	36	266		49,185
1986	18,519	16,996	33,508	1,131	83	733	5	55	256		51,635
1987	25,346	22,761	37,792	1,081	111	645	19	44	260	2	61,634
1988	20,369	18,705	39,737	1,666	542	791	31	40	259	2	60,108
1989	23,695	21,811	38,680	1,210	210	650	37	45	262	6	61,701
1990	25,681	23,880	32,541	1,054	165	506	65	52	258	8	57,475
1991	28,201	26,249	28,533	1,554	505	505	58	52	425	8	56,335
1992	28,104	25,909	29,490	1,566	438	642	67	57	355	8	56,965
1993	27,446	25,056	27,054	1,402	316	621	63	48	345	8	53,512
1994	27,348	24,443	24,713	1,187	139	586	58	58	337	9	50,343
1995	25,465	23,055	19,565	1,395	110	647	57	59	511	11	44,014

(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	DODa	Other[b]	DOE[c]	DOC	DOI	USDA	NSF[d]	DOT	Total Space
1996	25,049	22,677	20,773	1,493	83	852	65	67	416	11	44,944
1997	24,302	22,082	20,788	1,399	62	794	74	69	389	11	44,270
1998	23,895	21,572	21,638	1,470	180	762	75	68	374	11	44,680
1999	23,610	21,545	22,832	1,698	182	994	102	64	346	10	46,075
2000	23,040	21,211	21,922	1,788	278	974	102	75	350	10	44,921
2001	23,535	22,003	23,694	1,756	240	954	99	60	384	20	47,453
2002	24,208	22,585	25,628	1,921	270	1,049	104	46	433	20	50,134
2003	24,546	22,942	30,975	2,085	305	1,037	118	67	538	19	56,003
2004	23,984	22,336	29,810	2,283	326	1,162	111	95	571	19	54,429
2005	24,517	23,058	29,802	2,348	347	1,221	106	110	545	18	55,208
2006	24,367	23,109	32,416	2,414	359	1,261	120	123	534	18	57,940
2007	23,234	22,211	31,985	2,397	285	1,301	124	93	576	17	56,593
2008	23,922	23,063	34,653	2,373	273	1,205	126	82	669	18	60,089
2009	24,592	23,900	36,702	2,584	277	1,491	89	37	671	19	63,187
2010	25,683	25,001	36,297	2,821	278	1,730	92	36	664	21	64,119
2011	24,782	24,064	36,616	2,938	308	1,941	89	26	554	20	63,618
2012	23,466	22,713	35,222	3,406	263	2,477	100	9	536	21	61,341
2013	22,554	21,867	14,026	3,343	240	2,418	109	26	530	19	39,236
2014	22,446	21,726	13,228	3,611	221	2,655	104	24	586	20	38,566
2015	22,648	21,830	12,984	3,785	229	2,796	104	24	610	23	38,599
2016	24,053	23,254	8,689	3,940	222	2,926	109	24	633	27	35,884
2017	24,082	23,273	12,641	3,670	211	2,713	104	25	588	30	39,584
2018	24,826	23,916	9,411	3,536	210	2,513	94	19	665	35	36,863
2019	25,246	24,395	11,707	3,057	255	1,957	99	22	682	43	39,159
2020	26,222	25,313	13,789	2,783	226	1,746	97	24	630	60	41,886
2021	26,089	25,160	16,928	2,757	237	1,700	95	30	645	50	44,845
2022[e]	25,206	24,282	16,251	2,661	247	1,596	89	31	573	47	43,194
2023[f]	25,384	24,488	22,800	2,592	229	1,657	92	35	531	48	49,880

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 CECR appropriated in Division N of PL 117-358.
* 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			
	2021 actual	2022 actual	2023 actual	2024 est.	2021 actual	2022 actual	2023 actual	2024 est.
NASA[b]	22,443	23,161	24,488	26,226	21,486	22,196	21,579	24,976
DOD[c]	15,100	15,500	22,800	26,100	15,500	16,700	21,700	26,100
DOE	211	236	229	221	207	241	238	225
DOC[d]	1,516	1,651	1,657	1,657	1,438	1,626	1,427	1,427
DOI[e]	84	85	92	110	84	85	92	110
USDA[f]	27	30	35	33	27	32	35	35
NSF[g]	576	559	531	540	544	543	546	536
DOT	44	45	48	49	44	49	47	49

a. Amounts rounded to the nearest million.
b. FY 2024 NASA Space Activities Outlay amount based on FY 2024 A-11 outlay totals.
c. DOD submitted estimates in billions of dollars, so the figures are rounded to the nearest hundred million.
d. For DOC, NWS authority and outlays includes the Space Weather Prediction Center only. NESDIS totals include supplemental funding,including IIJA and Disaster. FY 2023 totals were applied as FY 2024 estimates as obligation and cost plans have not been actioned yet.
e. For the Aeronautics and Space Report of the President, the USGS reports on actual and estimated funding levels (budget authority and outlays) for Satellite Operations (space category) and the 3D Elevation Program (3DEP) (aeronautics category).
f. Total budget authority for the Forest Service going into each new FY is unknown; these numbers use actual outlays for the retrospective estimate. The Forest Service used the amount spent in FY 2023 as the budget authority.
g. NSF Actual Obligations for FY 2022, includes American Rescue Plan (ARP) supplemental funds.

Appendix D-3

Federal Aeronautics Activities Budget

(in millions of dollars by fiscal year)[a]

Federal Agencies	Budget Authority				Budget Outlays			
	2020 actual	2021 actual	2022 actual[2]	2023 est.	2020 actual	2021 actual	2022 actual	2023 est.
NASA	829	881	935	996	763	883	896	959
DOD[b]	60,600	56,200	62,600	61,100	56,900	52,400	56,500	61,100
DOE[c]	2	3	6	27	1	2	4	3
DOI[d]	36	40	43	37	36	40	43	37
USDA[e]	69	85	106	110	75	88	106	114
DOT	3,193	3,119	3,179	3,179	2,907	3,228	3,230	3,486

a. Amounts rounded to the nearest million.
b. Total budget authority for the Forest Service going into each new FY is unknown; these numbers use actual outlays for the retrospective estimate. The Forest Service used the amount spent in FY 2023 as the budget authority.
c. DOD submitted estimates in billions of dollars, so the figures are rounded to the nearest hundred million.
d. DOE's 2024 Budget Authority estimate represents the amount planned for Fossil Energy and Carbon Management.
e. For the Aeronautics and Space Report of the President, the USGS reports on actual and estimated funding levels (budget authority and outlays) for Satellite Operations (space category) and the 3D Elevation Program (3DEP) (aeronautics category).

Acronyms

3DEP	3D Elevation Program

A

AAM	Advanced Air Mobility
AARGM-ER	Advanced Anti-Radiation Guided Missile-Extended Range
ACERO	Advanced Capabilities for Emergency Response Operations
ACO	Announcement of Collaboration Opportunity
ACSAA	Aircraft Certification, Safety, and Accountability Act
AEHF	Advanced Extremely High Frequency
AFFOA	Advanced Functional Fabrics of America
AFL	available for launch
AFLCMC HBAW	Air Force Lifecycle Management Center's Weather Systems Branch
AFPP	Announcement for Partnership Proposals
AFRL/RV	Air Force Research Laboratory Space Vehicles
AGS	Atmospheric and Geospace Sciences
AI&T	assembly, integration, and test
AIGA	American Institute of Graphic Arts
Air-LUSI	Airborne Lunar Spectral Irradiance
AIM	Assessment, Inventory, and Monitoring
AIT	American Institute in Taiwan
ALMA	Atacama Large Millimeter/Submillimeter Array
AM	additive manufacturing
AM Bench	Additive Manufacturing Benchmark Series
AMI	Auburn Manufacturing, Incorporated
AMS	Alpha Magnetic Spectrometer
AMS	Automated Modular Sensor
AMSP	Additive Manufacturing of Solid Propellant
AMSR	Advanced Microwave Scanning Radiometer
ANSWERS	Advancing National Space Weather Expertise and Research toward Societal Resilience
AOI	area of interest
AOS	Atmosphere Observing System
APH	Advanced Plant Habitat
APNT	alternative positioning, navigation, and timing

AR	Aquatic Reflectance
ARC	Aviation Rulemaking Committee
ARMD	Aeronautics Research Mission Directorate
ARS	Agricultural Research Service
ASB	Agricultural Statistics Board
ASCAT	Advanced Scatterometer
ASCR	Advanced Scientific Computing Research
ASE	Aviation Survivability Equipment
ASR	Atmospheric System Research
ASSURE	Alliance for System Safety of UAS through Research Excellence
AST	Astronomical Sciences
AST	Office of Commercial Space Transportation
ASU	Aircraft Sector Understanding
ASuW	Anti-Surface Warfare
ATMS	Advanced Technology Microwave Sounder
AVC/ESC	Office of Emerging Security Challenges within the Bureau of Arms Control, Verification and Compliance
AVS	Aviation Safety Organization

B

BEA	Bureau of Economic Analysis
BICEP	Background Imaging of Cosmic Extragalactic Polarization
BIG	Breakthrough, Innovative, and Game-Changing
BLM	Bureau of Land Management
BLOS	beyond line of sight
BMC2	Battle Management Command and Control
BMC3	Battle Management Command, Control, and Communications
BNL	Brookhaven National Laboratory
BOEM	Bureau of Ocean Energy Management
BPA	Brine Processor Assembly
BPSD	Biological and Physical Sciences Division

C

C2	Collection 2
C2	command and control
C3	command, control, and communications
CAEP	Committee on Aviation Environmental Protection
CANDLE	Calibration using an Artificial star with NIST-traceable Distribution of Luminous Energy
CAPS	Cislunar Autonomous Position System
CAPSTONE	Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment
CASIS	Center for the Advancement of Science in Space
CCP	Commercial Crew Program
CCOR	Compact Coronagraph
CCRPP	Civilian Commercialization Readiness Pilot Program
CCSFS	Cape Canaveral Space Force Station
CDEDT	Change and Disturbance Event Detection Tool
CDL	Cropland Data Layer
CDP	Commercial Data Program
CDR	Critical Design Review
CEERS	Cosmic Evolution Early Release Science

CENTCOM	Central Command
CEPS	Center for Earth and Planetary Studies
CERISS	Commercially Enabled Rapid Space Science
CFR	Code of Federal Regulations
CFT	Crew Flight Test
CHAPEA	Crew Health And Performance Exploration Analog
CIF	Center Innovation Fund
CINEMA	Cross-scale Investigation of Earth's Magnetotail and Aurora
CIPHER	Complement of Integrated Protocols for Human Exploration Research
CLD	commercial low-Earth orbit destinations
CLEEN	Continuous Lower Energy, Emissions, and Noise
CLICK	CubeSat Infrared CrossLink
CLPS	Commercial Lunar Payload Services
CMB	Cosmic Microwave Background
CMEx	Chromospheric Magnetism Explorer
CMS	Carbon Monitoring System
CNES	Centre National d'Études Spatiales
CO_2	carbon dioxide
COBRA	Crater Observing Bio-inspired Rolling Articulator
COE	Center of Excellence
CoECI	Center of Excellence for Collaborative Innovation
CONUS	conterminous United States
COSMIC	Constellation Observing System for Meteorology, Ionosphere, and Climate
COSMO	Coronal Solar Magnetism Observatory
CPR IAWG	Changed Product Rule International Authority Working Group
CPT	Command Post Terminal
CropCASMA	Crop Condition and Soil Moisture Analytics
CrIS	Cross-track Infrared Sounder
CRP	Constant Rate Production
CRS	Commercial Resupply Services
CRSRA	Commercial Remote Sensing Regulatory Affairs
CSA	Canadian Space Agency
CSJWG	Civil Space Joint Working Group
CSLI	CubeSat Launch Initiative
CVAT	Computer Vision Annotation Tool
CVW	Carrier Air Wing
CWDP	Commercial Weather Data Pilot

D

DA-ASAT	direct-ascent anti-satellite
DAO	decentralized autonomous organization
DARPA	Defense Advanced Research Projects Agency
DART	Double Asteroid Redirection Test
DASI	Distributed Array of Small Instruments
DCCS	Dream Chaser Cargo System
DCS	Data Collection and location System
DEIA	Diversity, Equity, Inclusion, and Accessibility
DEM	digital elevation model
Desert RATS	Desert Research and Technology Studies
DG DEFIS	Directorate-General for Defense Industry and Space
DIU	Defense Innovation Unit
DKIST	Daniel K. Inouye Solar Telescope
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)

DMO	Distributed Maritime Operations
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
DRACO	Demonstration Rocket for Agile Cislunar Operations
DSA	Distributed Spacecraft Autonomy
DSCOVR	Deep Space Climate Observatory
DSN	Deep Space Network
DSO	Dynamic Space Operations
DSOC	Deep Space Optical Communications
DSSC	Delta System/Software Configuration

E

EABO	Expeditionary Advanced Base Operations
EAG	Exotic Annual Grass
ECCCO	Extreme ultraviolet Coronal Mass Ejection and Coronal Connectivity Observatory
ECI	Early Career Initiative
EDGE	Experimental Demonstration Gateway Event
EEAS	European External Action Service
EGS	Exploration Ground Systems
EHP	Extravehicular Activity (EVA) and Human Surface Mobility (HSM) Program
EHT	Event Horizon Telescope
EO/IR	electro-optical/infrared
EPA	Environmental Protection Agency
EPOC	Exploration Production and Operations Contract
EROS	Earth Resources Observation and Science
ESA	European Space Agency
ESCAPADE	Escape and Plasma Acceleration and Dynamics Explorers
ESDMD	Exploration Systems Development Mission Directorate
ESIP	Early Stage Innovations and Partnerships
ESMU	Electromagnetic Spectrum Management Unit
ESO	Earth System Observatory
ESP	Environmental Studies Program
ESS	Environmental System Science
ESS	Evolved Strategic SATCOM
ESSIO	Exploration Science Strategy and Integration Office
ETa	evapotranspiration
ETM	Enhanced Thematic Mapper
EUMETSAT	Exploitation of Meteorological Satellites
EU	European Union
EUS	Exploration Upper Stage
EVA	Extravehicular Activity
EVI-1	Earth Venture Instrument
EW	Electronic Warfare
EWS	Electro-Optical/Infrared (EO/IR) Weather System
EXPAND	Enhancing eXploration Platforms and Analog Definition

F

FAA	Federal Aviation Administration
FAB-T	Family of Advanced Beyond-Line-of-Sight Terminals
FACET-TP	Frontier Aerospace Corporation Engine Testing Tipping Point
FARA	Future Attack Reconnaissance Aircraft
FAS/GMA	Foreign Agricultural Service's Global Market Analysis
FAST	Fueling Aviation's Sustainable Transition
FBCA	Flow Boiling Condensation Experiment
FC	fire control
FCC	Federal Communications Commission
FDSS	Faculty Development in Space Sciences
FFP	Firm Fixed Price
FGST	Fermi Gamma-ray Space Telescope
FIA	Forest Inventory and Analysis
FLRAA	Future Long Range Assault Aircraft
FLUTE	Fluidic Telescope Experiment
FORGE	Future Operationally Resilient Ground Evolution
FOSS	Fiber Optic Sensing System
FROSTE	Frozen Return Of Samples To Earth
FSA	Farm Service Agency
FSP	fission surface power
FTUAS	Future Tactical Uncrewed Aerial Systems
FVL	Future Vertical Lift
FVL(MS)	Future Vertical Lift Maritime Strike
FWS	Fish and Wildlife Service
FY	Fiscal Year

G

G-LiHT	Goddard's LiDAR, Hyperspectral and Thermal
GADAS	Global Agricultural and Disaster Assessment System
GBD	Global Burst Detector
GBO	Green Bank Observatory
GBT	Green Bank Telescope
Gbps	gigabit per second
GCOM	Global Change Observation Mission
GCS	Ground Control Station
GDMS	General Dynamic Mission Systems
GEDI	Global Ecosystem Dynamics Investigation
GEE	Google Earth Engine
GEO	Geosynchronous Earth Orbit
GeoXO	Geostationary Extended Observations
GEP	Ground Entry Point
GIS	geographic information system
GLAM	Global Agricultural Monitoring
GNSS	Global Navigation Satellite System
GOES	Geostationary Operational Environmental Satellite
GONG	Global Oscillations Network Group
GOSAT-GW	Global Observing SATellite for Greenhouse gases and Water cycle
GPS	Global Positioning System
GS	Geospace Section
GSP	Geospatial Strategic Plan

H

HALO	Habitation and Logistics Outpost
HALO	Hypersonic Air-Launched OASuW
HAO	High-Altitude Observatory
HEP	High Energy Physics
HERA	Human Exploration Research Analog
HIAD	Hypersonic Inflatable Aerodynamic Decelerator
HiCAM	Hi-Rate Composite Aircraft Manufacturing
HLS	Harmonized Landsat and Sentinel
HLS	Human Landing System
HRP	Human Research Program
HSA	Hybrid Space Architecture
HSM	Human Surface Mobility
HyCAT	Hypersonic and High-Cadence Airborne Testing Capabilities
HyTEC	Hybrid Thermally Efficient Core

I

I-Hab	International Habitat
IC	Intelligence Community
ICAO	International Civil Aviation Organization
ICFS	International Communications Filing System
ICG	International Committee on Global Navigation Satellite Systems (GNSS)
ICN	Info-Centric NAS
ICNO	IceCube Neutrino Observatory
IHE	Institutions of Higher Education
ILC	Initial Launch Capability
ILLUMA-T	Integrated Laser Communication Relay Demonstration (LCRD) Low-Earth Orbit User Modem and Amplifier Terminal
ILY	International Lunar Year
INL	Idaho National Laboratory
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport
IOAG	Interagency Operations Advisory Group
IOC	Initial Operational Capability
IOP	Interoperability Plenary
IP	intellectual property
IPAD	International Production Assessment Division
IR	infrared
IRA	Inflation Reduction Act of 2022
iROSA	ISS Roll-Out Solar Array
ISAM	In-space Servicing, Assembly, and Manufacturing
ISPF	In-Space Propulsion Facility
ISR	Incoherent Scattering Radar
ISR	Intelligence, Surveillance, and Reconnaissance
ISRO	Indian Space Research Organisation
ISS	International Space Station
ITA	International Trade Administration
ITAR	International Trafficking in Arms Regulations
ITE	Improved Turbine Engine
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radiocommunication Sector
IWG	Interagency Working Group

J

JADC2	Joint All-Domain Command and Control
JAXA	Japanese Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
JPSS	Joint Polar Satellite System
JPSS-2	Joint Polar Satellite System 2
JSC	Johnson Space Center
JWST	James Webb Space Telescope

K

KARI	Korea Aerospace Research Institute
KSC	Kennedy Space Center

L

L1	Lagrange Point 1
L5	Lagrange Point 5
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LANDO	Lightweight Surface Manipulation System (LSMS) AutoNomy capabilities Development for surface Operations
LANL	Los Alamos National Laboratory
LaRC	Langley Research Center
LASP	Laboratory for Atmospheric and Space Physics
LAT	Large Area Telescope
LBNL	Lawrence Berkeley National Laboratory
LCMS	Landscape Change Monitoring System
LCRD	Laser Communication Relay Demonstration
LDB	Long Duration Balloon
LDEP	Lunar Discovery and Exploration Program
LE	Launched Effects
LEO	low-Earth orbit
LIBOR	London Interbank Offered Rate
lidar	ight detection and ranging
LiDIA	Lightweight Deployable Integrable Antenna
LIGO	Laser Interferometric Gravitational-Wave Observatory
LIS	Land Information System
LiSS	Lithium-Sulfur Specific Energy Improvements
LLNL	Lawrence Livermore National Laboratory
LOCE	Littoral Operations in a Contested Environment
LOFTID	Low-Earth Orbit Flight Test of an Inflatable Decelerator
LRASM	long-range anti-ship missile
LSIC	Lunar Surface Innovation Consortium
LSC	Legal Subcommittee
LSII	Lunar Surface Innovation Initiative
LSO	Launch Services Office
LTS	Long-Term Sustainability
LuSEE-Night	Lunar Surface Electromagnetics Experiment at Night
LUSI	lunar spectral irradiance
LuSTR	Lunar Surface Technology Research

M

M-OLV	Multi-orbit Logistics Vehicle
M-STAR	Minority University Research and Education Project (MUREP) Space Technology Artemis Research
M2M	Moon to Mars
M4SS	Modularity for Space Systems
MAAX	Magnetospheric Auroral Asymmetry Explorer
MAF	Michoud Assembly Facility
MAGTF	Marine Air Ground Task Force
MALE	Medium Altitude Long Endurance
MCO	Mars Campaign Office
MD	missile defense
MEO	medium-Earth orbit
MEP	Manufacturing Extension Partnership
MERCRII	Metallic Environmentally Resistant Coatings Rapid Innovation Initiative
MIT	Massachusetts Institute of Technology
ML2	Mobile Launcher 2
MLME	machine learning model ensembles
MLO	Mauna Loa
MMRTG	Multi-mission Radioisotope Thermoelectric Generator
MODIS	Moderate Resolution Imaging Spectroradiometer
MOSA	Modular Open System Approach
MOU	Memorandum of Understanding
MOXIE	Mars Oxygen In-Situ Resource Utilization Experiment
MPC	Minor Planet Center
MPLAN	Minority University Research and Education Project (MUREP) Partnership Annual Notification
MPW	multi-project wafer
MRI	Magnetorotational Instability
MRLC	Multi-Resolution Land Characteristics
MRO	Mars Reconnaissance Orbiter
MSFC	Marshall Space Flight Center
MSI	minority serving institutions
MSolo	Mass Spectrometer Observing Lunar Operations
MSR	Mars Sample Return
MTA	Middle Tier of Acquisition
MTBS	Monitoring Trends in Burn Severity
MUOS	Mobile User Objective System
MUREP	Minority University Research and Education Project
MUX	Marine Air Ground Task Force (MAGTF) UAS Expeditionary
MVC	Minimum Viable Capability
MW/MT	missile warning and missile tracking

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
NASEM	National Academies of Sciences, Engineering, and Medicine
NASM	National Air and Space Museum
NASS	National Agricultural Statistics Service

NCAR	National Center for Atmospheric Research
NDVI	Normalized Difference Vegetation Index
NE	Nuclear Energy
NEO	near-Earth object
NEON	National Ecological Observatory Network
NEON	Near-Earth Orbit Network
NERSC	National Energy Research Scientific Computing Center
NESDIS	National Environmental Satellite, Data, and Information Service
Next-Gen OPIR	Next Generation Overhead Persistent Infrared
NFS	National Forest System
NGRTG	next-generation radioisotope thermoelectric generator
NGSO	non-geostationary-satellite orbit
NIAC	NASA Innovative Advanced Concepts
NISAR	NASA-ISRO Synthetic Aperture Radar
NIST	National Institute of Standards and Technology
NLCD	National Land Cover Database
NM	nautical mile
NMB	National Mall Building
NMNH	National Museum of Natural History
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOFO	Notice of Funding Opportunity
NOIRLab	National Optical-Infrared Astronomy Research Laboratory
NOTAM	Notice to Air Missions
NOx	nitrogen oxides
NP	Nuclear Physics
NPS	National Park Service
NPRM	notice of proposed rulemaking
NRAO	National Radio Astronomy Observatory
NRCS	Natural Resources Conservation Service
NRDZ	National Radio Dynamic Zones
NREL	National Renewable Energy Laboratory
NRHO	Near Rectilinear Halo Orbit
NRI	National Resources Inventory
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
NSF	National Science Foundation
NSN	Near Space Network
NSO	National Solar Observatory
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
NUSO	National Uncrewed Systems Office
NWRS	National Wildlife Refuge System
NWS	National Weather Service

O

O&I	Operations and Integration
OC	Operation Center
OCP	operations commissioning phase
OCX	Operational Control System

ODA	organization designation authorization
ODME	On-Demand Manufacturing of Electronics
OECD	Organization for Economic Cooperation and Development
OEM	original equipment manufacturer
OES/SA	Office of Space Affairs within the Bureau of Oceans and International Environmental and Scientific Affairs
OEWG	Open-Ended Working Group
Off-SEL	off the Sun-Earth line
OLI	Operational Land Imager
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, Security, Regolith Explorer
OSTP	Office of Science, Technology, and Policy
OSW	ocean surface wind
OT	Other Transaction
OTM	Office of Transportation and Machinery
OUSuW	Offensive Anti-Surface Warfare

P

PC	production certificate
PCC	Prizes, Challenges, and Crowdsourcing
PCDL	Predictive Cropland Data Layer
PEO	Program Executive Officer
PFP	PWSA Future Programs
PHA	potentially hazardous asteroid
PHY	Physics
PI	Principal Investigator
PIR	Program Independent Review
PNT	Positioning, Navigation, and Timing
PolSIR	Polarized Submillimeter Ice-cloud Radiometer
PPE	Power and Propulsion Element
PPPL	Princeton Plasma Physics Laboratory
PREFIRE	Polar Radiant Energy in the Far-InfraRed Experiment
PRIME-1	Polar Resources Ice Mining Experiment-1
PSD	production, supply, and distribution
PTD	Pathfinder Technology Demonstrator
PTES	Protected Tactical Enterprise Service
PTS	Protected Tactical SATCOM
PTW	Protected Tactical Waveform
PWSA	Proliferated Warfighter Space Architecture

Q

QIST	Quantum Information Science and Technology
QuIX	quantum inertial measurement unit (IMU) experiment

R

R2O2R	Research-to-Operations-to-Research
R&D	Research and Development
RAPID	Readily Accessible Propellant in Diverse Orbits

RCMAP	Rangeland Condition Monitoring Assessment and Projection
ReARMM	Regionally Aligned Readiness and Modernization Model
RF	radio frequency
RFI	Request for Information
RFSoC	Radio Frequency System on Chip
RID	Remote Identification
RMA	Risk Management Agency
RO	radio occultation
ROAMX	Rotor Optimization for the Advancement of Mars eXploration
ROK	Republic of Korea
ROMEX	Radio Occultation Modeling Experiment
ROS	rain-on-snow
RPS	Radioisotope Power Systems
RPT	Rocket Propulsion Test
RSLP	Rocket Systems Launch Program
RSTA	Reconnaissance, Surveillance, and Target Acquisition

S

SABRS	Space and Atmospheric Burst Reporting System
SAF	Sustainable Aviation Fuel
SAIC	Science Applications International Corporation
SANS	Spaceflight Associated Neuro-ocular Syndrome
SAO	Smithsonian Astrophysical Observatory
SAS	Safety Assurance System
SATCOM	Satellite Communications
SBEM	Space Based Environmental Monitoring
SBIR	Small Business Innovative Research
SBIRS	Space Based Infrared System
SCaN	Space Communications and Navigation
SCIT	SDA Capability Integrated Test
SCN	Satellite Control Network
SDA	Space Development Agency
SDA	Space Domain Awareness
SDB II	Small Diameter Bomb II
SDTF	seasonally dry tropical forest
SETO	Solar Energy Technologies Office
SFNP	Sustainable Flight National Partnership
SII	Spectrum Innovation Initiative
SIL	secure interoperable-middleware layer
SLE	Service Life Extension
SLS	Space Launch System
SMAP	Soil Moisture Active Passive
SMD	Science Mission Directorate
SMEX	Small Explorer
SMM	small- and medium-sized manufacturers
SMOS	Soil Moisture and Ocean Salinity
SMS	Safety Management System
SNL	Sandia National Laboratories
SNSPD	superconducting nanowire single-photon detector
SoFIE	Solid Fuel Ignition and Extinction
SOTF	Spaceport of the Future
SPT	South Pole Telescope
SRAG	Space Radiation Analysis Group

SRL	Sample Retrieval Lander
SRM	Standard Reference Materials
SRR	System Requirements Review
SSA	Space Situational Awareness
SSA	System Safety Assessment
SSC	Stennis Space Center
SSL	Space Sciences Laboratory
SSPSF	Space Security and Power Systems Facility
SSEBop	Operational Simplified Surface Energy Balance
SSG	Senior Steering Group
STA	special temporary authority
STC	Space Traffic Coordination
STEM	Science, Technology, Engineering, and Mathematics
STMD	Space Technology Mission Directorate
STORM	Sheet Tracking, Opacity, and Regolith Maturity
STRATO	Strategic Radio and Tactical Overwatch
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
SWAC	Space Warfighter Analytics Center
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
SWPC	Space Weather Prediction Center
SWxC	Space Weather Centers of Excellence

T

T0TK	Tranche 0 Tracking Layer
T0TL	Tranche 0 Transport Layer
T1DES	Tranche 1 Development and Experimentation System
T1TL	Tranche 1 Transport Layer
T2	Technology Transfer
T2TK	Tranche 2 Tracking Layer
T2TL	Tranche 2 Transport Layer
T2TL-α	Tranche 2 Transport Alpha
T2TL-β	Tranche 2 Transport Beta
TacGEO	Tactical GEOINT
TacRS	Tactically Responsive Space
TACSATCOM	tactical satellite communications
TACTOM	Tactical Tomahawk
TALOS	Thruster for the Advancement of Low-Temperature Operations in Space
TASA	Taiwan Space Agency
TBIRD	TeraByte InfraRed Delivery
TBO	Trajectory Based Operations
TC	type certificate
TDM	Technology Demonstration Missions

TECRO	Taipei Economic and Cultural Representative Office
TEMPO	Tropospheric Emissions: Monitoring of Pollution
TESS	Transiting Exoplanet Survey Satellite
TIP	Technology, Innovation, and Partnerships
TITAN	Tactical Intelligence Targeting Access Node
TM	Thematic Mapper
TRACERS	Tandem Reconnection and Cusp Electrodynamics Reconnaissance Satellites
TraCSS	Traffic Coordination System for Space
TREAT	Transient Reactor Test
TRIDENT	The Regolith and Ice Drill for Exploring New Terrain
TRISH	Translational Research Institute for Space Health
TRL	Technology Readiness Level
TROPICS	Time-Resolved Observations of Precipitation Structure and Storm Intensity with a Constellation of Smallsats
TWG	Technical Working Group

U

UA-UA	unmanned aircraft to unmanned aircraft
UAG	Users' Advisory Group
UAS	Unmanned (or Uncrewed) Aircraft Systems
UASSC	UAS Standards Collaborative
UFO	UHF Follow-On
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
UNGA	UN General Assembly
USDA	U.S. Department of Agriculture
USDA-NRCS	U.S. Department of Agriculture Natural Resources Conservation Service
USFS	U.S. Forest Service
USG	U.S. Government
USGEO	U.S. Group on Earth Observations
USGS	U.S. Geological Survey
USINDOPACOM	U.S. Indo-Pacific Command
USMC	United States Marine Corps
USN	United States Navy
USNDS	U.S. Nuclear Detonation Detection System
USPTO	United States Patent and Trademark Office
USSF	U.S. Space Force
USTP	University SmallSat Technology Partnerships
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
VIPER	Volatiles Investigating Polar Exploration Rover
VLA	Very Large Array
VLBA	Very Long Baseline Array

VLF	Very Low Frequency
VSFB	Vandenberg Space Force Base
VSRP	Voluntary Safety Reporting Program

W

WAP	World Agricultural Production
WASDE	World Agricultural Supply and Demand Estimates
WCDMA	Wideband Code Division Multiple Access
WFC	Warfighter Council
WFOV	wide field of view
WHMO	White House Military Office
WIN	Written Impact Narrative
WRC-23	World Radiocommunication Conference
WSTF	White Sands Test Facility

Y

YH	Yttrium-Hydride

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